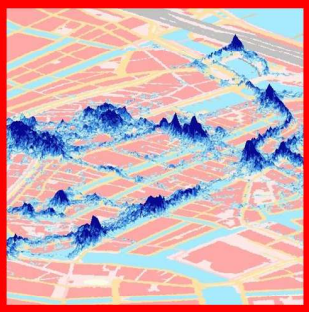
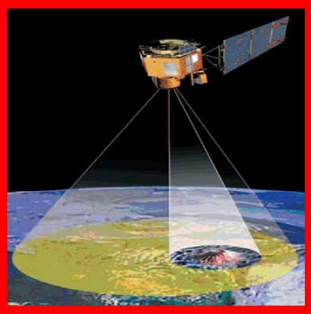
Sensing a Changing World

Proceedings workshop Nov. 19-21 2008





Edited by: Lammert Kooistra and
Arend Ligtenberg

WAGENINGEN UNIVERSITY
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Workshop Sensing a Changing World

Proceedings Workshop November 19-21, 2008

Lammert Kooistra and Arend Ligtenberg (Eds.)

Centre for Geo-information, Wageningen University and Research Centre

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Preface

These proceedings compile the papers presented at the international workshop Sensing a Changing World, held in Wageningen from November 19th to 21th 2008 and hosted by the Centre for Geo-Information of Wageningen University and Research Centre (WUR). The workshop was held within the scope of two research projects which are part of the Dutch research program Space for Geo-Information (RGI): Sensors as source for the Dutch Geo-Information Infrastructure (RGI-189) and People in Motion (RGI-160).

Current developments in sensor technology provide increasing opportunities to analyze human behavior and monitor environmental processes in a changing world. Access to vast amounts of data from mobile (e.g., gps, mobile phones), in situ (e.g., meteorological, groundwater, seismic) and remote sensing sensors allow scientific researchers access to complex but very interesting spatial-temporal data sets. The challenge however will be to develop concepts and applications that can provide timely and on-demand knowledge to end-users in different domains and at a range of scale-levels.

Therefore, the goal of this workshop was to bring together researchers, technology developers and users working with sensor networks in different application domains to elucidate common concepts on aspects like data communication, processing, standardization, knowledge discovery, representation, and visualization. As a result the workshop gives an overview of the state-of-the art developments in a broad range of application fields: oceanography, air quality, biodiversity and vegetation, health, tourism, water management, and agriculture. In addition, the workshop identifies future research challenges to improve the application of sensor networks and sensor webs in the environmental sciences domains.

Over 50 participants representing 15 countries from all over the world attended the workshop. In total 31 oral presentations were given during the first two workshop days. In addition, several participants presented posters or even live demonstrations during the demonstration fair at the end of the first day. On the third day of the workshop, an excursion was made to the LOFAR facility. This is an astronomy project targeted at building a new type of radio telescope consisting of 15000 individual antenna nodes covering a radius of 100 km. A great example of how to deal with large amounts of sensor data in a complex infrastructure.

To make the results of the workshop also available to the research community at large we have asked the presenting authors to prepare a short paper for their presentations. The papers in this proceedings are grouped according to the thematic sessions of the workshop:

- Sensor network design and technology
- Data integration and information extraction
- Real-time processing and visualization
- Geo-sensor networks: implementation and experiences
- Discovery and accessibility of sensor data: future challenges

All material, information and conclusions represented in these proceedings are the responsibility of specific authors and not of RGI or WUR. The proceedings were printed directly from the authors' manuscripts without any changes. Therefore the editors are not responsible for misprints or errors in the text.

A lot of people have assisted us to make the workshop a success. We are especially grateful to the sponsors of this workshop: the research program Space for Geo-information (RGI), Wageningen University and Research Centre, TNO through the eWater project, Astron and LOFAR.

We hope that the workshop Sensing a Changing World contributes to the exploration and implementation of sensor networks to improve quality of life in a changing world.

Lammert Kooistra and Arend Ligtenberg (Editors)

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Sensor network design and technology

Sensor Webs: A Geostrategic Technology for Integrated Earth Sensing

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Abstract: The paper begins with definitions and continues with perspectives on integrated Earth sensing. This is followed by some highlights of sensor web project experience, as well as recommendations on where the emphasis should be placed in the future to advance sensor webs in the context of Earth observation. The paper concludes with some thoughts on how sensor webs and integrated Earth sensing fit into the larger context of geostrategic technologies.

Keywords: remote sensing; Earth observation; sensor web, vegetation monitoring.

1. Introduction

A broad definition of modern-day remote sensing would encompass human and machine vision, astronomy, space probes, most of medical imaging, non-destructive testing, sonar, observing Earth from a distance, and still other areas. The setting for this paper is modern-day terrestrial remote sensing, but its potential benefits were anticipated long ago. Socrates realised in 700 B.C. that we "must rise above the atmosphere and beyond to fully understand the world in which" we live. From the mid-nineteenth to the mid-twentieth century, remote sensing was mainly developed for military reconnaissance and surveillance purposes. Since then, it has become of wider interest to society with the advent of weather satellites, the Landsat program, and many other satellite missions that address an incredible variety of applications.

Remote sensing can be defined as a technology used to acquire information about an object by detecting energy reflected or emitted by that object when the distance between the object and the sensor is much greater than any linear dimension of the sensor. More practically, a short, dictionary-style definition could be that remote sensing is "sensing from a great distance". We restrict our discussion to terrestrial remote sensing by satellite and aircraft sensor systems, a field of aerospace study that is only decades old.

In-situ sensing can be defined as a technology used to acquire information about an object when the distance between the object and the sensor is comparable to or smaller than any linear dimension of the sensor. A short, dictionary-style definition of in-situ sensing could be "sensing in place". Because many observations are made from nearby locations that are not strictly speaking in-situ, the expression proximal sensing has been adopted in some disciplines. A short, dictionary-style definition of proximal sensing could be "sensing from close range" (as in close-range photogrammetry, for example). For the present purposes and in practice, in-situ sensing is often considered to encompass proximal sensing.

As for sensor webs, there is no widely accepted definition. An early definition for in-situ systems was that of Delin [1]: "a system of autonomous, wireless, intra-communicating, spatially-distributed sensor pods that can be deployed to monitor and explore new environments", i.e., "a smart macro instrument for coordinated sensing". The sensor web concept is also being explored in terms of cooperating, interoperable satellite platforms (satellite webs) and their associated sensors (e.g., [2], [3]). A distinction that has been made between sensor networks and sensor webs is that the former consist of elements that collect data, whereas the latter consist of elements that collect and share data and modify their behaviour on the basis of collected data. In the early years, at least for some people, the "web" in "sensor web" was intended to convey intelligent coordination and did not refer to the World Wide Web, although it was always clear that an end-to-end sensor web system must also be World-Wide-Web-enabled. However, the tide of events has superseded this more hardware-based and architecture-based perspective, and sensor webs are now seen by many as being more at the information

level, connecting sensor networks. In any event, it is the convergence of these different levels that will lead to progress on sensing a changing world.

2. Integrated Earth Sensing

Space-based Earth observation sensors provide unique and unprecedented measurements of geophysical and biospheric variables globally and repetitively. These measurements are all the more critical and valuable because the Earth as a system changes constantly over a wide range of temporal and spatial scales. Nevertheless, it has long been recognized that ground data collection remains an essential source of information, even in surveys that rely heavily on remote sensing [4, 5]. The perspective today is that significant advancements in Earth observation are expected to come about only by developing more systematic capabilities for the fusion of remote sensing observations and in-situ measurements for use in models, at relevant scales, to generate terrestrial information products that address applications on an operational basis. The fusion process is a challenging one that involves placing remote sensing and in-situ measurements self-consistently in the same physical reference frame. Such an integrated Earth sensing capability can provide essential validated information for decision making if it involves interagency cooperation, common data processing standards, and timely access to data and information products on a long-term basis. The majority of space agencies now agree that an integrated approach to monitoring the Earth demands that in-situ sensing be an integral part of the solution (World Space Congress 2002 Panel on An Integrated Approach to Monitoring Planet Earth). This is in keeping with the integrated approach proposed for the emerging Global Earth Observation System of Systems (GEOSS) (http://earthobservations.org/). Unfortunately, it is estimated that ground-based (in-situ) monitoring systems currently fall short in density by at least three orders of magnitude.

3. Sensor Web Project Experience

In the Year 2000, the Canada Centre for Remote Sensing (CCRS), a branch of Natural Resources Canada, embarked on an in-situ sensing program. The goal of the in-situ sensing program, which the author led at CCRS, was to develop the capabilities to monitor remote environments, hazards and disasters, and natural resources using new data acquisition strategies and systems for integrated Earth sensing [6, 7]. Three broad objectives were identified: development of the sensor webs themselves, development of advanced methods to fuse data and assimilate them with models, and the incorporation of sensor web data and/or metadata into geospatial data infrastructures. The motivation was to test ideas in the contexts of real natural resource and environmental monitoring applications, using mainly commercial-off-the-shelf technology as opposed to exploring controlled environment applications or miniaturized systems. The program also involved several Canadian companies and, in collaboration with other interested research funding agencies and centres of excellence, provided leverage funding to enable Canadian universities to explore sensor web concepts.

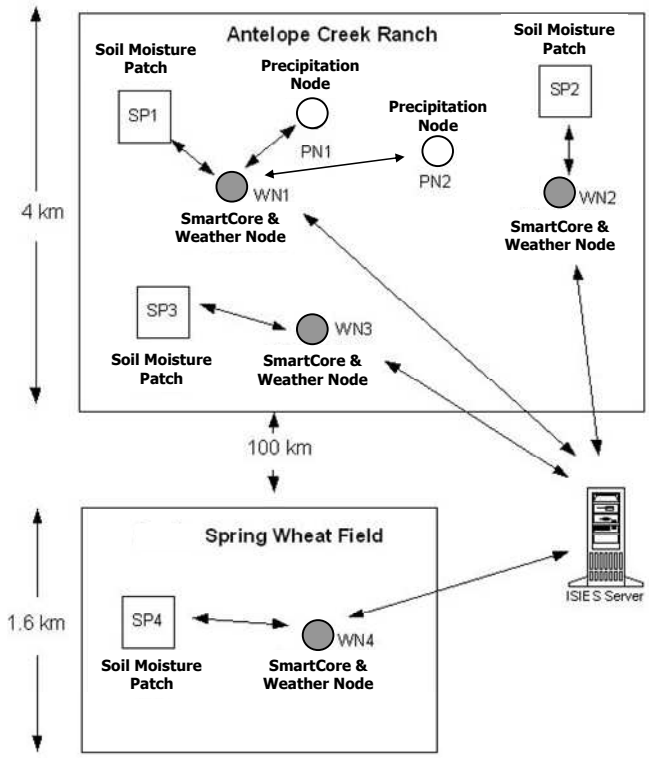
The first extended field deployment was to the Province of Manitoba, where spring flooding is an annual problem that becomes disastrous once or twice a decade. Flood hazard potential is related to soil moisture content and so flood forecast modelling benefits from soil moisture maps and other parameters on local and regional scales. Since radar backscatter correlates strongly with surface-layer soil moisture, synthetic aperture radar (SAR) image data from satellites such as Canada's Radarsat can be used to provide surface-layer soil moisture maps. If the maps can be calibrated using strategically located in-situ sensor webs, they can be used to monitor soil moisture changes in space and time without field work. In the Manitoba project, five sensor network nodes plus a base station were deployed, spread out across approximately 50 km of the Roseau River Sub-Basin of the Red River Watershed, thus forming a coarse prototype sensor web [8, 9]. Sensors operated autonomously on a continuous basis from September 2002 to June 2003, gathering met parameters as well as soil moisture and temperature readings at various depths at 15-minute intervals. Real-time wireless data access was demonstrated from a server in Ottawa. The soil moisture data in particular were sent via satellite telecommunication, including routings from each node independently and/or via the base station. Validation of in-situ and satellite-based soil moisture estimates was done against independent in-situ measurements at dozens of locations across the study area. A lot of experience was gained in the wireless deployment of autonomous sensor systems in difficult outdoor environments.

The most extensive deployment took place in 2004 and 2005 in the Province of Alberta in the context of crop yield and rangeland productivity assessments. The project was called Intelligent Sensorweb for Integrated Earth Sensing (ISIES). The ISIES sensor web incorporated automatic and continuous in-situ measurements,

advanced vegetation growth models, and leading-edge sensor-web-enabled OpenGIS compliant web services [10]. A key component of each in-situ sensor web node was SmartCore, a compact device developed by CCRS to control sensor data traffic autonomously and to communicate wirelessly in two-way mode with the ISIES central server. The system server integrated the in-situ sensor web data with remote sensing data and vegetation models automatically to provide maps of leaf area index, soil moisture and biomass, as well as improved predictions of crop and rangeland yield.

The main features of SmartCore included two-way cellular or satellite telecommunication, a variety of sensor hardware connection options, remotely configurable event monitoring and autonomous event notification, remote power management, remotely configurable device handling and sensor data aggregations. Examples of event monitoring rules included: send event notification if more than 25 mm of rain fall in a rolling 24 hour period; send event notification if the soil temperature remains below 10 degrees C for a rolling 24 hour period; send event notification if the soil moisture stays above 35 percent for a rolling 24 hour period.

Figure 1. Schematic diagram of the ISIES sensor web



ISIES developed a prototype sensor web for crop and rangeland monitoring applications (Figure 1). In particular, the project developed prototype operational tools to integrate monitoring data from diverse sources to drive prediction models, something that remains relatively rare in the Earth observation community. While it was shown that Earth science sensor webs have the potential to become an integral part of scientific endeavours and government policy and decision support domains, more still needs to be done to develop smaller, cheaper and smarter sensor systems for environmental monitoring, to integrate sensor web data and metadata into geospatial data infrastructures, and to fuse on a more routine basis in-situ and remote sensing data and assimilate them into models to generate validated data and information products.

Thus, with the ISIES project, fledgling in-situ sensor web technology was transferred to Canadian industry and new knowledge provided to the Earth and environmental science community via publications and conferences. Unfortunately, as ISIES was being completed, the in-situ sensing development program was ended as a result of organisational changes and financial decisions. A window of opportunity had been opened, but it was closed abruptly.

Since then, sensor network concepts and technologies have continued to develop rapidly around the world in many applications contexts, including in-situ environmental monitoring, but the linkages to Earth observation still constitute too small a proportion of these endeavours. Some recommendations on where the emphasis should be placed for advancing sensor webs in the context of Earth observation are as follows. Today, there are a lot of amazing technologies that can be brought together and a lot of interesting research that can be done. Ultimately, however, the benefits will come when the resulting sensor webs become more autonomous and intelligent, reliable and robust, and deployed in far greater numbers. A parallel effort is needed to develop benchmarks, mechanisms, quality standards and accuracies for data and information products. The integration and fusion of multi-source data and the extraction and fusion of multi-source information remain challenging for quantitative applications requiring high accuracy. There is much to be done before sensor webs can contribute, in plug-and-play or transparent ways, to societal needs on an operational day-to-day basis.

Recommendations on satellite webs are beyond the scope of this paper, but some recommendations for in-situ sensor webs to support satellite webs, in the author's particular areas of interest in satellite radiometry and vegetation monitoring, are as follows. Data and information that would be tremendously helpful for automated tasking of satellite image acquisition include: atmospheric optical conditions, surface reflectance properties, and soil moisture conditions. Initially at least, the current, loosely coordinated, networks of terrestrial in-situ test sites for sensor calibration and data product validation should be instrumented with in-situ sensor webs, so that

the sensor web acquisition of these parameters can be tested in support of Earth observation satellite web operations.

4. Geostrategic Technologies and Perspectives

The 2002 Woodrow Wilson Global Foresight Conference put development of the capability to understand and manage global systems as goal #8 on its list of top 10 goals for the world. Examples of the global systems mentioned include the hydrologic cycle, carbon and nitrogen cycles, oceanic circulation patterns, global climate systems, biological communities at all scales - in ranges appropriate to achieving an ethically and rationally designed planet. A Canadian Science and Technology Foresight project noted in 2003 that geostrategic technologies will include geospatial data sensing and ubiquitous peer-to-peer sensor webs. The Millennium Project of the American Council for the United Nations University noted in its 2007 *State of the Future* report that the costs are falling for "environmental sensors, which can be connected to global information systems via satellite, potentially making environmentally damaging actions known instantaneously and worldwide." These broader considerations make it clear that sensor webs constitute an important geostrategic technology. It is hoped that the concept of integrated Earth sensing, also an important geostrategic technology, will help bridge the gap between different research and development endeavours dedicated to sensing a changing world.

Acknowledgments

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SensorSA Data acquisition System

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Abstract: The Austrian Research Centers (ARCS) recently developed a first prototype of the "SensorSA data acquisition system" (SensorSA DAS). This network capable appliance allows seamless integration of various sensors in Sensor Service Architecture (SensorSA) compliant network. In 2009, SensorSA DAS will be used to test and demonstrate "plug and measure" as well as "generic access to sensors" capabilities of the SensorSA.

SensorSA embraces OGC Sensor Web Enablement (OGC SWE) in the "acquisition domain". As a result, the complete SensorSA DAS functionality is exposed over OGC SWE interfaces. A Sensor Observation Service (SOS) interface allows access to sensor data, management data, and history of alerts. The Sensor Planing Service (SPS) interface is used for configuration, and combination of the Sensor Alert Service (SAS) and Web Notification Service (WNS) interfaces allow configuration of events and alerts.

In order to support the "plug and measure" type of operation foreseen by SensorSA, sensors are connected to a programmable transducer platform. The platform itself is seen as a "smart sensor" by the SensorSA DAS. Currently, three types of smart sensor platforms are supported by the SensorSA DAS: Crossbow "micaZ" and Soldata "microns" wireless ad-hoc sensor nodes, and CAN-bus based "IMI-CAN" built by ARCS can be used to connect sensors providing voltage-, current-, impedance-encoded and digital outputs. In particular, the IMI-CAN sensor platform supports Bayern-Hessen protocol over RS232 interface. This protocol is mainly used for air-quality monitoring systems.

Keywords: Open Geospatial Consortium (OGC), OGC Sensor Web Enablement (OGC-SWE), SANY IP, ORCHESTRA IP, Sensor Service Architecture, SensorSA, Sensor Observation Service (SOS), Sensor Planning Service (SPS), Data acquisition, plug and measure

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Algorithms for energy efficient data extraction from wireless sensor networks for environmental monitoring applications

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Abstract: Wireless sensor networks (WSNs) can provide high resolution spatial and temporal data for environmental applications if they are densely deployed. However, as the nodes which make up the network are typically battery operated, a major problem faced by WSNs is limited network lifetime. In order to extend network lifetime to several years, the radio transceiver and attached sensors need to be managed carefully to minimize power consumption. This paper provides an overview of two separate solutions that we are currently testing in a real-life application on the Great Barrier Reef (GBR). The first algorithm minimizes transmissions by taking advantage of spatial correlations of sensor readings while the second algorithm minimizes sensor sampling operations by taking advantage of the temporal correlations that exist between successive sensor readings. Both the solutions have been developed as part of our efforts together with the Australian Institute of Marine Science, to deploy a large scale WSN on the Great Barrier Reef (GBR). This network will be used to study the effects of global warming and agriculture on the coral reefs. Details of our deployment of sensor nodes on the GBR using buoys are also described.

Keywords: sensor networks; environmental monitoring

1. Introduction

Densely deployed wireless sensors networks (WSNs), can provide high resolution spatial and temporal data. However, WSNs are generally made up of sensor nodes that are battery powered. Thus in order to have a network that is able to run for long periods without carrying out battery replacements, the various protocols running on the sensor nodes need to be designed to maximize energy efficiency. One of the main techniques to improve network lifetime is to reduce the duty cycle of the transceiver on a sensor node as it is one of the primary sources of energy consumption. The tradeoff is that the amount of data that can be transmitted by every node in the network is greatly diminished. This can be a major problem especially when the end-user requires every sensor node in the network to report its readings periodically as it leads to excessive energy consumption and also to reduced data quality caused by high rates of data loss due to the limited bandwidth. Depending on the application, the sensor sampling operations may also consume a substantial amount of energy.

In this paper, we present an overview of two separate algorithms we have developed, that minimize energy consumption by reducing the amount of data that needs to be transmitted and by reducing the number of sensor sampling operations. Both the solutions have been developed as part of our efforts together with the Australian Institute of Marine Science, to deploy a large scale WSN on the Great Barrier Reef (GBR). This network will be used to study the effects of global warming and agriculture on the coral reefs. Details of our deployment of sensor nodes on the GBR using buoys are also described. The first algorithm takes advantage of the spatial correlations of sensor readings that may exist between adjacent nodes. The algorithm uses a few as

representative nodes that perform in-network aggregation. This reduces the total number of transmissions. Data quality is also greatly improved by minimizing data loss rates.

The second algorithm exploits temporal correlations that may exist between consecutive sensor readings. We describe an adaptive sensor sampling scheme where nodes predict readings instead of sampling sensors when the readings follow a predictable trend. Our technique does not have any significant detrimental effect on data quality.

2. Application scenario

We are currently working together with the Australian Institute of Marine Science (AIMS) to set up a large-scale wireless sensor network to monitor various environmental parameters on the Great Barrier Reef (GBR) in Australia. Scientists at AIMS intend t o use the collected data to study coral bleaching, reef-wide temperature fluctuations, and the impact of temperature on aquatic life and pollution. One of the reefs under study is the Davies Reef, which is approximately 80km northeast of the city of Townsville in North Queensland, Australia. Currently, AIMS has a couple of data loggers situated on the reef that records temperature at two separate depths once every thirty minutes. Scientists from AIMS need to visit the reef periodically to download the data from the loggers. The drawback of the current system is that it only allows single-point measurements. Thus it is impossible to get a true representation of the temperature gradients spanning the entire reef, which is approximately 7km in length. Also, the practice of collecting the data once every few weeks makes it impossible to study the trends of various parameters in real-time. Deploying a sensor network would not only allow high resolution monitoring in both the spatial and temporal dimensions, but would also enable scientists to improve their understanding of the complex environmental processes by studying data streaming in from the reef in real-time.

The primary assumptions that motivate the algorithms outlined in this paper are the fact that due to the high density deployment of nodes on the reef, we can expect the sensor readings to be correlated in both the spatial and temporal dimensions. We have verified these assumptions based on data collected from an actual deployment in Nelly Bay in the GBR, Australia. Our initial findings also indicate how data collected from Nelly Bay demonstrates a spatial correlation that remains significant over an extended period of time. Additionally, every sensor's readings also demonstrate a strong autocorrelation. The details of our initial deployment can be found in [1].

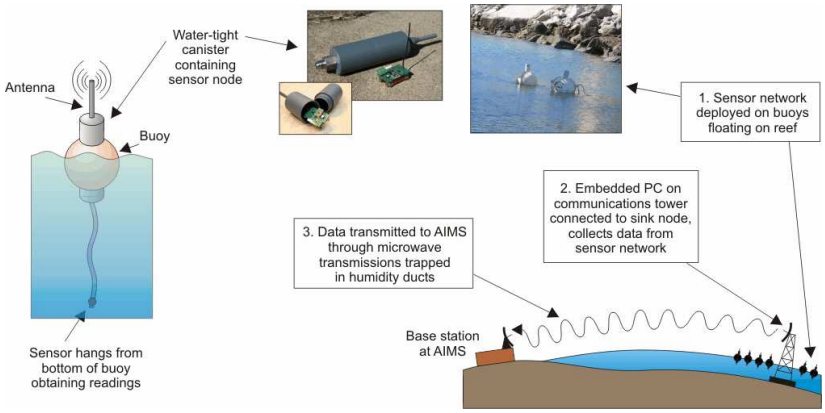

Figure 1 Overview of data collection system at Davies Reef

2.1. Proposed deployment at the Great Barrier Reef

The new data collection system that we are deploying at Davies Reef in the GBR can be broken down into three main components as shown in Figure 1:

- *Ambient µNodes*: These are the sensor nodes from Ambient Systems that will be placed in water and shock-proof canisters and then placed in buoys around the reef.
- *Embedded PC*: An embedded PC will be placed on a communication tower and will act as the sink node collecting data from all the sensors in the reef.

- *Microwave link*: This will allow data to be transmitted from the Embedded PC to the AIMS base station 80km away using microwave transmissions trapped inside humidity ducts that form directly above the surface of the sea.

The algorithms described in this paper are designed for the first component, i.e. Ambient µNodes.

3. Data aggregation based on spatial correlations

Taking advantage of spatial correlations between neighboring nodes would enable nodes to filter out redundant data. This in turn will help reduce problems such as excessive energy usage, buffer overflows and reduced data quality. Instead of transmitting every acquired sensor reading to the sink node, a node which discovers a correlation with its neighboring nodes only transmits the correlation information followed by its own readings. Thus the sink node can then predict the readings of the neighboring nodes using the correlation information and the transmitted readings from the node performing the correlation. This is illustrated in Figure 2.

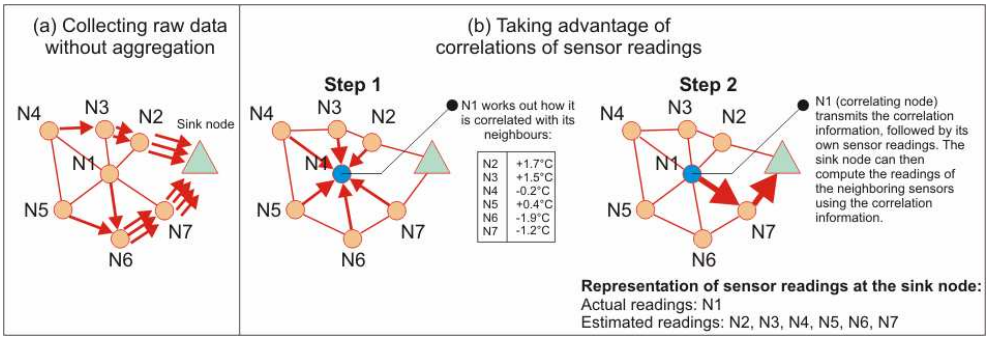

Figure 2 Advantage of using correlation information (a) instead of transmitting raw data (b)

It would not make sense for all nodes to send correlation information to the sink node simultaneously as this would involve sending more information than even transmitting raw sensor readings. Thus when one node is transmitting correlation data, the neighboring nodes should refrain from doing so. This implies that while nodes transmitting the correlation information (i.e. correlating nodes) are represented at the root node by their *actual* own) readings, their neighbors however, are represented by *estimated* readings which are based on the correlation information transmitted by the correlating nodes. Note that a correlating node initially transmits the correlation information followed by its own sensor readings. Thus two neighboring nodes should not act as correlating nodes simultaneously at any instant of time. Furthermore, it is important to ensure that at all times, every node in the network is represented at the sink node either by an actual reading or an estimated reading. This in turn means that if a node is not a correlating node at a certain time, it must be connected to at least one neighboring correlating node.

Having a static scheduling scheme which fixes the correlating nodes for the entire lifetime of the network is not desirable. This is because it would mean that while there are a number of correlating nodes sending their own sensor readings in addition to the correlation information, a significant proportion of the nodes would always be represented at the root node by only estimated readings. Thus such a scheme would be prone to errors in the event that the correlating node fails for some reason and starts sending erroneous correlation information to the sink. We address this, by introducing a rotating scheme which forces every node to act both as a correlating or non-correlating node at different times. Specific details of the algorithm can be found in [1].

4. Adaptive sensor sampling using temporal correlations

This technique takes a two-pronged approach to reducing energy consumption by not only reducing sensor sampling operations but also reducing the number of messages transmitted. This is carried out by exploiting the temporal correlations that may exist between successive sensor readings. The basic idea is to use *time-series forecasting* to try and predict future sensor readings. When the trend of a particular sensor reading is fairly constant and thus predictable, we reduce the sensor sampling frequency and message transmission rate. However, when the trend changes, both the sampling rate and message transmission rates

are increased. The lower sampling frequency used in such a sampling scheme may result in certain important events being missed. In order to minimize the chance of this from occurring, our sampling scheme tries to ensure an acceptable level of coverage by allowing nodes in the network to adjust various parameters autonomously rather than using fixed values that are predefined prior to deployment. This allows the nodes to operate in a more energy-efficient manner as they are able to automatically adapt their operation to not only the variations in the environment but also to the user-specified coverage requirements. We refer the reader to [2] for specific details of this adaptive sampling mechanism.

5. Results

Both algorithms have shown to result in significant energy savings. Data quality is also not adversely affected in both cases. Figure 3(a) shows the improvement of network lifetime by up to 83.5% (Epoch = 120s) when we use our data aggregation algorithm which takes advantage of spatial correlations (DOSA [1]) as opposed to raw data collection. Note that *Epoch* refers to how often readings are acquired by the sensors. DOSA also helps significantly improve data quality. When collecting raw data, a large number of messages are lost due to buffer overflows. When messages are lost, certain epochs do not have any readings. Figure 3(b) illustrates that for sampling rates greater than 30 seconds, DOSA manages to eliminate message loss due to buffer overflows completely.

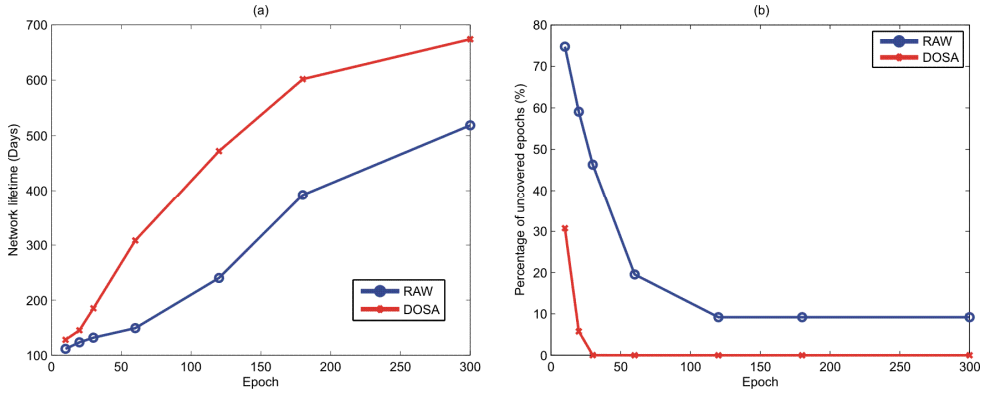

Figure 3 Improvement of network lifetime and data quality

The adaptive sampling scheme which takes advantage of correlations between successive readings is also highly beneficial. Based on data gathered from Nelly Bay, our results indicate energy savings of up to 87% when compared to raw data collection. Furthermore, around 98% of the readings collected fall within the user's data quality requirements.

5. Conclusion

This paper presents an overview of two algorithms used for energy-efficient data collection using wireless sensor networks for environmental monitoring applications. It illustrates how network lifetime can be significantly increased by taking advantage of the inherent spatial and temporal correlations of sensor readings gathered from densely deployed wireless sensor networks. These algorithms are specifically designed for a real-life sensor network application in the Great Barrier Reef which is used to monitor various parameters in a coral reef.

Acknowledgements

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Towards remote sensing of vegetation processes

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Abstract: The latest advances in imaging spectroscopy of vegetation enabled remote sensing (RS) of plant reflected or emitted signals associated with photosynthetic processes as the photoprotective transformation of xanthophyll pigments or the chlorophyll fluorescence (Chl-F). A potential future European Space Agency (ESA) satellite mission FLEX is expected to sense, apart from other parameters, so-called steady-state chlorophyll fluorescence (Chl-F_S) signal, which may be potentially used for monitoring of photosynthesis (vegetation canopy carbon assimilation rate). Nevertheless, geometric complexity of plant canopies and signal disturbing atmospheric factors require a proper approach for scaling the information of a single leaf optical properties up to the RS image data of anisotropic vegetation canopies. Such up-scaling approach can be established only via synergic measurements of ground based and air-/space-borne optical sensors. Our initial experiment revealed that Chl-F_S, being strongly driven by the air temperature, is able to accurately indicate on-set and off-set of the photosynthetically active period for the evergreen plants. Next field experiment, carried out with the VNIR imaging spectroradiometer AISA Eagle (SPECIM Ltd., Finland) mounted above the montane grassland and Norway spruce (*Picea abies* /L./ Karst.) canopies, showed that the fluorescence signal is retrievable from passive optical imaging spectroscopy data. Further analyses revealed that some of the vegetation 'process-related' optical indices (e.g., photochemical reflectance index - PRI) are closely correlated to the parameters measured over the experimental canopies by eddy-covariance flux systems. The future objective is to continue in development the leaf-canopy Chl-F up-scaling approach by setting up local scale experiments employing the field pocket-size cost effective instruments measuring the leaf optical indices and Chl-F parameters simultaneously with canopy reflectance acquired by RS sensors from tower and aircraft platforms.

Keywords: 'process-related' remote sensing, imaging spectroscopy, plant fluorescence and reflectance, vegetation optical indices

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1. Introduction

Natural ecosystems are increasingly facing environmental pressure of the global climate change. Remote sensing (RS) systems represent the only global tool for a spatio-temporal monitoring of the natural ecosystems. Traditionally, properties such as leaf chlorophyll or water content and leaf area index (LAI) are being estimated

from RS data. However, recent interest of RS community is to capture more dynamic physiological processes of plant photosynthesis related to carbon assimilation and primary production. First laboratory evidence of what can be called 'process-related' RS appeared in 1990, when Bilger and Bjorkman (1990) observed rapid plant absorbance changes around 515 nm of the electromagnetic (EM) spectrum. Shortly after this study, Gamon et al. (1990) described dynamic changes in leaf reflectance spectrum at 531 nm, 685 nm and 738 nm, occurring after sudden transition of leaf from dark to light environment. Changes around 531 nm were attributed to the pigment transformation of violaxanthin to zeaxanthin, quantified by PRI vegetation index (Physiological, Photochemical or Plant Reflectance Index, calculated as $(R_{531}-R_{570})/(R_{531}+R_{570})$, where R is reflectance at subscripted wavelength), which was shown to be related to the leaf Light Use Efficiency (LUE) (Nichol et al. 2002). Quantitative retrieval of LUE from RS data may significantly contribute to more accurate estimates of vegetation GPP and NPP at global scale (Ahl et al. 2004). One of the first promising results obtained for the Moderate Imaging Spectroradiomerer (MODIS) images were reported by Rahman et al. (2004). Leaf reflectance changes at 685 and 738 nm were attributed to the photosystem II (PSII) emissions of chlorophyll fluorescence (Chl-F) (Zarco-Tejada et al., 2000), and related to the photosynthetic processes of plants (Maxwell and Johnson 2000). Still, recent passive spectroradiomenters can capture only signal of 'steady-state' Chl-F (Chl-F_S), which is continually super-imposed by the leaf reflectance. Moreover, Chl-F_S signal alone is an integrative function of many photosynthetic processes (Papageorgiou and Govindjee, 2004). Therefore, a further research is needed to interpret properly the informative content of this signal.

2. Experimental section

2. 1. Spring-autumn monitoring of chlorophyll steady-state fluorescence

Measurements of annual variations of Chl-F_S were performed in Nové Hrady (48°47′ N, 14°46′ E, SW of the Czech Republic, elevation 541 m a.s.l.) during two springs (March-May 2005 and March-April 2006) and one autumn (October-November 2005), with daily mean air temperature between -10 to 15°C. Chl-F_S of identical five sunlit and five shade adapted current and 1-year-old shoots of *Picea omorika* (Puncic) Purk, and ten sunlit leaves of *Rhododendron × hybridum* was measured six times during the morning hours (10:00–11:00 a.m.) with the open version of kinetic imaging fluorometer FluorCam (Photon Systems Instruments Ltd., Czech Republic) equipped with far-red optical filters (RG695 and LP760) (Nedbal et al. 2000). The Chl-F measurements of one day were averaged in order to resemble integral signal detectable by RS sensors.

2. 2. Sunlight-induced fluorescence imaging experiments at forest and grassland test sites

The 23 years old *Picea abies* (L.) Karst. experimental forest stand (density of 2600 trees ha^{-1}, hemi-surface leaf area index of $11m^2m^{-2}$, mean (± std.) tree height and stem diameter at 1.3m of 8.5 ± 0.1m and 10.1 ± 0.1 cm) is situated on the permanent CARBOEUROPE network test site Bílý Kříž (Moravian-Silesian Beskydy Mts., 49°33′ N, 18°32′ E, NE of the Czech Republic, elevation 908 m a.s.l.). The grassland test site, characterized by high plant species biodiversity (association: *Nardo-Callunetea*, class: *Nardo-Agrostion tenuis*, the most abundant species: *Festuca rubra agg*. (L.), *Hieracium sp*., *Plantago sp*., *Nardus stricta* (L.), and *Jacea pseudophrygia* /C.A. MEYER/), is situated at the same location. Daily nadir clear-sky hyperspectral images (spectral range of 400-940 nm, 260 spectral bands with 2.2 nm full width at half maximum) were acquired with a VNIR imaging system Airborne Imaging Spectroradiometer for Applications (AISA) Eagle (SPECIM, Ltd., Finland). The forest site images were acquired at one hour intervals on 30th and 31st August 2005, from 13:30 to 16:30 and from 9:30 to 16:30 of the local time, respectively. The AISA sensor was mounted on a tower at the height of 20 m (approx. 10 m above canopy), resulting in pixel resolution of 1cm and total imaged area of about 50 m^2. The grassland images were obtained on 2nd September 2005 from 9:30 to 16:00 of the local time at half-hourly intervals. AISA was placed 4 m above canopy, resulting in pixel size of 2 mm and total imaged area of about 6 m^2. The acquired images were converted into the reflectance values and segmented by the supervised Maximum Likelihood classifier into the sunlit and shaded parts. The photosynthetically active sunlit leaves were separated from a dry grass litter by an appropriate threshold of the green normalized difference vegetation index (green NDVI= $(R_{554}-R_{677})/(R_{554}+R_{677})$).

