Sensor Web Enablement

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NCG Nederlandse Commissie voor Geodesie Netherlands Geodetic Commission 45

Delft, July 2008

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Nederlandse Commissie voor Geodesie Netherlands Geodetic Commission 45, 2008
ISBN: 978 90 6132 305 1

Published by: NCG, Nederlandse Commissie voor Geodesie, Netherlands Geodetic Commission, Delft, The Netherlands
Printed by: Optima Grafische Communicatie, Optima Graphic Communication, Rotterdam, The Netherlands

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The NCG, Nederlandse Commissie voor Geodesie, Netherlands Geodetic Commission is part of the Royal Netherlands Academy of Arts and Sciences (KNAW)

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Editorial

In the geo-information community in the Netherlands the concept of Spatial Data Infrastructures has gained increasing attention. In the last two years this has led to several implementations especially in geoportals, operational web mapping services for governmental data, updated data policies and renewed governance and institutional support. Today the Geo Data Infrastructure in the Netherlands is under development with a strong focus on realization of web (services) accessibility of geo-information through geoportals and web mapping services.

The type of geo-information these geoportals and web mapping services deliver consists mainly of static geo-information. The accessibility of dynamic geo-information within the context of the Geo Data Infrastructure concept still has to start. Dynamic geo-information is considered here as geo-information, that is acquired almost real-time from some kind of sensor.

Today sensors are part of daily life and are accepted as elements of the information society. Cameras in shopping areas, noise sensors networks around the national Airport Schiphol, traffic sensors in the national highways and of course weather sensors are as normal as the weather itself. But also the specific location sensors for tracking and tracing of people, goods and vehicles are common nowadays. Sensors and sensor networks have become inevitable in business, government and public life of citizens.

In the recent past sensors were expensive and therefore were only applied in specific application fields. Also technological limitations restricted the application of sensor technology a large scale. Nowadays sensor technology and hardware are relatively cheap and easy to integrate in existing Internet based information infrastructures. The market, the applications and the technologies are there. The way RFID has gained an enormous market adoption in the last couple of years gives an indication of the further developments and application of the sensor web enablement. Almost every sensor is connectable to a wired and/or wireless network. Sensors are controlled through the network, sensors can be search for, can be identified and there location is known or can be determined on demand. For the geo-community especially location-based sensors are import. Location-based sensors are sensors for which the location of the sensor or the location of the sensor information is crucial for further processing of sensor data and/or for the information demand.

In the Netherlands, the adoption and integration of sensor data in SDI environments did not gain much attention up till now. The last couple of years, SDI environments and geospatial developments were focussed on the delivery of static geo-information using the web services standards of the Open Geospatial Consortium (OGC). Integration of sensors and sensor networks in the SDI environment, that requires the application of open standards as well, was lacking partly because the OGC open standards for the Sensor Web Enablement were under development. The Sensor Web Enablement (SWE) framework of the Open Geospatial Consortium consists of different semantic and technological standards for sensor information exchange. In order to have SWE adopted on a large scale, first awareness and best practises are necessary.

The seminar 'Sensor Web Enablement' of the Netherlands Geodetic Commission was devoted to the creation of awareness of the Sensor Web and the OGC sensor web interoperability standards. The seminar aimed to improve the understanding of SWE; concepts and applications, but also future trends and scenarios on location and sensor services. We hope that the seminar has resulted in lasting new contacts between all people in the Netherlands with an interest in sensors, location and sensor services, sensor networks and in particular the SWE standards.

The contributions in the seminar proceedings reflect both the future perspective on the position and value of sensors and sensor technology, the conceptual framework of processing sensor data, as well as the ins and outs of the Sensor Web Enablement family of sensor standards, it's test beds and applications, but also issues and items for discussion. This publication is a reflection of the different seminar contributions.

The first paper 'Location Awareness 2020. A foresight study on auto-identification and location in year 2020, and the implications for mobility' by Euro Beinat (SPIN-Lab Vrije Universiteit Amsterdam and Salzburg University) and John Steenbruggen (Rijkswaterstaat) introduces a way to explore the future of the application of sensors and sensor networks. The authors have developed scenarios for location awareness and sensor services in 2020 with an emphasis on transportation and mobility. This paper outlines the relevant drivers and trends for the adoption of sensor services and sensor networks for future location awareness, as well as barriers for the adoption. In the paper some of the recent results that have been obtained from the Location Awareness 2020 study conducted for the innovation program on Transportation and Water management in the Netherlands (in contract of Rijkswaterstaat) are presented. The authors conclude that interoperability will be the kernel of successful adoptions of location and sensor technologies in transportation.

Zoltan Papp and Henk Hakkesteegt from TNO Science and Industry address the issue to make sensors and sensor web networks more applicable in practice, namely the handling of sensor web data from interpretation to monitoring, control, maintenance and decision making. Their paper investigates how the potential of data richness can be fully utilized. More specifically, it attempts to answer questions around the integration of sensor networks and sensor web into the data interpretation process. They illustrate that the data interpretation process has to be adjusted in order to accommodate the advantageous features of the sensor web based observations. Without these adjustments the sensor web is still useful, but cannot deliver its promises. They advocate the use of SWE and illustrate this in a water management example. At the same time, they come up with some drawbacks and issues that need further attention.

In the next paper, Alexander Walkowski (Westfälische Wilhelms-Universität Münster) introduces the main concepts and ideas of the Sensor Web Enablement initiative. One of the main objectives of SWE is finding all sensors available via the world wide web. Walkowski advocates the advantages of the standardization of access to sensors and sensor data by SWE. The SWE framework is outlined from the information model perspective and services model perspective. A use case scenario illustrates the possibilities of SWE. It is concluded that after the long period of evolution and testing, it is the time to start applications based on the SWE framework.

In their paper 'A testbed for SWE technology' Rowena Smilie, Yves Coene (both Spacebel), Philippe Merigot, Didier Giacobbo (both Spotimage), Steven Smolders and Caroline Heylen (both GIM) outline the use SWE technology in a number of projects of the European Space Agency (ESA). They illustrate the maturity of the used SWE concepts in several testbed projects of ESA and OGC, like the Observations and Measurements standard of the SWE information model and the application of the SWE Sensor Observation Service and Planning Service. All projects are related to the ESA Services Support Environment (SSE). Issues faced in these projects with the application of SWE concepts are raised by the authors, e.g. missing SOAP bindings in the SWE service specifications. Furthermore, future work on application of SWE within SSE is elaborated on.

Another example of the use of SWE is given by Jan Jellema (TNO) and Peter Gijsbers (WL | Delft Hydraulics) in their paper 'Sensor Networks, basis for the Dutch Geo-infrastructure'. The paper gives a short overview of a recent started project on application of Sensor Web Enablement framework for water management. This project is the sensor innovation project under of 'Space for Geo-information' program in the Netherlands. The goal of the project, conducted by a consortium of major scientific institutes and sensor suppliers, is to explore SWE concept and test it's advantages and disadvantages.

The last paper 'Research topics for SWE' is by the editors Michel Grothe (Rijkswaterstaat) and Jan Kooijman (TNO). This short paper reflects the discussions and brainstorm during the seminar. The input of the seminar participants is used here to sum up the research topics for Sensor Web Enablement.

Acknowledgements
The seminar day was organized by the Subcommission Geo-Information Models of the Netherlands Geodetic Commission, and was held at TNO Utrecht on February 1, 2007. We wish to thank the sponsors of the seminar as well for helping to make the day free of costs for all participants. These sponsors are TNO Utrecht, Rijkswaterstaat and the Netherlands Geodetic Commission. We are grateful to Arnold Bregt of Wageningen University – chair of the Subcommission Geo-Information Models – for chairing the seminar. We are further grateful to Frans Schröder of the Netherlands Geodetic Commission for his support in realization of this publication. Finally, we hope that this publication will help to increase the adoption and application of the open sensor web

concept (SWE) and sensor networks and the integration of sensor information in the Geo Data Infrastructures concept. We express our thanks to all speakers at the seminar, as they are the main contributors to this publication, and the participants for the lively discussions at the seminar.

The editors,
Michel Grothe and Jan Kooijman

Location awareness 2020
A foresight study on auto-identification and location in year 2020, and the implications for mobility

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Abstract
With the rapid evolution of location technologies, wireless communication and sensors, it becomes increasingly feasible to identify and locate any valuable resource or individual in real time anywhere. This capability underlines a fundamental development: we are becoming increasingly used to know the 'where' of people or things, in a way that is similar to our general ability to know precise time. Organizations that adopt these technologies are faced with some fundamental questions, which are in part typical of early-stage technologies but which are magnified by the deep and pervasive implications of location and identification technologies and the internet of things. How will organization operate in a hyper-connected world? What will be the boundary between the inside and outside of an organization? How can the benefits and risks be assessed while there is a major uncertainty on technology and its acceptance? What does privacy mean when all information can be interrelated without individuals being aware of it? How should the organisation look at these developments and take the intrinsic long-term uncertainty into account for investment decisions? How do there developments affect the organisation mandate and its scope of activities? Should the organisation simply adapt to market developments or should it proactively influence how it evolves? Questions like these are at the core of any organisation that depends for its core activities on location and identification of people or goods or things. This paper illustrates a scenario analysis that tries to address these issues.

The Location Awareness 2020 study
Rijkswaterstaat (RWS – Dutch Ministry of Transport and Waterways) ensures a proper functioning of the road and waterway network in the Netherlands. RWS mandate is to ensure mobility of goods and people, accessibility to transport infrastructures and safety of transportation. RWS is one of the largest users of location information in the Netherlands and its Geo-ICT infrastructure is at the forefront of developments in this sector. The growing adoption of sensor based environments, in addition to the traditional Geographical Information Systems and satellite technologies, provides a new development space for RWS, an option which is attractive given the relevance of location information for RWS.

RWS has found that location services can add value to their processes, make them faster and/or more efficient (see [1]). The technology for travel management, as well advances in car and transportation technology, implies that the core activities of RWS need to take into account, anticipate and adapt to technological innovations that shape the transportation industry and the information provision to travellers. They are necessary to respond to an increasing demand for transportation safety, road charging, environmental monitoring, congestion reduction, mobility and accessibility.

Sensor-based environments such as RFID, provide means to link the physical world (e.g. cars) and the virtual world (e.g. the ICT infrastructure). They make it possible to manage, monitor and serve transportation in a much more sophisticated way. The speed of development of these technologies and services, and their disruptive nature, underlines a range of opportunities for RWS, but also the need for long-term mapping these developments, managing the change process and addressing fundamental challenges such as privacy and information control.

The study *Location Awareness 2020* (see [2]) looks at the evolution of location aware technologies and sensor services, and of their adoption, in year 2020. The study was carried out at two different levels: the first level addresses generic scenarios for location and sensor services in year 2020, independent of their use in mobility and transportation. The second level is the interpretation of these scenarios for the transportation industry and for mobility. These two levels provide a way to look at drivers and trends for the adoption of location and sensor services, as well as the barriers for the adoption.

Location awareness

Location based services are context aware services, where the role of location is of primary importance for defining the context of the user and thus of the information services that can be provided to the user. More in general, time, location, identity and activity are primary context variables which are usually measured through some form of electronic of other sensor . They are raw information, which usually require additional sources to make the information useful. For example, latitude and longitude coordinates can be translated into a street address or section of highway, which are usually more relevant pieces of context information compared to the plain coordinates. This derived information is called secondary context, and is the basis upon which location awareness and location services are built (see Figure 1).

Location Awareness can be defined as "The ability of individuals or machines to make decisions based on the awareness of present (past and possibly future) location of themselves and/or of the objects that have a bearing on the decision".

Location awareness may affect planning decisions, travel choices, allocation of mobile resources, inventory of firms etc. The information systems that support location awareness are called location aware systems, and the information services that they provide are called location-based services.

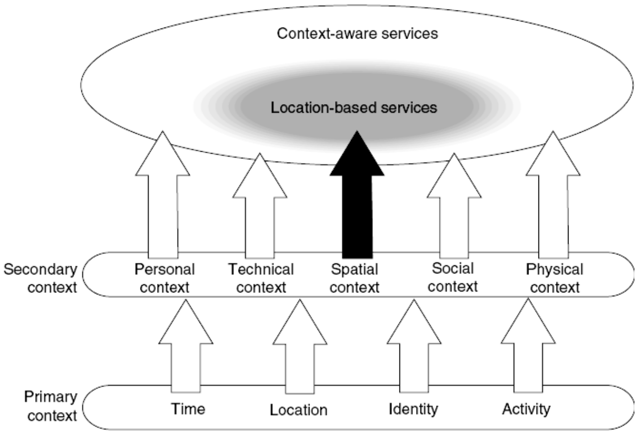

Figure 1. Location based services and context aware services [3].

In the recent past location awareness was limited by technology constraints. The only truly widespread and standardised location technology was satellite location, which is widely available but has a range of limitations, the most important one is the failure of GPS location in indoor or covered environments. The emergence of sensor-based networks and commercial RFID solutions make it possible to address the 'where' in general terms, independent of the surrounding environment. It is now possible to locate a car with GPS, a person with a mobile phone, a parcel with an RFID tag. In other words, technology is reaching the level of maturity that makes location and identification determination feasible – economically and technologically – in every environment and surrounding where it is useful for personal information management and business process support.