In order to examine the detectability of process related reflectance changes by the AISA Eagle imaging system, half of the observed experimental grassland plot was artificially dark adapted (i.e., covered for 30 min

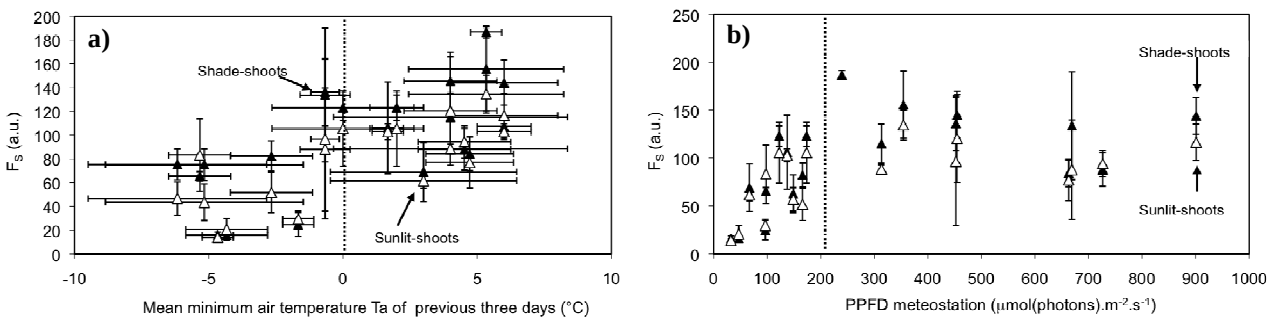
prior to spectral measurements by a black non-transparent blanket), while the rest of experimental plot was exposed to natural radiation regime (control plot). Three subsequent AISA scans were acquired at 5th, 90th, and 200th second after blanket removal. Subtraction of successive reflectance images of mantled plot acquired after blanket removal was expected to detect the dynamic reflectance differences of sun exposed green grassland pixels. Photosynthetic process related vegetation indexes (VIs) (see Table 1) were defined based on the shade-removal experiment results that revealed wavelengths of dynamic reflectance regions. Finally, these VIs, derived from AISA reflectance per pixel and thereafter averaged, were correlated to the canopy parameters measured over the experimental sites by the eddy-covariance system Edisol (University of Edinburgh, UK). For calculation of Net Ecosystem Exchange (NEE), gross primary production (GPP), gross Radiation Use Efficiency (gRUE) and Radiation Use Efficiency (RUE), half-hourly averaged H_2O vapor and CO_2 fluxes were used. For a more detailed description of eddy-covariance system observables see Urban et al. (2007).

3. Results and Discussion

3.1. Chlorophyll steady-state fluorescence – temperature driven indicator of vegetative season

As shown in Figure 1a, the Chl-F_S measurements of both sunlit and shade adapted *Picea omorika* shoots were significantly sensitive to changes in air temperature. Once the mean minimum air temperature of last three days (nights) reached values around 0°C (dashed line in Fig. 1a), the Chl-F_S values 'jumped' from 10-100 to 60-200 a.u. The positive linear regression of Chl-F_S on incident photosynthetically active photon flux density (PPFD) measured by a near by meteorological station was found only for very low PPFD values up to 200 $\mu mol.m^{-2}.s^{-1}$ (dashed line in Fig. 1b). No significant relationship was revealed in case of PPFD values higher than 200 $\mu mol.m^{-2}.s^{-1}$ (see Fig. 2b). Exactly the same results were obtained for Chl-F_S measurements of *Rhododendron × hybridum* leaves. Moreover, our findings are in accordance with results of Louis et al. (2005) that observed the increase in passively sensed Chl-F at the oxygen line during the spring recovery of photosynthetic activity in boreal forest using the prototype of Passive Multi-wavelength Fluorescence Detector. Subsequently, we concluded that abrupt changes in Chl-F_S can indicate on-set and off-set of photosynthetic activity in evergreens, driven by the air temperature of last few days rather than illumination intensity.

Figure 1. Relation of the steady-state chlorophyll fluorescence (F_S in arbitrary units – a.u.) to **a)** the mean minimum air temperature (Ta) of three days before measurement, and **b)** the incident photosynthetically active photon flux density (PPFD) obtained for sunlit (empty triangles) and shade adapted (filled tringles) *Picea omorika* shoots (each data point represents a mean value of six measurements and the error bars show respective standard deviations).

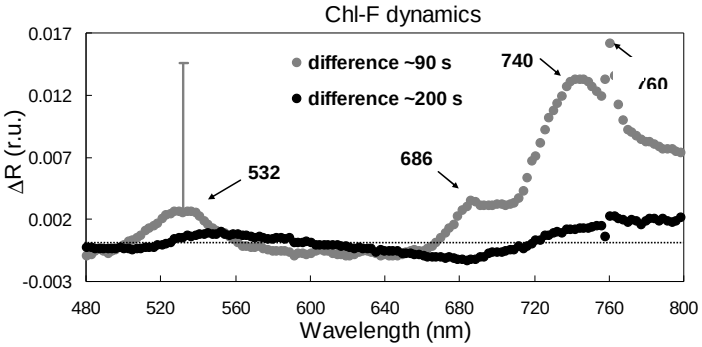


3.2. Effects of sunlight-induced fluorescence on apparent canopy reflectance

Effect of sunlight-induced Chl-F emissions on apparent canopy reflectance intensity with peaks centered at 532, 686, and 740 nm was observable when subtracting pixels of mantled subplot acquired at 5th and 90th s after uncovering (Fig. 2, grey closed circles). Next reflectance subtraction of the same pixels acquired at 90th and 200th s after uncovering did not reveal these significant reflectance amplitude changes (ΔR) anymore (Fig. 2, black closed circles) because the grassland plants became adapted for a incoming light of higher intensity. The observed rapid changes in reflectance and a subsequent reflectance steady-state achieved in at least ~90 s after

uncovering of the dark-adapted subplot are in the agreement with the leaf level reflectance kinetic studies of Zarco-Tejada et al. (2000) and Chl-F induction experiments of D'Haese et al. (2004). These results provide evidence that even standard imaging spectroradiomaters such as AISA Eagle can be potentially (under certain conditions) used to retrieve the Chl-F signals measured under the natural light conditions.

Figure 2. Reflectance difference (ΔR in relative units – r.u.) observed within 480-800 nm when subtracting the reflectance of green sunlit pixels of mantled subplot acquired at 5th and 90th second (●) and at 90th and 200th second (●) after removal of non-transparent blanket, inducing the dark adapted canopy (n > 400 000, vertical bar indicates standard deviation). Arrows indicate Chl-F wavelengths with rapid reflectance changes.



3.3. Correlation of 'process related' vegetation indices and eddy-covariance flux parameters

In the next analysis investigated correlation of 'process related' VIs, based on reflectance of fluorescence dynamic wavelengths at 532, 686, and 740 nm (see Table 1a), with physiological parameters derived from eddy-covariance flux tower measurements at forest and grassland ecosystems together. The highest Pearson correlations coefficients were found between the ratio R_{686}/R_{630} and NEE, GPP and RUE (Table 1). The ratio R_{740}/R_{630} as well as PRI showed strong correlation with gRUE, but PRI with lower Pearson correlation coefficient of 0.61. Nevertheless, it is important to note that GPP, NEE, and RUE were all highly inter-correlated (Table 1b).

Table 1. Summary of Pearson correlation coefficients computed between vegetation indices (VIs) and physiological parameters derived from measurements of the eddy-covariance towers at forest and grassland ecosystems. Gross Primary Production (GPP [μmol CO_2 m^2s^{-1}] = NEE + R); Net Ecosystem Exchange (NEE [μmol CO_2 m^2s^{-1}]); gross Radiation Use Efficiency (gRUE = GPP/PPFD [g C MJ^{-1}]); Radiation Use Efficiency (RUE = NEE/PPFD [g C MJ^{-1}]). Values of eddy-covariance derived parameters are half-hour averages and values of VIs are averages of more than 400 000 image pixels. (n = 23). R represents reflectance at subscripted wavelength and PRI was calculated as $((R_{532}-R_{570})/(R_{532}+R_{570}))$.

a) VIs	GPP	NEE	gRUE	RUE	b)	GPP	NEE	gRUE	RUE
PRI	0.16	0.25	0.61	0.52	**GPP**	1			
R_{686}/R_{630}	0.93	0.91	-0.45	0.73	**NEE**	0.98	1		
R_{740}/R_{800}	0.33	0.22	-0.93	0.09	**gRUE**	-0.51	-0.40	1	
					RUE	0.82	0.84	-0.21	1

4. Conclusions

Results of our field experiments showed the possibility to map remotely Ch-F_S signals and the potential to relate them with parameters of plant photosynthetic processes (e.g., length of photosynthetically active period and ecosystem production parameters as NEE, GPP, or RUE). However, one has to pay full attention to real informative content of the steady-state Chl-F signal to ensure that satellite missions like the Fluorescence

Explorer (FLEX), proposed to the European Space Agency (ESA) as observer of the vegetation photosynthetic activity (Rascher, 2008), will be successful in their purpose. Such an investigation can be achieved via set of ground experiments combining field networks of the in-situ leaf Chl-F detectors with RS sensors recording Chl-F of heterogeneous canopies. We are planning within a future project to establish this kind of experiment at the permanent research sites of the Institute of Systems Biology and Ecology by means of the cost effective fluorescence and VIs measuring pocked-size instruments produced by Photon Systems Instruments Ltd. (Czech Republic, see http://www.psi.cz/products/pocket-sized-instruments/). Network of these leaf sensors will be running continuously alone with RS observations of the AISA Eagle VNIR system from tower and aircraft carriers in order to achieve the physically sound mechanism up-scaling Ch-F signal from leaf to canopy scale.

Acknowledgements

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Fieldservers as Real-time Monitoring Tools for Ubiquitous Sensor Networks

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Abstract: The fieldserver is an Internet based observation robot that can provide an outdoor solution for monitoring environmental parameters in real time. The data from its sensors can be collected and sent to central server infrastructure and published on the Internet. The information from the sensor network will contribute to monitoring and modeling on various environmental issues in Asia, including agriculture, food, pollution, disaster, climate change and etc. An initiative called Sensor Asia is developing GIS and Sensor integration system to realize easy and low cost installation and operation of ubiquitous sensor networks using fieldservers.

Keywords: fieldservers, sensor networks, ubiquitous network

1. Introduction

The Fieldserver (FS) is an Internet Field Observation Robot that consists of a set of multiple sensors, a web server, an Internet Protocol (IP) camera, as well as Ethernet and wireless interfaces. It can provide an outdoor solution for environment monitoring and it can be used for a wide range of real time sensing applications. At the heart of the FS are a built-in webserver and an Analog-to-Digital converter. The analog voltage from sensors are converted and shown on webpage as table formatted data. With a variety of sensors, the Fieldserver can be use for any kind of monitoring application such as agriculture, landslide, pollution, environment and climate monitoring just to name a few.

In addition to the set of sensors, the FS is equipped with an IP network camera attached to it. The network camera can deliver video images and sound in real time. The camera is equipped with Ethernet network interface. The camera has built-in pan (left/right) and tilt (up/down) mechanism which can be controlled through a web browser to change the direction of the camera lens. The camera can also be preset to move to different rotation and zoom positions at fixed time intervals.

With the wide-spread advent of communication technology, the fieldserver can be now be deployed to gather data anywhere in the world where there is availability of an Internet connection. At the same time, advances in electronics and Integrated Circuits technology mean that sensors and sensing devices are getting inexpensive and more easily available. However, due to numerous technical aspects involved such as the requirement of extra data acquisition circuitry and the required knowledge of sampling, quantization and calibration equations, only highly skilled people generally use sensors in their applications. For wide-ranging reach and use of sensor networks, a system that supports sensor ‘plug&play’ is necessary so that even non-technical people can implement their own sensor systems easily and obtain data seamlessly.

Figure 1. Typical Fieldserver.

An initiative called Sensor Asia has been started to fill this need with the aim of providing truly ubiquitous capabilities to sensor networks. Under this initiative, field-side agent boxes based on Sensor Observation Service (SOS), called SOS Stations, have been developed. Although the fieldserver in itself is an excellent platform for data collection, the sensor connection, data archiving and transfer to outside world are not easy tasks for ordinary users. The use of SOS Stations with facilities of the Sensor Service Grid (SSG), under Sensor Asia initiative, can simplify these tasks for any user.

2. Sensor Service Grid (SSG)

SSG is a sensor data middleware which provides users with a platform to receive data from remote field sensor networks. As it follows OpenGIS standards and specifications, other applications can be built based on the SSG. The SSG implementation has been designed to run in two parts – one at the sensor node in the field, i.e. the SOS Station, and the other at the SSG central servers. The SOS Station is a combination of fieldserver with a small Linux Box which gives a high capability for storing sensor data and provides data connectivity to outside servers using standardized data exchange protocols. The SOS Station is based on Sensor Observation Service (SOS) and the sensor data can be obtained in SensorML Observation and Measurement (O&M) encodings.

The SOS Station is capable of controlling more than one fieldserver and their cameras. It also has the capability to collect data from several types of weather stations and data loggers. Once deployed in the field, the SOS Station can be used to register sensors and fieldservers at the SSG central servers. The sensor set can be added or changed easily with a user-friendly interface; the calibration equation and other parameters will be selected appropriately to obtain the correct sensor output, with a feel of sensor ‘plug&play’. Once registered, the SOS Station can be controlled and configured remotely from the SSG itself. The SOS Station has been made resilient to overcome firewalls and NATs, so that sensor data can be sent from any kind of Internet connection. The SOS Station has its own webserver, which is capable of displaying sensor data and images in the local network even if connection to the SSG is lost.

The primary work of the SSG implementation at the central servers is the collection of data from all such SOS Stations around the world, the management of all such stations, and the dissemination of information collected through the Internet. One of the main features of Sensor Asia is user-friendly data visualization. After the SOS Station is registered at the SSG, and it starts sending data, the SOS Station will automatically appear on the Web GIS map, together with its list of sensors as shown in Figure 2.

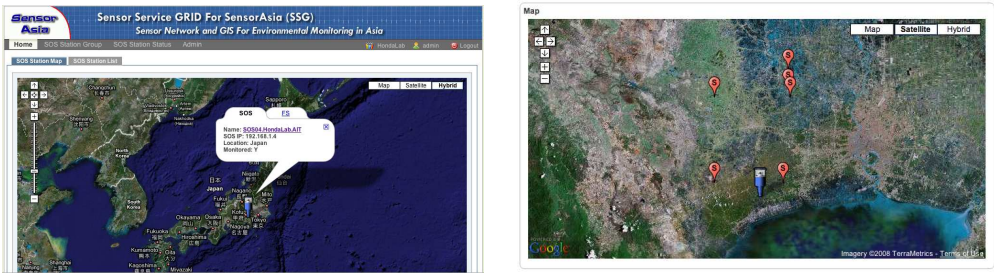

Figure 2. SSG showing the remote field location of SOS Station on Web GIS map.

The data being received from the SOS Station can easily be viewed in real-time in the form of simple dials and graphs as show in Figure 3. This web-based application provides functionalities to choose the duration of data to be viewed. The data can also be obtained in SOS based O&M format.

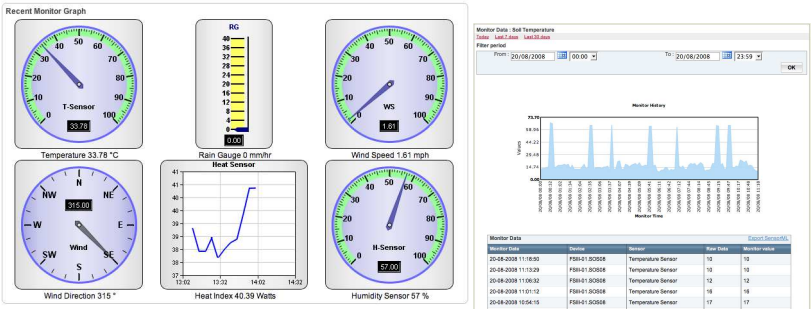

Figure 3. Data viewed in simple graphs and dials.

Along with the remote management of SOS Stations, the SSG application provides several levels of user management depending on authentication. This provides access to management of the remote field servers from anywhere at any time with the reliability that all data is being stored at the SSG. The Sensor Asia application also provides an interface to view images from the fieldserver camera as show in Figure 4. There is a provision to provide 10 pre-sets positions for the camera, according to which the camera will rotate periodically and transfer images in all these positions.

Figure 4. Camera interface of Sensor Asia application.

The SSG provides a platform for ubiquitous and open sensor networks. The queries and response to and from the Agent Boxes are based on standardized XML. At the core of the implementation is the OpenGIS Sensor Observation Service; sensor data are formatted in standard Observation and Measurement (O&M) encodings. Third party applications can obtain sensor data through standard XML interface. Sensor manufacturers can easily make their sensors to ‘plug&play’ using the data feeder template programs of the Sensor Asia application.

3. Field Applications

Authors have been setting up fieldservers for various applications such as crop monitoring, landslide monitoring and glacier monitoring, as test-beds of SSG development in various parts of the Asia Pacific. Fieldservers and SOS Stations have been deployed for agricultural monitoring in Chiang Mai, Thailand, for landslide monitoring in Banjarnegara, Indonesia, and for glacier lake outburst flood (GLOF) monitoring of Imja Lake (5000m) in the Everest Region Himalayas, Nepal.

Figure 5. Fieldservers and wireless relay station for monitoring Imja Lake (5000m).

4. Conclusions

One of the problems in setting up of a fieldservers and sensors in the field and their operation is that the work requires highly skilled engineers. It results in high installation cost and eventually will hinder the deployment high density sensor network. SSG has been developed to solve this issue. SSG supports sensor plug&play, registering sensor nodes, archiving, publishing, and visualization. These functions are important to lower the cost of installation and the make the fieldserver as off-the-shelf products for everyone. SSG supports SOS (Sensor Observation Service), as a base technology to standardize sensor information exchange within and outside of the system. The plethora of different sensors available for climatic, meteorological and agro-hydrological phenomena can be connected to the fieldservers. Sensor Asia applications based on the SSG are ideal for ubiquitous field sensor networks for any kind of environmental monitoring.

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The exploration of Sensor Web technology for highly dynamic geo-processes observing hydrological events

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Abstract: A research is proposed to explore the potentials of a sensor web technology in studying highly dynamic geo-processes. In this context hydrological events function as example of a dynamic geo-process which has a large spatial dependency as well. A Sensor web integrates the characteristics of both in-situ sensors (high spatial density and high temporal resolution) as remote sensors (large areal coverage). The expectations are that in this way the spatial-temporal monitoring of these geo-processes can be improved into a large extent. In addition, a Sensor web offers the possibility to control or act according to data themselves and also to model and information needs given by the users. It is expected that a Sensor web not only will improve our understanding of hydrological events, but also will improve their forecasting with models and in this way the operational water management when real events occur.

Key words:
In-situ sensing, remote sensing, sensor web, hydrological event, real-time and location specific monitoring, modelling and forecasting, water management, water excess

1. Research proposed

Recent advances in sensor, computation and communication technologies has allowed for a radically new macro instrument concept: the Sensor web (Delin and Jackson, 2001). A sensor web is a system or network of wireless, intracommunicating, spatially distributed sensors that can be deployed to monitor and explore environments. In addition, the sensor web provides a new means to think about environmental monitoring and creating a continued and virtual presence. For this reason, the sensor web is a new instrument concept, capable of being developed into a wide range of applications (Delin and Jackson, 2000; Delin et al., 2003). In this context it is important to stress the unique feature of the Sensor web in comparison to sensor networks: while sensor networks (also called distributed sensors) merely collect data, Sensor webs also can react and modify their behaviour on the basis of the collected data (Delin and Jackson, 2001).

The sensor web itself is achieved by connecting the distributed and heterogeneous in-situ and remote sensors by open, interconnected networks to an information centre that collects, processes, fuses and distributes the sensing information (Liang et al., 2005). Those individual networks can be seen as a separate node that functions as a web itself. This leads to sensor web as a concept of linked webs. Interoperability is the key to integrate all the components and the functionalities a sensor web consists of (Delin and Jackson, 2000).

The development of cheaper, miniature, faster, and smart in-situ sensors has opened new data acquisition pathways to the generation of local information (Tao, 2003). This has led to the development of more systematic capabilities for in-situ data acquisition, the accessibility of in-situ sensor data and / or metadata from on-line geospatial data infrastructures and for the fusion of remote sensing observations and in-situ measurements: the concept of integrated Earth sensing (Teillet et al., 2002b). In addition, this allows the use of uncommon larger quantities of in-situ sensors in a certain area. The collection of in-situ (or ground) data or site-specific observations is an essential source of information (Beven, 2007). It provides ground-based benchmarks and calibration possibilities for remotely sensed data on a continuous base. In-situ sensors are less expensive per unit, have higher accuracy, and have better temporal resolution, while remote sensors provide much greater spatial

extent than do in-situ sensors. According to Liang et al. (2005), the benefit of the sensor web is that it integrates both in-situ and remote sensors and thereby achieves truly integrated sensing. Sometimes it is even the only way, data of required type and quantity can be obtained directly at the surface-atmosphere interface (Delin and Jackson, 2000). According to Chien et al. (2006), many science applications desire the high-resolution data gained by in-situ sensing. And at the 2002 World Summit on Sustainable Development, Aschbacher (in Teillet et al., 2003) even pointed out that "space-derived information generally needs to be combined with in-situ measurements and models to obtain a holistic picture of the Earth's environment. There is no Sustainable Development without adequate information about the state of the Earth and its environment". The properties of in-situ sensors in this context can be summarized as:

- limited area coverage;
- continual presence;
- instant response time;
- high temporal resolution;
- cheap hardware/deployment;
- dense spatial coverage.

and their functions as to provide:

- continuous and real-time data at specific locations;
- reference data for satellite-based retrievals;
- (on line) calibration data for model parameter assessments (and relations between parameters);
- (on-line) validation data for modelling processes on earth.

It is expected that the fusion of remote sensing observations and in-situ measurements for use in models at relevant scales, will lead to significant advances in the generation of validated geophysical and biospheric information products. The information gained has the potential to empower decision makers and managers to monitor remote environments, natural resources, hazards and disasters and to react upon via time-critical and location-specific decisions and management or via resource information management, risk assessment and hazard mapping. This allows for or is even essential to more accurate analysis and real-time processing / forecasting, and for more adequate control or management options (Teillet et al., 2002a and 2003). According to Beven (2007) it is the improvement of the representation of sites and boundary conditions that will be critical in the development of a new generation of environmental models that are geared towards the management of specific places, rather than general process representations. So, monitored data serve both diagnostic, warning and mitigation purposes (Delin and Jackson, 2001). In view of effective management a well-designed Sensor web should be flexible (different queries extract different data from the sensor network) and efficient (only relevant data are extracted from the network) (Dexheimer and Hannemann, 2004), and should also have a power saving protocol, which adapts to data load (Dam and Langendoen, 2003).

Continued and virtual presence is particularly important when investigating phenomena of a transient and spatial nature like natural disasters as floodings, forest fires and volcano eruptions. By its very nature, Sensor web provides spatial-temporal data consistent with that needed in a form for adequate investigation such disasters and also for environmental or geophysical modelling (Delin and Jackson, 2000). Such phenomena are characterised by a high spatial and temporal variability and this asks for an extensive monitoring and sensing system: Sensor web, which provides continuous, real-time data at specific locations. The significance of the Sensor web from a scientific (hydrologic) standpoint is that phenomena such as floodings can be mapped and assessed in real-time over a broad region rather than a collection of several individual observations (Delin et al., 2003).

The characteristics of Sensor web (especially in contradiction to conventional observations) can be summarized as:

- real-time acquisition of measurements;
- multi-mode acquisition of measurements;
- measuring in high spatial densities and at high frequencies;
- remote access and control of the sensor network;
- possibilities of feedback between Sensor web and model.

The corresponding advantages (as in comparison to conventional observations) are:

- real-time detection and reaction possibilities;
- location specific detection and reaction possibilities;

- improved process understanding;
- improved operational process / resource management;
- decreased management and mitigation costs;
- improved well-being of the society.

The scientific and technological challenges of this project are:

- The application of a sensor web for the spatially distributed and real-time monitoring of hydrological events by distributed information processing (what are the optimal spatial resolutions and optimal configurations of sensors, what type of sensors are needed (multi-mode acquisition), and what is their optimal measurement frequency);
- The combination of in-situ sensors with Remote Sensing to obtain estimations of events over larger areas to obtain more reliable and area representative data;
- The application of real-time feedbacks between spatial data bases, sensor web and models, and of on-line calibration and on-line validation of models;
- The use the sensor web results to improve the quality of modeled forecasts of hydrological events (via now-casting and data assimilation) and to improve location-specific and time-critical operational water management in order to adapt to or even to anticipate to these events.

2. Utilisation

Miniaturized sensors acquire a still increasing market share in the possibilities to observe reality. Together with remote sensors, they form a so-called web of different sensors: sensor web. In this project the application possibilities of such a sensor web take a central position. If this new sensor technology has been proven successful this project will stimulate the use and so the production of all kind of sensors in as much applications.

A sensor web is very useful in observing phenomena because it combines the advantages of a better temporal resolution with a greater spatial extent. Nowadays, this new technology is of great importance in the observation of phenomena in general and of those that change rapidly in time and space in particular. Especially in harsh, hazardous or particularly inaccessible environments (small) sensors will offer advantages by “seeding” small sensors via airplanes and by their remote access and control. This innovative technology will have as much impact on the use of all kinds of sensors as the Internet has had on the uses of computer technology. It will also cause a revolutionary leap in observation technology.

Sensor webs will appear to be quite helpful e.g. in giving an accurate (geographical) picture of the dispersion of air pollution substances. In former days this was a large problem because only a few sensors are used in a country and besides, these sensors take only a few samples of the air a day. With the arrival of small and cheap sensors large quantities of different sensors can be optimally distributed over a country to take air samples continuously and locally. In addition, Sensor web is also able to trace effectively the escape of dangerous air pollution substances. Sensor web must make it possible to cope with the distributed nature of the available data and to provide integrated information of these data.

Another example, which shows the extremely high importance of the application of a sensor web, is its use in natural disaster management, for example forest fires and floodings. Disasters typically are phenomena of a transient and spatial nature. With the aid of a sensor web water managers can observe real-time their management area in much larger detail than in former days, and next take corresponding measures adapted to the current and local situation. This might be joined by giving predictions or even public warnings. The robustness and built-in self-healing characteristics of the sensor system - also in harsh conditions like floods - are really necessary for its reliable functioning.

In this interdisciplinary project a detailed field experiment will be performed to observe water excess. This requires observation systems based on small sensors in combination with a wireless telecommunication system. This research project basically is aimed at two target user groups.

The first user group is the business sector concentrated around the development of (in-situ) sensor technology and its application in Sensor web technology. On the other hand, water boards (in this case of application) will become an important second user group who will apply solutions from Sensor web technology in their operational water management and want to take scientifically based time- and location specific measures.

Improved insight into rainfall – surface runoff events will provide better instruments to cope with these events or ways to minimize their unwanted impacts. In the context of water management - where situations of

climate change and the fact that the joint users make higher demands on the accuracy and the timeliness of the water management - actual information is becoming a more and more important asset in addition to all civil and water management facilities.

Even a third group of users can be distinguished: citizens and interested parties. They want to obtain actual data independently form thirds without the need to dispose of an own information system. From the safety and combating of calamities' point of view it is desired to make actual data available (generally and everywhere) and not only for the owners of monitoring and warning systems. The society wishes more and more data to be findable in a geographic context. Also people like to dispose of (near-) real time data of remotely accessible sensors.

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A practical implementation of a sensor network for geotechnical monitoring

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Abstract: GeoBeads is a sensor network for real time monitoring of ground stability and stability of infrastructural works. Alert Solutions started development of GeoBeads in December 2006. After laboratory testing Alert Solutions launched the first prototypes of GeoBeads for commercial use in July 2008. Its first application the monitoring of a continuous hillside landslide in the French Alps. A second prototype system is installed in the IJkdijk, a large test facility for stability of levees in the North of The Netherlands. In both areas the system is nonserviceable after installation. In October 2008 the first experience with GeoBeads and the first results of the IJkdijk experiment will be available for further analysis.

GeoBeads is built up by strings of sensor nodes. Each string consist of a cable that can measure up to 3900 feet and that can accommodate 128 sensor nodes. A total GeoBeads configuration can have numerous strings and can be extended with strings when applicable. The strings with sensor nodes surface the ground and connect to network gateways. These gateways send the data to a central network controller in an easy to export CSV file. Because of the miniaturised size of the sensor nodes (diameter 1 inch) the system can be installed by normal installation techniques, like hand drilling for vertical installation to limited depths or probing for larger depths. Each sensor node in GeoBeads can contain multiple sensors to simultaneously measure a collection of parameters. For its first applications the sensor nodes of GeoBeads were equipped with parameters important to analyse ground stability, such as pore pressure, temperature, inclination and moisture. Temperature measurement was added to indicate water flows through the ground package. Following the density of the network chosen at hand, a highly detailed and real time view of the underground can be retrieved.

Future research challenges

Following the first practical field tests with GeoBeads, future research challenges for large scalable sensor networks such as GeoBeads, include the following topics. Representation and visualisation of real time sensor data in a manner that supports decision making in events of calamity and integration of sensor data with mathematical modelling such as soil mechanics. Additionally for sensor networks installed in non-serviceable areas the following topics deserve further investigation. Increasing the life span of the sensors, self-calibration of the sensors in network topology, ensure reliability of measurement values through time, scale the network to very large areas (> 1 million sensor) without increasing complexity and adapt efficient methods of automated remote manipulation.

Data integration and information extraction

Making it explicit: The movement representation of Wireless Sensor Networks

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Abstract: This paper discuss one of the fundamental issues that is to develop movement representations as the unified model for understanding the creation (sensing), awareness (management) and sharing (use) of information being generated by WSN. In particular, it focuses on the main research challenges of the characterisation of spatio-temporal elements for such a movement representation. Originally, what is seen (or otherwise detected through sensors) is understood by focussing on specific sensory data that become the cue for modelling something else such as events (e.g. traffic accident, storms, and urban sprawl). WSN will act as disruptive, in the sense that it will provide continuous space-time views of objects and their environment. Therefore, it is important to highlight that any movement representation in continuous space unavoidably raises the issue of context. The GIS paradigm of representing the real-world as different layers containing information from different sources of mobile sensors will not be applicable anymore. The information generated by WSN will produce virtual worlds that will be understood through the interpretation of movement representations of sensors that do not necessarily have any connection with direct sensing.

Keywords: wireless sensor network; movement representation; mobile sensor data.

1. Introduction

Wireless Sensor Networks (WSN) have recently emerged as an important platform that allows retrieving context-environment information as well as the movement of objects such as people, cars, and animals. The sensors are increasingly being carried by the general public. These devices are being miniaturised and integrated in wearable artefacts, including clothing. They are becoming ubiquitous technology upon which the tracking of the location of these sensors will allow us to monitor dynamic geographical phenomena (e.g. traffic pollution) at a much more detailed level that would otherwise be possible. Without any doubts, WSN have emerged as a technology that will be applied to any purpose, in any place, at any time.

There have been a large number of conferences on various technical and scientific aspects of WSN and their applications, focussing on the huge amount of sensory *data* generated by WSN rather than on the kind of *information* to be generated by using them. The WSN data should be a ¨difference that makes a difference¨, that is, a measurement about which someone cares (Poore and Chrisman 2006, p. 520). Therefore, thinking of WSN should also put the emphasis on *meaning* in the sense that the data about the movement of objects and their environment can only be truly understood through the use of *space-time models* that need to be developed in order to interpret the diversity and the huge amount of direct sensory data to be generated by WSN (Galton and Worboys 2005, Goodchild 2000, Harley 1989).

However, the aim of building space-time models has been overlooked by the *paradigm of simplicity*. Despite the recognition that the world is complex, the spatio-temporal models have been developed to simplify the real-world, gather the essence of it by carrying on limited measurements (observations), and finally, be employed to construct ¨what-if¨ scenarios as an aid to understanding and structuring debate (Churchman 1968, Johnson 2001). This parading is gradually being shifted due to the realisation that WSN is changing the way measurements are collected, and in its turn, it will change the way space-time models are developed in the pursuit of accurate answers to social, environmental and economical problems. Batty and Torrens have already

stated that ¨… from predictions of the stock market and the general performance of the economy to more local issues such as demographic change and traffic movements in cities seem beyond our understanding, not least our control, in that extraneous events now seem to dominate their behaviour. Although this may always have been the case, the models that were fashioned a generation or more ago now seem wholly inadequate.¨ (Batty and Torrens, 2005, p. 746).

This paper discuss one of the fundamental issues that is to develop space-time models as the unified representation for understanding the creation (sensing), awareness (management) and sharing (use) of information being generated by WSN. In particular, it will focus on the main research challenges of developing a movement representation for WSN.

2. The elements of a movement representation

In traditional GIS, the geometric primitives point, line and polygon have been widely accepted as elements of object-based representations and regular grids or *raster* for field-based representations. In the case of movement, there is no universally established characterisation of the elements of representation for a moving object, although there are commonly used "metaphors" for analysing movement, such as "movement as trajectory", "movement as activity" or "movement as balance" [3]. However, WSN are composed of a large number of nodes, densely deployed within or very close to a phenomenon of interest (Akyildiz *et al*. 2002). This requires a movement representation that can allow us to improve the knowledge about the spatial distribution that best fit the scientific requirements for gathering sensor data (Werner-Allen *et al*. 2006). Data collected by the nodes are typically transmitted through the wireless network using a certain radio frequency to a node sink, which supports the storage of the transmitted data and their communication with other devices based on their spatial proximity. However, it is still very difficult to represent the overall spatial distribution of the movement of the nodes in a environment over time. Therefore, the question is what kind of movement representation could be deployed? There are probably four possibilities. They are: Trajectory, Vector, Network, and Flow.

Trajectories: They represent the spatial track of a node in a fixed time interval (Andrienko et al. 2008). Other authors use the term "spatial-temporal route" (Hagerstrand 1970) or "geospatial lifeline" (Hornsby and Egenhofer, 2002) giving emphasis to the temporal component. Thus trajectory refers to all positions occupied by a node between the start and the end of the movement. Although in practice not all positions are known, they may be interpolated from measurements. While the trajectory is the most commonly used element in the analysis of movement, it has several limitations that should not be neglected. For example, the specification of its start and end is always required for each trajectory, making more difficult the analysis of collective movement of the nodes (Figure 1).

Vectors: They are non-dimensional entities of which velocity and spatial-temporal position are known. Other attributes may be acceleration or rotation angle. Movement vectors differ from trajectories in that the former are a granular representation of movement and they are not associated to a specific node, therefore their previous and subsequent positions are not known (Figure 2).

Figure 1. Representations of trajectories: (a) the direction of trajectories, (b) the width is associated to speed.

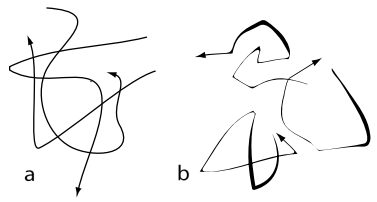
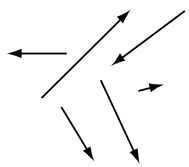
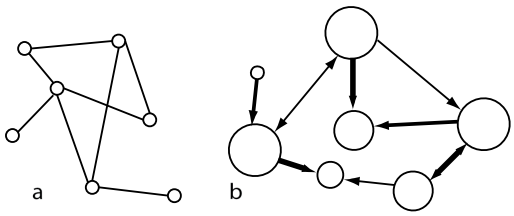


Figure 2. Representation of vectors showing the movement of a set of nodes.



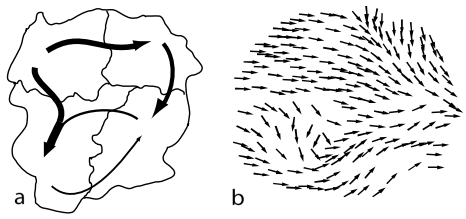
Networks: They are graphs representing the topology and geometry of the movement restricted to an interconnected linear system. Nodes represent origins, destinations or passing through while arcs represent the physical channels of movement with a finite capability. Arcs may be "direct" or "not directed" according to the specification or not of the direction of the movement. In the former case they may be "unidirectional" or "bidirectional". Besides, every arc may have an associated width representing the implied cost of an element to go through (Miller and Shaw 2001) (Figure).

Figure 3. Representations of networks: (a) nodes and arcs (b) radius is associated to node's number of connections and line's width is associated to cost.



Flows: They are representations of the amount of movement through the space. Although it is a term highly related to *networks*, flows have also been utilized to represent generalised movement properties. Tobler (2003) makes a clear distinction between two types of flow representations: (a) the "discrete flow" that is represented by vectors with origin and destination and (b) the "continuous flow" in which the whole space is occupied by a vector field representing the direction and velocity of the flow. These two types correspond with element-based and field-based representations respectively (Figure).

Figure 4. Representations of flows: (a) discrete flow (b) continuous flow.



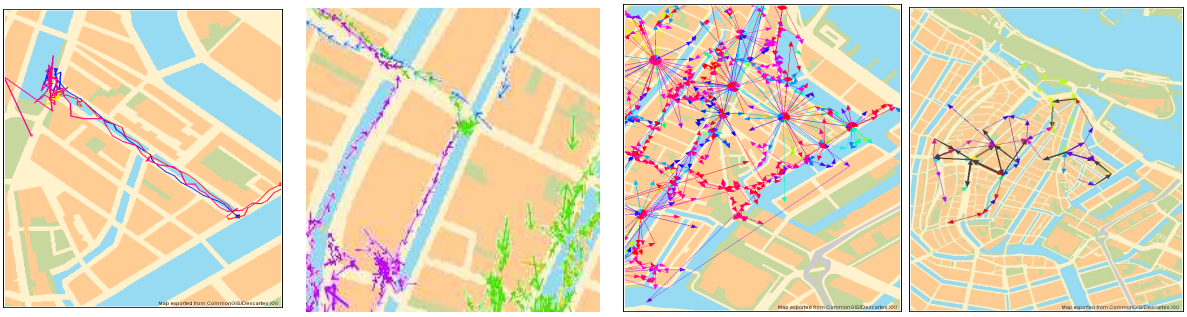
3. Computing the elements of representation

The experiment consists of a set of GPS locations of a set of 300 mobile sensors registered with 10 second intervals. The movement was represented as vectors, trajectories, networks and flows. The trajectories were generated by the interpolation of the positions of each node. The results were continuous paths with start and end times, movement duration, covered distance and average velocity (Figure 5a). In addition, velocity, time and distance for each segment of the trajectory were calculated. In order to create the vectors, the speed and the bearing for each position were calculated, thereby building a velocity vector for each recorded location of a node (Figure 5b). The networks were built from the aggregation of the trajectories between zones of interest (attractors), calculating the extent of movement between zones and the number of times each zone was visited (Figure 5c). The flows have been generated by the generalization of the trajectories (Figure 5d).

4. Conclusions and future work

WSN will act as disruptive technology, in the sense that it will provide continuous space-time views of nodes and their environment. Therefore, it is important to highlight that any movement representation in continuous space unavoidably raises the issue of realism. The GIS paradigm of representing the real-world as different layers containing information from different sources of mobile sensors will not be applicable anymore. The information generated by WSN will produce virtual worlds that will be understood through the interpretation of movement representations of nodes that will play an important role in the interoperability of WSN.

Figure 5. Examples of the computed elements for the movement representation of nodes



(a) Trajectories (b) Vectors (c) Networks (d) Flows

The primary research challenge is to determine what type of elements of a movement representation can be used to gather geographic knowledge of the spatial distribution of WSN over time. In this paper, we describe the four types of elements and their implementation through a practical experiment. They are: trajectory, vector, network, and flow. The results demonstrate that the environment clearly influences the collective movement, which is made evident by the patterns found in the network and flow representations. This indicates a common, emergent collective movement and the presence of structured flows among the different nodes. Moreover, the vector representation has also been useful to explain why the node's movement tends to reduce at high density areas. Further research will focus on applying the four types of movement representations to improve context-awareness for the interoperability in WSN.

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Inference Grids for Environmental Mapping and Mission Planning of Autonomous Mobile Environmental Robots

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Abstract: Mobile sensing platforms provide a new modality for exploring the natural world. Robotic vehicles can be quickly deployed to new areas of interest and can have their sensor payload configured to the specific natural and environmental processes to be investigated. Building integrated sensing architectures that coordinate the operation of stationary networks and mobile platforms will allow researchers to take advantage of the strengths of both modalities, opening up new opportunities for scientific research and environmental monitoring. Among the various challenges to be faced, there are two key interrelated issues that are common to autonomous mobile platforms: the representation and modeling of natural processes using the sensor data being collected, and the use of this information to provide guidance, navigation and control for the mobile platforms. Both are addressed using a stochastic lattice-based framework for robot mapping, planning and control called the Inference Grid. In this paper, we will review our work on environmental robotic platforms, discuss how Inference Grids are used for natural process representation as well as for planning and control of autonomous robot vehicles, and show selected experimental results from field tests.

Keywords: environmental robotics; environmental research and monitoring; robotic science platforms; aerobots; Inference Grids.

1. Introduction

Sensor networks with geographically stationary nodes can provide long-term observation of areas of interest with modest power and bandwidth requirements, at low to moderate complexity and cost. However, the sensor payload available at each node of a stationary network is limited and pre-configured prior to installation. Furthermore, these networks cannot be easily moved to another area when a new event occurs.

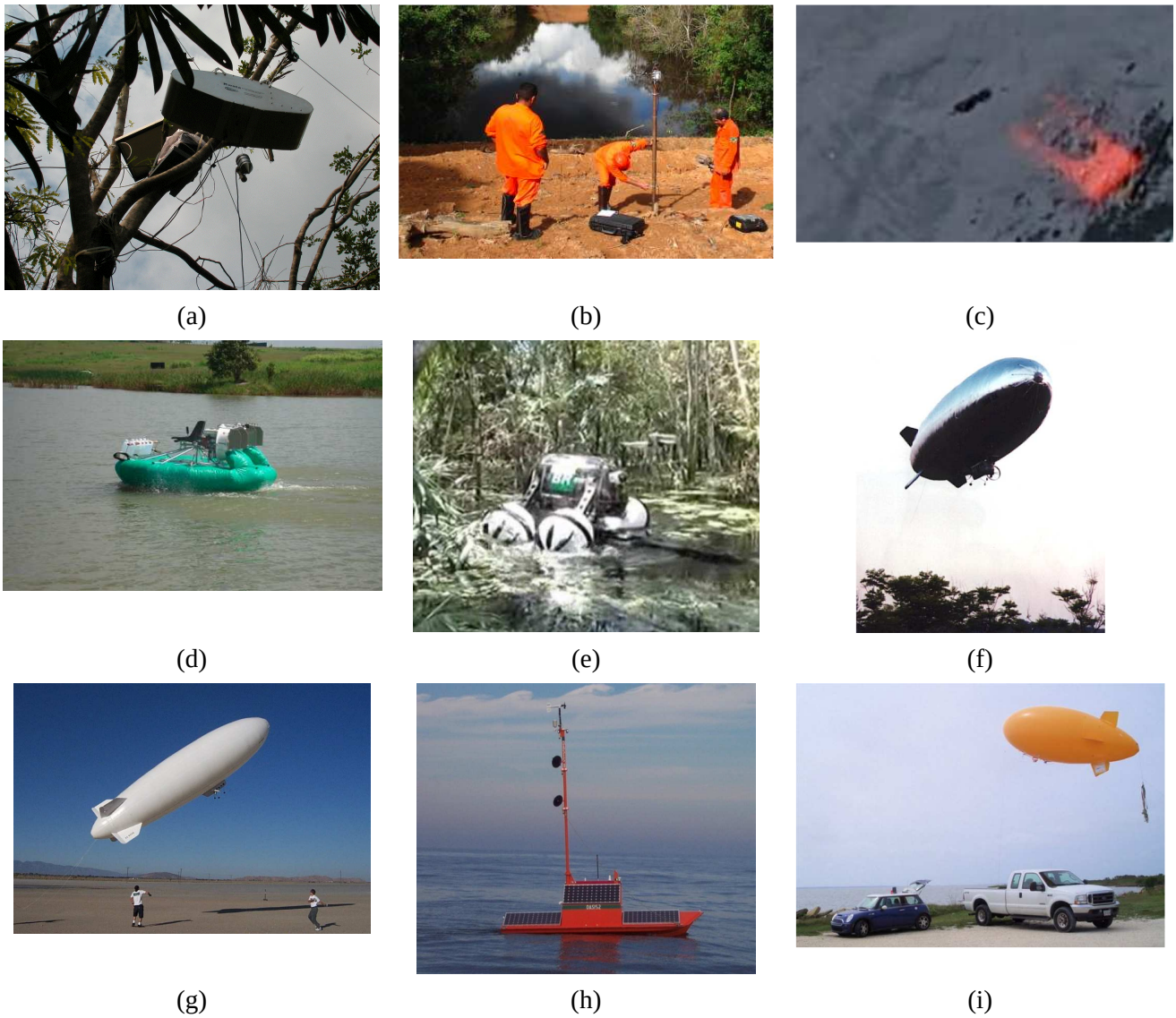
Mobile sensing platforms, on the other hand, can potentially be quickly deployed to new areas of interest and can have their sensor payload configured to the specific natural and environmental processes to be investigated. The drawback is that mobile platforms are also inherently more complex and expensive, and have greater power and bandwidth requirements. Building integrated sensing architectures that coordinate the operation of stationary networks and mobile platforms will allow researchers to take advantage of the strengths of both modalities, opening up new opportunities for scientific research and environmental monitoring.

The use of mobile sensing platforms for sensing a changing world faces several challenges. While robotic systems have provided very successful platforms for scientific research elsewhere in the Solar System (such as the Mars Exploration Rovers or the planned Mars Science Laboratory), it is noteworthy that the use of robot explorers on Earth is still in its infancy. Underwater remotely operated vehicles (ROVs) are being used extensively, and some groups have deployed fixed-wing unmanned aerial vehicles (UAVs) and autonomous underwater vehicles (AUVs) for atmospheric or oceanographic science data acquisition. However, very little has been done in exploring terrestrial environments and non-oceanic biota with other types of robotic vehicles.

Driven by a common interest in exploring the natural world, the authors have been developing and deploying a variety of sensing systems over the last fifteen years [5]. These include stationary sensor networks, remotely operated underwater vehicles, autonomous airships, ocean surface robot boats, and amphibious robot vehicles (Fig. 1). Some of these systems have been deployed in the Brazilian Amazon rainforest, while others are being tested in the Chesapeake Bay, the Mohave Desert, or in Campinas, Brazil.

In this paper, we discuss two key interrelated issues that are common to the systems we are developing: 1) the representation and modeling of natural processes using the sensor data being collected, and 2) the use of this information to provide guidance, navigation and control for the mobile platforms. Both are addressed using a stochastic lattice-based framework for robot mapping, planning and control called the Inference Grid.

Figure 1. Stationary and mobile sensing platforms. (a) A Kwata sensor node deployed from a tree in the Amazon floodplain and used to measure environmental variables and water height and (b) The Kwata-Erosion system, used to measure changes along a riverbank in the Amazon. (c) A ROV vehicle used to explore the bottom of the Rio Negro (Black River). (d) An experimental prototype of a robot hovercraft for Amazon research. (e) An amphibious rover for exploring the Amazon floodplain. (f) The AURORA robotic airship, developed for environmental monitoring applications [3, 4, 5]. (g) The JPL aerobot, an autonomous robotic airship, during tests in the Mohave desert [2]. (h) A NOAA-funded OASIS robot ocean surface research vessel during tests in the Chesapeake Bay [1]. (i) A JPL/CMU aerostat that operates jointly with the OASIS robots for detection of harmful algal blooms (HABs). Systems (a) and (b) were developed by R. F. Tavares Filho and A. Pavani Filho, and are commercialized through the SOLBET company, Brazil; (c) and (d) were developed by R. F. Tavares Filho and A. Pavani Filho at CTI, Campinas; (e) was developed by Ney Robinson, CENPES/Petrobras, Brazil; A. Elfes led the development of (f) while at CTI, Campinas, and of (g) at JPL; G. Podnar, CMU, leads the development of the coordination and control architecture for (h) and (i).



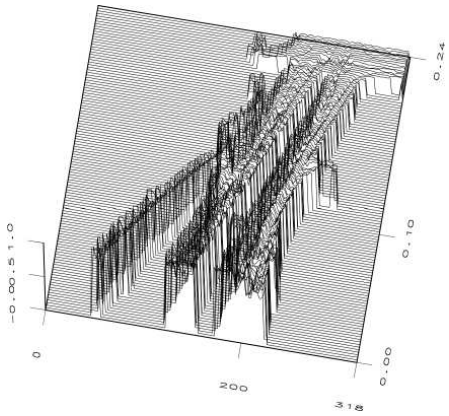
2. Modeling of Natural Processes and Robot Control Using Inference Grids

Observation of natural processes is limited by spatial and temporal sensor footprint, coverage, resolution, sampling rate, and measurement uncertainty. Markov Random Fields (MRFs) provide a natural formulation to represent spatially and temporally distributed observations, and are used extensively in the Inference Grid framework. We use a discretized version of MRFs, called a spatio-temporal Markov Random Lattice (ST-MRL), to encode the data obtained by the different sensors and agents. Each cell in the lattice corresponds to a spatial volume and a time slice, and stores a stochastic vector with the state estimates of the various processes that have been measured at the given location and time interval. Efficient estimation methods are used to update the lattice as new observations flow in from the various sensors and platforms being used [7]. Examples are shown in Figs. 2 and 3.

Associated with the ST-MRL we also maintain additional stochastic lattice-based layers for inference and decision, which are used to plan and control the activities of the robot platforms [4,]. These layers include vehicle navigation cost and risk to reach an area of interest; hypotheses of scientific events to be explored further; information metrics such as entropy to determine how the knowledge of a natural process is evolving, and where critical information is missing; and others. The augmented informational structure that incorporates both the ST-MRL and the information-theoretic inference and decision layers is called an Inference Grid (IG) [6]. An example is shown in Fig. 3.

Figure 2. Airborne identification and tracking of a road. (a) Imagery collected from the Aurora autonomous airship [4] (see also Fig. 1 (f)) is used for spectral identification and tracking of a road for environmental monitoring purposes. (b) A stochastic Inference Grid showing the spatial probabilities of road detection.

(a)



(b)

Acknowledgements

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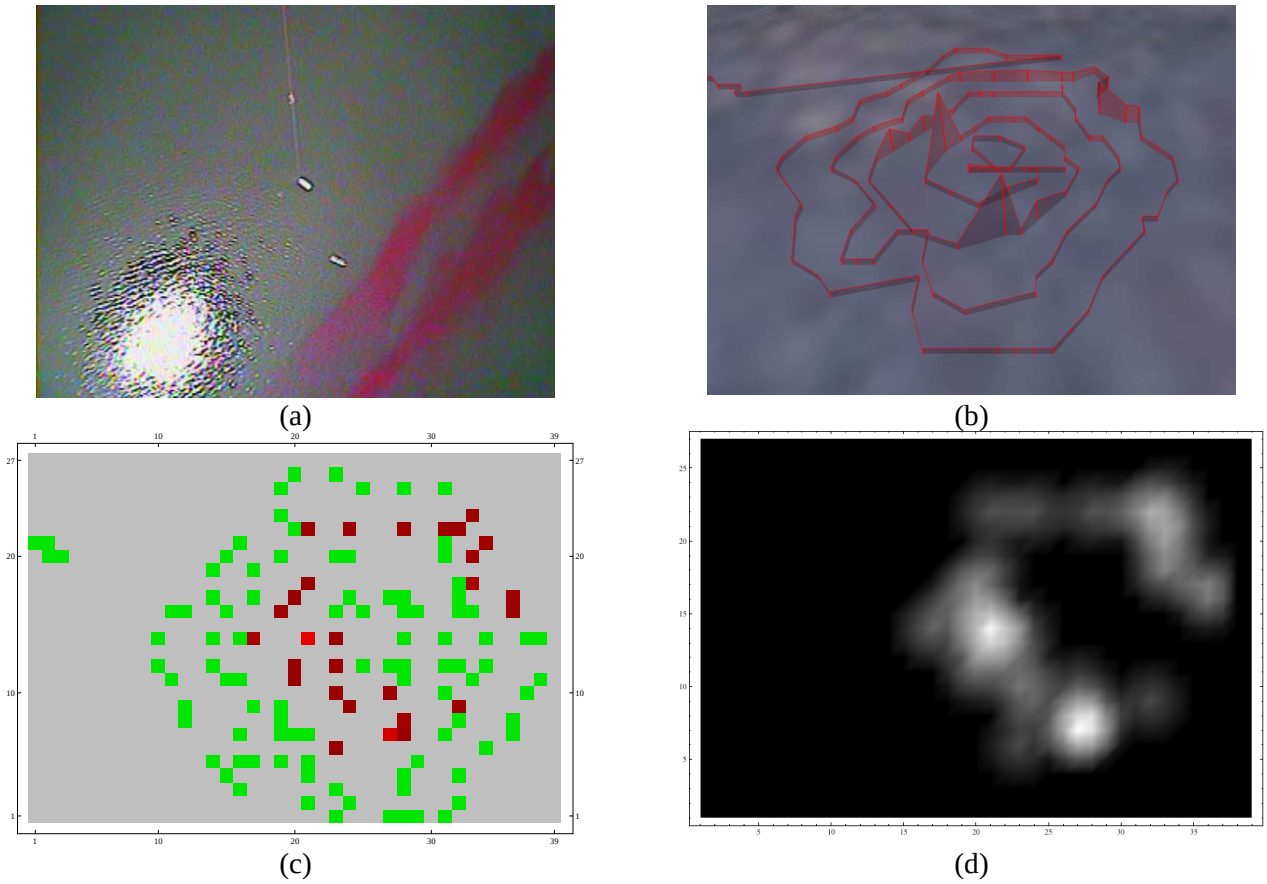
Figure 3. Identification and characterization of harmful algal blooms using the OASIS robot boats (Fig. 1 (h)) and the TAOSF coordination architecture [1]. Pane (a) shows an aerial view from the aerostat (Fig. 1 (i)) of the test area in the Chesapeake Bay; the OASIS robot boat platform (Fig. 1 (h)) is in the lower part of the image, close to the rhodamine dye tracks that serve as a surrogate for algal blooms during field testing. (b) The search pattern executed by the OASIS boat to find the surrogate algal bloom. (c) An Inference Grid showing the areas with high probability of dye presence (in red), high probability of dye absence (in green), and high entropy or lack of information (in grey). (d) An Inference Grid with inferred hypotheses of algal blooms (dye tracks). The areas of high entropy are used to replan the search pattern of the boat [1].



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A Location Sensing Healthy-Living Adviser Technology Development and Simulation

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Abstract: Location based technology can be employed to provide information which can change user behaviors. Our research focuses on the usage of information technology in the healthcare domain. We aim at exploring the possibility of developing a decision support system based on mobile and location technologies. The system is expected to locate users and provide them with advices on physical activities and help them adopt a healthier lifestyle.

Keywords: Location-based technology, mobile technology, health, physical activities, environment.

1. Introduction

1.1 Location-based technology

Location-based services (LBS) can be found in navigation guides, tourist/shopping guides, friends finding, etc. They use location-based technologies to identify your physical location, as well as your surrounding environment to provide information. Looking into those applications of location-based technologies, we find out that most of the location-based systems function as an information provider. Users can get information about their physical location, nearby services (e.g., hotels, restaurants), routes to their destinations, etc. More recent researches are regarding location-based systems extending into more personalized, interactive and dynamic, so that they provide the most suitable information for different individuals, such as GeoVecter (Geo Vecter, 2008), etc. At the same time, users can also attach information (messages, photos, etc.) to a geographic location, such as the application of Urban Tapestries (Urban Tapestries, 2008). In this way, some personal experience can be shared among common users who cross the same place. The communication platform provided by LBS can also enable a social network. Thus you can let your friends know where you are, find out where they are and chat with them on a real time basis (Facebook application, 2008).

Information can be provided in terms of actual information, describing the state of the system at hand or may be presented in terms of recommendations in an attempt to stimulate particular kinds of user reactions. There seems to be a general belief that the availability and use of information will positively impact the use of the built environment and improve comfort. We are interested in the influence of information, especially the location-based information on user behaviors.

1.2 Persuasive Technology

With the development of information technologies, the persuasion techniques also evolve in the 21st century. For example, computers can be used as a media to persuade people into certain behavior change. According to Fogg (2002), the technology either designed or employed to intentionally changes attitudes or behaviors through persuasion and social influence is defined as “Persuasive technology”. When the tools of persuasive technology are mobile devices, the persuasion can intervene at the right time, context and in a convenient way. Because people always carry them around, they are more also personal. But compared with less personal desktop machines, this mobile persuasion is on the risk of low acceptance due to privacy issues.

Persuasive technologies are regularly used in commercials, sales, politics, religion, public health and so on. Especially in the domain of healthcare, there exist many researches on how to persuade individuals to follow healthier lifestyles through tools (e.g. by monitoring blood sugar levels), media (e.g. by simulating the effects of smoking), or social influence (e.g. by comparing performance with others (Fogg, 2002). The application of persuasive technology in this domain stays in the focus of our attention.

1.3. Environment and Health

"We shape our buildings, and afterwards, our buildings shape us."—Winston Churchill

According to the WHO, in 2005 approximately 1.6 billion adults (age +15) were overweight, and at least 400 million adults were obese. Overweight and obesity can lead to many serious health problems. WHO further projects that by 2015, approximately 2.3 billion adults will be overweight and more than 700 million will be obese. Fortunately, this gloomy future is largely preventable by taking care of the daily diet and increasing the amount of physical activities -at least 30 minutes of regular, moderate/intensity activity on most days (Obesity and overweight, 2008).

There are many factors that can influence the exercise behavior. The research of WHO indicates a close relation between health and the built environment. For example, the availability of open spaces, the nature, and the recreational facilities can affect the amount of physical activity of the residents. Besides the location, the building materials, housing design and the air quality within the building can determine whether the environmental quality is good enough for daily activities, including exercising (Health places, 2008).

If people can receive information about the environmental conditions nearby their current location, they can make a better choice of where to exercise and how to exercise. Therefore, the relationship between users and their surroundings can be more interactive. In principle, location-based technologies and mobile technologies can be used to locate users and provide them with information and suggestions which may change their behaviors towards adopting a healthier lifestyle. With this initiative, we aim at combining location/mobile technologies and persuasive technologies together to motivate people to become more active and live healthier.

2. Research plan

The research question of our research is "how can we promote positive exercise attitude by means of location-based services?" To be more specific, the objective of the research is to explore the potential of location-sensing technology in the application area of improving human well-being. First we intend to find the suitable concept model concerning exercising behavior. Then we aim at developing a decision support system based on this concept frame with the employment of the location sensing technologies. Subsequently, we will elaborate models of user response to information provision in the system and testing the potential of the approach in real-life situations.

3. Concept model

The concept model we are looking for is about the behavior of doing physical exercises. Among the many models concerning attitudes and behavior, we focus on the one of HBM (health-belief model) which is developed by social psychologists Hochbaum, Rosenstock and Kegels in 1950s (Health belief model). This conceptual model is further explained by Glanz, K., Rimer, B.K. & Lewis, F.M. (2002) in **figure 1**. In this model, the likelihood of a health-promoting behavior depends on the demographic situation and the social status of people, their prior attitudes towards the behavior, their perceived threat of getting the health problems and also cues to action such as the reminder from the media. For example, the information provided by a decision support system can play the role as the "cue to action" to change the likelihood of behavior.

In addition to the concept model, we find other variables from the literature which can also influence physical activities. For instance, the environmental factors are not included in the HBM, which is indispensible in our system. For example, safety of the neighborhood, distance to the facilities, access to nature, and etc. can influence people in conducting physical activities (Alfonzo, 2005). To conclude, the variables are divided into three categories: individual factors, social factors and environmental factors.

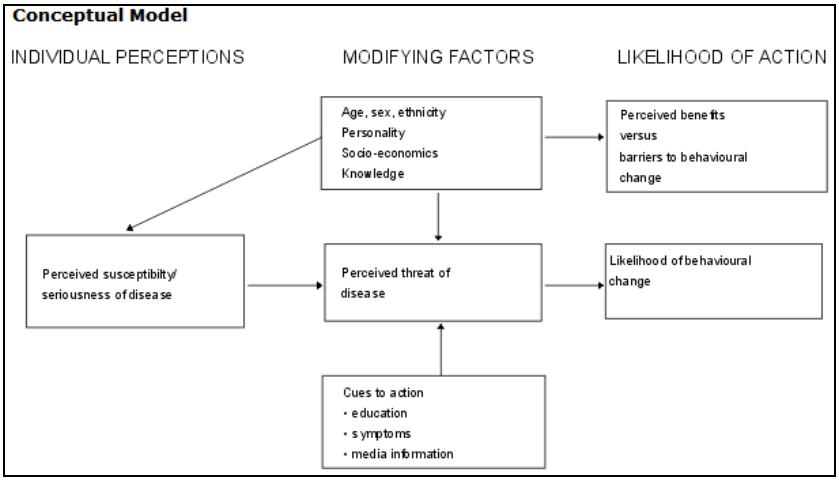

Figure 1. Health belief **model**

4. System Design

The system aims at promoting healthy living between its users and functions as a location-based activity adviser; its main use is to provide personalized advice and suggestions on where and when to exercise physical activity with a view to motivating users towards a healthier lifestyle.

4.1 System Architecture

The system is expected to include a mobile electronic device (e.g., mobile phone), a device monitoring user activities (calculating calories burning) and an activity adviser system. The system architecture is illustrated in **Figure 2**.

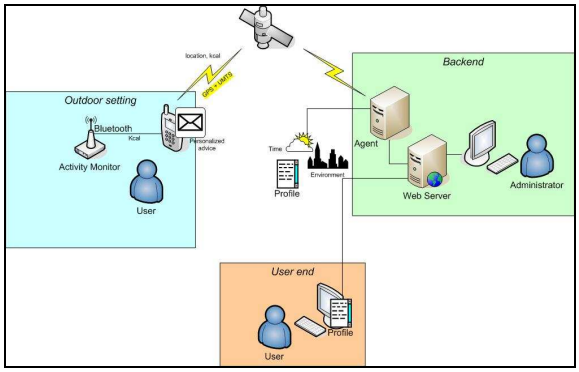

Figure 2.System architecture

4.2 System Components Architecture

This system is made up of the following components:

Location component

Based on the GPS coordinates of the user location, the agent identifies the current location such as at work, at home, on the road, etc. The features of urban/natural environments such as sports facilities, parks, lakes, bike routes, or sports events are also highlighted as good recommendations for exercising physical activity.

Environment component

This component takes location and time as input and retrieve surrounding environment condition through web server, for example, the ambient temperature, sun light, air quality, humidity, wind speed, etc.

Activity component

The amount of activity is measured by a specialized device in terms of calories. The calculation is based on the age, weight, gender, and the activity intensity of the users. This component takes both the activity target and current activity into account in order to decide the level of performance achievement.

Profile component

Personal profiles are defined by users which consist of gender, age, weight, height, possible health problems, daily activity, living area, working place, hobbies, family status, etc.

Time component

Time component specifies the time value like season, date, time of the day according to the current time. The time value is also a factor influencing the choice of activity.

Planning component

Daily agenda can be set beforehand and the previous activity is stored as a reference. Comparing the current activity with the agenda and history, the planning agent can check the consistency and prepare an activity plan for users.

5. Questionnaire design

Before we start the system development, it is essential to verify our concept model and the system design. Thus we design a questionnaire with the purpose to find out the user acceptance of this "activity-adviser" concept, and especially how they react to different kinds of the advices. From the results of our questionnaire, we expect to find out how the different factors (individual, social, environmental) will influence the attitudes towards advices and the activity patterns which the participants are following as well.

6. Further research

After analyzing the results of the questionnaire we will redefine the important variables that we consider related to the physical activities. The next step is to set up a "Wizard of Art" study with the preliminary system. We will use one mobile device with GPS and one activity measuring device. Based on personal profile, current performance and location we will provide activity advices ourselves by sending SMS. If they follow the advice and change their behavior towards more active, we can assume that this system can have impact on behavior change. This will give us the confidence to continue with developing the real system, which is able to generate advices automatically. After the development and implementation of the system, we will test it in a real experiment, verify and elaborate our concept model.

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Networked Architecture for Robotic Environmental Ocean Science Sensors

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Abstract:

This paper describes an architecture for environmental science sensors deployed on a fleet of networked unmanned extended-deployment autonomous ocean surface vessels. This architecture allows one land-based human scientist to effectively supervise data gathering through a web of widely-dispersed mobile sensors supported by multiple robotic assets to enable in situ study of phenomena at the interface between the ocean and the atmosphere. In addition to meteorological and ocean surface data, the system supports characterization of Harmful Algal Blooms (HABs).

Keywords: Telesupervision; Sensor Web; Harmful Algal Blooms; Inference Grids.

1. Introduction

Gathering and disseminating data on ocean processes is crucial for meteorological and ecological studies. This paper describes a multi-robot science exploration architecture and system called the Telesupervised Adaptive Ocean Sensor Fleet (TAOSF). TAOSF is based on the Multilevel Autonomy Robot Telesupervision Architecture (MARTA) [1, 2, 3]. TAOSF supervises and coordinates a fleet of robotic sensor boats, to enable in situ study of phenomena at the ocean/atmosphere interface, as well as on the ocean surface and sub-surface.

The TAOSF system is applicable to the study of dynamic processes such as coastal pollutants, oil spills, hurricanes or harmful algal blooms. More generally, it can be used in a variety of areas where multiple sensing assets are needed, including ecological forecasting, water management, carbon management, disaster management, coastal management, homeland security, and planetary exploration.

Environmental ocean sensing is typically supported by satellites, aircraft, buoys, and crewed research vessels. Satellites and aircraft are limited by cloud cover, temporal/geographical coverage, and resolution; while manned research vessels are expensive to deploy, and buoys cannot be repositioned to specific areas of interest.

The National Oceanic and Atmospheric Administration (NOAA) has been addressing some of these constraints through the development of robotic senor boats called OASIS (Ocean-Atmosphere Sensor Integration System) which are long-duration solar-powered autonomous surface vehicles (ASVs), designed for global open-ocean operations. One of the key objectives of our research is to enhance the science value of multiple robotic sensing assets, such as the OASIS vessels, by coordinating their operation, adapting their activities in response to sensor observations, and allowing a human teleoperator to supervise these multiple assets efficiently. This approach integrates well into the “Sensor Web” concept, that is, providing within a single information system a geographically and temporally wide array of sensor data. This is useful by providing simultaneous physical phenomena measurements that can otherwise only be achieved by laborious data collection and collation.

The first field application chosen for TAOSF is the characterization of Harmful Algal Blooms (HABs). In the following sections, we will discuss the TAOSF architecture, describe field tests of the system conducted under controlled conditions, and present a result from these tests.

2. Telesupervised Adaptive Ocean Sensor Fleet

2.1 TAOSF Architecture

The TAOSF system architecture (Figure 1) provides an integrated approach to multi-robot coordination and multi-level robot-human autonomy. It allows multiple robotic sensing assets (both mobile and fixed) to function in a cooperative fashion, and the operating mode of different robots to vary from full autonomy to teleoperated control.

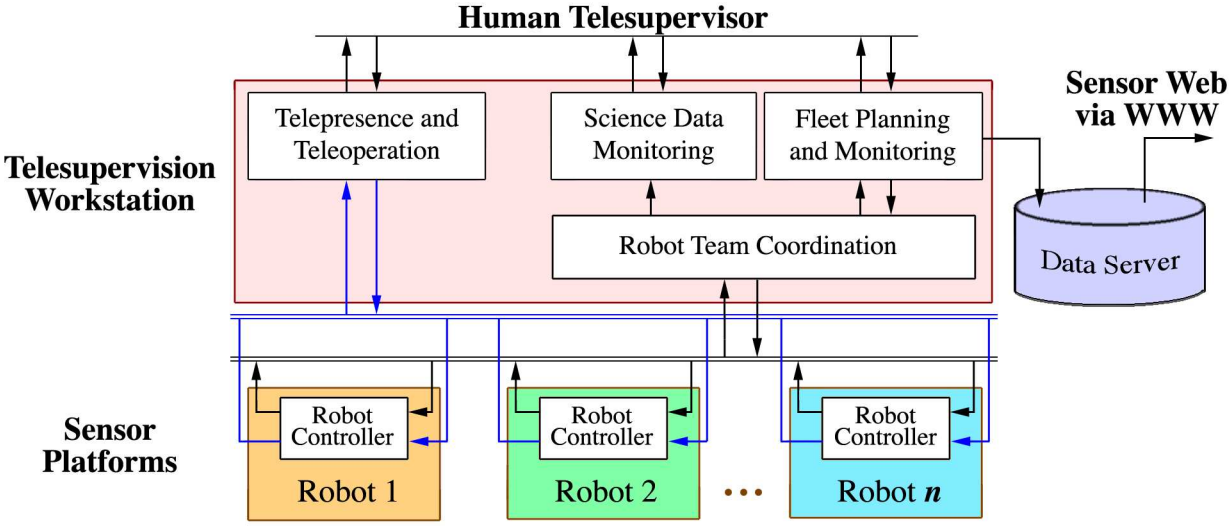

Figure 1. TAOSF Telesupervision Architecture.

High-level planning and monitoring allows a human telesupervisor to assign to a fleet of robotic assets high-level goals, such as specifying an area of ocean to investigate, which are then automatically subdivided and operational commands sent to each robot by the Robot Team Coordinator. As the robots execute these plans their operation is monitored both by the Robot Team Coordinator module and by the human telesupervisor. Adaptive replanning of the robot assignments is based on sensor inputs (dynamic sensing) and coordination between multiple assets, thereby increasing data-gathering effectiveness while reducing the human effort required for tasking, control, and monitoring of the vehicles.

Multi-level autonomy includes low-level autonomy on each independently-operating robot; autonomous monitoring of the fleet; adaptive replanning; and when necessary, intervention by the human telesupervisor either with manual replanning, or by taking direct control of a robot via teleoperation.

Algorithms for science analysis of the acquired data can perform an initial assessment of the presence of specific science signatures of immediate interest both onboard each robot, and at the telesupervisor's workstation. Web-based communications support both control and communications over long distances of the robotic fleet, and the sharing of currently-sensed and historical data with remote experts.

2.1 OASIS Platforms and Infrastructure

The NOAA-funded OASIS Platform is a long-duration solar-powered autonomous surface vehicle (ASV), designed for autonomous global open-ocean operations (Figure 2). The self-righting platform is approximately 18 feet long and weighs just over 3000 lbs. As a sensor-web-connected platform, each OASIS communicates via spread-spectrum radio, cellular data phone, or an Iridium satellite link.

Multiple platforms have supported development of higher-level system functions through real-world testing in Chincoteague Bay and Pocomoke Sound in southern Maryland. Environmental sensors onboard each

platform enable the collection of data on concentrations of chlorophyll-a (for algal concentration measurements), as well as water surface salinity and temperature data. Mast-mounted meteorological sensors allow acquisition of atmospheric measurements, including wind speed, wind direction, air temperature, barometric pressure, and relative humidity. A digital imaging system provides remotely-located scientists with images of atmospheric and sea conditions. The platforms have been augmented with fluorometers for measuring concentrations of rhodamine water-tracing dye. Dye is deployed in patches to simulate HABs thus allowing reliable development and testing of navigation and mapping algorithms.

In the current deployment configuration, both engineering telemetry (GPS position, roll, pitch, yaw, battery voltage, &c.) and science sensor data are communicated between each robotic platform and NASA's Goddard Space Flight Center via the Internet. It is from this point that NOAA weather researchers would receive data on ocean/atmosphere interface sensor data.

For investigating an algal bloom, researchers at Carnegie-Mellon University take control of the platforms and provide the high-level planning and monitoring. The weather-related data is not interrupted, but the additional sensing for investigating the algal bloom is brought online to map the extent of a bloom, chlorophyll concentrations, and with additional sensors, eventually allow a land-based biologist the ability to determine the species of the algae to assess whether it is harmful. If it is, local authorities can be notified at aquaculture businesses, fisheries, and beaches.

The data collected is archived on a data server where both immediate and historical data can be accessed by researchers via the World Wide Web.

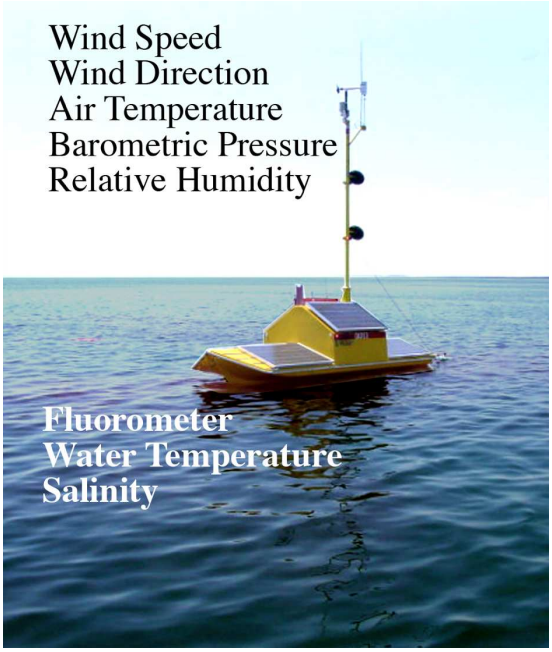

Figure 2. *OASIS Platform with atmospheric and sea water sensors identified.*

3. Experimental Results and Discussion

Figure 3. *OASIS-2 and OASIS-mapping a patch of rhodamine water-tracing dye.*

For controlled experiments such as mapping while compensating for drift currents, geometric patches of rhodamine water-tracing dye are laid; here as two parallel stripes (Figures 3 and 4). An aerostat, tethered to a manned tender boat, carries an instrument package aloft including GPS, altimeter, compass, and video camera to provide validation images of data gathered by OASIS platforms that are mapping with fluorometers.