Table 1 illustrates the main application areas for location and sensor services. For simplicity, the applications are categorised into business, public sector and consumer applications.

A long-term view on location awareness: drivers and trends for year 2020

Location aware services clearly have a potential for improving business processes and public services. However, even a superficial analysis of these services, makes it clear that their evolution cannot be addressed in technology terms alone. The ability of identifying and locating essentially any asset, vehicle or even person has a deep implication on how we structure businesses, implement personal or homeland security, manage mobility or health care. The range of applications, combined with the concerns related to privacy management and dataveillance (see [2]) imply that the adoption, or otherwise, of automatic location and identification depends on business, social and lifestyle choices, as well as technology capabilities.

At the same time, the complexity of technology, social and economic developments, and the impact of these developments on the evolution of location awareness, makes it impossible to look at the future of location and sensor environments in terms of

Area	Driver of the service demand	Application areas	Location technologies	Issues
Business	Growth in mobile work Need for constant communication and information Demand for efficiency and lower operations costs Demand for flexibility	Workforce management Asset and resource tracking Manufacturing management Warehouse management Transportation Distribution chain Health care	Satellite location Network (telecom) based location Wi-Fi and RFID	Uncertainty on ROI Unclear adoption by market Implementation costs Maturity of technologies
Public sector	Public order and safety needs Terrorism Public health Emergency services and disaster management	Emergency management Staff coordination Health care equipment, patient and staff location	Satellite location Network (telecom) based location Wi-Fi RFID	Interoperability Reliability Quality of services Maturity of technology Uncertainty on ROI
Consumer	Personal safety and security concerns Personalized services Penetration of mobile handsets	Personal and family tracking Personal safety Health care Navigation Community and social networks	Satellite Network (telecom) based location Wi-Fi	Privacy Fragmentation of technology offering Interoperability Quality of services and usability

Table 1. Classification of location aware services (adapted from [4]).

forecasts. The number of variables involved is prohibitively large and several trends are interrelated in ways that are only partly understood. It becomes therefore important to identify drivers (technology evolutions, societal changes, work conditions etc.) and trends that shape the possible evolution of location awareness, and cluster them into plausible ways to create multiple scenarios.

Scenarios are narratives of alternative environments in which today's decisions may be played out. They are not predictions, nor are they strategies. They are hypotheses of different futures specifically designed to highlight the risks and opportunities involved in specific strategic issues ([4]).

Drivers

Scenarios are based on drivers: those underlying factors that set the pattern of events and determine outcomes in the environment and timescale being considered. These are the elements that "move the plot of a scenario, that determine the story's outcome" ([6] pp. 36). Drivers are identified based on studies, reports, statistics and the input of key experts involved in research or business activities that shape the future of location awareness. Workshops, interviews, informal conversations, but also any other source of hints on the future are used to identify the set of drivers that define the scenario workspace.

Table 2 illustrates the drivers detected in the LA2020 study (see [2] for a full description of these drivers). As an example, consider the driver 'Attention for food quality'. The increased availability of information regarding health care and the cause-effect links between diet, food, life style and health has raised the awareness of citizens as well as triggered a demand for increased visibility and information regarding quality of food and its source. Consumers increasingly require full and detailed information on the source, treatment and processing of food and its components, implying the availability of food tracking on the global supply chain.

Food and animal tagging will represent one of the areas where diffusion of end-to-end visibility is virtually complete in year 2020. This will be a driver for the development of inexpensive, reliable and pervasive ways of tagging animals and food products and track the food supply from the origin to the consumer.

Each of these drivers points towards a specific direction of development as location and sensor services are concerned. They may facilitate or hamper the development, diffusion and adoption of these technologies.

Trends

Trends are the result of sets of drivers that appear to identify a broad direction of development. A trend is a cluster of drivers, pointing towards a structural change which is important to define a scenario.
Establishing a systematic understanding of the driving forces through clustering enables the exploration of interdependence and relations of causality among the drivers. The aim is to produce a set of clusters that will be internally coherent and separate one from the other, although some driving forces may suit in more than one cluster [6]. The interdependence between drivers and trends is not necessarily linear, nor there always is a direct cause-effect relationship between a driver and a trend. The clustering is a logical exercise, which aggregates drivers that together seem to pinpoint a certain evolution.
Trends are characterized by one or several levels, where a level represents a possible trend outcome. Levels usually are the degree to which a trend is realized (for instance strong or weak) or polar outcomes of the trend (such as the realization of a certain outcome instead of another). For instance, a trend "Open source and commercial software will be available for location services" may range between "Open source dominates the

software industry", to "Open source and commercial Software have comparable users shares" and "Open source will be a niche software offering".

The ten trends identified in the LA2020 study are the following.

Technology drivers	Society drivers	Business drivers
True (data) mobility	Attention for food quality	RFID in retail, supply chain and distribution networks
Emergency location mandate for telecom operators and VoIP.	Health care adopts sophisticated ICT	Data synchronization services
Standardization of sensors, identification and location technologies	The risk of epidemics on a global scale	eCall platform in Europe
Electronics is embedded in clothes	Environment and global change	Mobile payments
Electronics is embedded in cars and transportation infrastructures	Energy dependence and alternative energy sources	Content availability and bottom-up services
Electronics is embedded in homes and appliances	Counter movements to the market economy	Availability of service such as presence, location, authentication, payment
Micro sensors provide essential information on infrastructures, environments and networks	Terrorism and global crime	
Precise location determination is available as standard feature of communication networks	Blogs, bottom-up information services	
Multiple location and identification systems	Peer-to-peer and networked societies	
The semantic web	Individualism	
Open Source and common-based peer-production	Post-modern nomadism	
	Road and congestion charging	
	Personal safety and security	

Table 2. Drivers for the LA2020 study [2].

1. Availability of intelligent infrastructures for public services, business and personal use

Intelligent infrastructures, or smart spaces, are the result of an increased ubiquity of computing and of the increased adoption of contextual services in business and personal life. Efficiency, security and safety are among the key drivers for the increasingly common availability of intelligent infrastructures. Typical areas where this is developed include:

– Transportation networks, roads, railways, waterways for services like navigation, tracking, or road charging;
– Warehouses, for services like auto location an identification, automatic inventory management;
– Yards and hubs for distribution, for services like location of goods and wares, inventory management, supply management;
– Office spaces, for services like space utilization, emergency management, people and resource location and presence;
– Museums, entertainment locations, for theft prevention, asset security, flow management, access control, people safety.