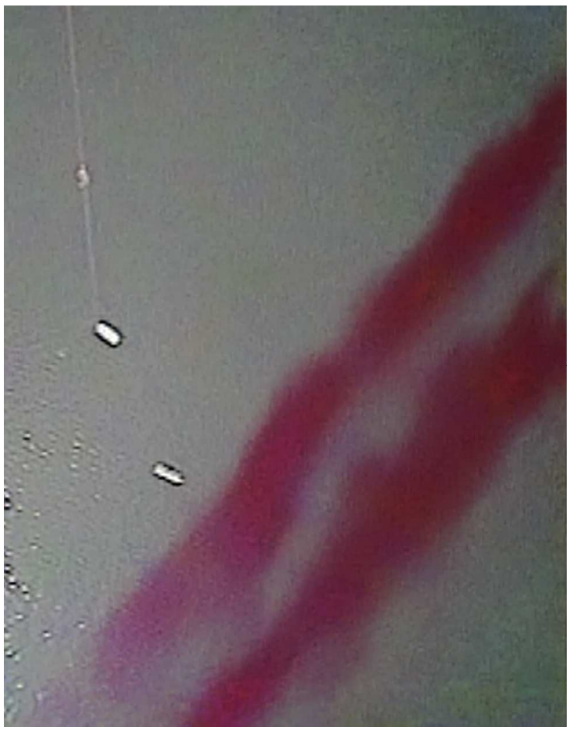

Figure 4. *Aerial view of dye patch, aerostat tender boat and OASIS platform.*

For analysis of science sensor data, we employ an implementation of Inference Grids [4] for bloom measurement and mapping. The rhodamine dye concentration measurements taken by the OASIS platforms during field tests were used as input to the Inference Grid mapping process. The fluorometer measurements were used to compute the presence, *or absence* of dye for each cell in the area traversed by each OASIS boat. The probabilistic sensor model was derived from information on the sensitivity and performance of the. The Inference Grid map of rhodamine dye for an initial mapping experiment is shown in Figure 5.

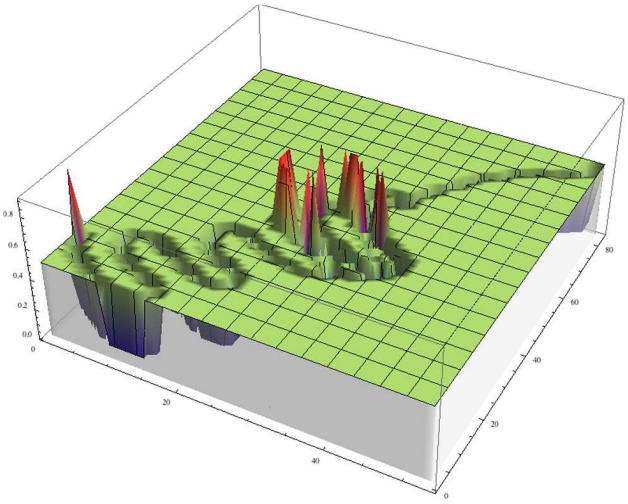

Figure 5. *Inference Grid probabilistic mapping of presence or absence of dye.*

4. Conclusions

The MARTA-based TOASF multi-level autonomy control architecture provides many advantages over existing systems for observing and analyzing HABs including: dynamic tasking and adaptation; higher in situ resolution and greater insensitivity to cloud cover (as compared with satellite systems); access to and greater agility in coastal waters than that available through buoys; real-time multipoint science data observations and generation of associated interpretations by remotely located oceanographers.

Using the TOASF architecture, increases data-gathering effectiveness and science return while reducing demands on scientists for robotic asset tasking, control, and monitoring. The data are also made available to other scientists via the world-wide-web both as they are collected, and from an historical data archive server.

Acknowledgements

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Geo Mindstorms: Investigating a sensor information framework for disaster management processes

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Abstract: The increasing availability of sensor information can generate added value and facilitate decision making when integrated in disaster management processes. In this paper we investigate and demonstrate the use of sensor data in two different setups, a laboratory and a field case. The first setup is a laboratory environment using a Lego Mindstorms NXT robot and sensors where technical challenges the integration of sensor data can be explored. The second setup is a serious gaming environment where the use of different sensor information is evaluated by disaster management operators in order to define its added value for the decision process. Preliminary results show that the Lego Mindstorms NXT offers an effective and more efficient framework to research and demonstrate several aspects of sensors, aspects which can then be tested in virtual scenarios.

Keywords: Lego Mindstorms, disaster management, sensor web enablement

1. Introduction

The recent availability and advances of real-time sensor information are of rising importance in areas such as Disaster Management [1,2]. For example, during a flood situation multiple sensor types can supply crucial real-time information for decision making by the disaster managers. Sensors can inform on water levels and dike strengths to allow the prediction of developments. Cameras can monitor the traffic on the highways or other sensors can measure the flow of traffic allowing for the informed definition of evacuation routes. Concentrations of toxic gasses measured by mobile teams together with real-time weather information are used to calculate gas clouds exposures. If no sensors were previously deployed in the area, mobile sensors can be used to report about the situation in real time. Examples of mobile sensors are wearable systems like the I-Garment [3], where sensors are embedded in the clothes of disaster fighters to report on their location, health and surrounding environmental conditions or sensors carried by Unmanned Airborne Vehicles (UAV). UAVs can be used to provide sensor information at affected sites which are in principle inaccessible to first responders [4,5]. Sensor measurements include the location and time allowing for location-aware services based on the measurements.

Real time sensor data can be useful on its own, but it can deliver even more added value when it is combined with spatial information of the area (such as demographic socio-economic or topographical data). Therefore, the incorporation of (processed) sensor data in a spatial data infrastructure (SDI) is of rising importance in areas such as disaster management and for early warning systems. For example, the mentioned gas cloud derived from sensor data is more valuable when it can be used in combination with population data to determine the number of people affected and to decide which area has to be evacuated [6]. Also, background road networks can be used to calculate safe routes for first responders depending on their location and status.

In the framework of the GDI4DM project [7], a Dutch Government funded project, we are studying and developing an infrastructure to support decision-making and information exchange during the disaster management phase. This infrastructure for disaster management will be tested and evaluated, with respect to sensor information, using two different approaches:

1. A laboratory environment where sensors are used and their data simulates potential real situations.
2. Serious gaming exercises: to evaluate the gathered experiences in practice.

In this paper we focus on the laboratory environment where we used an accessible framework based on the Lego Mindstorms NXT system. The serious gaming environment is planned to be carried out by disaster management organisations in the Netherlands in November 2008 and will show how sensor data can have a positive impact in the disaster management processes.

The following section elaborates on the framework that implements sensors data in an SDI. The relevant standards are introduced and the architecture is described.

2. Architecture and standards

The GDI4DM infrastructure [8] is based on Open Standards, such as OpenGIS (e.g. GML, WFS, WMS and CSW) and OASIS standards (e.g. BPEL). In order to integrate the sensor information in a SDI it is important to use standards allowing for interoperability. The Open Geospatial Consortium (OGC) initiative Sensor Web Enablement (SWE) [9] defines standards for e.g. discovering, managing and monitoring sensors. The SWE standards have been tested in the last OGC Web Services (OWS) initiative in the area of disaster management [10,11]. These testbeds are organized to demonstrate the interoperability of OGC standards.

The SWE defines several standards for discovering managing and retrieving sensor information of which the following will be used first:

- Observation and measurement (O&M) to encode the sensor data;
- Sensor Model Language (SensorML) to describe the sensor systems;
- Sensor Observation Service (SOS) to request, filter and retrieve sensor data.

Other specifications, such as planning and alert services can be added later depending on the evaluation of the disaster management exercises. The goal of Sensor Observation Service (SOS) [12] is to provide access to observations from sensors in a standard way that is consistent for all sensor systems including fixed and mobile sensors. It is therefore a critical element of the SWE architecture. Figure 1 shows the SOS concept.

Figure 2 shows some of the sensors which can be used during a disaster management process and how the sensor network fits in the general disaster management infrastructure. Some of the sensors have a fixed location and are often connected to a wired network, while others are mobile and communicate using wireless and even ad-hoc networks. The raw sensor data and/or the processed sensor information will be part of the Common Operational Picture which is essential for the situational awareness and effective decision support during a disaster.

Figure 1. Sensor Observation Service concept

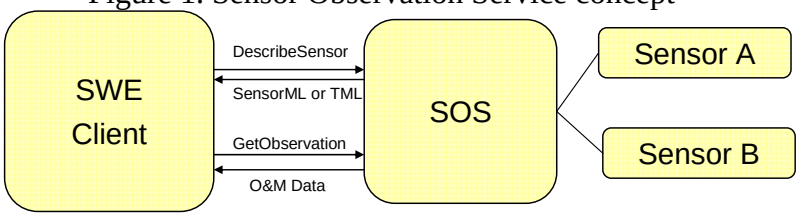
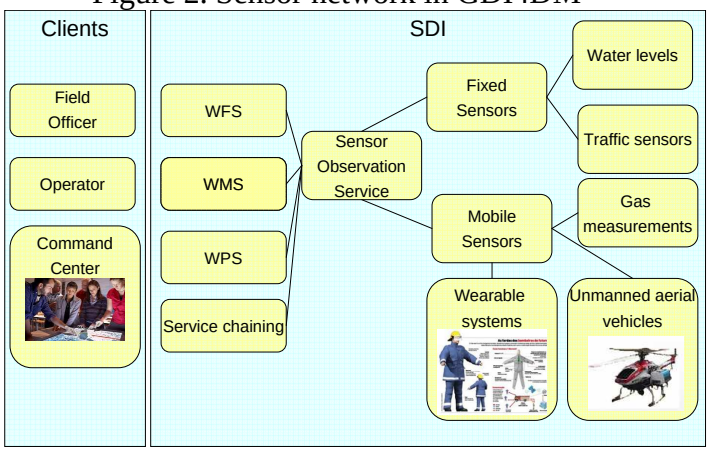


Figure 2. Sensor network in GDI4DM



3. Lego Mindstorms

The development of integrated systems for disaster management that use sensor data and its processed information comprises an additional challenge to the developers and system integrators. Often the sensors are not yet deployed and there is no access to the sensors data or processed information. This limitation makes it difficult to test the work processes in the system and developers then recur to the creation of their own test environments with sensors or simulated sensors to test the different parts of the processes. We explored the use of the Lego Mindstorms Robotic framework as a laboratory network of mobile and fixed sensors. The Lego Mindstorms is a programmable robot that supports different sensors and offers the possibility to examine, implement and demonstrate the usage of these sensor data in an affordable and inspiring way. Robotics is a flexible and powerful channel to demonstrate a variety of concepts [13]. Lego Mindstorms has already been extensively used in e.g. high schools, AI courses and used to test and demonstrate a wide variety of tools and techniques [e.g. 14,15,16]. This section describes the advantages of using this framework in the disaster management process.

As described above, sensors can be used in a multitude of ways in the case of Disaster Management. Therefore there are advantages in using a flexible tool, like the Lego Mindstorms, where different sensors can be easily deployed. Among others, benefits of using Lego Mindstorms include low costs, heterogeneous collection of sensor types (light, temperature, RFID, etc). Furthermore, this framework also enables flexibility in software development since it is already supported by many development platforms (e.g. Microsoft Robotic Studio) and open source initiatives [13].

Figure 3. Lego Mindstorms NXT based architecture

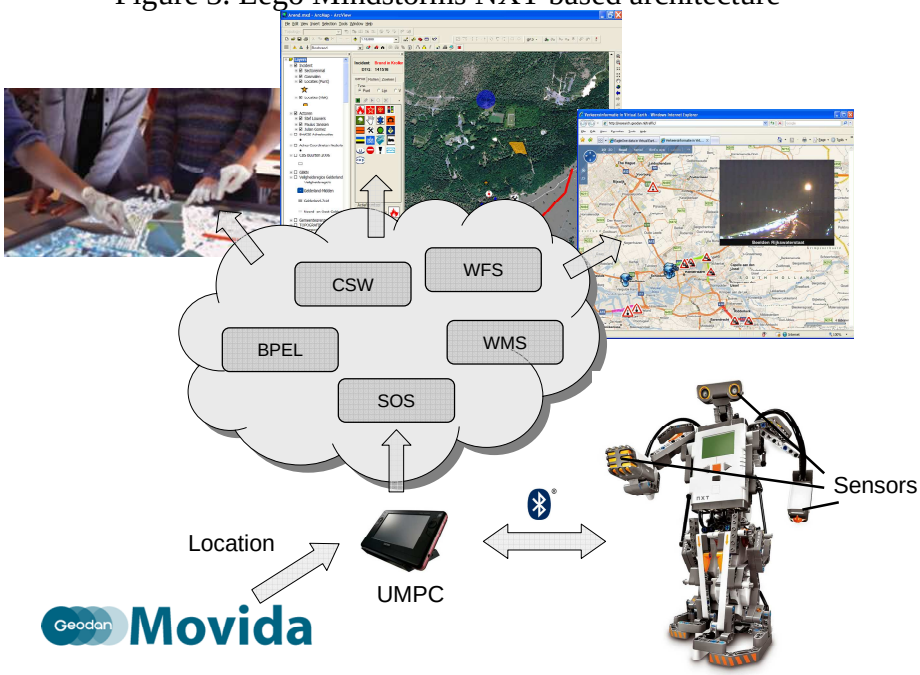


Figure 3 shows the architecture from figure 1 as it is used with Lego Mindstorms.

The Lego Mindstorms supports different sensors, like light sensor, measuring light intensities, and a sound sensor. You can also buy additional sensors like temperature, RFID and many more sensors. The sensors can be used for the different components of the OGC SWE, like the mentioned O&M, SensorML and SOS specifications and to test the integration into work processes and the spatial data infrastructure.

Determining the location of a robot by using the environment is not an easy task. In order to obtain the location of the robot the real-time location system Movida [17] is used. Movida is capable of locating the robot both indoor and outdoor using different techniques such as GPS, Wi-Fi, RFID or Ultrawideband. Based on its

location the robot can take predefined actions (e.g. navigate; react on Poi's, etc). Also other systems (e.g. robots, software) could react to the location of the robot.

Recent developments indicate that first responders in the future will wear wearable systems containing sensors. E.g. suits like the I-Garment [3] measure the health status of first responders and send this information to field officers and control centers. This information flow and the subsequent reaction by systems and people can be implemented using the SWE Alert Service.

A different implementation of mobile sensors is its use in autonomous vehicles like UAV. Such equipment is often expensive and therefore inaccessible to small scale investigations. With Lego Mindstorms an inexpensive prototype can be easily build. The robot was also equipped with an Ultra Mobile PC (UMPC) communicating with Wi-Fi and therefore it is capable of receiving commands from external systems, simulating in this way a command & control situation.

4. Serious gaming

The SDI as described above, tested with the Lego Mindstorms, will be evaluated in serious gaming environments. Several scenarios have been defined and will be carried out by disaster management organisations in the Netherlands. For example in November 2008 a scenario based on a flooding situation will be simulated. A large amount of (geographical) information is used in the exercise, some of which are sensor information. The information is integrated and visualised in a dedicated Virtual Earth infrastructure hosted on behalf of the disaster management organisations.

5. Conclusions

The Lego Mindstorms is a very affordable tool to investigate different geo related subjects in an extremely easy (and motivating) way. Lego Mindstorms offers an effective way to research and demonstrate several aspects of sensors, like the Sensor Web Enablement standards, integration into the workflow, mobile and fixed sensors and even autonomous vehicles based on command & control and sensor information. In addition, it also makes it possible to demonstrate in a lively way the concepts of the OGC Sensor Enabled Web and Location based services to the stakeholders.

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Developing a model to determine the impacts of climate change on the geographical distribution of tourists

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Abstract: Tourism industry is strongly affected by changing climate and extreme weather conditions. The impacts of changing climate are studied using different indicators such as accommodation and border statistics, qualitative surveys and by examining changes in destination. For the investigation of the weather dependence of tourism, we need more sensitive indicators than traditional statistics. The aim of this paper is to develop a model to link the spatial distribution of international tourists within a local destination with the temperature curve, using passive mobile positioning data. For the investigation of tourism, we use the database of the locations of roaming call activities in the network cells of Estonian mobile operators. Using this data, we modelled the weather dependence of tourists' spatial behavior in Estonia. This base model can be used for the assessment and forecasting of the impacts of climatic change on a system as complicated as tourism.

Keywords: Mobile positioning; tourism sensing; weather.

1. Introduction

Tourism is one of the largest and fastest growing industries in the world and therefore is essential to know about tourist's space-time behavior and factors affecting it. This information would give an advantage to a local destination for planning infrastructure as well as improving tourism supply (services, products) and tourism marketing more efficiently.

The space-time behavior of a tourist is affected by many external factors. Due to climate change there have been paid more attention to the weather and climate impact on tourists' destination choices (Lise and Tol 2002). However, so far no studies have observed the weather and climate impact on tourists' spatial behavior within a local destination (ten Hagen, Kramer et al. 2006).

This paper analyses tourists' spatial behavior using mobile positioning data collecting method (Ahas, Aasa et al. 2007). The aim of this paper is to examine the impact of weather/climate on tourists' spatial behavior within a local destination and to analyze implied spatial differences in the case of Estonia. This study attempts to give answer for the following research questions: How weather/climate affects tourist spatial movement and locations within a local destination? How seasonality varies the weather/climate impact on tourists by the tourist's origin of the country?

2. Methods and Data

Weather/climate impact on inbound tourists was studied during 45 months from April 1 in 2004 to December 31 in 2007. For this study, the inbound tourist is defined as the foreign visitor who visited Estonia irrespective of the purpose of the visit during that time used his/her mobile phone in the country's biggest mobile network provider during the study period.

Estonia is located on the eastern coast of the Baltic Sea in Northern Europe covering around 45000 km^2 (Figure 1). Regional climatic differences are affected by the Baltic Sea causing temperature differences between coastal and inland areas.

The tourism sector is an important source of income and contributes for about 17% of the gross domestic product (GPD) for Estonia (WTTC 2007). In 2007 1.9 million inbound tourists stayed overnight on an average of two nights. More than half of inbound tourists are from Finland. Roughly 2/3 of inbound tourists come for holidays and during the summer period the percentage rises up to 78%. Geographically Estonia can be divided into three tourism regions: North Estonia, West Estonia and South Estonia (Figure 1).

Figure 1. Map of Estonia and places mentioned in this study and main areas of summer tourism.

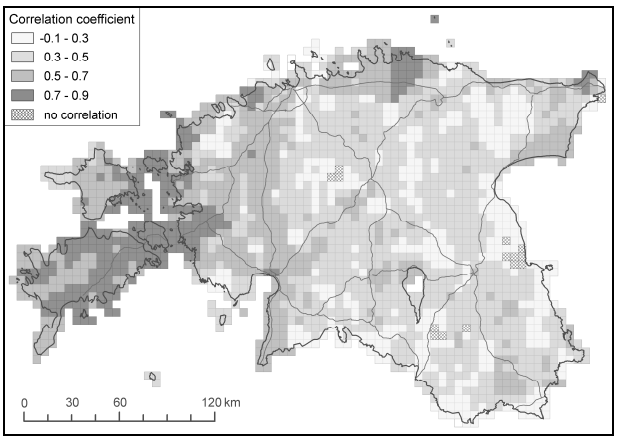

Figure 2. Correlations between daily mean air temperature and inbound tourists with the accuracy of 5x5km grid cells covering Estonia during the whole study period.

Passive mobile positioning data means that the location, time and phone ID of a call activity are stored to the log file (billing memory) of a mobile operator whenever a mobile phone interacts with the mobile network. The dataset was collected by Positium LBS in cooperation with mobile network provider EMT having half of the market share in Estonia. For this study passive mobile positioning data of all inbound tourists' call activities (roaming) was analyzed. The passive mobile positioning dataset contains over 35 million call activities made by foreign visitors. All call activities are anonymous and can not be associated with any particular person. Data collecting, storing and processing are in accordance with the Directive on privacy and electronic communications of the European Parliament and of the Council (DIRECTIVE 2002/58/EC).

The relationship between the locations of inbound visitors and air temperature is studied using the average daily temperatures of 22 weather stations for Estonia (Estonian Meteorological and Hydrological Institute).

For every base station a theoretical radio coverage area was calculated as Voronoi tesselation defining these radio coverage areas as network cells. The mobile network is distributed unevenly over a territory and hence the accuracy of a passive mobile positioning is variable in space: average positioning error in rural areas is about 4.3km and in urban areas respectively 1.7km (Ahas, Aasa et al. 2007). The network cells are spatially interpolated to a 5x5 km grid (Figure 2).

For assessing and ranking the relationships Spearman´s rank correlation was used (Siegel and Castellan 1988). Significance of the correlation was assessed in three levels of significance: weak (0.1), strong (0.05) and very strong (0.01).

2. Results

2.1. Temperature impact on inbound tourist in destination

The correlation between temperature and inbound tourists in the context of Estonia during the study period is high (rho = 0.76) which shows strong seasonal impact on inbound tourists (Figure 3). Number of inbound tourists visiting Estonia is highest in summer period (JJA) and lowest in winter period (DJF).

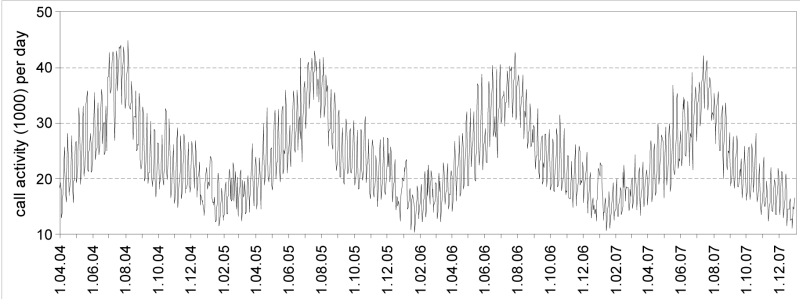

Figure 3. Number of inbound tourists visiting Estonia on a daily basis during the study period.

In addition to natural seasonality pattern human (tourists') behavior is clearly affected by societal factors, for example weekly pattern (workdays vs weekend). Excluding the noise caused by weekly pattern the correlation coefficient between air temperature and inbound tourists strengthen up to rho 0.83 – 0.87. The correlation coefficient varies also among seasons.

2.2. Distribution of correlations within a local destination

The relationship between inbound tourists and temperature during the study period differed considerably in the accuracy of 5x5 km grid (Figure 2) within a local destination i.e. Estonia. 12.1% of 2066 grid cells covering Estonia had strong (rho < 0.7), 67.3% of grid cells had medium and 20.5% of grid cells had weak correlation coefficient. For the whole study period grid cells where the strongest correlations between temperature and inbound tourists occurred were located mainly in Western Estonia and in the islands which are the main tourism areas for the recreational summer holidays in Estonia. Grid cells with medium correlation coefficients between 0.5 > rho > 0.7 occurred in other main tourism regions in Estonia.

The relationship between temperature and inbound tourists within a local destination differed by seasons. For example in the tourism areas for the summer holidays (Võsu) and in the spa resorts (Pärnu, Kuressaare, Narva-Jõesuu) the strongest correlations occurred in spring (rho 0.56 – 0.68) while in summer and autumn the correlation coefficients were weaker.

3. Discussion

The results showed that there was strong relationship between daily mean air temperature and number of inbound tourists visiting Estonia: the number of inbound tourists is highest in summer and lowest in winter. In addition to natural seasonality human (tourists) behavior is clearly affected by societal factor (weekly pattern). Excluding weekly pattern the correlation between daily mean air temperature and the number of inbound tourist's strengthen up to 0.87. This denotes previous studies (Gómez 2005) that climate is one of the most important factor affecting tourists' destination decision making process and thus tourists' spatial behavior.

The results are indicating that weather impact on inbound tourists is varying among seasons. The strong correlation occurred in spring and in autumn. The medium correlation occurred in summer while tourists have their summer holidays planned long before on the basis of climate information and despite of the actual weather during holidays. In winter the correlation between temperature and the number of tourists is weak. Therefore, during winter inbound tourists could be affected by other weather attributes like snow cover.

The study showed that the impact of climate on inbound tourists within a local destination is varying. Strong correlation between temperature and the number of inbound tourists occurred along coastal regions, especially around spa resorts as well as in the main recreational areas for summer tourism.

Seasonality has impact on the relationship between temperature and inbound tourists also within a local destination level. Like in the context of whole destination but also within a local destination the strongest correlations occurred in spring. However clear distinction in correlations occurred between summer recreation areas and two biggest cities in summer and in autumn: around the main summer recreation areas medium correlation occurred but on the contrary, within two biggest cities the correlation was weak, almost statistically not significant. This disparity could indicate that tourists do not take into account the weather when visiting bigger cities where there is diverse variety of indoor services and attractions for tourists.

4. Conclusions

In this paper the relationship between temperature and inbound tourists' spatial behavior within a destination and their spatial differences were studied on a daily basis during 45 months in Estonia. The study was carried out by using the passive mobile positioning dataset.

This study showed that seasonality affects significantly the number of inbound tourists in Estonia and that weather impact on inbound tourists is the strongest in intermediate seasons, especially in spring. In summer weather (temperature) impact is weaker while institutional factors are more dominant than climatic factors. Also in winter temperature impact was weak probably because winter tourists are more affected by snow cover.

The most weather/climate dependent regions within a local destination are summer tourism regions along the coast. In summer the biggest cities in the country are the least weather dependent thus firstly, they are the-must-go places for inbound tourists and secondly, there is diverse variety of indoor services and plenty of things-to-do and things-to-see attractions indoors for tourists despite of uncomfortable weather.

Mobile positioning has a great potential for studying tourists' space-time behavior within a local destination while this data collection method has advantages like convenience, cost of positioning data, accuracy in space and time, and all data is already in digital form that enables easy processing and analyses. However, it is essential to remember that with this data collection method the precision of tourists' spatial movements depends on the frequency of their use of mobile phones. The more call activities, the more detailed tourists' spatial behavior can be studied. One must also notice that the biggest disadvantage of the passive mobile positioning method is the absence of social attributes of the dataset which would enable to examine tourists' behavior more specifically, e.g. how does age or sex affect the impact of weather to his/her spatial behavior etc? In future studies it would be important to examine both inbound and domestic tourists' actual spatial movement within local destinations and how it is affected by weather attributes.

Acknowledgements

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Enhancing the landscape experience by Interactive Location Based Services

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Abstract: This paper discusses the possibilities to use interactive location based services as a tool to collect information about cultural-historic facts, figures and stories related to landscapes. The presented results are based on a Dutch survey in 2008. The results show the experiences of 150 people who made trips within a time and location restricted case area. In more detail the pictures they 'sensed' and stored have been analyzed with respect to the cultural-historic meaning. The results put forward new questions related to where and when certain pictures have been made, how they were linked to personal drives and how location base services could benefit from these data.

Keywords: Interactive Location Based Services, Locative media, Human experiences, Mobile technology, Sensing Cultural-historic objects, STEAD approach

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1. Introduction

Currently Interactive Location Based Services (ILBS) form a next stage – locative media- in the use of mobile phone technology. The last generation mobile phones offer functions to acquire by text, voice, pictures and video streams information of the environment at hand and at will [1]. One could state that humans equipped with such mobile devices could serve as part of a sensor network. Their role and behaviour is, however, very human-like and for that probably to unpredictable to become a serious link in a sensor net if no strict protocols are given [2].

Originally we did look at the hypothesis that such locative media support outdoor experiences and, in reverse, could help to collect outdoor experiences [3]. Especially the last item could mean that personal knowledge about locations could be more easily collect and become available.

Doing so we intend to open up and to unlock existing authorized cultural-historic information and the local history based stories without a profusion of panels, signs and information billboards visible in the landscape: the well known location based approach. Interactivity adds the potential capacity to find and explore new stories and facts to discover hidden layers of information which then can be easily visit and revisit [4].

In this paper we offer some results of 'human sensors' and try to grasp what they sense and how we could use these. First we introduce the project that has lead to these results, describe the methodology, describe some results and finally conclude upon.

2. Digital Dowsing Rod

Within the Digital Dowsing Rod [4] a project consortium develops and tests an interactive location based service. This service offers by default cultural-historic information. The project results in a pilot case based on the use of a personal digital assistant (PDA), equipped with GPS, UMTS/HSDPA and audio-video record and display functionality ('thin client' approach). The pilot application offers a variety of data types like cartographic maps, walking and hiking routes projected on these maps, point-of-interest (POI) locations, multimedia presentations of cultural-historic information and personal experiences in text, audio or video-format. Figure 1 presents the outline of the Service Oriented Architecture (SOA) on which DiWi is based.

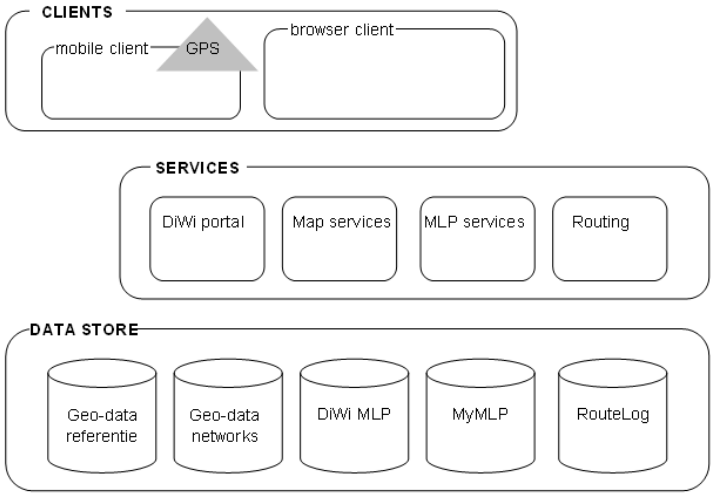

Figure 1: Digital Dowsing Rod Architecture

The architecture shows (geo) data stored at various servers. Oracle spatial offers the native data model for the storage of maps, routes and networks which are served as an OGC compliant Web Mapping Services (WMS) using ArcIMS.

The additional web portal, available via a web browser, offers users the opportunity to view routes they could and did walk or bike and their related personal experiences via annotated texts, pictures and movies. Figure 2 shows a screen dump of the DIWI portal showing a recording of a walk and of the DiWi mobile client. Personal routes will be available on the client after login in.

3. Methodology

During the project a regional wide media offensive by regional broadcast stations, newspapers, their related web sites, and via web sites of cultural-historic organizations informed people about the project and invited them to register for testing. Finally 168 persons applied for testing DiWi. During four weekends in March and April 2008 these people walked or biked a previously selected route within a time-slot of maximally three hours.

At their application on-line they filled in a questionnaire with questions about their interests and background to find out what kind of social and demographic group they belong to. At the day that they walked or biked they were instructed at the beginning of the trip. All trips were GPS-tracked. Even all their interactions with the device during the trip have been registered. When they finished their individual trip they fill in an extensive questionnaire in favour of the usability of the application. 150 persons delivered finally valid datasets which have been used for analysis.

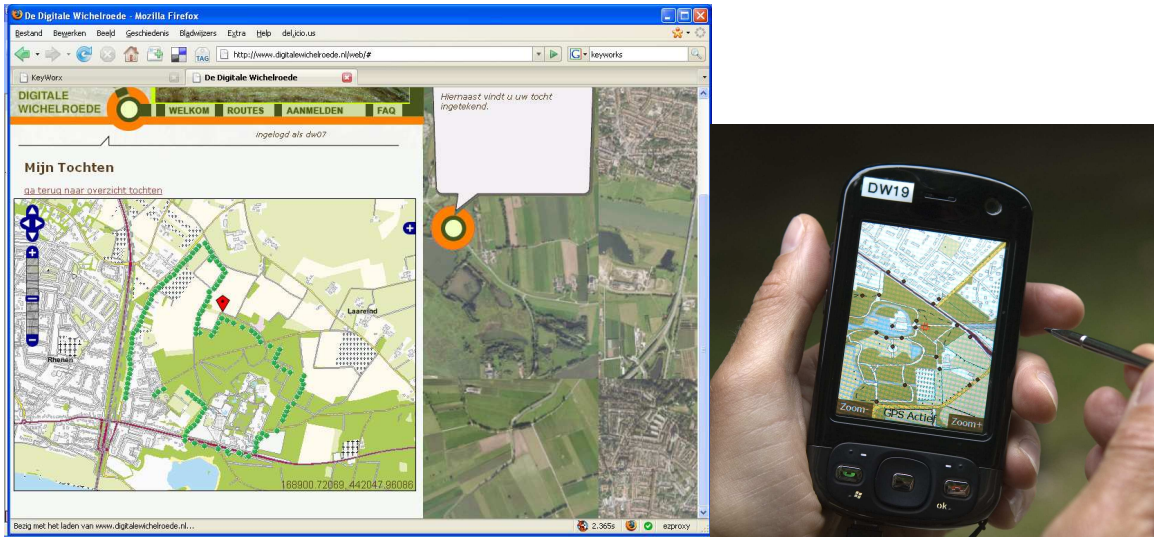

Figure 2: Web browser interface (login mode) and the PDA interfaces

In this paper we focus on the stored interactions that acquire texts, pictures and videos during the individual trips. These so-called "Parlance" ("Volksmond' in Dutch) objects were supported by the MLP services and stored in the MyMLP database (figure 1) and represent the personal sense.

All stored objects have been studied and classified. All these objects have been classified in a number of ways. First all text, picture and video objects have been divided. Then the pictures have been classified into cultural-historic objects, non cultural-historic objects and possible cultural-historic objects. Next we sub-classify the cultural-historic objects in buildings in detail, buildings in landscapes, landscapes and vistas [5].

4. Landscape experience

Based on this classification we do find the following results.

During all trips people stored 345 objects. These objects could be subdivided in 93 text objects, 17 video objects and 235 pictures. The 235 pictures we classified as 83 of relevance for cultural-historic interest, 38 of these pictures could be of interest and the other 114 were not of interest. All pictures that could be of interest have been subdivided in 62 that present buildings (in detail (40) and in a landscape context (22)). The others focus more on the landscape as such. 35 pictures show vistas and 24 show line views.

In general we could state that every person stored on average 3 objects per trip. Of these three objects 0.8 objects per person could be of interest.

Of all objects of possible interest we find that 40% of the pictures show details of buildings, 22% buildings in the landscape, 34% vistas and 25% line based landscape view. The analysis results, over time and in space, of all these objects are not yet available, but figure 3 shows a first clue of the spatial clustering of these objects.

5. Conclusion and what next

The DiWi results show that people are at least able to sense and deliver cultural-historic information via interactive location based services even when they are not really skilled in using such technology. We dare to say so because the test population shows an average age 48 years, were highly educated and represent the social groups that are interested in social-cultural phenomena. However the classification results of the pictures is a subject for further study.

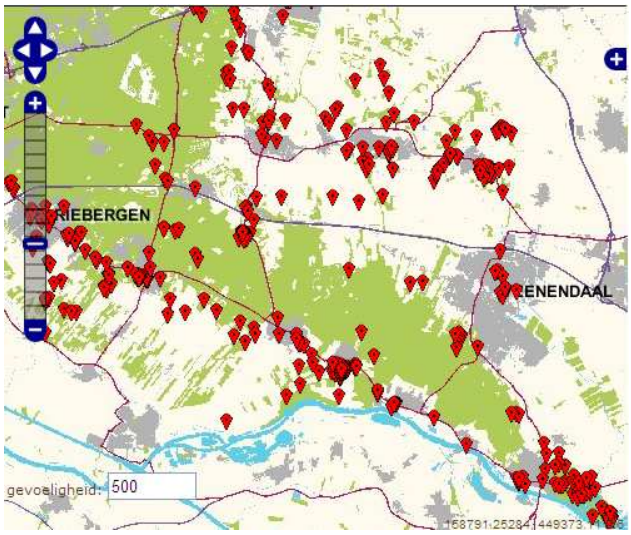

Figure 3: Density of acquired objects

Questions related to the stored objects deal with the usability of it. So far, the analysis of the after-trip questionnaire shows that most of these personal individual experiences as read and viewed by other users scored low. Another important usability item deals with the quality of pictures and the relevance for the experiences of other walkers and bikers.

From the perspective of 'sensing' it is of main of interest to find out *when* and *where* exactly such experiences are recorded and stored. This type of research we label *spatio-temporal experiences associated (stead)* and the results of it could lead to strategies for virtual outdoors story-telling, designing routes end other spatial planning related applications. Currently we work on analyzing the DiWi data in the context of this *stead* approach.

Acknowledgements

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The use of GPS for the analyses of movements of visitors flows in nature areas

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Abstract: This paper presents some approaches to the use of GPS-recording for the analyses of movement behavior of visitors of recreational areas. The core of this analysis lies in the use of Temporary Annotated Sequences (TAS) and trajectories. The examples presented in this paper are based on a case study carried out in the Dutch National Park Dwingelderveld. About 399 visitors were tracked using a GPS device. Based on these GPS recordings their trajectories have been reconstructed. Stops have been analyzed as well as the relation between the landscape in terms of openness and the speed of movement have been explored. Additionally a similarity analyses based on Fréchet analysis shows clusters of movements.

Keywords: Movement Analysis, GPS, spatial datamining

1. Introduction

It is well known that large numbers of visitors in nature area increased the burden on the management of these areas. Quality of these areas might be affected in several ways. Besides effects on the ecological quality of the area through disturbance by people also the recreational quality might be affected by crowdedness, noise, and differences in recreation behavior as found for example in situations where mountain bikers or horse riders meet walkers. Crucial to understanding the effects of visitor behavior on both ecological and recreational qualities is knowledge about the movement behavior of visitors and the relation with its current socio-spatial environment. Although established frameworks exist explaining these relations [1-3] aspect like behavior of individuals in relation with their physical environment, these interactions amongst individuals and differences in behavior are still difficult to measure and analyze.

The use of readily available GPS systems and positioning based on mobile phones enables for additional methods to analyze movement behavior). This research explores the additional value of using the "moving objects data" resulting from tracking.