2. Availability of personalized and auto-adaptive services

Location and sensor services will enable the creation of systems that are more intelligent, personalized, and user cantered. Enablers of these services are:
Autonomous information detection, decision making and adaptation. Examples are in smart building (that adapt to visitor preferences and needs, and optimize energy or maintenance based on presence), smart cars (that adapt to the driver and network circumstances), or smart planning (hospitals that dynamically address availability of staff and patients to optimize service delivery).
The web of things. Daily objects, appliances, doors, road lamps and virtually anything which requires some form of intelligence for delivering a service and for maintenance will be connected to the network with one of the many communication means available. This is the core enabler of personalized and auto adaptive services.
Service enablers. Location, presence, authentication and ubiquitous all-IP communications enable personalized and context-aware services and applications. It will be common, for instance, to use a service such as the popular MSN instant messaging (www.msn.com) and to enhance it with location of the buddy, or to see on the mobile phone display the location of the caller in the form of a map.

Smart, adaptive systems augment the physical environment with digital properties enhancing the way people interact with the surroundings while keeping the system out of sight.

3. Lifecycle visibility for goods and people are common

The need to streamline the global supply chain, to facilitate global transactions and coordination, partnership, subcontracting and outsourcing are the reasons to implement lifecycle visibility (cradle-to-grave) for goods. Lifecycle visibility needs to rely on

a technological support that allows the identification and location of individual objects from the producer to the sales point, or even extended to the entire life span of the good, for instance for maintenance purposes.
Food tracking and animal husbandry monitoring are sectors where systematic adoption of end-to-end visibility is dictated by legal requirements as well as by a pressing demand from consumers to prevent the diffusion of diseases. The pharmaceutical industry will be another industry to adopt auto-id systems to prevent counterfeit and the administration of the wrong medication to the wrong patient. Hospitals also need to streamline their supply chain to reduce costs and inventory and adopt a just-in-time approaches that are common in other industries. Automotive industry will adopt location and identification means as a standard feature of vehicles, either to provide additional services to drivers, or to comply with road charging, mobility management or other safety and environmental protection measures. Finally, public order and safety will adopt measures to prevent crime, terrorism and illegal immigration. Digital ID, and automatic personal identification will likely be among the measures adopted, along with the automatic recording of whereabouts of specific individuals and the automatic creation of history profiles for persons.

4. Public and business services require location and identification

Essential services that require location and identification will likely include:

- 112 emergency call for all mobile and fixed phones, and an eCall mandate for vehicles and cars;
- Automatic identification of cars and vehicles for road charging, or access to urban areas;
- Access control to workplaces, public spaces such as stadiums or cinemas, government offices with passport identification and personal ID;
- Patient identification in hospitals and identification/location of patients in case of chronic or disabled patients, based on persistent wearable IDs.

These services require extensive infrastructure to be in place, but also the adoption of possibly controversial measures, such as the compulsory use of auto-id based identity cards.

5. Virtual digital communities form important social structures

The current trend towards the creation of communities linked by interest rather than geography will continue to the point that these communities will become common social structures upon which societies are in part defined. Citizenship will gradually be extended to include virtual communities, which in part reflect the identity of a person. Given the richness of the information and multimedia offering, virtual digital communities will mesh up bottom-up content with openly available content to create digital experiences that are comparable to the most sophisticated commercial ones. The possibility of ubiquitous rich communication will also increase the relevance of these digital communities, which could become the primary source for information, advice, busi-

ness or entertainment. These communities channel the active participation of people and may partly replace traditional political representation or social inclusion.
Paradoxically, location information will then become increasingly important to the digital community, and serve as one of the interfaces between digital and real-world. Local information, friend-finders, presence detectors and similar services will provide a physical dimension to digital information.

6. Governments regulate location and sensor services

The intimate relation between location, identification and privacy raises concerns for the possible misuses of this information for surveillance, improper marketing and police activities. Governments will take action to protect citizens and introduce rules for preventing privacy intrusion. The debate on the introduction of RFID-specific legislation may lead to either the reformulation or adaptation of some generic principles or to the adoption of specific legislation tailored on RFID. Government will need to balance between the benefits of principle-based regulations which may be difficult to apply and leave space for improper interpretation, and the benefits of detailed legislation that can be rendered rapidly obsolete by technology innovation.
The role of government is also essential in the definition of services of general economic interest. Examples are the 112 mandate or the eCall initiative. In this case governments have a major impact in terms of stimulating technology adoption, timeline of adoption, standardization, interoperability and quality of services.

7. Privacy-enhancing technologies and privacy services are available

Privacy-enhancing technologies (PETs) provide solutions to some of the issues that may arise in the realm of privacy. Privacy technologies do not eliminate privacy concerns. They provide technical means to minimize the chance that privacy violations occur. These technologies may include: (1) RFID tag disabling, caging, jamming or killing (see for instance [8]); (2) Data anonymiser services; (3) Tag free zones; (4) Opt out technologies and alternative service availability.
The effectiveness of PETs relies on the ability to identify technical means to opt-out (exercise our right to communication of personal data). The implicit risk in PETs is that they will increasingly suffer from the 'arm race syndrome', where contrasting interests dissuade each other by adopting ever increasing sophisticated means to protect and retaliate. The risk of a major incident, should the system fail, is implicit in this arrangement.
The privacy concern will also open-up a vast business opportunity for serving concerned citizens with services that provide better security and privacy protection. Tools such as the 'privacy impact assessment' (PIA), or privacy threat analysis, will be available from advisors. As many operators and users of data-processing systems are not aware of the threats and possible abuses that concern personal data, a PIA could provide an overview of threats and possible mitigation measures.

8. Dataveillance is a social concern

After a certain point, ubiquity of information collection will be such that it becomes critical to business and end-users, but it will also be practically feasible to detect the identity and habits of a person by collating available information sources.

Not all parties will have a need to share information with others, but there will be many parties that will see tangible benefits in swapping and merging information. The extent, quantity and detail of data collected will however represent a formidable incentive to use it for business, legal advantage or criminal purposes.

Consumer advocates will increase the profile and political relevance of the dataveillance debate and their weight will become comparable to that of international NGOs such as the World Wildlife Fund, Green Peace or Amnesty International.

In location and sensor services there is a visible concern about privacy protection and dataveillance. This concern may explode and impact the business, suppliers and users of RFID should major privacy incidents occur. It may also remain latent, balancing the awareness on the pervasive nature of location and sensor systems with the good information available about them and the privacy protections being in place. In any case, it will increasingly be factored in the choice of suppliers, of organizations or even of places. The degree to which marketers and public authorities will be able to respond to this concern proactively will determine the degree to which the dataveillance concern will be translated into opposition and rejection of certain products, players or business practices.

9. ICT, communication and sensors increasingly interoperate

The deployment of location and sensor services will follow an arc similar to that of the Internet. We should expect a proliferation of local systems (such as in hospitals, highways, stadiums, single industries etc.) that support primary applications in areas where the added value of location and RFID is immediately visible and independent on the widespread standard-based adoption in other interrelated sectors. Eventually, these systems will be knitted together into larger ones, for instance, local or specialized supply chains (such as blood supply) and finally merge into the internet of things. Those interconnected systems will find it easier to exchange information, and small pools of data will be merged and refined to produce larger and more valuable collections. And as with the Internet, open architectures, service based architectures and open standards will form the base upon which to build new applications.

This standardization will be the result of economic and business needs as well as of regulatory push. Once RFID and sensor services will become ubiquitous, issues of proprietary technologies will heat up.

10. Business and community values compete for development guidance

Countries that want to grow and thrive in the 21st century are likely to seek how to close the income gap with the United States. The emphasis on competitiveness and the Anglo-Saxon world raises also the concern that Europe will become increasingly unequal, something that does not fit well with the European social tradition. A legitimate alternative view, one which is minority but which has an increasingly visible stand, is that of socio political movements and NGOs that underscore the failure of market economy and global trade, stress environmental concerns, global change, unfair labour practices, and social equity.

These two objectives are likely to be difficult to reconcile and societies will have to emphasis either efficiency or social equity until some adequate alternative development model emerges. Competitiveness and growth will be closely associated to open economies, globalization and the Anglo-Saxon experience, which also brings about inequality and tends to de-emphasize issues such as global change. On the other hand, social policies will be associated to regulations and practices that limit free trade, globalization and openness. Savvy models that combine elements of both extremes will be the core of the political agenda in the next decades.

Scenarios for location awareness in year 2020

Constructing scenarios from trends is the exercise of coherently combining trend outcomes into plausible sets, which correspond to scenarios. Technically speaking, any combination of trend outcomes is a scenario, but most of these combinations are either very similar or logically inconsistent. In spite of this, the number of scenarios that can be constructed based on the ten trends above is very large. Experience in scenario planning suggests limiting the number of scenarios to a handful of very different ones, which are able to shed light on plausible yet very different futures.

It is common to base this exercise on the identification of the pair of trends that are believed to have the highest impact on the defining a scenario and the highest level of uncertainty over the potential outcome. In the LA2020 study, the trends identified are: "ICT, communication and sensors increasingly interoperate" and "Business and community values compete for development guidance". These two trends serve as a broad template around which all other trends are aggregated.

The scenario matrix in Table 3 defines the four scenarios as combinations of the possible states of the two key trends identified above. The extremes proposed capture the essence of a world in which each trend has progressed to its extreme, with all the other trends and drivers discounted. Those are added to produce the general characteristics of each of the four possible scenarios as plausible and internally coherent stories [7].

All other trends, together with their underlying drivers, need to be combined to generate the different types of future. The tool used for this process is called Morphological Analysis. Morphological analysis aims to explore possible futures in a systematic way by studying all the combinations of trend levels and retaining those that are coherent and significantly different from each other ([9]).

The 'Free Play' scenario

This scenario is dominated by a business culture and by the availability of sophisticated open technologies that support location and sensor services (and other ICT). Location and sensor services are pervasive. They create opportunities for growth, for the delivery of essential and sophisticated services, and are at the basis of efficient global supply chains, as well as public order and safety organizations. There is a general positive attitude towards innovation and smart technologies and the fear for their misuse has been

	Closed systems	Open Systems
Business drives	**BIG BOYS** Closed systems: multiple competing standards, non-interoperable technologies, few large players Business leads, individual values, economic and political liberalism, growth, materialism	**FREE PLAY** Open systems: standardization, ubiquity, interoperable systems, many players of all size Business leads, individual values, economic and political liberalism, growth, materialism
Community drives	**STEP ASIDE** Closed systems: multiple competing standards, non-interoperable technologies, few large players Community leads, community ethics, social networks and responsibilities, cohesion, sustainability	**SOCIAL TECH** Open tech: standardization, ubiquity, interoperable systems, many players of all sizes Community leads, community ethics, social networks and responsibilities, cohesion, sustainability

Table 3. Scenario matrix and scenario names.

dispelled by several years of growing adoption, open communication, lack of incidents and measurable benefits.

Citizens and business will find it difficult to access services or operate without adopting, actively or passively, sensor and location technologies. Passports will be tagged, as well as personal IDs. Food, medicines, and most goods come with auto-id and location capabilities. Their use is safe under the widespread availability of privacy technologies, which ensure a high and reliable level of protection and especially a high level of control from the end user. Privacy management is flourishing industry that is able to channel the dataveillance latent concern into a business opportunity that satisfies the concerns of citizens.

Governments are important adopters of the technology for public order and safety, health care and homeland security. Governments do not interfere with business dynamics, and besides enforcing rules for fair play they leave to the market dynamics the adoption of location and sensor services. Worker rights in respect to location and sensor services are adapted to the minimum, to prevent clear abuse, but leaving to market players the task of finding an acceptable compromise.
This scenario is compatible with high economic growth, globalization, and fierce competition. It is also compatible with a business oriented attention to non-business themes, such as global change or equity, which are addressed by business instruments like trading or removal of labour barriers.

Snapshots

- Speed limits on roads are dynamically adjusted to traffic and environmental conditions. Road charging is dynamic (price depends on context of the transportation network). Advanced technologies allow for charging for use of the infrastructure, receiving compensation for not using the infrastructure, and trading the right of using the infrastructure between users.
- Electronic patient dossiers and personal IDs are linked thanks to wearable or implanted medical IDs.
- Cars are standard equipped with satellite navigation, RFID and biometric key, and electronic plate. Parking is paid automatically based on occupation of a parking space.
- Personal Identification Devices (integrated in e.g. phones or worn in clothes) are common for business and family purposes, to be always in contact and achieve a sense of security and being connected to a community of choice.
- SGoogle (Semantic Google) is able to compile the biography of a person, specific car, building, sports club, etc. just by entering the name.
- Privacy banks serve consumers who wish to coordinate and track their privacy transactions and maintain a full overview of their privacy account.
- Consumers can verify the history of a food item by typing in the EPC code of the item on the shop's web site.

The 'Step aside' scenario

This scenario is characterized by a diffuse perception that social concerns should prevail over plain business needs, and by the realization that this is not taking place effectively. Free market forces have taken advantage of an ambiguous position of governments as concerns trade, competition and liberalization to create strong positions in various economic sectors, such as retail, health care, automotive, infrastructures. In this scenario society priorities are out of sync with the economic sector.