As already pointed out by [4] movement behavior of people is strongly influence by the various constraints imposed by their environment and their capabilities. Reconstructing movement behavior from moving objects i.e. spatial temporal recordings might provide additional information to recreation researchers as well as policy makers. Currently research efforts in this field are directed to visual analytics i.e. the exploration of visual (graphical) representations of data using interactive visualization tools [5] and Geographical Knowledge Discovery [6]

2. Background

Analyses of movement behavior of visitors might serve the analyses of what is denoted as:

- Places: locations where people spend and certain amount of time *t* to discover things in their environment.
- Encounters: spatial-temporal interactions between people and the environment they are moving in or between people either intentionally or unintentionally.

The concepts of places and encounters are strongly related. Commonly the occurrences of places are the result of encounters and *vice versa*. Encounters often leads to formation of places while places generate encouters. Knowledge about places and encounters are important as they might provide indicators about the

effect of visitors on sensitive nature areas and, vice-versa, the attracting (or distracting) aspects of the area visited. The rest of this section discusses the basic concepts of the analyses of places and encounters based upon the analyses of patterns of movement data, in particular the analysis of Temporary Annotated Sequences (TAS) and Trajectories. Movements of objects trough space are generally recorded using TAS. In general a TAS consist of the minimum tuple: <id, x, y, t>. The id is an unique identifier, x, and y are spatial coordinates in some coordinate system and t is the data timestamp of the recording [7] resulting from objects (visitors) moving through a geographical space. These visitors might either broadcast their Space Time (ST) positions (mobile phones), store their ST positions (GPS, navigation devices), or allowing their ST position to be monitored (for example RFID).

Based on TAS, paths followed by the visitors can be reconstructed. Such a reconstruction of followed paths is generally referred to as geo-spatial lifelines or trajectories [8]. A trajectory by definition is a subset of the total recordings describing a visitor's movement. Each trajectory knows a begin and end and mostly a number of stops (places). The definition of a stop mainly depends on the scale of analyses. The question if a temporary non-movement is the begin or end of a trajectory or a stop depends on the goal of the analysis and the related spatial and temporal resolutions. Same counts for the question if a TAS is just a ST-point in the trajectory or a stop. For example the question if waiting for a crossing or a traffic light is to be regarded a stop or just a part of the trajectory can only be answered in the context of a crisp defined goal of analysis.

Once trajectories have been constructed various characteristics of the movements of visitors can be analyzed. Trajectory characteristics can be divided into characteristics based on a single trajectory and characteristics based on multiple trajectories. Single trajectory characteristic are, speed, acceleration, shape, number of stops and stop duration. Multiple trajectory characteristics are, amongst others: density in space and or time i.e. how many trajectories are within a certain time interval within a certain distance of each other, and interactions; how many trajectories interact in space and time. Interactions are for example crossing or convergent, divergent or parallel movements of trajectories within the same period and area.

3. Dwingelerveld case studie

To demonstrate the use of TAS and trajectories a number of analyses have been carried out using a GPS-tracking dataset of visitors of the Dwingelderveld National Park (DNP). This Dutch nature area – containing 3700 ha and situated in Drenthe, a province in north eastern Netherlands – was chosen because of its recreational attractiveness and ecological quality. The area is ecologically important as it is the largest wet heath land area in Northwest Europe (1550 ha). The heath land area is bordered by forest (2000 ha). The DNP is also a Natura2000 area, which means it is part of a European network of important nature conservation areas. The DNP receives at least 1.6 million visitors yearly. During a study amongst 399 visitors of the DNP in August 2006 detailed tracks where recorded using Garmin GPS devices. Of the 399 collected GPS tracks 311 (78%) were complete. The dataset was pre-processed by only considering recording within 25 m at each side of the paths in the path network this removing outliers due to erroneous registrations by the GPS device.

4 Analyses

To demonstrate how the mentioned trajectory characteristics might help getting insight in the movement behaviour of visitors the following are calculated:

1. Stops, both density of the number of visitors as a measure of the duration of the stop.
2. Walking speed in relation with the openness the type of landscape
3. Similarities amongst various trajectories.

4.1 Stops

Based on an analyses of the speed and directions, patterns of stops where generated. From the patterns various places of interest become visible for example the stops at 1 in Fig. 1 indicate the location of a visitor center with a parking lot showing high density of visitors stopping at a relative short period. 2 Indicates the position of a bird watching cabin having a limited capacity. Vistitors tend to stop there at a longer period. Stop 3 is an orientation center were not to many visitors spend a considerable time. Besides these well known POIs the maps show the various places where people tend to stop and enjoy the environment related to location have good viewpoint or a beautiful scenery.

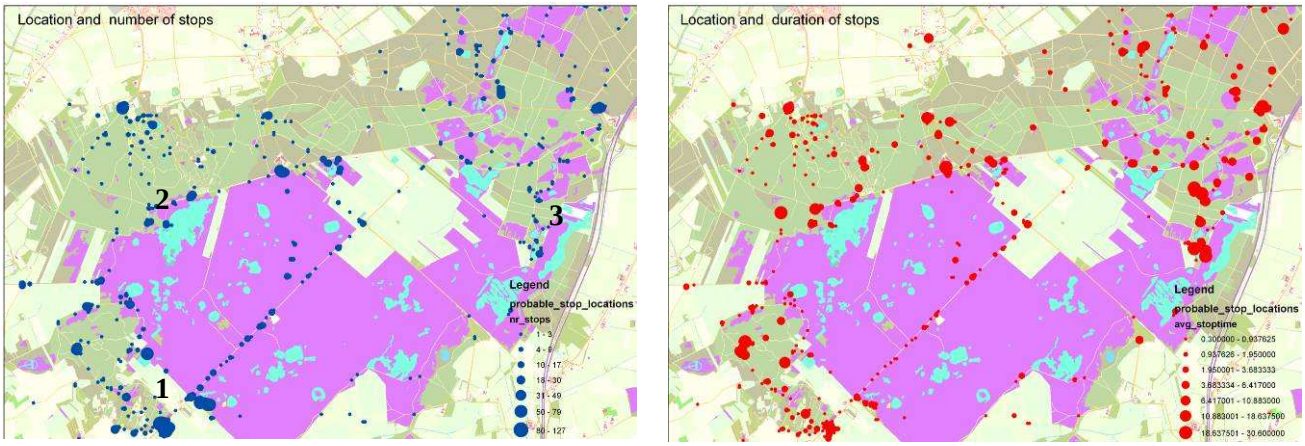

Figure 1: Analyses of stop: left number of stops made, right the average duration of stops.

4.2 Walking speed

As most of the visitors (65%) tracks in DNP follow marked trails, we expect specific landscape preferences of minor influence on the route choice. However, it would be interesting to know the effect of landscape type on the visitors' movement behavior (in this case the walking speed). To be able to analyze this a dataset have been prepared showing for all walking paths in the DNP the visibility of landscape for each paths segment (Fig2 left picture) [9]. These visibility was classified in 4 landscape types: closed, open, boundary and mixed. Based on the trajectories the speed between each TAS was calculated and combined with the classified paths network using GIS based procedures. The resulting dataset provides a detailed insight into the speed at all segments of the path network (see Fig. 2 right picture)

Next, using these two datasets the average speed for each path class was calculated showing the effect of the landscape difference upon the movement speed of the visitors. Although the differences are not very high and the observed standard deviations rather high this type of analyses might provide insight in the effects of landscape upon movement behavior (Fig. 3). At this moment the topographical map was used to generated the landscape typology. A more targeted analyses and validation of the dataset, with respect to the openness would probably lead to a better results. Additionally the used GPS device performed rather poor under forest cover leading to fluctuation in speed as a result of inaccurate positioning. Especially walking speeds as in this case this leads to relative high deviations.

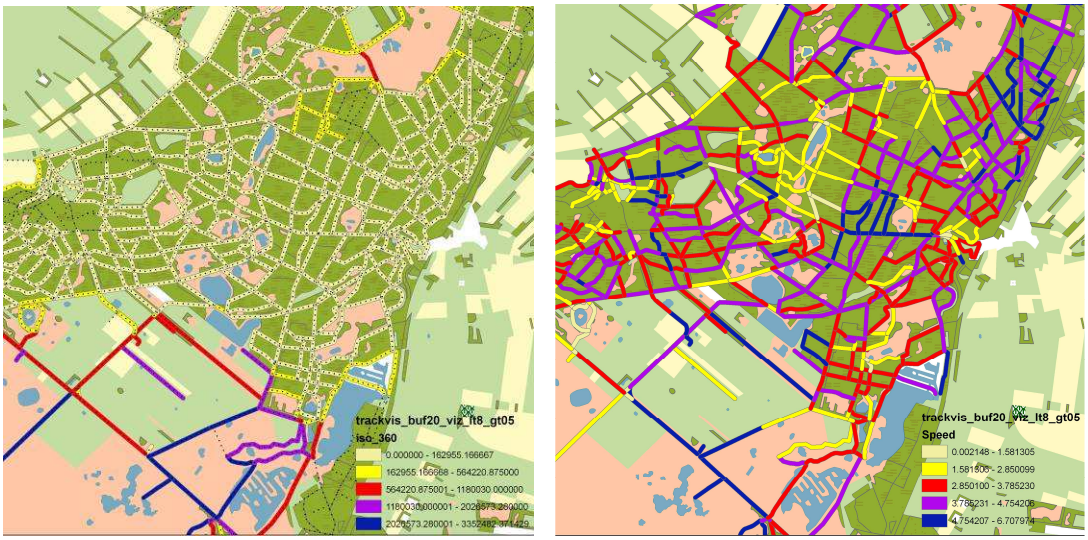

Fig 2: Fragment of the dataset showing left: part of the dataset showing the openness of the landscape based on the visible areas (m2) from a path (calculated at a 50 mtr. interval) and right: the average speed at the followed paths.

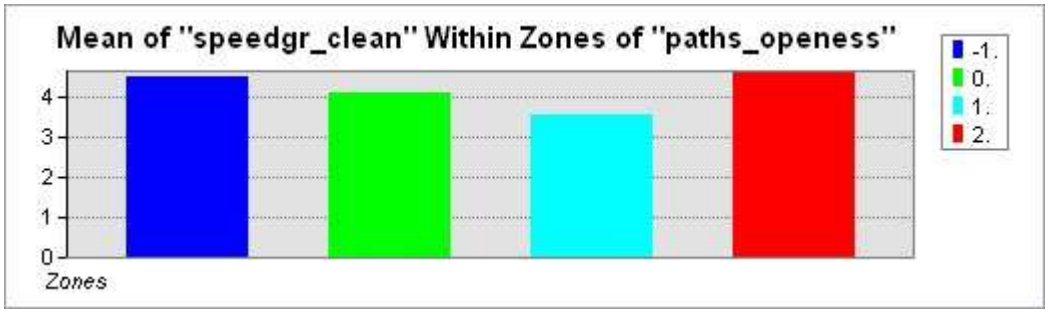

Fig 3: Average speed for 4 openness classes of the landscape (-1 closed, 0 = boundaries, 1 = open, 2 = mixed)

4.2 Similarities

A second type of analyses demonstrated here is finding patterns in data using data mining techniques. Fig. 4 shows the result of a cluster analyses based on the Fréchet distance, a distance measure that accounts for the continuity of the trajectories.[10]. For the clustering we used k-medoids algorithm [11] with as similarity measure the discrete Fréchet distance. Many applications consider the Fréchet distance for curves as a good measure for similarity between polylines (i.e., traces of trajectories). Because of the high computational cost of this distance measure the ``less correct'' derivate for polylines, called the discrete Fréchet distance is used. Clustering based on similarities can reveal various modes of use of an area in terms of frequently followed routes, and recreational pressure on certain parts of an area. The 4 clusters shown in Fig. 4 are based on visitors who stated not to follow a predefined route (browsers).

The clusters show links with the parking areas that define in most cases the begin en ends of the trajectories. This type of similarity analysis seems to be especially relevant for discovering patterns in movements of free moving visitors or movements over dense or large networks of paths.

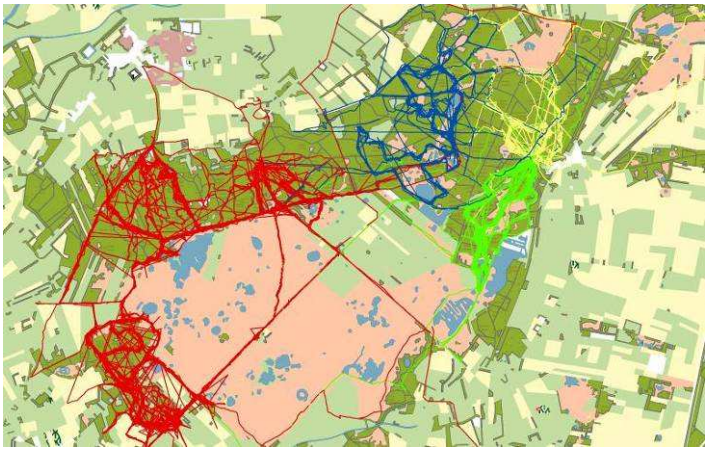

Fig 4: results of the discrete Fréchet similarity analysis (4 clusters) for routes followed by browsers (entire study area)

5 Discussion

The techniques shown in this paper are merely an illustration to show the use of moving object data for additional analyses of visitors behavior. It illustrates techniques to explicitly include environmental characteristics into analyses of movement behavior. There is however, the need to test and validate these type of analyzes for their practical applicability in recreation research. A complicating aspect at this moment seems to be the quality of current GPS recordings. They often are unstable, hampering the tracking of the subtle differences in movement behavior in individual trajectories. They easily get blurred in the noise caused by inaccurate measurement of GPS. The launch of the Galileo network will probably offer a better accuracy combined with a better performance in forest areas.

Data mining techniques like similarity matching and clustering offer additional insight in the general spatial and/or temporal patterns of movements cause by visitors. Managers and policy makers can use these patterns to

increase their insight in the use of an area in different periods. However, before these techniques successfully can be applied additional research is needed into the relation between movement, environment and resulting patterns. There is a strong need for the development of concepts and methods that relate data-oriented models commonly applied in data-mining, the spatial modeling of geo-science and social models used in recreation research.

Acknowledgements

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Sensing Human Activity: GPS tracking

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Abstract: The enhancement of GPS technology enables the use of GPS devices not only as navigation and orientation tools, but also as instruments used to capture travelled routes: as sensors measuring activity on city or regional scale. TU Delft collected data on pedestrian movement in three European cities: *Norwich, Rouen and Koblenz*; in another experiment 15 families were tracked in Almere for one week. The question is what is the value of GPS as sensor technology measuring activities of people? The conclusion is that GPS offers a widely useable instrument to collect invaluable spatial-temporal data on different scales and in different settings adding new layers of knowledge, but the technology and deployment have their issues and limitations as well.

Keywords: GPS; Tracking; People; Behavior; Mapping; Movement.

1. Introduction

The availability of GPS devices is increasing: more and more people have a *navigation system* such as TomTom, a *GPS for orientation* for outdoor uses, biking and geo-caching or a *mobile phone or handheld with built-in GPS*. Mainly, these devices are used for orientation, navigation and determining of ones location. But, the devices can also be used to save a travelled route into a track log. This ability makes the technology useful to collect spatial-temporal data and thus as sensors for observing and measuring activities of people (Shoval). The questions are what is the contribution of GPS to traditional methods? What is the performance of GPS as sensor instrument? In what ways can GPS be deployed?

In this short paper I will describe two experiments using GPS to track people for different purposes and on different scales. In the first experiment GPS devices were deployed in the Spatial Metro project to observe pedestrians visiting the historic city centers of Norwich, Rouen and Koblenz (Spek). In the second experiment the technology was used to track the activity patterns of families in Almere. In both case the collection of spatial-temporal data took one whole week and was accompanied with a questionnaire.

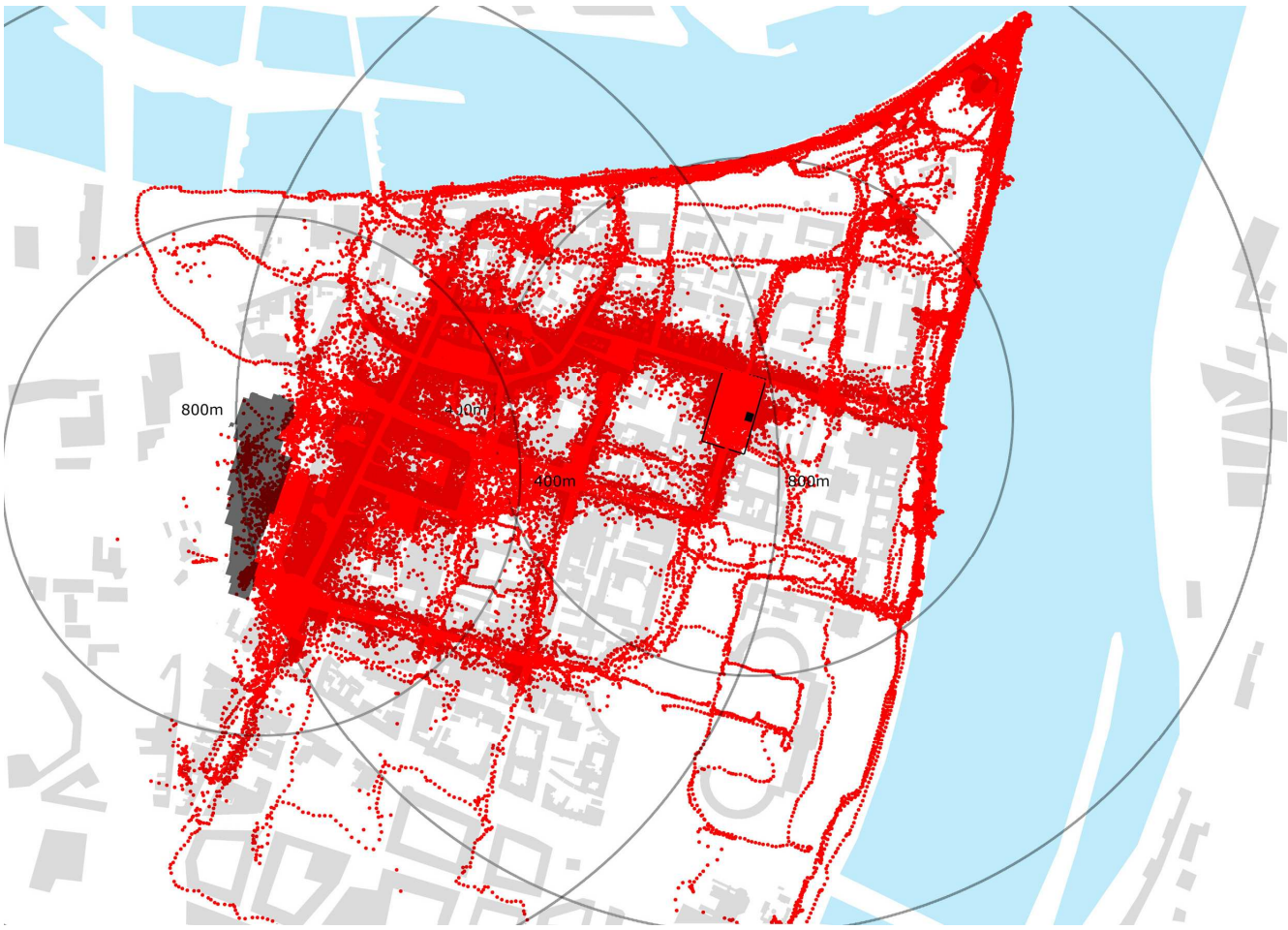
2. Results and Discussion

In the Spatial Metro project in total 1300 pedestrian were tracked and interviewed. In average 60% of the data was valid due to issues with fixation, batteries, blur (clouds of points) and fragmentation. The origin of these issues is clear (see also Raper): the reception in dense urban areas is weak; signals reflect on buildings, people tend to go into buildings, and pedestrians move relatively slow. Nevertheless, substantial information was available to map different patterns based on the social/demographical characteristics and trip aspects.

In Almere each member of 15 families were tracked for one week leading to several hundred trips. The data provides excellent information about use of the network by different modes of transportation and the radius of activities. The collection encountered some expected issues leading to incomplete data: time to first fixation (fix), charging of batteries, forgotten or switched off device. Lacking data were not added.

3. Experimental Section: SPATIAL METRO

Figure 1. GPS tracking results in Koblenz: pedestrians tracked from two access points for one week (all track points at 5 seconds frequency; image prepared for: LBS2008, Salzburg)



2.1. Way of working

For the Spatial Metro project the GPS tracking devices were distributed at two parking facilities in each city for one week (Spek). These locations form the access points to the city centre and the location were people start their journey on foot. Here people were asked to participate in the research. The GPS saved the position information at a frequency of five seconds. A questionnaire was filled in on return of the device. No sensitive, private information was collected, only trip-related and general demographic background data. Data was only collected during the day: the distribution and collection locations opened at 10am and closed at 6pm.

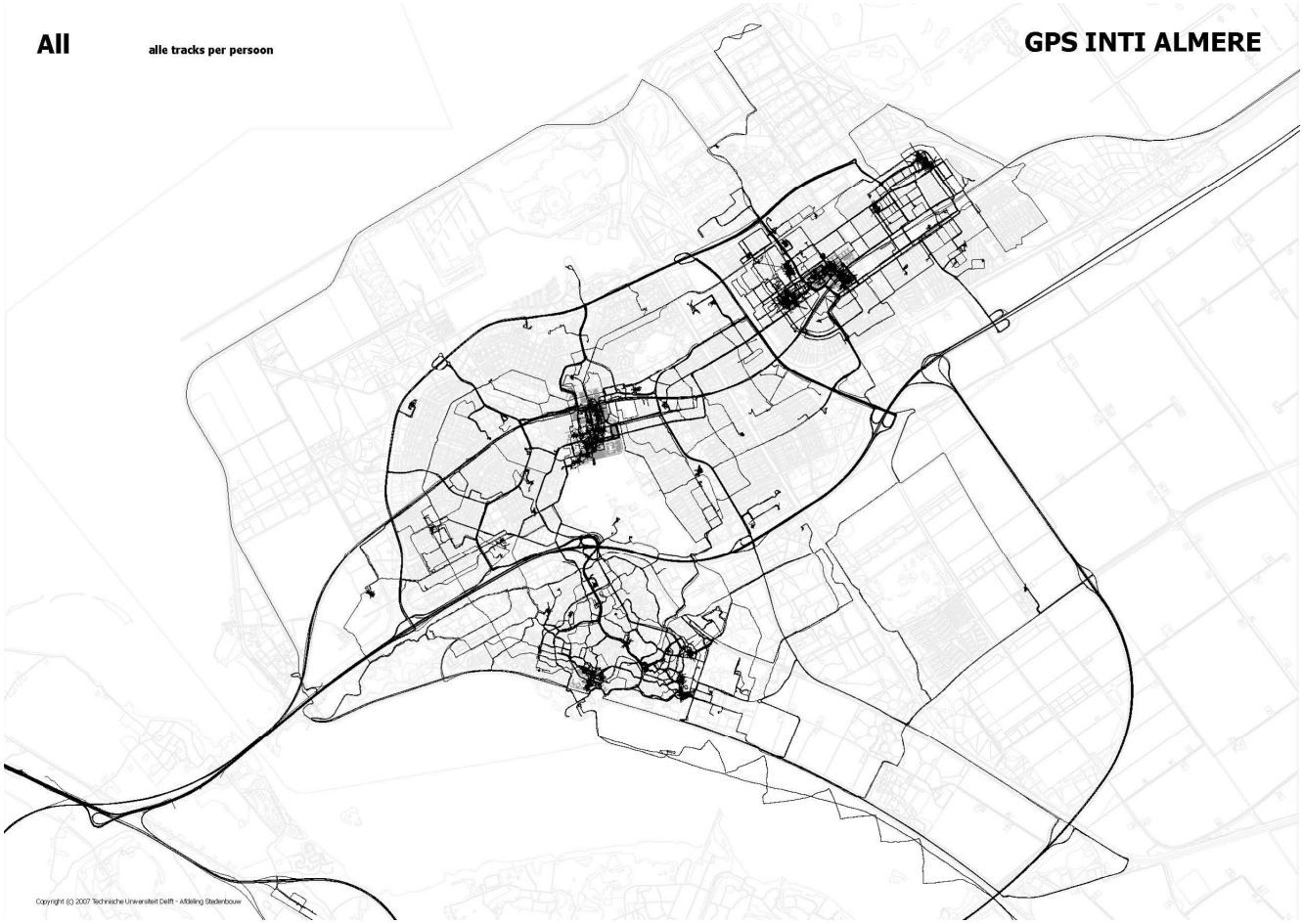
In the next phase the spatial-temporal data was processed: evaluation, cleaning and validation. After that, the valid tracking data layers were projected in GIS. In the following phase two types of drawings were made: the first one based on projection of the data on top of other geographical information and the second one based on density analysis of the data determined by the themes of the questionnaire.

The first type of drawings combines spatial-temporal data with e.g. aerial image, access routes and arrival points, commercial activities, points of interest and investments. These result in analysis of spatial conditions in relation to actual behavior of the tracked sample. The second type of drawings delivers a set of specific spatial patterns based on the aspects of origin, familiarity, purpose and duration (Spek) and age, gender and group type. These result in comparison of spatial patterns for specific groups of participants.

Both ways of visualization -either static or dynamic- offer tremendous insight in pedestrian behavior, leading to conclusions and opportunities for application in practice.

3. Experimental Section: ALMERE

Figure 2. GPS tracking results in Almere: mapping activity patterns of 15 households (50 people) for one week resulting in a map based on actual use of the urban tissue



Almere is a poly nuclear Newtown in the 'Flevopolder' which exists of spatially separated suburbs. The last decade, TU Delft developed and applied out several traditional methods to analyze the functioning of the city and the relation between the different parts. GPS tracking offers a new layer of actual observed behavior in this ongoing research, offering new perspectives and contradicting or confirming the developed theory. It is interesting to see how people really use the available network.

Within three suburbs families consisting of a father, a mother and one or two children aged 16-18 were approached by the municipality to participate in the research. Fifteen families agreed leading to around 50 participants. Before starting up the collection of data, a meeting at the participant's home was organized to fill in a questionnaire, give instructions and handover the GPS devices and battery chargers, one for each member.

The spatial-temporal data was collected at an interval of 2 seconds. All data of one week was stored in the GPS device. After eight days the devices were picked-up again and a second interview was taken. Hereafter, processing of both spatial-temporal and personal data started. The first step of processing was evaluation and cleaning. The second step was to split up tracks into trips based on an activity. The third step was to manage all data according to the protocol. Using a query based on the questionnaire, a range of layers could be selected in GIS to perform analysis, e.g. point or line density analysis.

Compared to the first example, here activities are undertaken either individually or in different combinations of individuals. Besides, the mode of transportation is not limited to pedestrian, but needs to be determined. Finally, each trip consists of one or more activities, which could each be for different purposes.

4. Conclusions

TU Delft used GPS tracking technologies in two experiments on different scales and in different ways of deployment. In both cases the GPS delivered spatial-temporal data next to background information gathered by a questionnaire. The spatial-temporal data delivered a new layer of information on top of other geographical information. The strong feature of the method is the combination of spatial-temporal data (behavior in space and time), spatial conditions, social-demographic information of the participants and characteristics of the trips. This enables to split up patterns based on personal and trip related aspects. The method adds information to the traditional ways of analysis and does therefore not a priori replace existing ways of collecting information, such as counting and observing.

Technically and practically GPS tracking still has its issues. Technically, GPS is not ideal in dense urban environments. New technical development, such as integration with the mobile phone system, is essential to improve the quality of spatial-temporal data collection: battery life, time to (first) fix, accuracy and avoiding blur and fragments. Tools, such as scripts and data-mining algorithms, need to be developed to further improve and speedup data processing.

Practically, the distribution and collection of devices limits the deployment of the technology to a pre-defined environment. Today this process is time consuming and limits the type of participants. Nevertheless, the experiments delivered a lot of results. But, if GPS would be available wider and people could just share their tracks, the only thing needed is a *platform and protocols to upload spatial-temporal data*. This would enable open-source collection of spatial-temporal data en therefore feature GPS as a worldwide applicable sensor technique collecting *spatial-temporal data*, *quantitative information* and *qualitative information*.

Acknowledgements

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Real time processing and visualization

Geosensor Networks: New Challenges in Environmental Monitoring using Wireless Sensor Networks

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Abstract: Advances in microsensor technology as well as the development of miniaturized computing platforms enable us to scatter numerous untethered sensing devices in hard to reach terrains, and continuously collect geospatial information in never before seen spatial and temporal scales. Sensor networks deployed in geographic space to detect, monitor and track environmental phenomena are called geosensor networks. Geosensor network technologies are revolutionizing the way that geospatial information is collected, analyzed and integrated with existing large-scale sensor platforms and historical data, with the geospatial content of the information being of fundamental importance. Analysis and event detection in a geosensor network is performed in real-time within the network.

In this talk, I will present an overview of the technology, look at the current state of the art in geosensor networks, and present some of our own current research work in the Geosensor Networks Lab at the University of Maine. I will also attempt a look in the future of geosensor networks, and their integration into a large-scale, global, real-time sensor web environment.

OSIRIS: Combining pollution measurements with GPS position data for air quality monitoring in urban environments making use of smart systems and SWE technologies.

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Abstract: OSIRIS (Open architecture for Smart and Interoperable networks in Risk management based on In-situ Sensors) is a Sixth Framework Programme Integrated Project of the European Commission, aligned with GMES (Global Monitoring for Environment and Security). The main objective of OSIRIS is to enhance the overall efficiency of the in-situ data processing chain by connecting the in-situ sensors via an intelligent and versatile network infrastructure that will enable the end-users to access to multi-domain sensors information. An essential aspect which drives the OSIRIS project consists in its practical deployment in four operational situations reflecting the reality: forest fire, fire in an industrial building, water pollution management, air pollution management. OSIRIS architecture follows the Service Oriented Architecture principles, implements and complements the Sensor Web Enablement specifications, contributing to the Open Geospatial Consortium (OGC). In the case of air quality, a new and advanced monitoring and management capability is set up thanks to the OSIRIS architecture deployment over a mobile and heterogeneous network of sensors. This combines sensor and communication technologies in a flexible and expansible system, allows the use of mobile units and facilitates the management of a sensor network. In addition, it offers the possibility of measuring the pollution concentration continuously and automatically without intervention of specialized teams and with no duration limits of the measurements. Mobile and geo-referenced data can be easily managed and exploited over the WEB. The operative system, which is aimed to measure NO, NO2 can be easily expanded to include new sensors of other phenomena of interest like CO, CO2, O3, SO2, PM10 and PM2,5. For the demonstration, the sensors are integrated in a fleet of Buses in order to obtain the pollution measurements from a number of sampling points. The sensors used are integrated thanks to an On Board Unit allowing data fusion and smart validation of the real-time measurements applying filters and validation rules. The data are sent automatically via GPRS to an exploitation center, where OSIRIS Web Services and applications are deployed.

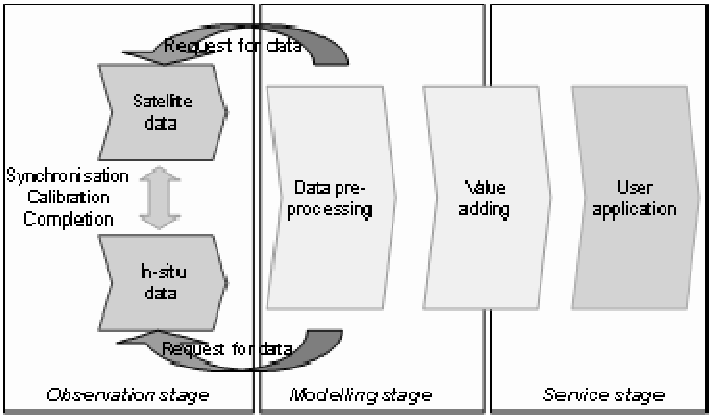
Keywords: OSIRIS, Pollution Monitoring, GIS, Bus Sensors, Fleet Sensors Network, SWE, SOS, O&M.

1. Introduction

OSIRIS [1] implements the GMES [2] three steps process:

- Observation, relying on space-based and in-situ sensing capacities (OSIRIS focuses on in-situ sensors),
- Modelling, dedicated to the processing of the data generated by the above mentioned observation systems,
- Service production and delivery.

Figure 1. GMES Service 3 steps process.



OSIRIS builds an architecture based on standards, and delivers functions ranging from In-situ earth observation to end-users following the concept of Service Oriented Architectures. The functions are dedicated to the surveillance and the crisis management, and enhance the global efficiency of the user related operations. OSIRIS does not only address architectural concepts or simulations, but it implements and tests real in-situ observation systems. All the services are defined, developed and tested within the timeframe of the project. Several services are defined and implemented – validated thanks to the experiments. For the specific case of a Monitoring Scenario for Air Pollution in urban environment the system comprises a heterogeneous network based on the information obtained from the former fixed sensors used to monitor the pollution of the city and a number of mobile sensors installed in a fleet of buses. The mobile sensors take air pollution measurements following the routes scheduled by the Control Centre of the fleet, collecting air and spectroscopic samples that are later fused with GPS position and processed by the On Board Unit (OBU) [3] which sends these measurements to the Control Centre via GPRS link in order to be post processed and exploited by the final users.

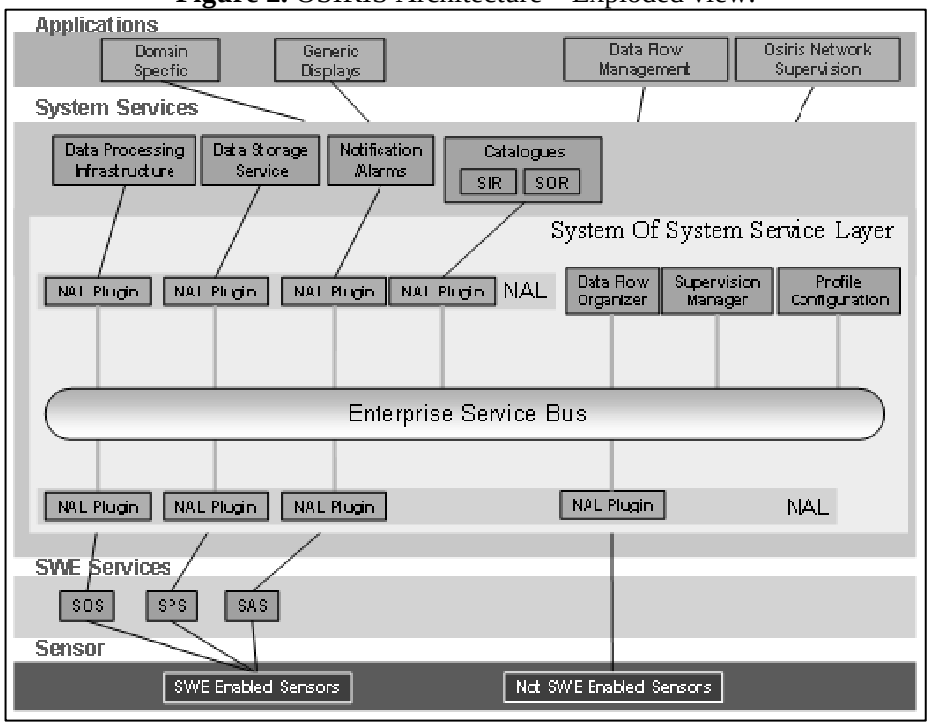
The services are divided in three set of services addressing different levels, as illustrated in figure 2.
From the bottom to the top, this corresponds to:

- **SWE Services** [4]: OSIRIS provides a set of services for accessing sensor data and controlling sensors. Standardization is a very important step in order to reach interoperability, thus those services are based on the SWE, adjusted for OSIRIS. The main improvements are done in conjunction with OGC, and are participating to the new revisions of the standards. Mature implementations are provided as an Open Source.
- **System services** providing additional capacities upon sensor services, better addressing a system level:
    - One dedicated set of services is implementing the necessary glue between the other services; it is called the System of System Service Layer composed of:
        - Registration of services participating to the system, and supervision of the services (and sensors).
        - Data Flow Organisation: using any data provider service (SWE or WS or other) as data source to feed the Data Storage.
    - Data processing infrastructure, managing and orchestrating processing means. An easy and documented way to integrate processing means is provided,.
    - Data Storage offering storage capabilities and smart access to the stored data, hiding the complexity of the underlying data sources involved.

- Alerting means, allowing users to be notified according to their profile and the events occurring within the system and either external alert provider. This service supports major alerting protocols.

- **Applications:** addressing in particular the display of the sensors data. Applications are delivered for supervision purpose, and exploitation of the services (tasking of sensors for example as well as mission control) and data access. Thanks to the SWE standardized languages (SML, O&M), generic applications can be delivered, able to auto-configure according to the sensor capabilities.