The public sector operates hands-on as concerns privacy protection and enforces measures that slow down or prevent some applications and services. Nonetheless, governments are unable to fully represent and interpret society feelings, and unable to counterbalance the dynamics of large strong players. This leaves space for a strong following for NGOs, which somewhat replace political representation and counterbalance the strength of economic players.

This creates the conditions for the adoption of location and sensor services only in selected environments and for specific services, such as services of clear public interest (emergency, road charging, pollution control). At the same time, players that lead in some business areas adopt these technologies to foster their bottom line, but create islands of adoption, possibly using proprietary implementations that optimize results without the overhead of open standards.

The level of adoption of location and sensor services is high but fragmented. This is similar in other ICT domains and the development of digital communities is somewhat hampered by technology walls, although widespread as a community glue.

Dataveillance is not a major concern. Technology limitations make it difficult to profile individuals efficiently, combined with the strong government hand in regulating the handling of personal information, reduces the chance and the incentive of privacy intrusion.

This scenario is compatible with medium/high, but unbalanced, economic growth, with globalization in some sectors and regionalization in others. It is compatible with a strong attention to themes such as global change or equity, which however are poorly reflected in the structure of the business economy. This creates a situation of unrest and tension which does not favour innovation.

Snapshots

- Telecom operators have acquired the right to provide advanced commercial Galileo services (level 3) on an exclusive basis.
- Profiling of consumer habits is prohibited by law.
- China adopts its own EPC global-like system, to which western countries need to adhere to do business with the Far East.
- Congestion/road charging is adopted in major and highways: the rest of the network is not covered.
- NGOs have successfully launched tag-free shopping centres, becoming a retail power for the opt-out community.
- Legislation imposes the 'kill' feature in RFID tags, to deactivate them after purchase.

The 'Social tech' scenario

This scenario describes a society with attention to community topics, such as social inclusion and sustainability, in a high-tech world where ICT plays a major role in economic development and service provision.

Location and sensor services, as well as other ICT are highly standardized and interoperable. The ICT industry is dynamic, innovative and accommodates large players and a wide spectrum of small enterprises that rapidly gain visibility for providing innovative services.

In this context both industry and government play an important role as well as business factors in the need to account for non-trade issues, such as sustainability, social inclusion and protection of the individual. Innovative location and sensor services are widely adopted and used, but their introduction and evolution is strongly supervised, and some times limited, by the public sector on ethics or precautionary principles.

This impacts the diffusion of location and sensor services which are adopted by industries and the public sector in areas where the balance between benefits and business/social costs are clearly favourable.

The space for a market for privacy services is limited, because of the heavy intervention of public sector in this area, supported by strong NGOs and the voice of public opinion. Dataveillance is nonetheless a hot topic because public opinion recognizes the availability of sophisticated interoperable technology which is kept at bay by regulation.

This cap is unstable by definition and the possibilities of technology are such that it is virtually impossible to completely avoid free riders and unwanted exploitations.
At the same time, communities and services based on the ability to mesh a variety of content sources create entertainment, cultural and social digital communities, becoming a fundamental source of socialization but also education and service provision. The availability of 'Open source RFID' marks a departure from industry supported standards and allows even very small players to adopt very sophisticated technologies.
This scenario is compatible with medium/high economic growth, with emphasis on innovation rather than globalization, on reduced dependence from fossil fuel and on environmental sustainability. It is compatible with a strong attention to themes such as global change or equity, which are addressed with a positive attitude towards the possibilities of technology and the solutions that it may offer. This creates a positive, but selective, attitude towards innovation, and in particular those innovations that foster community and social values.

Snapshots

- Human auto-id and chip implantation is prohibited by law.
- Open source RFID is available: 'Open ECP Global' is available free of costs based on peer-to-peer, managed by the Open EPC Global foundation.
- Venture capital investment in location and identification technologies exceeds that of biotechnologies.
- Lyon adopts the first city-wide ID and emergency chip service. A small, standardized, card extension to mobile phones that provides authenticated access to all public spaces, mostly entertainment venues, and all public transport, including payment.
- Wall Mart has institutionalized the position of a consumer representative, co-selected together with consumer organizations, in the executive board of directors.
- National Authorities supervise the use and collection of location and RFID data: they audit operations and may stop businesses on grounds of threats of privacy violation.
- Cars are equipped with envirometers , that measure environmental impact in addition to consumption and speed, based on location and external information provided by the network.
- Road use is charged per kilometre travelled with rates changing during the day depending on traffic conditions.
- Dataveillance stories are common in evening news, together with environmental issues and cooperation with developing countries.
- Digital *communes* share information and whereabouts between members to create global digital cohabitation experiences.

The 'Big boys' scenario

This is a scenario where economics is dominated by large multinational players which have a strong degree of control over several sectors of the economy. The attitude towards these players is not negative and a general business attitude permeates society. Business needs are the main drivers for adopting location and sensor technologies.

Governments are largely hands-off as concerns limitations or incentives to innovations, without the ability or mandate to compensate the strong role of business players. Privacy regulations are limited to basic prescriptions.
This unbalanced division of power results in many walled garden service offerings, many diverse devices, serving different needs and managed by different players in a maze of subscriptions and commercial offers.
Governments, on the other hand, are heavy users of location and identification technologies for security and emergency services. Governments have a strong position in these areas, partly to ensure that business and economic activities can flourish even under the permanent threat of terrorism or criminality. Security needs have pushed governments towards measures that limit personal freedom and allow the collection of large amounts of personal information on grounds of safety needs. Although privacy concerns are widespread, there is also a common understanding that these measures are necessary and thus acceptable.

Public services are regularly outsourced to commercial players, from transportation to health care or justice on grounds of better efficiency. This has created powerful business conglomerates that heavily influence the speed and type of innovation. Small companies thrive in the business culture, but face difficulties as soon as they start competing with the dominant players, making it difficult to small players to emerge.
Dataveillance is a major concern. The realization that few players have a large degree of influence over the handling of personal information, and that governments exploit identification and location technologies for prevention purposes, is a source of concern for citizens, who regularly use privacy enhancing technologies to counterbalance the threat.
This scenario is compatible with medium/high economic growth, with emphasis on corporate business. Large social inequalities are normal in this context, and plain business practices are regarded as appropriate social glue. This scenario is also compatible with a strong attention to growth, liberalization, and thin government, without much attention to issues such as social inclusion or environmental aspects. This creates a positive attitude towards innovation and technology in general, but mainly as a means to serve the interests of big players or security.