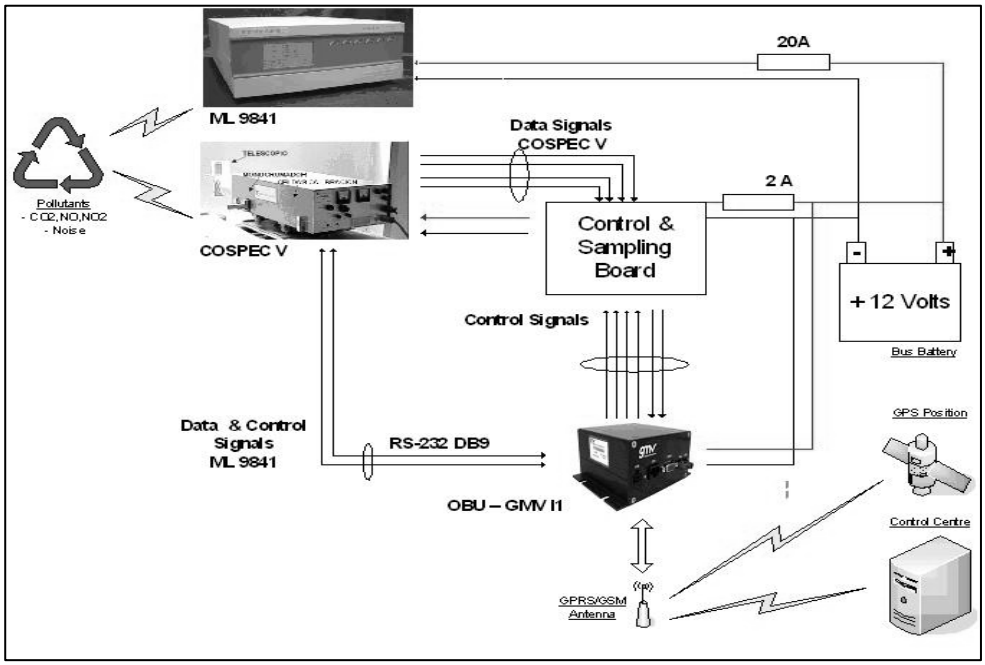
Figure 2. OSIRIS Architecture – Exploded view.



2. Results and Discussion

The mobile units of the monitoring system for air pollution work in an automatic mode carrying the scheduled tasks and being able to receive new commands from the control centre and updating their configuration and tasks to fit the orders sent by the control centre. The sensors utilized to measure the NO and NO2 concentrations are a spectroscopic COSPEC V [5] and a commercial air sample monitor Europe ML 9841.

Figure 3. OSIRIS Architecture – Implementation view for Fleet Sensors Network.



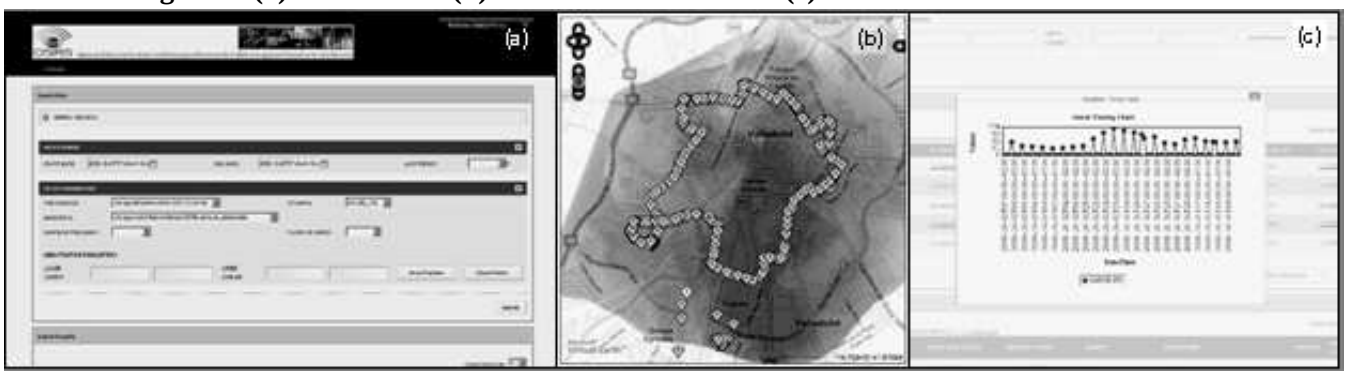
The Sensor fleet can include as many vehicles as needed or required by the user, each one having installed a customized number of sensors and an OBU that will act as a system monitor and communication manager.

This system architecture has been already successfully implemented in one prototype bus of the fleet that is fully operative running under the scope of the OSIRIS project in the city of Valladolid.

3. Experimental Section

All the measurements of the sensors of the bus are fused with a GPS location and a time-stamp before being sent to OSIRIS platform. In addition, the firmware of the OBU I10 can be changed and configured easily to add new rules in the data fusion or new functionalities. A specific user interface for air monitoring has been designed and developed to deal with the information retrieved from the fleet sensor network and fixed sensor network according to the requirements of the final user. The information can be searched from the OSIRIS platform, visualized into a GIS and exported to other formats like KML and ASCII in order to be used from other GIS tools like Google Earth or other specific tools for post-processing, interpolating etc.

Figure 4. (a) Search Tool. **(b)** GIS for mobile stations. **(c)** Scattered time line for fixed stations.



4. Conclusions

OSIRIS contributes with a great impact in the use of current mobile units allowing managing a fleet sensor network with the possibility to have a continuous and automatic acquisition of NO2 and NO concentration without manual operations or limits for the period of measurement. The system can be easily expanded including new sensors to measure other phenomena of interest like CO, CO2, O3, SO2, PM10 and PM2.5 in the same bus or sorted in different buses of the fleet.

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An integrated sensor web design, acquisition, and evaluation framework for intelligent, adaptive environmental monitoring

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Abstract: Our research group has developed several tools for designing, configuring, and operating distributed sensor networks, and for evaluating sensor data in spatial decision support. By using GIS and Sensor Web Enablement (SWE) standards as key architectural elements, the tools may operate independently or be chained together to create integrated solutions for complex monitoring problems. REASON is an ontology-based decision support system that couples GIS with an expert system engine and applies models of sensor network infrastructure to its evaluation techniques. IWT is used to design a heterogeneous sensor network in a GIS environment; the Designer configures the hardware and sends SensorML specifications to a target Sensor Observation Service (SOS), and the Operator communicates with the field hardware, transforming incoming data into O&M for the SOS. ENGINE is a transformation engine that converts SensorML and O&M documents into ontological representations in real time. ECO-COSM is a landscape-agent simulation modeling framework that can simulate sensor networks, including sensor and communication errors, on a dynamic GIS landscape. ECO-COSM can feed its simulated data to an SOS or to the IWT Operator for testing and advanced analysis.

By integrating sensor networks, data collection, and GIS directly into a spatial decision support framework, some new capabilities emerge: 1) Sensor network deployment becomes a problem definition and design problem rather than a hardware programming and configuration problem; 2) The sensor observations can be automatically evaluated with the full context of the sensors making the observations, the landscape being observed, and the specific monitoring problem; and 3) The decision support system can use this information to adjust the behaviour of the sensor network in real-time response to significant environmental events (e.g rainfall, hillslope tremors, etc.). This move to an adaptable, 'intelligent' monitoring approach focuses on spatial information and meaning, rather than spatial data, which can change the way we can conduct -- and even think about -- environmental monitoring for research and management.

Sharing sensor data with SensorSA and cascading Sensor Observation Service

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Abstract: SANY IP consortium (http://www.sany-ip.eu) recently developed several interesting service prototypes that extend the usability of the Open Geospatial Consortium "Sensor Web Enablement" (OGC SWE) architecture. One such service prototype, developed by the Austrian Research Centers, is the "cascading SOS" (SOS-X). SOS-X is a client to the underlying OGC Sensor Observation service(s) (SOS). It provides alternative access routes to users (or services) interested in accessing data. In addition to a simple cascading, SOS-X can re-format, re-organise, and merge data from several sources into a single SOS offering. Thanks to the built-in "Formula 3" prototype, a kind of time series library, SOS-X will be enabled to derive new data sets on the fly executing arbitrary algebraic operations on one or more data input streams. This article will discuss the SOS-X development status (focusing at end of 2008), further development agenda in year 2009, and possibilities for using the SOS-X outside of the SANY IP.

Keywords: Sensor Observation Service (SOS), cascading SOS, Open Geospatial Consortium (OGC), OGC Sensor Web Enablement (OGC-SWE), Global Earth Observation System of Systems (GEOSS), Global Monitoring for Environment and Security (GMES), SANY IP, ORCHESTRA, data acquisition, UWEDAT, Service Oriented Architecture, Events Driven Architecture.

1. Introduction

Our strategies to conserve and develop the environment in a favourable way often depend on detailed knowledge not only about single observable properties, but about ecosystems, its parts, relationships, and dependencies. Building such know-how was often a tedious task, as data acquisition has been expensive and data integration a labour-intensive task of conversions and transformations, often implying information losses. Unsurprisingly, both "Global Monitoring for Environment and Security" (GMES, see http://www.gmes.info/), and "Global Earth Observation System of Systems" (GEOSS, see http://www.earthobservations.org) aspire to remove the obstacles for sharing and using the environmental information.

Imposing a single technical infrastructure to all environmental systems is not feasible due to (1) high costs of transition and mismatch between short-lived technology and long-lived environmental monitoring. In addition, 2) defining a single information model for all types of environmental information may not only be difficult and prohibitively expensive, but probably even impossible, because the appropriate data model depends on the purpose for which the information has been published [1].

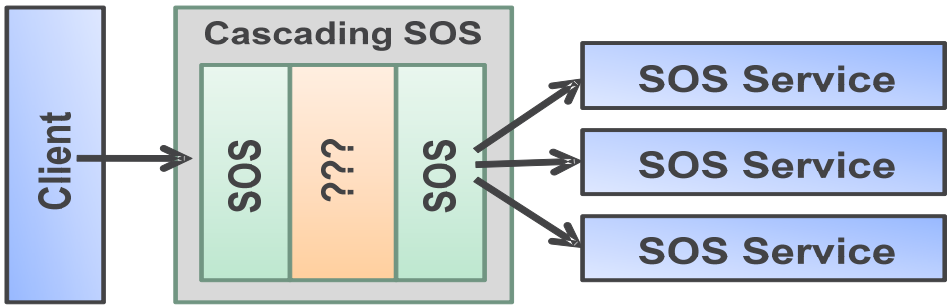
FP6 Integrated project "Sensors Anywhere" (SANY IP) [2] recently published a first version of the Sensor Service Architecture (SensorSA) [3], which is believed to answer the major issues preventing the exchange of environmental information, at least for the in-situ sector of GMES.

In addition to defining the SensorSA, the SANY consortium developed a prototype infrastructure for services and three prototype applications covering the area of air quality, bathing water quality, and urban geo hazards. This article concentrates on prototype implementation of the Cascading SOS (SOS-X) service.

2. Cascading SOS Use Cases

Cascading Sensor Observation Service (SOS-X) is a client to the underlying SOS service(s) and provides alternative access routes to users (or services) interested in accessing data (Figure 1). In its simplest form, SOS-X provides an alternative route to accessing the data offered by underlying SOS service with no changes to the information model. However, the real power of this service lies in its capability to optimize the data flow, manipulate the meta-information, and to (pre-)process information before re-publishing.

Figure 1. Cascading SOS

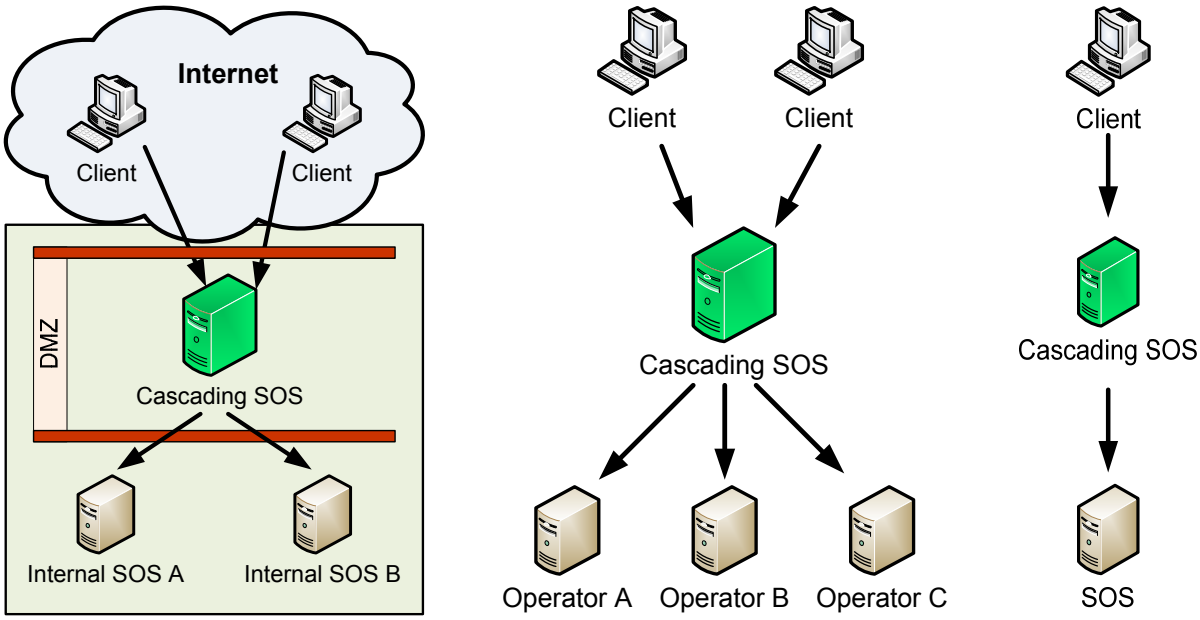


Capabilities of the SOS-X are best understood on the basis of use cases (UC):

2.1. UC1: Publishing

In this use case, the cascading SOS is situated in a DMZ and used to publish a subset of internally available data to the outside world (Figure 2a). This mode of operation allows clean separation of the data into "confidential/internal" and "public" part, without the need to replicate the data. In addition, the SOS-X can be instructed to customize the view to the data before re-publishing (UC2, Figure 2b)

Figure 2. From left to right: **(a)** UC1 "data publishing"; **(b)** UC2 "custom view to data"; **(c)** UC3 "Protocol Transducer"



2.2. UC2: Custom View to Data

In this use case, the cascading SOS is used to provide a single point of access to data from several sources (Figure 2b). The data served by SOS-X itself remains unchanged in this process, but the meta-information and the way data is presented to the users may be altered in the process.

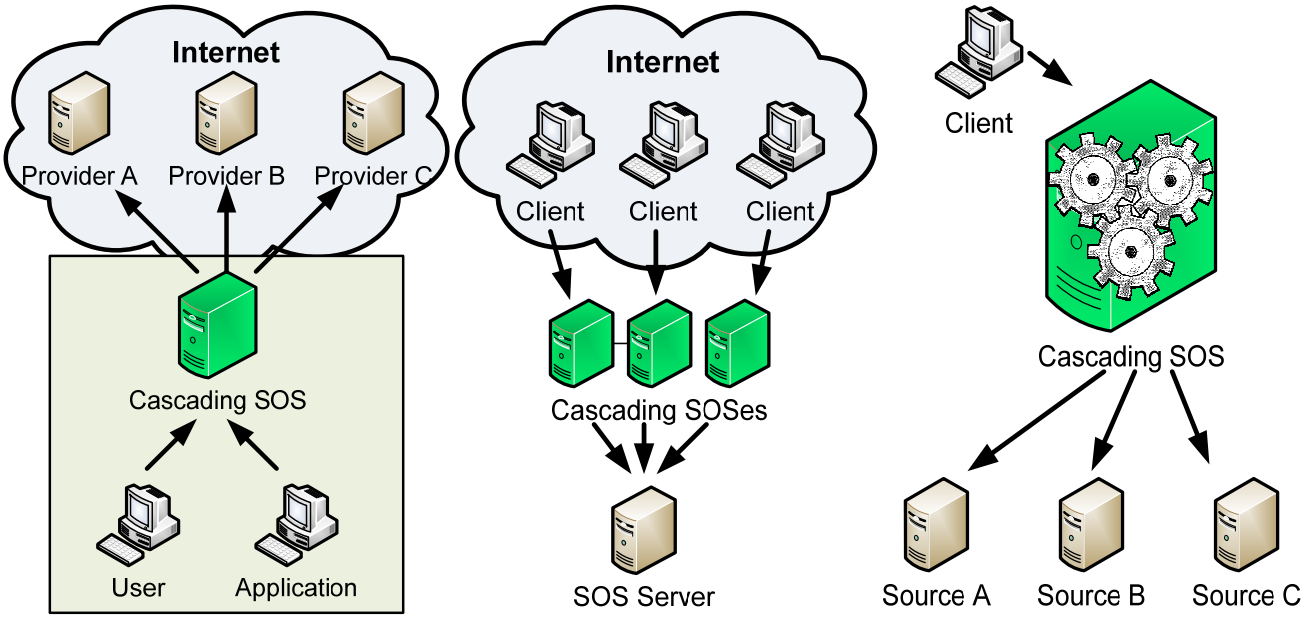
2.3. UC3: Protocol Transducer

Cascading SOS can be used to bridge the technology gap between providers and users of information (Figure 2c). The SOS-X implementation architecture is modular, and (back-end) clients can be written for various legacy services. In addition, the front-end interface is also implemented in a way that allows easy exchange or even simultaneous access to data over several interfaces.

2.4. UC4: SOS Proxy

SOS-X residing on a users LAN could greatly improve the quality of service by pre-fetching and caching the data (Figure 3a). In addition, the SOS-X could implement advanced mechanisms for serving large data sets.

Figure 3. From left to right: **(a)** UC4 "SOS Proxy"; **(b)** UC5 "Load Balancing"**; (c)** UC6 "Value Added SOS"



2.5. UC5: Simple Load Balancing

In emergency situations, the number of requests for information may rise far beyond the average needed server capacity. In addition, most requests concern only a tiny subset of the data. This, and the stateless nature of the SOS service assures that scaling-out is a good answer for emergency overloads.

SOS-X allows a very simple mechanism for scaling out: the original server is moved to the background, and replaced by a group of SOS-X servers (Figure 3b). Each of the SOS-X servers is configured to act as exact replica of the original system, and a load balancer assures that the load is evenly distributed over all servers. Thanks to SOS-X caching mechanism, most of the requests can be handled by one of the SOS-X servers, without the need to consult the original SOS service.

2.6. UC6: Value Added SOS

This use case is an advanced version of the UC1 and UC2. SOS-X features a built-in mechanism for performing arbitrary algebra operations on time series (Figure 3c). The algebra operations are performed by the "Formula 3" (F3) engine, which is developed in parallel with the SOS-X, and may in the future even be made available as

a stand-alone software independent from cascading SOS. Unfortunately, no publicly available documentation of F3 has been published so far. Typical (pre-)processing tasks that can be performed by SOS-X include units conversions, building of indicators and re-sampling of data.

2.7. UC7: Sensor Data Store

The "Sensor Data Store" use case can be seen as an advanced version of the "SOS Proxy" (Figure 4b). In use cases 1 to 6, we presume that the cascading SOS does not need to keep a local copy of the original or derived data, except for performance reasons. This implies that (1) the original data will be available on the source server in the future, and (2) all changes to original data must be reflected in the SOS-X.

In some cases these assumptions may not be true, and the SOS-X needs to manage the data on its own. Typically this will be the case when underlying SOS servers are the data acquisition systems with limited resources.

3. Development Status and Outlook

The development of SOS-X started in Q1 2008. In the meantime, a first working prototype has been presented to potential users on the SANY SP4 (Air Quality) demonstration event (04.11.2008 in Vienna, Austria). The software is written in Java (J2EE) and uses 52 North's implementation of the SOS specification as it's front-end.

The seven use cases introduced in Section 2 should be seen as simplified development specifications, and do not reflect the current development status. The current prototype is capable of demonstrating the use cases 1, 2, 3 and 6 in a controlled environment, but it does not fully support all optional features of the SOS specifications (e.g. space filtering has not been implemented yet) and is definitely not ready for being used in a productive environment. As a proof of concept, the current SOS-X prototype can currently (1) provide custom views to data originating from other SOS servers and from a proprietary UWEDAT system [8]; (2) alter meta-information provided by the source system and add missing meta-information to the data; (3) perform the calculation of a moving average on time series; and (4)translate between SOS 0.31 and SOS 1.0 protocols

Further financing of the development is assured through SANY-IP until the end of 2009, and our immediate development agenda aims to establish a solid software architecture and to maximize the usability of SOS-X in various SANY demonstrations:

- Q4 2008: bug fixing and stabilization of the existing code; clean separation of the 52 North SOS code from the SOS-X code developed by ARC; assuring compliance with SOS specifications.
- Q1 2009: implement permanent data storage and a simple mechanism for pre-fetching and caching of data; define a SensorML representation of meta-information to indicate the "time to live" and frequency of updates.
- Q2 2009: implement *one* simple mechanism for handling large data sets; improve F3; add preliminary support for event processing; automatic recognition of meta-information relevant for caching; demonstration of all seven Use Cases.
- Q3/Q4 2009: consolidation of the development done so far; concentrate on performance and bug fixing; if possible add support for SOS over SOAP, user management, authorization and authentication.

4. Conclusions

Cascading SOS is a very promising concept, with the potential of becoming a very important infrastructure building block for the in-situ sector of GMES, GEOSS, INSPIRE and other large in-situ environmental monitoring networks. The results of the first development cycle are encouraging and no conceptual problems have been discovered so far.

However, the software is still in an early stage, and the usability of the final product is highly depending on the performance of the SOS-caching method(s), which cannot be determined before Q3 2009.

In order to improve the visibility of the project, and build communities interested in further development beyond the end of the SANY IP, ARC decided to publish SOS-X under Open Source (GPL license). All information concerning the development status and instructions for downloading and installing the software is available on the SANY-IP web site (http://sany-ip.eu/results/sos_x).

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The development of a dynamic web mapping service for vegetation productivity using remote sensing and in situ sensors in a sensor web based approach

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Abstract: This paper describes the development of a sensor web based approach which combines earth observation and in situ sensor data to derive regular products which are made available through a dynamic web mapping service (WMS). A demonstrator has been developed which provides daily maps of vegetation productivity (Gross Primary Production) for the Netherlands with a spatial resolution of 250 m. We developed an automated processing facility implemented using Python scripting which downloads daily available MODIS surface reflectance products (MOD09) from the NASA ftp server. In addition, meteorological data (global solar radiation, temperature) of 17 weather stations in the Netherlands are requested from the SWE server of the Royal Netherlands Meteorological Institute (KNMI). Using the GetObservations request of the Sensor Observation Service (SOS) operated by KNMI, data are imported within the processing scheme on a daily basis. This report presents the methodology for estimation of vegetation productivity, the data-sources which were used in this study and the implementation of the WMS. Finally, an evaluation is made of the opportunities and limitations of sensor web based approaches for the development of dynamic web mapping services which include both remote sensing and in situ geo-sensor data sources.

Keywords: earth observation, meteorological parameters, OGC SWE standards, WMS

1. Introduction

Recent advancement of sensor web technology [1] has shown a promising potential in the analysis of temporal dynamic change on vegetation conditions within local landscapes [2]. Measurements from a sensor web could be one of the key variables to monitor and analyze ecosystems at local to global scales. Sufficient availability of real-time sensor web data can increase the understanding and detection of vegetation status of varied landscapes. One application domain is the opportunity of better estimation of local vegetation productivity where land use variability is dominant across landscapes.

At the global scale and in view of issues related to global change, terrestrial plant productivity is one of the most-modeled ecological parameters, with models that differ markedly in approach and complexity but often yielding comparable estimates. For example, a 8-day MODIS product (MOD17A2) is available which models gross primary production (GPP) at a 1 km resolution. However, for regional applications (e.g., farmers monitoring crop productivity or river managers monitoring vegetation biomass in floodplains) both the spatial and temporal resolution of this product are to coarse. In addition, this product has been developed for a global scale, this means that several of the input parameters of the estimation model are not taken into account the regional heterogeneity of land use and meteorological parameters.

In this study we have been developing a sensor web based approach which combines earth observation and in situ sensor data to derive regular products in automated processing facility which are made available through

a dynamic web mapping service (WMS). Within the study a demonstrator has been developed which provides daily maps of vegetation productivity for regional to national scale. We will elaborate this approach in a case study for the Netherlands.

2. Methodology and implementation

During the last 20 years, several remote sensing based approaches have been developed to estimate vegetation productivity from global to regional scales [3]. For the estimation of vegetation productivity we adopted the methods for estimating plant productivity from observations of the fraction of absorbed photosynthetically active radiation (FPAR) and light use efficiency as proposed by Monteith in 1972 [4]. The underlying concept for many remotely sensed measures of carbon uptake is that the ratio of absorbed light to carbon assimilation inmost plants is relatively constant. This ratio is called the light use efficiency ($\varepsilon_{g\text{-}max}$) and is used to translate remotely sensed estimates of light absorption in GPP (gC m^{-2} day^{-1}) as described in the following formula [4]:

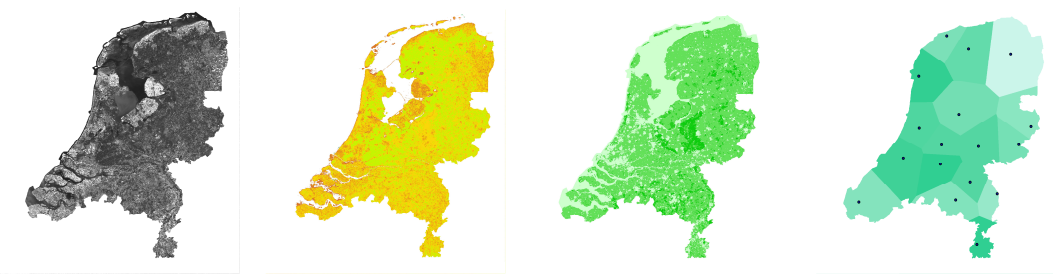
$$GPP = \downarrow PAR \times FPAR \times (\varepsilon_{g\text{-}max} \times S_{Tmin} \times S_{VPD}) \quad (1)$$

where ↓PAR is the incoming photosynthetically active radiation (MJ m^{-2} day^{-1}) and FPAR is the fraction of absorbed photosynthetically active radiation (unit less). ↓PAR was derived from measurements of Global Solar Radiation generally available from meteorological stations. In addition, regional and global scale vegetation productivity studies require accurate estimates of FPAR and $\varepsilon_{g\text{-}max}$. Therefore, FPAR was derived from spatial continuous earth observation data where the Normalized Difference Vegetation Index (NDVI) was used as estimate for FPAR. In this case, we used medium resolution (250 m) MODIS images which have a daily acquisition frequency. From literature it is known that $\varepsilon_{g\text{-}max}$ exhibits spatial variation over vegetation types and temporal variation at individual sites [4]. In this study we used an approach which reduces the potential $\varepsilon_{g\text{-}max}$ with scalars for minimum temperature (S_{Tmin}) and water availability (S_{VPD}) to estimate the actual efficiency. For these scalars, temperature and pressure data from meteorological stations were used.

Within this study an automated processing facility was developed to map vegetation productivity by combining earth observation and in situ meteorological data in a sensor web based approach. The resulting products are made available through a WMS. The whole procedure consists of different modules and the python programming language was used to link the activities within the components together. The following processing steps are carried out:

1. The MODIS surface reflectance product (MOD09) is downloaded from the MODIS ftp site on a daily basis, with a delay of up to ten days. Images were processes and converted to ASCII rasters depending on the availability of the image at the ftp site, two main tools were used for processing: the MODIS Reprojection Tool to clip and reproject the images (Figure 1) and GDAL to convert the images from GeoTiff to ASCII;
2. Cloud coverage was calculated from the red band of MODIS, all pixels with a value lower than 0 and higher than 1500 are defined as clouds, and converted to no data, to be left out of further processing;
3. For meteorological data a GetObservations request for data on Global Solar Radiation is send to the SWE server of the Royal Netherlands Meteorological Institute (KNMI) on a daily basis through the SOS protocol. The response data is directly interpolated (by Thiesen polygons) using the data of 17 available weather stations into a ↓PAR map covering the whole of the Netherlands (Figure 1);
4. NDVI derived from MODIS surface reflectance (Figure 1) was used as estimate for FPAR and stored as dynamic grid file (ASCII raster) with 250 m spatial resolution;
5. $\varepsilon_{g\text{-}max}$ or LUE is a static grid file (ASCII raster) with 250 m spatial resolution (Figure 1), The data is aggregated to 250 m resolution from the original dataset with a 25 m resolution taken from the Dutch Land Use Database (LGN4);
6. Meteorological data (↓PAR, T_{av}, T_{min}): these are dynamic point observations which are made spatial continuous by using Thiessen polygons as spatial interpolation technique. Finally, this also results in a derive dynamic grid file ASCII raster with 250 m spatial resolution;

Figure 1. Input data-layers for productivity mapping (from left to right): MODIS reflectance product, NDVI, LUE, and PAR for May 5th 2008.



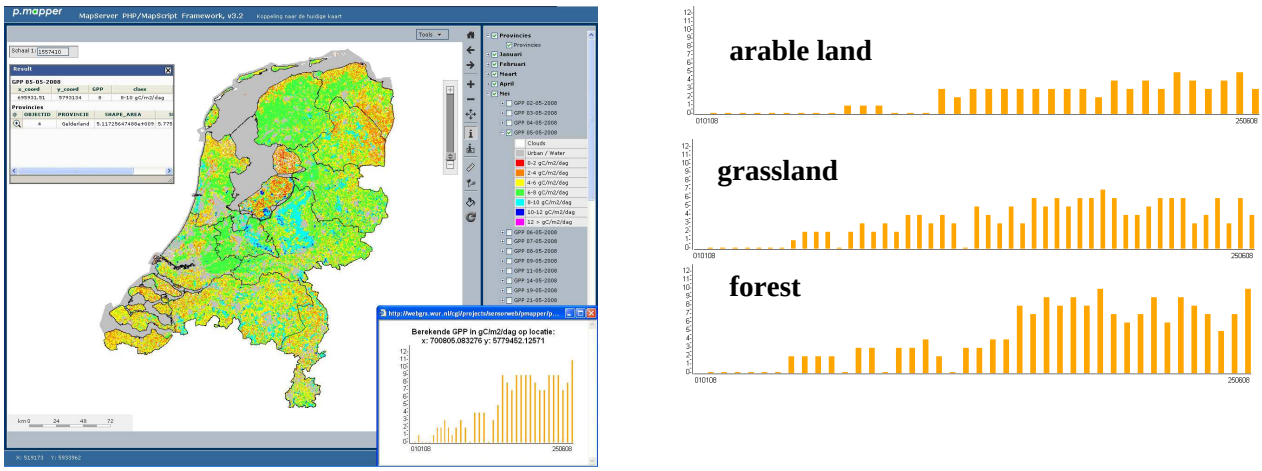
7. Based on these datasets, a per pixel calculation is made to calculate GPP according to the approach described in formula 1. Calculations are made for the land surface area as determined from LGN4 while no GPP calculations are made for cloud covered pixels, these will remain as no data;
8. The final products for vegetation productivity are then stored in a ASCII rasters and made available through a web mapping service using UMN Mapserver (http://mapserver.gis.umn.edu/) together with pmapper (www.pmapper.net). The procedure is carried out for the land surface area of the complete Netherlands and the time-series starts from the January 1, 2008.

3. Demonstration Dynamic Web Mapping Service

The final result of this study is visualized in a dynamic web mapping service (WMS)[1] which presents the vegetation productivity for the Netherlands for both agricultural and natural vegetated areas (Figure 2). Within the software standard functionality is already available (e.g., zooming and panning, measure distance, make layers transparent, printing and downloading). In addition, some dedicated functionality was added to the WMS in order to present actual changes in vegetation productivity:

- Information on most recent vegetation productivity: after selection of a pixel, actual values of vegetation productivity are listed for all opened layers of WMS (Figure 2: upper left);
- Trajectories of vegetation productivity: after selection of a pixel, the time-series of vegetation productivity for all available dates is presented for the most recent year available (Figure 2: right).

Figure 2. In right column: viewer of web mapping service including point (left) and time (right) graphics functionality. In left column: Examples of vegetation productivity time-series (Jan 1 – Aug 25, 2008).



4. Evaluation and outlook

Within this study a limited number of sensor web based meteorology stations was available. This is of course mainly related to the fact that the OGC SWE standards have only recently become available and most

[1] http://webgrs.wur.nl/cgi/projects/sensorweb/pmapper/pmapper_gpp/map.phtml

organizations responsible for in situ geo-networks haven't yet introduced this in their actual processing facility. The expectation is that the coming 5 till 10 years this will change and a large number of nodes in the currently running geo-networks (meteorology, groundwater etc.) will have a SWE character. In addition, dedicated networks (e.g., protection of dikes) which are newly developed will more quickly be adapted to new available technology. However, limitations with respect to sensor energy and communication still need improvement.

An important limitation in the use of optical remote sensing data for daily monitoring is the problem of cloud coverage. For the Dutch situation, on average between 40 and 60 days per year have a cloud coverage smaller than 30% for the Netherlands during the MODIS overpass. As a result it will not be possible to produce daily maps of vegetation productivity with a complete coverage and also the frequency of coverage per pixel will be variable. At this moment, actual processing and visualization of vegetation productivity is not real time but has a delay up to 10 days. Main reason is the time delay due processing and archiving of the MODIS images. This could be reduced by downloading the raw MODIS data (available within 1 day). However this would require development of a hardware and software set-up for (automated) processing of satellite data from raw data to surface reflectance which would be quit an investment. Another option would be to develop a facility for direct broadcast of satellite data from the satellite to a host institute (e.g., WUR) by a dish receiver. However, this would also require the development of a processing facility for raw data. For the Dutch situation with its relatively heterogeneous landscapes and short-scale variability, the medium resolution of 250 m to 500 m for MODIS data will often be to coarse. However, higher resolution satellite based remote sensing sources (10-30 m) are only limited available (Landsat, SPOT). In that respect, recent developments in the field of remote sensing data fusion [5] could be of interest to improve the spatial resolution to relevant management units (< 30 m). Recent developments within NASA and ESA are aiming at provision of real-time earth observation products to the end-users, so the expectation is that within the coming years, the real-time availability of earth observation data will improve. Within ESA, several projects [6] are dealing with the use of (OGC) SWE technology to connect in situ sensor webs with remote sensing sensors which are brought together in the ESA Service Support Environment. Within NASA, fast delivery of EO-1 remote sensing products has initiated several projects which use SWE to control and access earth observation sensors to monitor the development of hurricanes and wildfires.

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Combining sensor and forecast information to aid decision making: real-time determination of hydrological peat fire risk in Kalimantan

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Abstract: This paper demonstrates how Delft-FEWS can be used to bring together satellite derived precipitation estimates (TRMM), a regression-based groundwater model and an ensemble of seasonal forecasts (CFS) to estimate the current and predicted risk of peat fire occurrence for a site in Kalimantan. It does so by using TRMM based precipitation estimates in combination with the groundwater model to simulate groundwater levels in the peat soils of Kalimantan. These groundwater levels have shown to be a good indicator of peat fire risk in the region. A preliminary application that includes the Climate Forecasting System (CFS) demonstrates good forecast skill up to 30 days lead time. For the longer lead times (up to 270 days) better skill may be obtained by using alternative bias corrections, by using ensemble statistics instead of using the ensemble median and by using other sources of seasonal precipitation forecasts.

Keywords: Peat Fire risk, Delft-Fews, Seasonal forecasting

1. Introduction

Peatland fires are an increasing environmental problem in several parts of the world, particularly in Indonesia and Russia. The number and intensity varies between years and they are more limited in scale than forest fires. However, peatland fires can burn much longer because of the presence of a large fuel stock (the peat). In the process, they produce huge amounts of smoke and carbon emissions that can make up a significant amount of global carbon emissions Several fire early warning systems exist or are being developed that are based on detection of current fires from satellite images, sometimes with limited rainfall monitoring and/or forecasting capacity added. These systems can tell if peatland fires are a problem at a certain moment, and if fire risk is likely to increase in following days. However, the usefulness of these systems appears debatable. The impact of fire fighting efforts in many peatlands is questioned, because peatland fires are often simply too large and too far away from populated areas and water sources to be extinguished by anything other than loss of fuel or substantial rainfall. In general, fire prevention seems a more promising way of reducing fires, but this requires a far longer warning time than can be provided by current systems. We report on a preliminary feasibility study into a forecasting system that aims to provide the long lead times needed to invest into management and awareness programs that may prevent the occurrence of peat fires. Peatland groundwater levels have shown to be a good indicator of peatland fire risk [2]. Water depth classes can be related to the occurrence of peat fire. In the absence of on-line groundwater level monitoring the groundwater levels can be simulated using a simple water budget model that has shown to give fairly good results for locations in Kalimantan [2] and that needs to be driven by precipitation data only. Because a good coverage of real time

rainfall data from ground measurements is not available for Kalimantan, rainfall estimates from the Tropical Rainfall Measuring Mission (http://trmm.gsfc.nasa.gov/, [3]) were used. Several years of ground based measurements of rainfall and groundwater level have been used to establish the performance of the TRMM bases rainfall estimates. For this initial setup use was made of the freely available CFS model output. The Climate Forecast System (CFS) was developed at the Environmental Modeling Center at NCEP [5]. A new forecast consisting of four ensemble members is available every day. We combined ten days into a 40 member time-lagged ensemble for the semi operational setup. For bias correction of the forecasted precipitation climatology derived from the ERA 40 dataset [pers. comm. Rens van Beek, University Utrecht] was available.

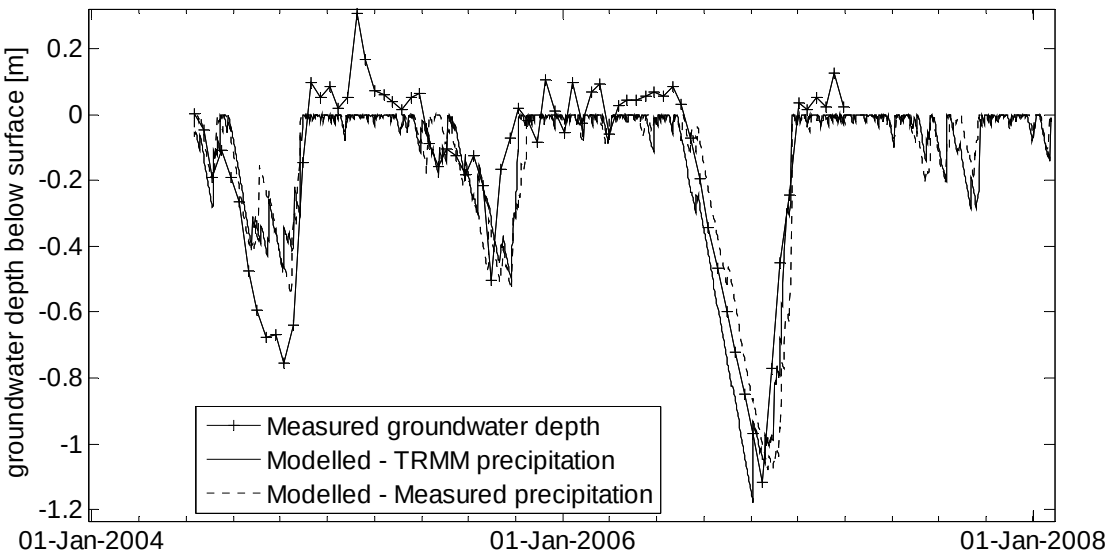
The tool used to combine all of the above into a working system is Delft-Fews. Delft-Fews, has taken a new approach compared to traditional model centered forecasting systems, by placing the data process central to the system [6]. It includes a generic user interface and a collection of utilities to deal with processing of data in the context of flood forecasting. All modules interface with a high performance central database. The structure of the system and it's ability to process large amounts of (gridded) data efficiently, has allowed it to grow well beyond the scope of flood forecasting and it has proven to be a platform on which many operational systems can be made regardless of the underlying models [1].

This paper discusses three research questions: *(1)* Can the TRMM precipitation estimates be used to reliably (as good as the simulations with the ground based data) simulate peatland groundwater levels in the selected areas in Kalimantan? *(2)* Can de CFS forecast be used to drive the groundwater model and what is the maximum lead time for which the peat fire risk can be forecasted? *(3)* Can Delft-FEWS be used to set-up a near real-time hydrological peatland fire risk forecasting system based on the available data?

2. Results and Discussion

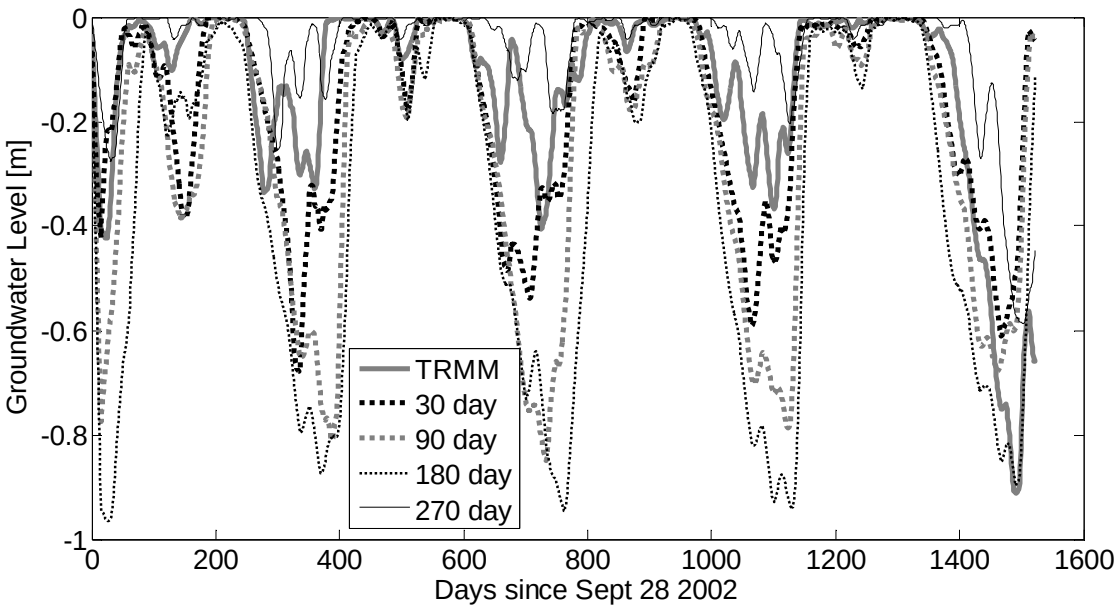
Monthly measured and TRMM observed precipitation totals were correlated for Palangka Raya in Kalimantan. Overall, correlation coefficient (R2) was reasonable good at 0.61, whereas dry and wet season R2 were 0.72 and 0.34 respectively, indicating a better correlation for monthly dry season precipitation. Over a 5-year period (February 2002 – December 2007) measured precipitation was 18 % lower then TRMM observed precipitation for Palangka Raya. The peatland water budget model was run for both measured precipitation and TRMM observed precipitation. The model results compare well with measured groundwater depths. The model runs with either measured Palangka Raya precipitation or TRMM observed precipitation results in similar groundwater depths (Figure 1).

Figure 1. Measured (average of 3 dipwells) and modeled groundwater depth (m) for degraded peatland.



The groundwater model was programmed in the pcraster language [7] that had been embedded into Delft-Fews thus allowing the model to be run on a grid for all peat occurrences in the region. First a reference run was made of the groundwater model using TRMM data only for the period 2002 to (and including) 2006. This run was used for comparison with the model output using the CFS forecasted data. For the same period the retrospective forecast of the CFS system were downloaded and imported into the system. These reference forecasts consist of 15 forecasts each month for the same period. The forecasts are combined into one 16 member ensemble forecast per month. The 16th member was made using the ERA 40 climate dataset. Next, forecasts were made for every other day with forecast start times ranging from January 1 2002 to January 31 2006. Thus, the actual CFS forecast data used in each forecast will change once a month but the part of the forecast up to the time of forecast will change for each forecast as this is replaced by the TRMM precipitation estimates, setting the initial groundwater levels the start of each forecast using the best available method, replicating a real time system. For each forecast fixed lead time series are extracted for 10, 30, 60, 90, 120, 150, 180, 210, 240 and 270 days lead time using the 15 member ensemble median. A selection of the fixed lead-time forecast is shown in Figure 2.

Figure 2. Simulated and fixed lead time forecasted groundwater level for the period between September 2002 and September 2006. Simulations (thick blue line) have been performed using the TRMM data. Fixed lead-time forecast traces have been made for extracting the respective lead-time (30, 90, 180 and 270 days) from forecasts that have been made for every other day (15 ensemble members) over the whole period.



Model performance [4] rapidly decreased with forecast lead time ranging from 0.90 (10 day) via 0.59 (30 day) to 0.08 for the 60 day lead time forecast after which the model efficiency becomes negative. A large part of this is due to the increasing bias. Clearly, the very long lead times needed for management operations are not forecasted accurately enough to be meaningful in the current setup. Several options are available to remedy this. This first evaluation only looks at the ensemble median. An initial review of the results for the whole ensemble indicates that the lack of forecast sharpness that is demonstrated in Figure 2 may be alleviated somewhat by looking at the ensemble statistics. In the predictions all years are equally dry. However, there is a difference in skewness of the ensemble distribution between the dry and wet year that may be used. The presently applied bias correction – in which the difference between the climatology of the CFS model and the ERA40 dataset is used to correct the forecasted precipitation – is fairly crude and other methods may be used. For example, a high resolution climatology has been calculated from TRMM data recently. The CFS model is not the only seasonal forecast model and research has shown that others may perform better [Florian Pappenberger, pers comm.], Perhaps a multi NWP model ensemble may be used to increase performance.

Setting-up the system in semi operational mode using Delft-Fews proved to be straightforward. The CFS data can be read into the system directly while a simple conversion tool could be made to prepare the TRMM data for import. The system was run on a desktop computer and scheduled to perform a forecast (using the time-

lagged 40 ensemble members once a day. Each forecast consist of 40 model runs including all the data preprocessing and takes approximately 15 minutes on a standard desktop PC. Due to the high compression rates in the database the size of the operational database can remain limited to 8 GB. The retrospective forecast runs took a bit more time. A total of 29200 forecast runs were performed, each run processing over 8GB of data. This took one week on a fast PC (a 3Ghz Dual core system).

3. Conclusions and further research

This research shows that near real time TRMM data can be used in combination with a groundwater model to get a good estimate on current peatland groundwater levels and thus on the current hydrological fire risk. Using a first setup using CFS forecast data in which ensemble median was used to forecast groundwater levels proved to provide forecast skill up to 60 days ahead. All data needed to run the system is freely available and the system itself can be run at very low costs (a single PC with an internet connection). More work is needed to fully qualify the actual forecast skill of the system. This will be done later using probabilistic methods, better bias correction and by investigating other seasonal forecast sources.

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Distributed Decision Making in a Sensor Enabled Environment

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Abstract: Advances in sensor technology will revolutionize the way that real-world events are collected and interpreted. The ability to ubiquitously capture data will generate an unprecedented amount of data making distributed data management and decision making key challenges in the deployment of this technology. The demands for intelligently managing real-time data and integrating it into applicable business processes have propelled the emergence of a new breed of distributed software systems. The challenges are broader than simply creating such a software platform to manage and integrate the sheer volume of sensor data. Mechanisms that permit the application of contextual and application knowledge into the distributed decision making infrastructure are required. We base the design of such software on the theory of event which permits events to be states, or processes. In managing real-time data and information from distributed heterogeneous sensors, the notion of the event is attractive for several reasons. First, modeling data in terms of events parallels the way humans conceptualize and relate information. Second, the notion of events, especially the differentiation between significant and non-significant events may be used to filter data. Third, the definition of an event provides an implicit data wrapper may be used to link sensor data through event relationships. These relationships may be used to reason in an enterprise application context. Finally, the event-based approach is well suited to associating autonomous, heterogeneous sensor nodes by means of the inherent properties of events such as time and space. Thus these sensor nodes may be integrated into a complex decision making networks through event-based communication. In this paper we describe the design and development of such a distributed software platform which can acquire data from heterogeneous sensors, integrate, and provide distributed decision support. The raw data is processed at multiple levels of abstraction and using context information combined to form higher-level events that enable real time decision making. A multi layered event representation and reasoning model is implemented that feeds sensory data derived from low level sensors such a into higher-level event structures, which can then be exploited by appropriate event handlers. The event handlers are described using business rules making system and operational characteristics directly accessible to the analyst (rather than the programmer) We describe the deployment of this software platform in a large US public transportation system to ensure operational and user criterion.

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Geo-sensor networks: implementation and experiences

Agriculture benefit from the LOFAR infrastructure

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Abstract: In the Netherlands an ICT infrastructure is being build around LOFAR. The infrastructure is based on the concept of abundant data gathering, and specifically designed for astronomy. High speed data net is connected to supercomputer processing power. This paper reports the project in which it was investigated whether the LOFAR infrastructure also suits agriculture. A few dedicated projects for arable and dairy farming were set up to design, implement and test the whole data chain for gathering 'real time' data from the field, store and manipulate this in the ICT infrastructure and use them in model calculations.

Keywords: ICT data structure, modeling, concept.

1. Introduction

LOFAR introduction

LOFAR (www.lofar.nl) is a unique international ICT project that originates from the ambition of Dutch astronomers. They want to build a new type of radio telescope that is hundred times more sensitive then present ones. The LOFAR consortium builds an antenna that consist of a network of thousand(s) sensors. These sensors cover an area with a diameter of more than 100 km, and it is mainly located in the Northern part of the Netherlands. Data form these sensors are transported by a high capacity fibre network and analysed by using a super computer. Such a system is unique in the World.

It was soon realised that LOFAR could be turned into a more generic Wide Area Sensor Network with opportunities for the improvement of the economy and infrastructure in Northern Netherlands. Several applications are being considered, given the increasing interest in sensor networks that "bring the environment on-line." The integrated LOFAR project (LOFAR Noordelijke Componenten) consist of the following 5 sub-projects:

- Enhancement of LOFAR for geophysical and seismic research (LOFAR Geo)
- Enhancement of LOFAR for precision agriculture (LOFAR Agro)
- ICT development for distributed sensor network ("Science and Operations Centres")
- Connection to and optimal use of the "Streaming Super Computer"
- Development of LOFAR antennas.

LOFAR Agro

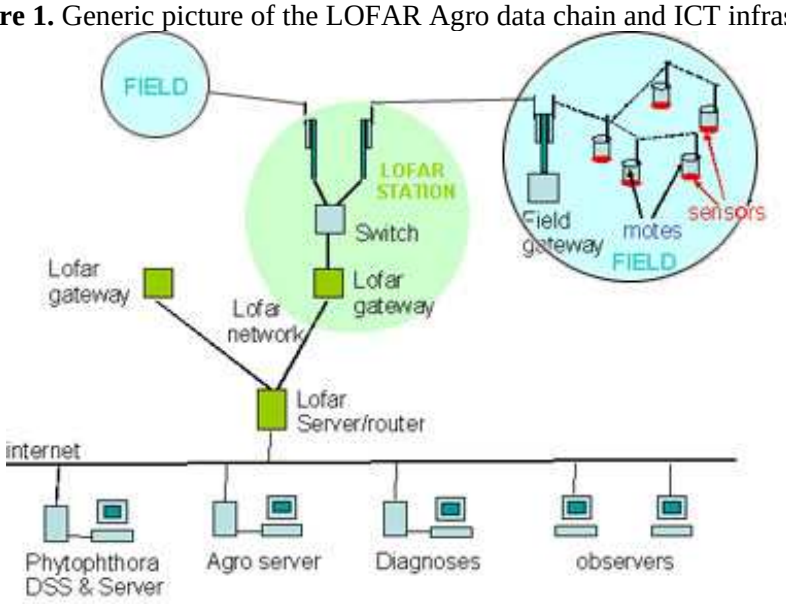
LOFAR Agro investigated whether this infrastructure with high data capacity and processing power is also useful for agricultural related applications. Inspired by the concept of precision agriculture, the development in wireless sensing ('smart dust') and the Internet a four years research programme was conducted. This programme ended in September 2008, and was financed by the EU (Regional Funds), the Cooperation Northern Netherlands (SNN) and contributing partners.

Within the research programme four projects were conducted. Each project focused on a specific part of the data chain that used the LOFAR infrastructure. The chain is formed by data collection in the field of plants, soil and animals by using wireless sensors, data communications in a rural area, data storage in a agro-server, interpretations of data by using models, processing models on a super computer and the interactions with the farmer. Each project also had a scientific and a social challenge.

2. Results and Discussion

Figure 1 gives a generic picture of the whole data chain and the ICT infrastructure. The design, implementation and test of this infrastructure is directly connected to real agricultural questions. To get the feeling whether this infrastructure might be useful in the agricultural sector these real situations were important. In the 'Precise Soil and Water' project also 6 arable farmers were partner in the project. Besides these arable farmers and researchers several Small and Medium Enterprises (SME's) were partner in the LOFAR Agro projects.

Figure 1. Generic picture of the LOFAR Agro data chain and ICT infrastructure.



The following paragraphs give insight in the four projects that were performed in the LOFAR Agro research program.

LOF -- Ag 01 Phytopthora: micro climate modelling

This topic is of interest for LOFAR because a dense static network of wireless sensors is needed to capture variability in micro climate in a field. The size of the network is of interest to test communication protocols and the amount of the data is of interest for LOFAR by the use in dynamic improving a simulation model to predict the micro climate. Use of weather forecast gets value when used by the simulation model that are validated and improved by local monitoring. These two are also identified as scientific challenges.

The economic and social relevance is based on diminishing the use of pesticides. In this project the following components were build: network protocol for wireless sensing (TU Delft), setup of sensor systems and measuring procedures (WUR A&F), realisation of architecture (WUR A&F, TU Delft, Vertis, Opticrop,

Kverneland), integration with Agro Datawarehouse (Vertis), development of Decision Support System (Opticrop), development of Website (WUR A&F), micro climate modelling (WUR), and self learning principles (WUR A&F). Components were integrated into field experiments in 2005 and 2006. In 2007 and 2008 they were upgraded to farm level and integrated with other LOFAR Agro experiments.

LOF – Ag 02 Precise Soil and Water: dynamic real time decision support model

In this project we look for an interaction of researchers with farmers and industry in the region. Through an interactive process the choice was made to focus on the scientific challenge to improve the model based decision support of nitrogen fertiliser application during the growing season. When uncertainty in weather, precision in the field, and 'real-time' observations from plants, soil, weather and soil water content are incorporated in the decision model, the high processing power of LOFAR is needed.

The project is build around the next topics:

- Interaction between farmers and researchers in several meetings. In this project the experiences and backgrounds of the farmers and the researchers concerning the used techniques were be collected and communicated.;
- an observation component (sensor networks were possible) to determine real time information from soil, plants, product and environment;
- a data-infrastructure to handle the geographic data and to make them available for the decision models and the end users;
- a set of decision support applications based on crop growth simulation models that take weather, soil moisture and soil nitrogen into account. They will be extended to be able to incorporate weather uncertainty and site specific precision in the fertilizer application decision;
- a set of tractor-implement applications for controllable variable rate applications;
- communication: this is partially taken up in point 1, but goes further to scientific publications and presentations.

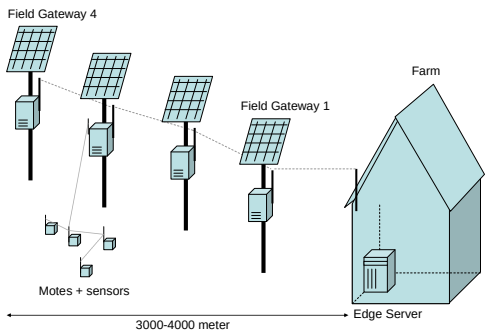
In a time line 2006 is planned for initial orientation, 2007 for working with single weather and a few management zones, and 2008 for working on 'square meter' level with uncertainty in the weather forecast.

LOF – Ag 03 Last Mile (Agro): entrance to the agro infrastructure

Wireless sensor fields are used in agriculture to increase efficiency or quality by monitoring e.g. soil, crops or animals. When using sensor fields in agricultural applications, it is desirable to gather and process data from different sensor fields at one central location. This requires a reliable, low-cost and wireless solution for last mile communication between field gateways at the sensor field and edge servers that are located at the farm.

The network architecture is based on using a multi-hop wireless meshing protocol (FLAME) in an ad hoc IEEE 802.11 network. It includes time synchronization and power management, which is necessary at the solar-powered field gateways.

Figure 2. Basic idea of the LOFAR Agro last mile concept



LOF – Ag 04 Livestock: tracing and tracking of moving objects

The Lofar Agro programme originally started only with projects with focus on arable farming. Looking to the overall ambitions and concept of LOFAR and the agricultural developments in the region of Northern Netherlands it became clear that there is also a need for orientation on the animal sector in general and dairy farming more specific. Looking to the dairy sector, the developments in the sensor techniques, and the portfolio of the LOFAR agro programme it was logical to focus on the real time possibilities of tracing and tracking of moving objects, in this case cows, but can also be applied to transport vehicles, and human to be able to unravel the complex situations of contact structures.

In 2006 some activities were done on measuring signal propagation and measuring rumen PH. At the end of 2006 a reorientation was made and the focus was set on following cows as moving objects and translation of activity data into 'new' daily and comprehensive management information for the dairy farmer. A cooperation has been setup with the BSIK program "Ruimte voor Geo Informatie (Space for Geo-Information)" who were working on the same concept. In 2007 this resulted in a system set-up to measure real time actual location and behaviour of cows (in the barn and in the meadow), procedures to transform data into management information, and test on two different locations (experiment Ossenkampen) on technique, experiment Nije Bosma Zathe on farm integration and exposure. In 2008 this is scaled up and the real time component is worked out in more detail.

3. LOFAR Agro lessons

In short the following lessons were learned form the LOFAR Agro research programme:

- Processing power is really needed for decision support in the concept of precision agriculture and uncertainty in weather scenarios.
- The LOFAR infrastructure should be of a hybrid structure, to be used also for agro applications. This means that beside the glass fibre the LOFAR infrastructure must be connected to the 'normal' Internet and the wireless nodes.
- The prototype of the AgroServer for data storage functions well. However, for full use of the LOFAR infrastructure it is needed to adopt a good business model.
- Cooperation between forefront arable farmers, small and medium enterprises and researchers functions best when you are working on a concrete prototype or situation. Own experiences discussed in a group gives most added value for all partners. Management of expectations is crucial in this type of activities.
- The use of deterministic explanatory models in real time dynamic decision environments requires a lot of knowledge form the advisor and end user. It should be considered whether more descriptive oriented models like "advanced monitoring and control" fit the decision circumstances better.
- Working with wireless sensing and networks show some persistent technological problems with concern to energy use, range, and reliability. These are not related to agriculture. This has led to some new international and intersectoral projects were agriculture show to deliver appropriate cases.

Acknowledgements

LOFAR Agro was financed by the EU (Regional Funds), the Cooperation Northern Netherlands (SNN) and contributing partners. The authors express there gratitude to the cooperating partners ASTRON, Agrovision, DACOM, Hilbrands Laboratory, Kverneland, Ordina (Oracle Solutions and Technical Automation), RINGAdvies, Soil Company, TU Delft, Twente Institute for Wireless and Mobile communications, Wageningen UR (Animal Science Group, Plant Research International, Meteorology), and the arable farmers Bosker, Fledderman, Hamster, Tuin, te Velde and Wage.

Open access to sensors

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Abstract: This paper reports on the experiences of a two-year national project during which Sensor Web Enablement was implemented and tested as the sensor data exchange protocol between major scientific institutes of the Netherlands

Keywords: OCG, SWE, sensor, measurement network

1. Introduction

Several leading scientific institutes in the Netherlands have cooperated in the investigation of the applicability of the OGC open standard Sensor Web Enablement. The study used a multi-disciplinary approach involving the domains of Meteorology, Hydrology, Groundwater, Agriculture, Geo-engineering and Data-communication

This two-year project is ended in 2008 and the conclusions are presented in this paper. Within the project a demonstration site was set-up were several sensor types were tested on their ability to communicate with end-user based on OGC SWE standards and protocols (Figure 1).

2. Results of the project

2.1. Cooperation requires standardization

Co-operation on data sharing becomes easier when standards are applied. The main advantage appears when different kinds of measurement have to be combined. Many different combinations are possible. Between institutes, between domains, between scale of application and between time related applications. The last combination needs further explanation. For a location the older data from a database can be combined with recent measurement data and further combined with prediction data coming from models. A smooth exchange and combination is enhanced if all involved parties agree on the exchange method(s) applied. Standardization may lead to cost savings and efficiency gains.

2.2. Organizational restrictions

The technical introduction of SWE usually took two to four weeks. Within the project, good assistance was given by the IFGI –institute from Munster, Germany. However, the major stumbling block preventing good cooperation and exchange appeared to be administrative regulations.

Four examples are given;

- The meteorological Institute is obliged to be very restrictive in its data supply, since the sensor data is, by law, not public.

- The knowledge on soil humidity is allocated to Alterra, but they do not maintain public databases on this domain. This situation prevents other users to built required public databases.
- The Hydrological Institutes working under contracts for the National Government are only allowed to release data after receiving an official permit.
- The pressure to earn part of the institutes income on the market, prevents small users to go through the financial registration and bureaucracy to obtain their data

Figure 1. The demonstration site at Gendt near Nijmegen were a meteorological and hydrological sensors were installed and made available via SWE.

2.3. Trend in field sensors conflicts with SWE

To reduce energy-consumption in field sensors, the present trend is to smaller and smaller sensors, with restricted short bursts of data. Energy supply depends on batteries and changing batteries is expensive. Also the amount of data should be as small as possible. This trend is contrary with the SWE protocol, which easily inflates the amounts of bits tenfold. SWE offers a planning service with the intention to provide instructions to the sensor at any time. This concept is also contrary to the current design philosophy the sensor equipment is in control for contacting the data centre.
The above mentioned limitation is not applicable to all sensor sites and furthermore it depends on the domain, e.g. for ground water level a daily measurement can be sufficient whereas for other sensors a continuous sensor operation and high temporal data update is required. When SWE is used for the institute to institute exchange of sensor data the power consumption is irrelevant.

2.4. Every domain needs a standard profile

SWE is an open standard, so every method name or dimension is accepted as input. In addition, large freedom exists in the format to package the actual numerical values. The receiving party is not always prepared to handle strange dimensions like orthodox calendars, yards, feets or imperial gallons, or a variety of complex data formats. For every domain profiles should restrict this freedom en prescribe method name, dimension, chosen axes (positive-negative) and symbols for visual presentation as well as formats for the numerical values.

2.5. Separate fixed (meta) data from variable (measurement) data

One of the reasons why the amount of bits is inflated, is the repeated transfer of fixed metadata. Fixed data like measurement method, owner, location, sensor-limits could better be send separately and added later. Most measurement data like laboratory data, medical data, warning data, have only an indirect relation to a fixed location or object. This means that GML should be optional for measurement data, which considerably decreases the initial investment in time and man hours.

2.6. Plug-and-play applications/services will stimulate the introduction of SWE

Presently every institute is building its own services and possesses its own applications for input, archiving, and quality testing of data. GIS-presentations and display of time series are made again and again (Figure 2). Good ready-made applications will surely stimulate the future introduction of difficult standards for small offices, local companies and farmers.

Figure 2. One of the applications build within the project. The grey arrow indicates the sensors at the Gendt test site.

3. Conclusions

The introduction of SWE is technical feasible but has still to reach maturity by simplifying the protocol, developing profiles and ready-made applications. Furthermore not all elements of SWE are available. The introduction should start on high level between institutes and only later be introduced for direct contact with a sensor. Laboratory sensors and sensors on the power grid are a better target for early introduction than field sensors. Although there is a large need in the society to combine data from domains and different scales, bureaucratic decisions, outside the scope of the scientists, often prevent good application.

Acknowledgements

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MOBESENS: monitoring water quality, at large and in the long term

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Abstract: MOBESENS provides a scalable and modular ICT-based solution for water-quality monitoring. It enables data to be gathered quickly and reported across wide areas. The low-power wireless sensor network gathers data samples, which are time and location stamped and automatically entered into the grid-based information system to facilitate analysis and issue alarms when needed. Mobility is a unique feature of MOBESENS sensors, which are capable of navigation and both surface and sub-surface measurements. This extends range, enables 3D area measurement campaigns and facilitates operations, even in bad weather conditions. MOBESENS may form ad-hoc networks enabling the rapid and reliable reporting as well as relative localization and tracking (e.g. of contaminants). Opportunistic communication between MOBESENS and fixed and mobile buoys is also envisioned. Finally, the use of on-board renewable energy can provide MOBESENS with self-sustained operations.

Note: the MOBESENS project is funded by the European Commission under the FP7 programme

Keywords: Water quality monitoring, mobility, wireless sensor network, grid, sensors.

1. Introduction

Management of water quality requires regular measurements and monitoring. Multiple point measurements are needed to cover an area. The process needs to be automated and extended to provide rapid and effective monitoring. In the MOBESENS project, the objective is to get autonomous, mobile and self-healing network for water quality monitoring, in order to identify trends and to help localize and track potential problems and issue alerts when required. This stresses the importance of the accuracy of the measure, its relevance and its availability in near real-time.

In the real world, it is impossible to get all measurements done and reported all the time, because this process would be too expensive, especially when some specific parameters are considered. The selection of parameters to measure must take into account previous knowledge of place where system will be installed, the state of the art, and the cost/benefit analysis: for example, it is more interesting to measure pH at the input of a waste water treatment plant than at the output, but the measurement of phosphates is more important at the output.

MOBESENS will provide a solution for water quality monitoring for some of the defined parameters in the Water Framework Directive.

In the FP7 MOBESENS project[2], communication ranges between nomadic sensor nodes of up to several km are possible using multi-hop, making wide area coverage achievable with a limited number of sensor nodes and a minimum of relay and/or gateway nodes. This includes developments of new technologies for water-specific sensors, allowing the measurements in the three dimensions. The use of energy scavenging (e.g., solar power, motion of the waves), combined with low-power operations, is envisioned to enable self-sustained and environmental friendly operation of the autonomous MOBESENS nodes over long periods of time.

It is necessary to have means of measurements, producing large quantities of data over long periods of time, to perform qualitative and quantitative analysis (analytical or statistical). As a consequence, sensors, means for deploying and exploiting the sensors, methodologies for measurement campaigns, tools to store, retrieve and exchange the collected data, to perform valuable analysis are required. In this perspective, the MOBESENS project will provide a specific data management organisation. The MOBESENS wireless sensor network serves as a front-end for gathering water quality information and reporting back to water quality management information systems, where it can be shared with other environmental monitoring systems. Unlike other solutions though, MOBESENS plans to deploy sensors capable of autonomous or controlled navigation towards measurement-wise interesting areas. The mobile water quality sensors are capable of forming self-configurable wireless networks enabling rapid and reliable reporting of information as well as relative localization and tracking (e.g. of contaminants). The presentation will focus on the innovation and benefits brought by MOBESENS.

2. The Water Framework Directive

The Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 (WFD) establishing a framework for Community action in the field of water policy Water Framework - also known as the Water Framework Directive (WFD) - is a European Union directive which commits European Union member states to achieve good qualitative and quantitative status of all water bodies, including marine waters up to kilometre from shore, by 2015. The WFD is a framework in the sense that it prescribes steps to reach the common goal rather than adopting the more traditional limit value approach.

The directive defines 'surface water status' as the general expression of the status of a body of surface water, determined by its ecological status and its chemical status. Ecological status refers to the quality of the structure and functioning of aquatic ecosystems of the surface waters. Good ecological status is defined locally as being lower than a theoretical reference point of pristine conditions, i.e. in the absence of anthropogenic influence.

3. The scenarios

The MOBESENS project addresses three different environments, which have different requirements in terms of deployment, mobility, sensors, density, frequency, number of points to be measured, etc. even though the objective is the same: water quality monitoring for alert. The first is a still freshwater body [1], the second is sea and coastal lagoon and the third is a river.

The objective is the same for all three scenarios (water quality monitoring for alert), as the water bodies have different problems, dynamic behaviour and reaction time, the interesting parameters to measure, the place and situation to be sampled, and number and frequency of the measure will be different.

4. The MOBESENS vision

In order to fit together the 4 main parts of the puzzle (sensors, communications, mobility and energy), the following questions must find answers: how much energy needs a specific sensor, or probe coupling several sensors, to make a measure? how much energy needs a communication system to send a byte? how many bytes must send a sensor to have information? how much energy the mobility system needs to make a displacement; how much information must be sent to control de mobility system?

MOBESENS promotes the vision that answers will be found by operating mobile elements which are capable of navigation, facilitating operation, even in bad weather, and enabling a rapid relative localization and

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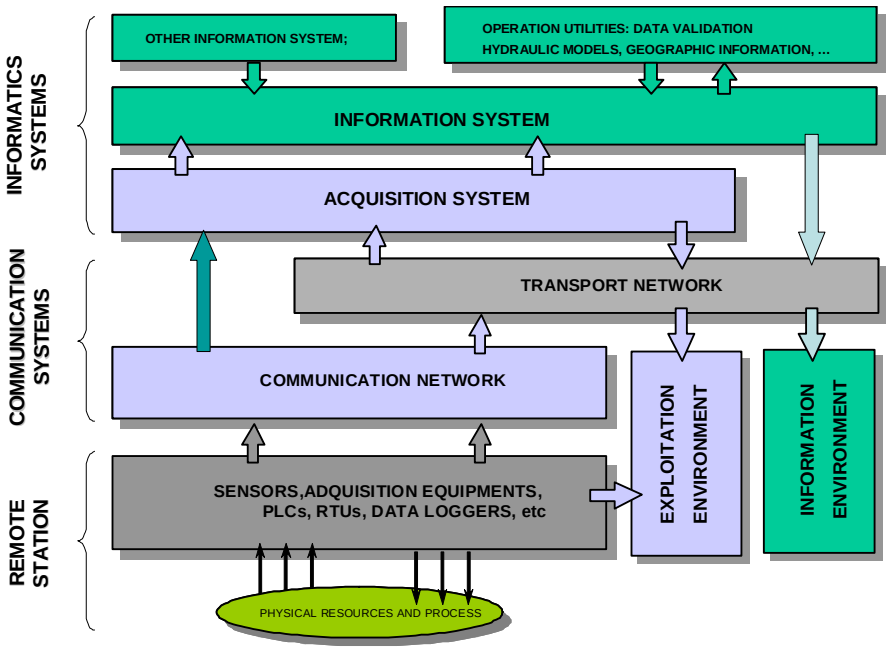
[2] The MOBESENS project is funded by the European Commission under the Framework Program 7

tracking (e.g. of contaminants), which are capable of both surface and subsurface measurements and which rely on an communication infrastructure made of ultra-low power, autonomous, self-organising mobile wireless sensor networks [2]. These networks collect and forward measured data samples with timestamp and location information. Later, this data samples are entered automatically into the information system (aka. grid) as raw data and then consolidated with previous data to facilitate analysis, issue alarms and serves as validation information for decision-making and prediction processes. The MOBESENS system is captured in Fig. 1.

Figure 1. Interactions in the MOBESENS system



5. Mobility

From a technical point of view, the mobility parameters are often related to the position (including the z component), the speed, the acceleration, the attitude, etc. Attributes of these characteristics are precision, resolution, consistency and replicability, etc. MOBESENS deals with several kinds of mobility: mobility of groups of nodes forming a network, mobility of nodes inside the network, mobility of networks in a multi-network application, mobility of the sensor (including disappearance and re-appearance, especially when depth is considered. Also, the mobility can be active when the node is guided from one position to another. It is passive when the movement takes place by the influence of physical phenomena such as the movement of waves. MOBSENS takes into account the problems raised by such mobility in the communications.

6. Localisation and synchronisation

As a consequence of the mobility, surface localisation of sensors, nodes and networks is central to the MOBESENS behaviour and quality. In this purpose, absolute and relative positioning techniques are applied so that the localisation process is flexible and reliable enough to be as fast and as precise as required by the application. the 2D position is completed by the depth value for sub-surface measurements. Eventually, the quality of the localisation information with which sensed data is tagged will have a direct impact on the relevance and importance of this data.

But the time information is required in models that deals with dynamic processes, such as water quality evolution. Moreover, the alerting system must be completed by time-based investigation processes, which determine the origin of water quality evolution. The same stands for the prediction. The MOBESENS system therefore uses a similar approach for time-keeping as used for localisation: absolute and relative time are used in the system. For example, absolute time can be given by the GPS that may be present on some nodes of the network and the relative offset estimated on the other nodes will provide a local time reference. Incidentally, the same GPS is used for the absolute positioning.

7. Energy in the MOBESENS system

The networks used in MOBESENS can be of any size. However, it is foreseen that in most situations, some nodes will be equipped with sensing parts (as such they will produce data) and other nodes will "only" serve as communication relays, positioning components or guides for reaching a destination. In general, it is expected that the sensor or motorised nodes will be powered by sufficiently dimensioned power supplies. However, the rest of the population could probably operate from minimal power supplies combined with energy-harvesting devices, thus extending their life-time. The devices that are studied for inclusion into the MOBESENS system are solar cells, micro-turbines (tethered sensors or craft mounted for generation with water or air), inertial devices and buoyancy based generation [3] (tethered sensors). The power that can be provided by such device is determined by the "length" of the volume of the node. It is likely for typical MOBESENS installations that nodes have characteristic lengths between 1 and 10 cm.

8. Data storage, processing and dissemination

Once data has been transmitted over the wireless sensor network, it is stored on the information system, called the "grid" so that it can be retrieved and analysed for immediate use through potential warnings and alerts. More generally, the grid defines a flexible structure and the means for accessing the database that covers the needs for data exploitation (representation and processing). Processing of the data includes data storage (raw, by automatic insertion mechanism with data validation, and consolidated data, with time continuity and reliability information of data quality), validation (based on several criteria, e.g. likelyhood, correlation, records of past reports) and decision support (for decision-making and for decision implementation).

It is also planned to use this data in future analysis, such as statistics and prediction or model verification. In order to make the data collected by the MOBESENS systems available and reused by the scientific or industrial communities, the representation of the information will be standardised.

9. Conclusions

Water monitoring is a concern for years and the Water Framework Directive determined the need for concrete actions. One of the concern is the water quality of natural resources, which are generally large and difficult to monitor. The MOBESENS system shortly described in this paper aims at solving parts of the equation: doing measurements frequently over long periods of time, accurately, at the right place and at the right time, with the right instrument. In addition, the collected data is transferred automatically.

The MOBESENS project is still in its infancy, but the advances in the above-mentioned domains show that it can result in a real valuable tool for water resources monitoring at large (with many sensors measuring a large set of parameters) and in the long term (with long life-term sensor systems), for the benefit of a large public (through the availability of validated, highly relevant and standardised data).