Snapshots

- Berlin and Copenhagen have decided to adopt road charging based on the Road+ system. Five major competing systems are currently available and adopted in cities across Europe.
- The RPI show (Real Privacy Intrusion Show) on EuropeTV, also knows as Orwell show, is a major success. Movies, clips, tracks and stories from privacy intrusion provided by people are collated together into 'horror' stories.
- All transit passengers at the Amsterdam airport must carry an electronic ID that contains full biometrics. Each passenger is associated to a risk score computed based on the synchronization of thousands of public and private sources worldwide. Passengers with a score lower than 54 are not allowed on board.

The implications for transportation and mobility

The EC estimates that 7500 km of the TEN infrastructures, i.e. 10% of the road network, is affected daily by traffic jams. In 1998 energy consumption in the transport sector was responsible for 28% of all emissions of CO_2. Under the current traffic growth estimates CO_2 from transport can be expected to increase by around 50% in 2010. Road transport is the main culprit since it alone accounts for 84% of the CO_2 attributable to transport. Reducing dependence on oil from the current level of 98%, by using alternative fuels and improving the energy efficiency of modes of transport, is both an ecological necessity and a technological challenge.

Governments and local authorities are looking at various measures to address congestion, safety and environmental impacts of mobility, such as:

- Stimulating the shift from road to rail and water transport, by increasing infrastructure availability but also by stimulating multimodality in terms of price and tax and in terms of information provision.
- Managing the excessive environmental impact of transportation, on the one hand penalizing pollution and on the other hand stimulating alternative fuels and energy sources and vehicle designs.
- Improving road safety, minimizing the chance of incident but also of implementing fast and reliable emergency management systems (see for instance the e-Call initiative).
- Charging for transport, in particular for infrastructure use (road charging) either for congested areas such as urban environments (congestion charging) and/or for the use of the road infrastructure.

Information technology has a potentially important role in addressing these issues. Informatics in cars will provide ways to manage consumption and is essential to operate hybrid vehicles. Navigation systems combined with traffic information help to better allocate cars on the road network, or for informed multimodality. Real-time location and identification is the basis for implementing large scale road or congestion charging. Automatic location of callers in case of incident is essential to provide rapid emergency services.

The transport sector is one of the main drivers for the development and adoption of location and auto-identification technologies. At the same time, these sectors will be significantly affected by the availability of means to locate vehicles and users in real-time, and the ability of tailoring information provision to them in a contextually related manner.

Road safety, road and congestion charging, mobility management, travellers information, travel planners or parking space allocation are areas where the ability to identify and locate vehicles and users in real time makes it possible to implement services or measures which are unfeasible at present.

The scenario analysis above illustrates that the future of location and sensor services, and therefore their adoption and utilisation may develop in radically different ways, based on factors that are only in part influenced by transportation and mobility needs.

Technology for location and identification will simply become available and especially vehicles will increasingly adopt it as standard safety and information provision features. The automotive industry will embrace these technologies to comply with mandates (such as e-Call or 112), to differentiate their products and to address emission management and possibly road charging. Travellers will increasingly familiarise to navigation and safety features that will be considered standard vehicle features rather than expensive optionals. To the extent to which the decision to adopt these technologies is left to the producers (automotive industry) or the users, a growing adoption if not market saturation is a realistic expectation for year 2020 for selected services of immediate benefit to the individual user or to the manufacturer.

Applications such as road charging schemes, automatic parking permits or payments, gate detection, speed recordings and limitations require direct government intervention and a potentially far more intrusive role of the data collector with respect to the end user.

For road charging, for instance, technology is already mature to provide means to detect travellers on a specific road section, to measure speed and emissions, to assess the level of congestion and to anticipate on its future levels. The implementation of these technologies will require technology adoption at the level of travellers and at the level of infrastructure (road).

One of the first issues to be addressed by public authorities is who will be the owner of the enhanced road infrastructure, in particular of the set of sensors, ICT and other instruments that will need to be embedded in the physical infrastructure to support road charging, emission management and safety. Governments have a very patchy record of running and maintaining ICT infrastructures, and this would suggest starting with either pure private players or with public-private partnerships since the beginning of this development. The privatisation of telecoms, for instance, is a proof of the level of efficiency and service improvement that a competitive market can offer compared to a public monopoly. Nonetheless, governments will need to ensure interoperability of solutions as well as competition between multiple market players to prevent that inefficiency in transportation will lead to inefficiency in the information management sector.

The usefulness of these infrastructures will grow with their ubiquity, while their marginal adoption costs will decrease correspondingly. The London congestion charging system is an island of adoption which, in spite of its positive results, is very expensive to maintain and is sub-optimal in terms of ICT because of its uniqueness and isolation. If the same system would be adopted by other cities or for other purposes, then the overall exploitation costs would rapidly decrease and the overhead on single users or city administrations would be very low. This suggests the need for strong coordination at the early adoption stages between multiple cities or road infrastructure managers.

The ubiquity of these infrastructures raises the spectrum of information control and dataveillance. The amount and detail of information available will be a formidable incentive for business and governments to exploit it for purposes different from the original one. The scenarios above indicate that this may play out in various ways, but that addressing the dataveillance concern cannot follow a 'retrofitting' approach but must be considered as a design aspect of the new ICT infrastructure for mobility and transportation. Failure to do so may raise privacy and information control objections so strong to put off the deployment of road and congestion charging of many years. Among the various ways to address the privacy issue, the most attractive ones are those that leave to the end user the option to disclose as much information as wanted for the purpose necessary, and to have full control of it at all times. This would give governments and the concessionaries of their services a minimum role of data collectors and aggregators.

Interoperability will be the kernel of successful adoptions of location and sensor technologies in transportation. While standardisation is a generic trend in ICT, there will be a formidable incentive to exploit a massive captive market with proprietary solutions. The short term advantage for local and central authorities is that proprietary systems are usually available earlier than generic standardised ones, and that the short term benefits are very tangible in terms of speed of implementation and possibly short term costs. This is however a major risk for the overall success of these initiatives. Should few major players dominate road charging, emission registration and the like, end users and governments will pay more, be exposed to privacy risks as well as major inefficiencies in the exploitation of the results. This would be comparable to transferring the benefits to few monopolistic users rather then the community. Of all issues to be addressed by cities and governments in the adoption of location and sensor services, this, together with privacy, will likely have the largest long term implications.

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Sensor Web, Sensor Networks: New possibilities and new challenges

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Abstract

The advances in modeling of water systems on one hand and in sensing, computation and communication on the other help answering the new challenges water management is facing in the new millennium. Real-time, high resolution data streams become available, which can be fed into high-fidelity simulation models, automated control/management systems and decision support systems offering insight and soundness never experienced before. Sensor networks and the sensor webs are the key ingredients for providing this data rich environment. Converting the full potential of these new technologies into practical results needs a thorough rethinking of the data interpretation process. The paper summarizes the promises of the new technology developments, identifies the new problems they create and suggest solutions to overcome the difficulties. The paper concludes with sketching a 'smooth' development path, which allows for gradual introduction of the elements of these new technologies.