Acknowledgements

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SoilWeather: wireless in-situ sensor network for agriculture and water monitoring at river basin scale in southern Finland

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Abstract: Sensor networks are increasingly employed for environmental monitoring and agriculture to provide spatially accurate and continuous environmental information and (near) real-time applications. The sensor networks provide huge amounts of data which pose challenges on ensuring data quality and on finding relevant information. In the present paper we describe a river basin scale wireless sensor network for agriculture and water monitoring, SoilWeather. The network is analyzed from user and maintainer perspectives concentrating on data quality and network maintenance. By analyzing log files of the sensors and error reports produced by the automatic data quality control, we have assessed performance of the network. The results showed that the SoilWeather network was working relatively reliable way, but it also revealed that maintenance and ensuring data quality by automatic algorithms and calibration samples require lot of efforts, especially in continuous water monitoring over large areas. We see great benefits on sensor networks enabling continuous, real-time monitoring, while data quality control and maintenance efforts highlight need for tight collaboration between sensor and sensor networks owners to decrease costs and increase quality of sensor data in large scale applications.

Keywords: sensor networks, agriculture, environmental monitoring, data quality, network maintenance.

1. Introduction

The rapid development of sensor and wireless communication technologies has increased the use of automatic (wireless) sensors in environmental monitoring and in agriculture [1]. The smarter, smaller and inexpensive sensors measuring wider range of environmental parameters has made possible continuous-timed monitoring of environment and real-time applications [2], that were not possible earlier when monitoring based on water samples and laboratory analyses or on automatic sensors wired to the field loggers needing manual download. Sensor networks have been developed for agro-environmental monitoring, alerting systems on frost and crop diseases and predicting yield [1,3,4,5]. In precision agriculture the studies have concentrated on spatial data collection and integration from different mobile and in-situ sensors and in precision irrigation and fertilization [1,6]. Sensor networks also monitor water quality and hydrology of rivers, lakes and reserves, and are used for alerting e.g. for flooding [7,8,9,10].

The sensor networks, and even more the sensor webs, have or are going to have profound effects on collecting and analyzing of environmental data. The data is very heterogeneous, varies in temporal and spatial resolutions, in accuracy and content [11]. Furthermore, the users have less control over quality of data and information need to be searched among huge amounts of heterogeneous data. This highlights importance of

metadata describing the sensors and data and their quality as well as data mining tools and sensor calibration [7].

We present here a wireless sensor network (WSN), called SoilWeather, which aims to provide spatially explicit information on high temporal resolution, data services and (real-time) applications for water monitoring and agriculture at river basin and farm scales. In the present paper we concentrate on analyzing quality of the provided data and maintenance of the SoilWeather WSN, and discuss on implications they pose from the perspectives of user and network maintenance.

2. SoilWeather sensor network

SoilWeather is an operational in-situ WSN that provides spatially accurate, near-real time information on weather conditions, soil moisture and water quality with high temporal resolution (15 min – 1 hour) and all-year round. The network hosts 55 compact weather stations (a-Weather station) with sensors of air temperature and humidity, precipitation and wind speed and direction, 30 sensors of soil moisture (Decagon ECH2O and FDR), 18 optical sensors for water turbidity (Obs3+), 5 pressure sensors for water level (Keller 0.25 bar) and 4 nutrient measurement stations. The nutrient measurement stations include S::Can spectrometer, which measure water turbidity and nitrate concentration using UV-VIS wavelengths, and sensors of water level and temperature. Water turbidity values are used to estimate total phosphorus and suspended solids.

The network is established in Southern Finland during years 2007 and 2008, and covers the entire Karjaanjoki river basin (2000 km^2) with three areas of intensive measuring: 1) Hovi farm, which enables field parcel level measuring and analysis, 2) Vihtijoki sub-catchment for nutrient leaching modelling, and 3) Lake Hiidenvesi for lake monitoring and studying nutrient retention. The sensors are mainly located in land of private farmers and in the rivers.

Soilweather WSN uses off-the-shelf sensors, nodes and server services provided by the sensor vendors (a-Lab Ltd and Luode Consulting Ltd). The sensor nodes employ GSM techniques in communicating data from sensor nodes to the servers and can be controlled remotely by SMS messages or locally by connecting sensor node to laptop. The data are made available and downloadable through two internet-based data services provided by the sensor vendors. The weather stations are able to alert, e.g. on frost or moisture conditions predisposing to plant diseases, automatically using SMS messages. At the moment, weather measurements from last month are freely available in the web site http://maasaa.a-log.net/ (in Finnish).

Data quality (DQ) is considered by choosing representative location for probes, by regular and when-needed maintenance and cleaning, by utilizing automatic cleaning (compressed air or wipers), by regular calibration sampling and finally by developing automatic DQ control algorithms and alerting system for missing and erroneous measurements. Currently, basic DQ algorithms, which are able to track missing data and measurement values outside of predefined limits, have been applied to all measured parameters, but more sophisticated quality tests are under the development. All the maintenance and cleaning activities are stored to log files which are available in the data services.

SoilWeather WSN is multifunctional network, which is already utilised in several applications during the two-year pilot project: in predicting potato blight risk; in developing interpolation of basic weather parameters in fine grid; in monitoring water quality and nutrient retention in rivers and in constructed wetland; in improving leaching and hydrological model; and in precision agriculture. It has also been used to study relationship between local weather condition and nutrient leaching through the seasons. The SoilWeather WSN may be used by private farmers in planning and executing the management practices.

3. Data quality and maintenance of the network

Data quality control was seen as a broad concept which includes deploy, maintenance, cleaning, calibration and automatic data DQ algorithms. The base of data quality was a careful deploy of sensors and correctly chosen high-quality equipment. The installing place should be representative considering the parameter measured. For instance weather stations were located in open and relatively flat area and water turbidity sensor in the main run-off in location which does not have nearby discharging ditches or tributaries. In the SoilWeather the deployment was done as far as possible by the same experienced field technicians and by following the sensor specific procedure. However, the final location of the sensor probes was always compromised by application and land owner. Thus, systematic sampling was not employed, but the spatial coverage and aims of

the applications were considered. The sensor instruments were also located so that they do not complicate cultivation practices nor recreational use of the river, and that their maintenance was easy and safe.

All the water sensors and soil sensors were calibrated against soil or water samples, respectively. For the weather stations no calibration in field was done. Calibration samples for water measurements were taken once a month to ensure quality of the sensor measurements and that the sensors are functioning correctly. For all the water measurements we also got run-off from the close located point. Calibration samples for the soil moisture sensors were taken soon after the deploy.

All the sensors were maintained twice a year; in spring and autumn. During the regular maintenance batteries were changed (in autumn), fixation of instrument was checked and recovered if needed, and equipments were cleaned. The sensors in the water get dirty easily and therefore the spectrometers equipped by automatic cleaning with air-pressure and five of the water turbidity sensors by automatic wipers. The sensors were also manually cleaned in regular basis: in winter time every month and in summer time, approximately once in two weeks. The sensors which did not have automatic wipers were cleaned even more often. Thus, to decrease field work caused by sensor contamination, wipers will be installed to all turbidity sensors in the future.

The maintenance was also carried out when problems occurred. In general weather stations seemed to work relatively well, although some occasional problems occurred. 12 of the weather stations had fall over at least once. This causes errors e.g. to wind and precipitation data. Another problem was that tipping buckets of rain gauges (18 so far) tend to fill up with tree leaves, bird droppings etc., causing distortion to the precipitation data. Also vandalism has to be taken account, few times water level sensors had been pulled to shore. Unexpected problems with data transfer or battery voltage were not too uncommon either. Cleaning the turbidity sensors caused relatively much work before the wipers were installed.

In the beginning of the project as there were only few station's data to be checked, quality control was done only manually. As the amount of the stations and therefore the amount of the data grew rapidly, it became essential to develop an automatic quality control system. At the moment there are four different tests running near real-time to detect missing and erroneous measurements. Firstly, there is a test for checking if the sensor has sent any measurements in a certain time scale. Secondly, the system checks if there are occasional missing observations or short gaps in the data. The third test is for checking if there are variation in the data or does the sensor measures the same value all the time. Finally, the range test tests that measurement lays between predetermined range values. For meteorological parameters limit values were configured based on seasonal climate extremes and limits values vary according to the month and the climatic zone. Limit values for meteorological parameters were provided by Finnish Meteorological Institute. Soil humidity, turbidity and water level ranges were defined for every sensor separately, depending of the characteristics of soil or riverbed. All the tests save error messages, and report from the past 24 hours is sent daily by e-mail to the data quality controller. The quality controller checks the data manually and informs the maintenance team on problems and its urgency. With these basic automatic quality control tests we were able to spot relatively well the most obvious problems in the sensors and in data transfer.

More sophisticated automatic algorithms are currently under development. For example spike test tests if the measurements have changed too much in a certain time. More information about correctness of the measurement values is also got by comparing measurements of different sensors (e.g. turbidity and precipitation) or by comparing same sensors of neighboring stations. Data from turbidity sensors cause special demands on quality control. The optical sensors are prone to different kinds of external disturbance (e.g. biofouling and entangled plants), and the data can easily become erroneous. After developing efficient and reliable error tracking system, automatic data correcting algorithms can be developed.

4. Conclusions

The SoilWeather WSN provides more detail information on nutrient leaching in different weather conditions and seasons than was obtained earlier, and enables research on impacts of management practices and water protection activities. For instance, earlier unnoticed nutrient leaching peaks due to the heavy winter rains, are now caught, which enables more accurate estimations of nutrient leaching through time. WSNs also enable near real-time alerting systems, as has been demonstrated in the SoilWeather WSN by alerting on potato blight risk.

Other side of the coin is, however, huge amount of data, which poses challenges on tracking and correcting erroneous or missing measurements and for network maintenance. It is very time-consuming and difficult to manually control all the data sent by hundreds of sensors. Therefore automatic quality control is essential for sensor network in this scale. Automatic algorithms should reliably detect and inform on erroneous observations.

The sooner the problems causing errors are detected and solved, more reliable data are obtained. Therefore, effective cooperation with the maintenance group and the data quality controller is important. Equally important we see regular calibration samples for water measurements to confirm data quality and correct functioning of sensors.

Monitoring over a large area, and especially continuous sensing of water, requires maintenance resources. Calibration samples and their analysis, cleaning, data transfer costs and other maintenance tasks increased costs of the WSN. Thus, amount field work and maintenance costs may not be less than earlier. The maintenance of the network, however, should not be underestimated, because it plays a key role in ensuring quality of sensor data.

Considering both data quality issues and high maintenance efforts, cost-effective (agro)environmental monitoring calls tight collaboration among sensor and sensor network owners. Maintenance costs decrease if work is carried out close to sensor location, whereas synergy is obtained if data quality procedure and algorithms are developed and employed in collaboration. The needed open standard protocols and interfaces for easy integration of different sensors and sensor data, and for storing and communicating data are already defined in Sensor web enablement (SWE) of Open Geospatial Consortium (OGC) [12].

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Discovery and accessibility of sensor data: future challenges

Geo sensor networks: the future for spatial data infrastructures?

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Abstract: Spatial data infrastructures (SDIs) are emerging phenomena worldwide. The last decade governments and organizations have invested millions of euro's in their development. The key aspect of an SDI is the coherent and long-term organization of geo-data supply for all kinds of spatial issues/problems in society.

A SDI consists of the components spatial data, technology, standards, policy and people. It can be considered as a socio-technical system. For a successful SDI a balanced development of both the technical (spatial data and technology) and the socio (standards, people and policy) components is essential. The current SDIs, seen for instance www.geo-network.org, serve mainly static spatial data, such as topography, soil, land use, etc. However, for a better support of particular spatial issues/problems, such incident- and water management, dynamic and actual geo-data is required. Geo-Sensor Netwoks (GSN) offer this opportunity.

In the presentation an overview of SDI's and their potential extension towards geo-sensor networks is discussed. The SDI components also apply to geo-sensor networks. Similarities and differences between SDI and GSN on component level is discussed. Finally, based on experience with the implementation of SDIs some lessons are formulated for successful GSN development.

Towards Open Navigation, Download, and Analysis Services for Large Multi-Dimensional Sensor Repositories

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Abstract: The Web Coverage Processing Service (WCPS) Implementation Standard is currently under voting by the Open GeoSpatial Consortium (OGC). WCPS defines a request language for multi-dimensional raster data, suitable for specifying navigation, download, and analysis of sensor, iamge, and statistics data. As such, it is an extension to the Web Coverage Service (WCS) Implementation Standard; further, it embeds itself into the Web Processing Service (WPS) Implementation Standard. In this contribution we present WCPS in a sensor data service context.

Keywords: standards; WCS; WCPS; OGC; sensor data management; raster services

1. Introduction

Sensor data increasingly contribute to today's geo data mix. Technically, measurements often can be represented as multi-dimensional raster data, such as 1-D timeseries, 2-D imagery, 3-D image time series or geophysical data, 4-D climate/ocean data, and n-D statistics data with "abstract", non-spatiotemporal axes. While today's efforts still emphasize mere data availability through open, easy-to-navigate extraction interfaces, the next quality of service foreseeably will include on-demand analysis capabilities.

In the family of open geo standards which the Open GeoSpatial Consortium (OGC, www.opengeospatial.org) develops it is the Web Coverage Service (WCS) which offers raster (ie, "coverage") data access [2]. WCS defines a service interface for data extraction based on spatial and temporal subsetting, range ("band", "channel") subsetting, reprojection, and data format encoding.

This data retrieval service currently is being extended by the Web Coverage Processing Servicw (WCPS) which adds a coverage processing language for flexible ad-hoc navigation, extraction, and analysis [1]. By nesting expressions, tasks of unlimited expressions can be formulated. WCPS, therefore, has already been dubbed "SQL for coverages". The Web Processing Service (WPS) is extended by WCPS with a means to not just invoke static functionality, but also allow run-time request composition by clients.

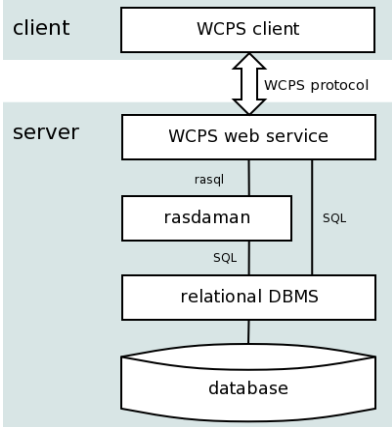
The following example inspects coverages Modis1, Modis2, and Modis3 in turn, picks those where the average red intensity exceeds 127, and delivers the difference between red and near-infrared (nir) band, encoded in TIFF:

```
for m in ( Modis1, Modis2, Modis3 )
where
avg( m.red ) > 127
return
encode( abs( m.red - m.nir ), "TIFF" )
```

The reference implementation of WCPS is based on the rasdaman raster DBMS [3]. Figure 1 shows the overall architecture. WCPS requests are translated into queries of the rasdaman query language, rasql. Queries are internally optimized and then executed against raster objects stored in a standard relational database, partitioned ("tiled") into Binary Large Objects (BLOBs). Due to the semantics formalization there is a clear,

stable interface which allows implementations to perform manifold optimizations and exploit hardware parallelism.

Figure 1. WCPS Reference Implementation Service Stack.

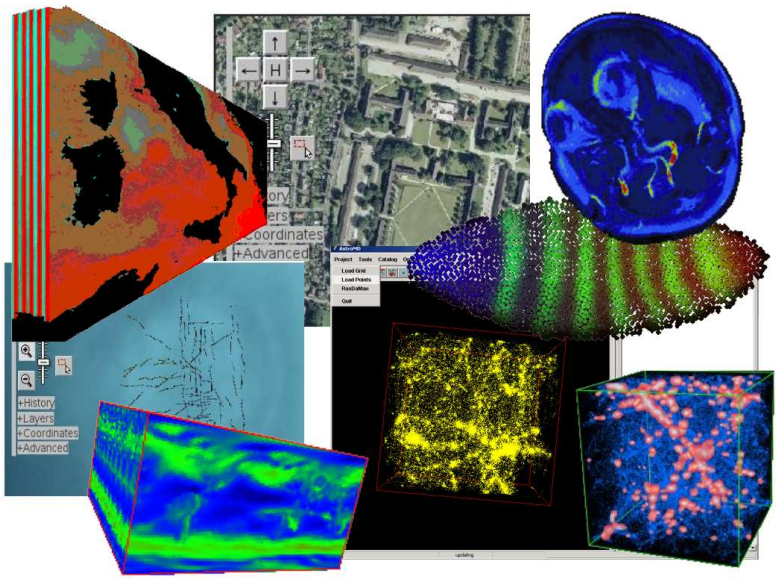


Query optimization is a wide research area and one of our core research domains. Algebraic optimization rewrites queries Q into other queries Q' such that Q and Q' deliver the same result, but Q' faster. Parallel evaluation allows both concurrent database access and performance increases by tasking more than one CPU with answering a query. Additionally, installed graphic cards are engaged in query processing.

A demonstration website, www.earthlook.org, has been established for showcasing the capabilities of WCPS in 1-D to 4-D application scenarios.

In summary, standards-conformant, value-adding services on n-D sensor data have become feasible. In August 2008, WCPS has been adopted as an official OGC Implementation Standard. Among the next steps are: evaluation of WCPS in as many different earth science application domains as possible (like it has been done before with the rasdaman system, see screenshots in Figure 2); theoretical investigations on raster languages and their expressiveness; further exploiting the optimization potential to fully leverage the potential of this forthcoming raster processing standard.

Figure 2. collage of geo and life science applications
(all but one screenshots from rasdaman/WCPS projects).



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Metadata behind the interoperability of Wireless Sensor Networks

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Abstract: There is a current need not only to achieve, but also to maintain the interoperability of Wireless Sensor Networks despite frequent changes in network status. The aim of this paper is to describe a context-aware model for the interoperability of Wireless Sensor Networks. We focus on the definition of four context awareness levels based on metadata elements. Additionally, three self-awareness tasks are used to illustrate how the model can be used to maintain the dynamic interoperability of Wireless Sensor Networks.

Keywords: wireless sensor network; context-aware model; dynamic interoperability; metadata.

1. Introduction

Sensors and sensor networks are becoming an essential source of information for planning, risk management and other scientific applications. They are revolutionising the way of geospatial information is collected and analysed (Stefanidis and Nittel 2004). Their interoperability has already been pointed out as an important issue by the Open Geospatial Consortium for the implementation of integrated sensing systems (Botts *et al.* 2007). In this paper, we focus on the interoperability of Wireless Sensor Networks (WSN) based on two perspectives: *data interoperability* and *network interoperability*. The interoperability of sensor data aims to ensure the exchange and integration of sensing data from distributed heterogeneous sensors with other kinds of information systems (Lee and Reichardt 2005). To combine data from multiple heterogeneous data sources, these data must have a well-defined syntax and semantic through metadata specifications (Balazinska *et al.* 2007). On the other hand, the purpose of network interoperability is the integration between network components, where they must exchange and act on information provided by other components or external networks (Moe *et al.* 2007). Components and networks must share their memory, energy, communication and sensing resources; therefore interoperability is needed to perform the communication between the network gateway and users as well as among networks, to exchange messages and handle the network communication (Chang and Gay 2005).

In the sensor domain, the standardisation initiatives carried out by the Institute of Electrical and Electronics Engineers (IEEE) and the Open Geospatial Consortium (OGC) are oriented to overcome the heterogeneity of devices, communication protocols, networks, data formats and structures. However, in order to support the interoperability of dynamic WSN over time is necessary to address the changes in the network status, components and functionalities (De Roure *et al.* 2005; Grace *et al.* 2008). Previous research has demonstrated that the adaptation to state changes of computing environments and sensor networks can be achieved through the use of metadata describing the system status at different periods of time (Dini *et al.* 2004, Indulska *et al.* 2006, Di Marzo Serugendo *et al.* 2007).

The main research challenge is to develop a model based on metadata for handling such a dynamic context of WSN. In a general sense, metadata provides a description of observations, processes and functionalities of WSN, as well as their configuration and status to enable the understanding of a network itself and to ensure the

interoperability with other sensor networks and devices. These metadata elements integrated with self-adaptive and self-organise mechanisms are needed to maintain the dynamic interoperability through time and in despite of the network status changes. Therefore, in this paper we describe the first results of our attempt to develop a context-aware model to maintain the dynamic interoperability based on metadata elements.

2. The role of metadata in a context-aware model

Dynamic interoperability allows the monitoring of operations of different systems and their responses to changes (Manso *et al.* 2008). To maintain this dynamic interoperability among WSN, a new approach is needed to define a context-aware model that will be able to (a) provide the information needed to maintain the interoperability through time, and (b) support the mechanisms of self-adaptation and self-organisation. Previous developed context models mainly consider sensors as a mechanism to capture information about the context (Baldauf *et al.* 2007). In contrast, our model focuses on the relevant context related to the achievement and maintenance of the sensor dynamic interoperability.

In the proposed context-aware model, the metadata can generate the knowledge of the state of the sensing system in order to maintain the dynamic interoperability of WSN. Metadata are the common thread that will connect all the states and functionalities of WSN and will preserve the context of the collected data. On the one hand, they must describe dynamically the network state changes and report it back to other components and systems. For example, if a node of a network changes its position or get damaged, the system must be able to broadcast a message containing metadata in order to inform about these changes to other networks and users. On the other hand, metadata must be automatically generated and updated, since real-time data need real time metadata as well. For example, if a node fails, the network should automatically (i.e. without human intervention), reconfigure new routes to send data. In the same way if a node changes its location, the data collected (and their metadata) must reflect the new position.

The proposed context-aware model consists of four context awareness levels. They are the sensing, the node, the network and the organisational contexts.

- The *sensing context* describes the sensing conditions, performs the sensing operations, and help to evaluate and understand the potential sensor data (Campbell *et al.* 2008). It is related with the sensing metadata that contains (a) the spatial information, such as the sensor and data localisation, spatial reference or local reference; (b) the temporal information, such as instant time or interval of observation; and (c) thematic information, such as feature of interest and phenomena (Sheth *et al.* 2008). Other descriptive metadata of this context are the data capture and observation processes, data collection characteristics (periodic, continuing, or reactive), etc. The OGC Observation & Measurement data model and Sensor Model Language are related to this context.

- The *node context* describes the state of memory, communication devices, sensors, actuators, and processor for each individual node. The nodes could be able to participate in collaborative tasking through different networks, such as data transmission processes, and in-network data aggregation. A standard specification related to this context is the IEEE 1451 that describes the transducer interface to communicate it with other components. It focuses on the static hardware and specifies the TEDS (Transducer Electronic Data Sheet) which contains detailed information for sensor identification, model and functionalities. Another specification is the Sensor Model Language that defines an XML encoding to describe the sensor system and processes with the aim of discovering sensors, locating and processing low-level sensor observations and listing taskable properties. Previous work has mentioned a hybrid description of sensors that automatically embed information from TEDS into SML (Indulska *et al.* 2006; Hu *et al.* 2007).

- The *network context* describes the current configurations and topologies of interoperable networks. These metadata are dynamic and some of them could derive from the node context as emergent properties of the network. Some examples are the network composition (homogeneous, heterogeneous), organisation (hierarchical, flat), mobility (stationary, mobile), density (balanced, densely spaced), distribution (regular, irregular), size (small, medium, large), topology, residual network energy and memory, sensing coverage area, communication coverage area, in-network process capacities, etc.

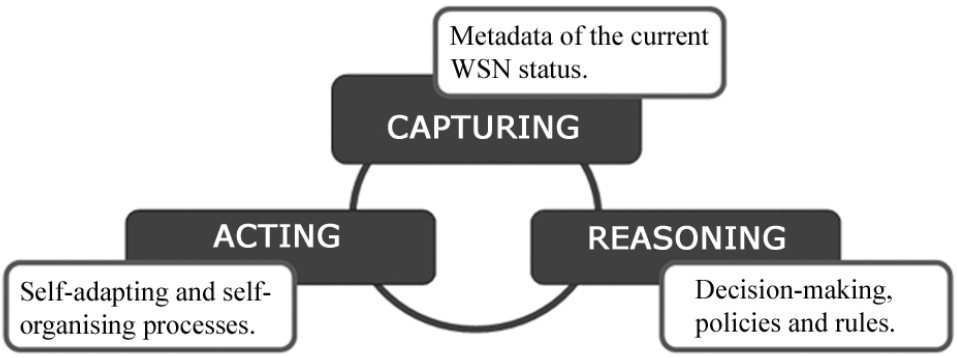
- The *organisational context* is related to how organisational aspects of the WSN affect its dynamic interoperability. It is associated with goals, restrictions, security, and privacy issues. For example the

interoperability of a WSN may be forbidden for security reasons; or certain nodes can have limitations to interoperate because of restrictions imposed to conserve their energy.

The first three awareness levels are associated with the network itself, while the fourth is associated with non-physical aspects of the WNS. Furthermore, these contexts are related among them. For example, to compute the network coverage area (network context) is necessary to know the position of the nodes (node context). On the other hand, for security reasons only authorized systems (organisational context) are allowed to access to certain sensing functionalities (sensing context).

Three main tasks of self-awareness have also been defined in our model to maintain the dynamic interoperability in WSN. They are capturing, reasoning and acting (Figure 1).

Figure 1. The self-awareness tasks of the proposed model



The *capturing* task collects metadata that describe the sensing system, the current network configuration, and the environment restrictions. The network dynamics should be automatically captured and described (i.e. self-descriptive). In the *reasoning task* some rules and policies are applied to maintain the dynamic interoperability over time. These rules are fed by the metadata of the WSN current state. Then a decision making process determines what should be done to maintain the dynamic interoperability. The *acting task* runs the self-adaptive process internally in the network and self-organising process to maintain the relations with other WSN.

The main goal of the proposed context-aware model is to manage the self-awareness tasks using the context-awareness level to maintain the dynamic interoperability of WSN. For example, several WSN have been integrated with the goal of sensing a physical phenomenon (e.g. acoustic, humidity, temperature) with an adequate spatial coverage. The capturing task generates metadata about the node positions of the different interoperable sensor networks. The reasoning task can use this metadata to generate the geographical knowledge about the current status of the sensing system. In doing so, it is discovered that two nodes are too close one to each other. Based on the rule "*If the nodes are less than 5 meters away, then it must continue capturing data from only one of them*", the reasoning task uses policies to "choose" one of them. It is also important to point out that in order to perform this reasoning, a common vocabulary and ontology is needed. Finally, the acting task triggers a self-adaptive process to only capture data from the selected node using a common service interface.

3. Conclusions and future work

In this paper we provide the description of a context-aware model to maintain the dynamic interoperability in WSN. This model consists of the interaction between context awareness levels (sensing, node, network, and organisational) and tasks (capturing, reasoning, and acting). The context awareness levels describe the context in which the dynamic interoperability takes place, meanwhile the self-awareness tasks collect metadata from the context awareness levels, support the decision-making using the metadata contexts, and trigger self-adaptive and self-organise processes in order to maintain the interoperability. It shows how metadata is a key factor to maintain the dynamic interoperability in the proposed model. At this time, we are using the metadata elements for the context model focused on the capturing task. Further research will be focused on extending the metadata

elements for the reasoning and acting tasks. We will also implement the context model (i.e. context awareness level and self-awareness task) as a proof-of-concept.

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Discovery Mechanisms for the Sensor Web

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Abstract: This paper addresses the discovery of sensors and OGC Sensor Web Enablement (SWE) services. Whereas services like the OGC Web Map Service or Web Coverage Service are already well covered through catalogue services, the field of sensor networks and the according discovery services is still a challenge. The focus within this article will be on the use of standardized sensor web encodings (i.e. the OGC Sensor Model Language) and interfaces for harvesting the necessary metadata and integrating it into a registry. However in addition also an outlook on further challenges that need to be addressed in the future will be given.

Keywords: Sensor Networks, Sensor Web Enablement (SWE), Sensor Discovery.

1. Introduction

The Sensor Web Enablement (SWE) initiative of the Open Geospatial Consortium (OGC) has now reached a solid and mature state. Thus, its concepts are being applied in a broad range of use cases (e.g. water management, detection of environmental pollutions, public security, etc.). However, there is still one challenge left that has to be addressed within this context: the discovery of sensors and SWE services. Although the current OGC catalogue provides a good basis, several open issues resulting from the specific characteristics of sensor networks need to be solved. Especially the highly dynamic nature of sensor networks as well as their specific data models and concepts have to be taken into account. This paper will provide an introduction into the challenges of sensor discovery as well as a presentation of an approach for harvesting metadata that is necessary for creating discovery mechanisms.

1.1. Sensor Web Enablement

The OGC is an international consortium consisting of more than 350 institutions and companies. The work of the OGC aims at developing open standards for geospatial data and services. These standardization activities follow an approach which is based on an open consensus process.

To realise its goals the OGC is developing interoperable (geo-) data models and service interfaces. The resulting standards are made publicly available in order to make them broadly accessible. With regard to this paper, the integration of sensor networks into the Geospatial Web is of special interest. This subject is discussed by the SWE initiative.

The SWE initiative creates a framework for realising the Sensor Web which shall provide the following functionalities (Botts et al. 2006):

- Standardised access to measurements performed by sensors (this includes real-time as well as time-series data).
- Retrieving information about sensor metadata for determining measurement capabilities and the quality/reliability of measurements.
- Controlling sensors and simulation models.

- Alerting based on the values measured by sensors.
- Accessing sensor parameters and automatic processing of measurements based upon pre-defined processes.

Furthermore, the discovery of sensors is within the scope of the SWE initiative. However, as the topic of discovery is not yet sufficiently addressed by the existing standards, this paper provides a first approach for developing an according solution

The SWE framework architecture consists of two basic aspects: the Information Model and the Service Model. The Information model comprises all aspects related to encoding data and metadata of sensors, measurements and observations. Thus the Information model provides important means for describing the information that is necessary for developing discovery mechanisms for the Sensor Web. The SWE Information Model standards comprise:

- Sensor Model Language (SensorML): description of sensors, sensor systems and processes.
- Observations and Measurements (O&M): encoding of observations and measurements performed by sensors.
- Transducer Markup Language (TML): encoding of sensor data and metadata with a special focus on providing an efficient support of streaming data.
- SWE Common: provision of basic information building blocks on which the other encodings can be based upon.

The SWE Service Model comprises the service interface definitions of the SWE framework. These services provide functionality for retrieving sensor observations and descriptions (Sensor Observation Service (SOS)), subscribing to alerts based on user defined conditions (Sensor Alert Service (SAS)), and for controlling sensors (Sensor Planning Service (SPS)). They form the interface between users/clients and sensors or sensor data. Thus any discovery mechanism for sensors must also take into account the discovery of SWE services which encapsulate the matching sensors. In the following sections it will be shown how automated harvesting mechanism can be used for discovering sensors but also for finding the according SWE services.

1.2. Challenges of Sensor Discovery

As stated previously the discovery of sensors and sensor data comprises several special characteristics that have to be taken into account.

In the previous section, the SWE information model was introduced which comprises standards for describing sensor data and metadata. For harvesting discovery relevant information about sensors and SWE services these OGC specifications form the most important basis. Thus, it is on the one hand necessary to investigate on how to analyse and extract the needed information from metadata documents (i.e. from SensorML documents). On the other hand there is a need for mapping the extracted metadata to a catalogue data model which should be ideally compliant to existing approaches like the OGC Catalogue service. Furthermore the specific interfaces of the different SWE services must be considered as they provide the operations which make the retrieval of metadata possible.

Besides the specific metadata formats that are used within sensor networks also their highly dynamic structure (e.g. rapidly changing sensor positions) creates the need for an optimized discovery approach. Whereas the data contained in a conventional OGC web service (e.g. a Web Map Service) is relatively stable, the data measured by sensors can vary significantly, especially in case of mobile sensors. Thus, it is possible that one sensor is available through different SWE services during the course of time or that sensor data for a certain domain/area is only temporarily measured. For this reason, the time dependency has a more important influence on the requirements for discovery mechanisms.

Closely related to the dynamic structure of sensor networks is also the consideration of the sensor status. Information like the operational state, the availability and internal parameters of the sensors form a valuable additional input. For example, the integration of the sensor status allows sensor network operators to discover those sensors which are defective or need to be serviced (e.g. changing the battery).

Finally, semantics play an important role within the discovery process. The use of semantic concepts allows the development of more powerful search tools so that for example all sensors can be found which m not fit exactly to the search term a user provides but which might be sufficiently related to the requested search.

Whereas this section has given a more general introduction into the challenges of Sensor Web discovery mechanisms, the subsequent sections will focus on one of these aspects: the need of specific harvesting mechanisms for the Sensor Web.

2. Results and Discussion

In the following section, the harvesting mechanisms for sensor metadata are presented. The focus is put in the interaction with the SWE service interfaces whereas the analysis of SensorML documents is only shortly addressed.

2.1 Design of Metadata Collection Mechanisms

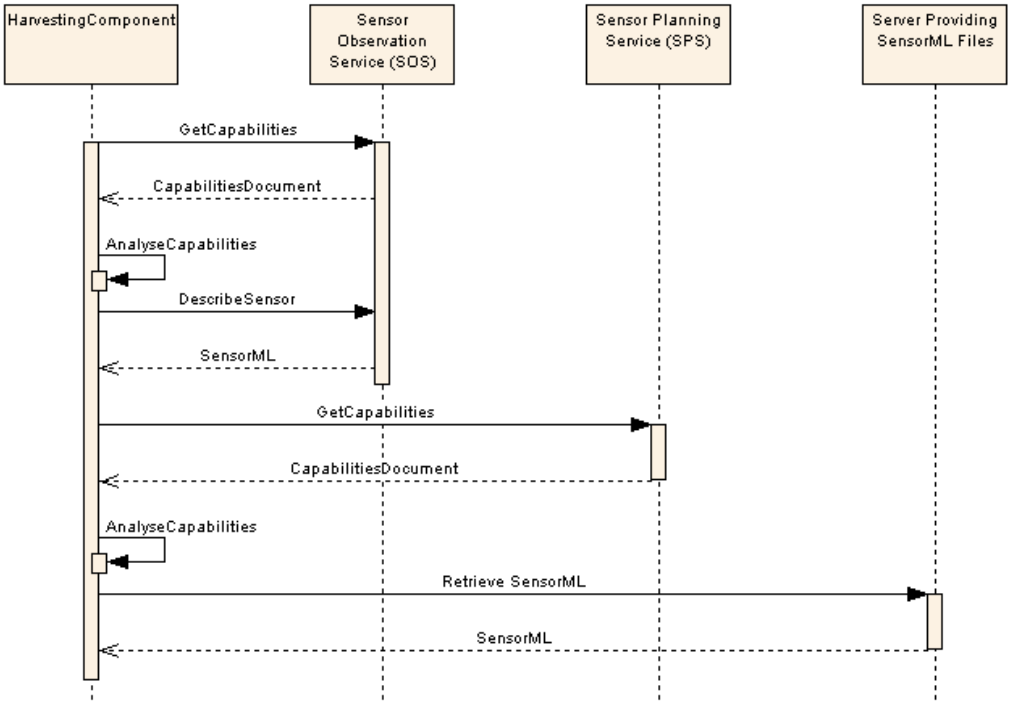
The harvesting mechanisms for retrieving metadata are making direct use of the according operations as specified within the different OGC standards. In order to avoid redundancies, we focus in this paper on the Sensor Observation Service and the Sensor Planning Service.

As all OGC web services the SOS offers the getCapabilities operation. This method returns a general description of the according service including information about available operations, provided data and the service provider. In case of a SOS this is general information about the content of the service including a list of sensors. Within this sensor list an id for each sensor is given which can subsequently be used for requesting more detailed metadata. This is achieved through the DescribeSensor operation which returns the according SensorML document for each sensor (defined by a parameter containing the sensor id).

Due to the fact that not every SWE service offers the DescribeSensor operation a further mechanism that covers services like the SPS is needed. Like in the SOS example, at first a Capabilities document of the SPS instance is retrieved. However, within this document there is no reference to sensor ids which could be re-used in DescribeSensor requests, as this operation is not defined for the SPS. Instead the Capabilities document can offer direct links to the according locations of the necessary SensorML documents.

After all SensorML documents have been retrieved, the SIR is able to analyse their content (see section 2.2) and to integrate the harvested metadata into spatial, temporal and thematic indices which enable the search according to discovery requests the SIR receives.

Figure 1. Sequence diagram illustrating the mechanisms for collecting sensor metadata.



2.2. Extraction of Search Relevant Metadata from SensorML documents

SensorML documents provide a powerful encoding for describing nearly any type of sensor and SWE service metadata. Within the harvesting mechanisms that resulted from our work SensorML documents are analysed, so that the following information is extracted:

- Phenomena that are observed by sensors
- Unit of measurement in which observations are provided
- Area that is covered by a sensor
- General textual elements regarding the classification and description of the sensor

Furthermore basic information about the time dependency of sensor metadata is retrieved. However during the work on this SensorML analysis approach, it became apparent that the generic structure of the SensorML specification created additional difficulties. As most metadata has an optional character within the SensorML specification and as there are often several ways for encoding the same metadata, the creation of a SensorML discovery profile has been identified as an important work topic for the near future. Such a profile would ensure that SensorML documents contain at least a minimum set of information that is needed for building reliable discovery solutions.

3. Experimental Section

The previously presented concept for harvesting sensor and SWE service metadata has been integrated into the implementation of a Sensor Instance Registry (SIR) which has been published as free software through the open source initiative 52° North (http://52north.org/). Furthermore this implementation is applied within the EC funded project OSIRIS (http://www.osiris-fp6.eu/). During this project the SIR is used for harvesting and searching all kind of SWE services. It has been successfully integrated into the implementation of four different use cases ranging from water and air pollution detection to forest fire fighting.

4. Conclusions

This paper has given a quick overview on challenges that arise in the context of sensor data and SWE service discovery. By introducing the OSIRIS Sensor Instance Registry a solution on specialised harvesting mechanisms has been presented. However, further challenges remain to be solved. These comprise the dynamics of sensor networks, the status of sensors as well as the integration of semantics.

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