Introduction

Water management is facing new challenges in the new millennium. Effects of global warming, flood protection, water supply, sanitation, sustainability, mobility and transportation are among the factors, which have crucial impact on the developments. These developments result in complex engineering artifacts, which are integrated into and interact with every aspect of our everyday life – thus their global impact cannot be overestimated. The monitoring and control of these complex interactions are of primary importance in order to assure efficient, clean and safe operation. Consequently modeling, simulation and observation play important roles in the process.

The advances in modeling of water systems on one hand and in sensing, computation and communication on the other, help answering the challenges. Sophisticated spatial-dynamical models, high-performance distributed computing platforms, new and affordable remote and in-situ sensing solutions, (wireless) sensor networks are the most prominent examples of the recent achievements. Real-time, high resolution data streams become available, which can be fed into high-fidelity simulation models, automated control/management systems and decision support systems offering insight and soundness never experienced before. At least these are the promises of the data rich environment and 'cheap' computation and communication enabled by the technological developments. When looking into the details, however, it turns out that converting these promises into practical results is not an obvious, self-driven evolutionary process.

In order to fully utilize the potentials offered we should prepare ourselves for a 'paradigm shift'. This involves thorough investigation of both 'what we are doing' and 'how we are doing'.

This paper approaches the problem from sensing perspective and investigates how the potential of data richness can be fully utilized. More specifically it attempts to answer questions around the integration of sensor networks and sensor web into the data interpretation process [1]. As it will be shown the data interpretation process has to be adjusted in order to accommodate the advantageous features of sensor web based observation. Without these adjustments the sensor web is still useful (e.g. more economical to maintain, possibly wider coverage, etc.), but cannot deliver its promises.

The paper is organized as follows. First the paper summarizes the main trends of the recent technological developments on sensing, data processing and their impact on monitoring and control. The following section details the role of modeling in data interpretation and its consequences with respect to networked sensing. Section 'Sensor Web Enablement: What does it offer?' briefly summarizes what the Sensor Web Enablement (SWE) effort of the Open GIS Consortium offers for answering the questions raised in the modeling section. The paper concludes with showing a step-by-step approach to 'embrace' SWE compliant sensor systems. The paper gives an illustrative example (water throughput measurement in waterways) to help 'bridging the gap' between the conceptual and the practical side of modeling in general and sensor web enabled instrumentation in particular.

The context: advancement in technology

It is considered a 'natural process' that computers become smaller, more powerful and less expensive at a logarithmic rate. The level of component integration lays behind these trends: Moore's law [1] describes the pace of development and – though it is based on empirical observations and the future validity is debated – there are a still a number of years ahead (Figure 1).

As the computing performance is proportional with the number of transistors integrated and the price of unit silicon surface can be considered constant the cost of unit computing capacity is exponentially decreasing in time. This makes the computing 'embeddable' to various devices, many times at a negligible price level.

Similarly the communication technology went through breathtaking developments during the last decades – partially fuelled by the development described above. Also in the wireless communication domain a number of standards were developed covering great diversity of distance, data rate and power ranges (i.e. there are matching standards

[1] In the following we use the 'sensor web' term to denote any distributed sensing solutions, which provides data via (possibly public) network infrastructure (wired or wireless). The conceptually notable feature of the sensor web as defined above is that there is no dedicated connection between the data source ('producer') and data sink ('consumer').

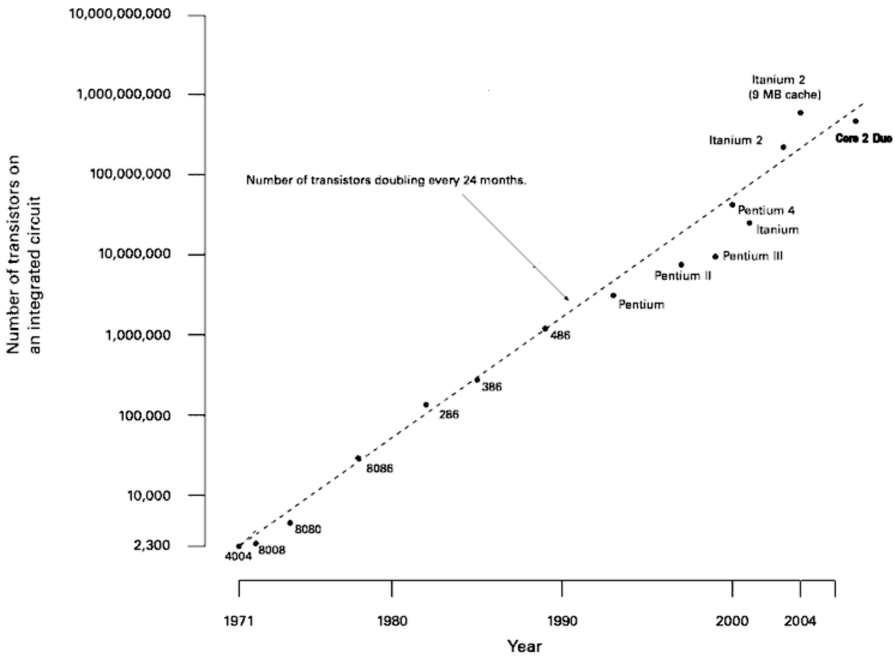

Figure 1. Moore's Law [2].

available for a variety of applications). The wide industrial support drove the prices down making the communication available almost 'for free' [2].

From these two advancements the affordable networked embedded computing emerged. The parallel development in material technology, micro-machinery and sensory technologies resulted in a new class of 'smart' sensors capable of complex measurements, data (pre)processing and communication – establishing the foundation of the sensor web. These incremental changes created 'something big' at the end: they paved the road to (relatively) easy deployment of sensory systems, (relatively) inexpensive maintenance, higher throughput, real-time availability of data – thus to the data rich environment. Figure 2 shows the history of wireless sensor nodes and the forecast for the coming years[3]. As the figure indicates the cost of manufacturing of the embedded computer and communication component of a typical 'smart sensor' goes from the last decade's 'decisive level' to the coming decade's 'negligible level'. Ubiquitous smart sensors extend the scope of what we can observe and change the way how we can observe features of the phenomenon/process we are interested in.

[2] The figure is a modified version of the original from the Wikipedia article on Moore's law (http://en.wikipedia.org/wiki/Moore%27s_law).

[3] The data were collected from market research reports and various trend analyses (Harbor Research, ComputerWorld Mobile & Wireless, CFO.com (Economist Group), Intel Corporation).

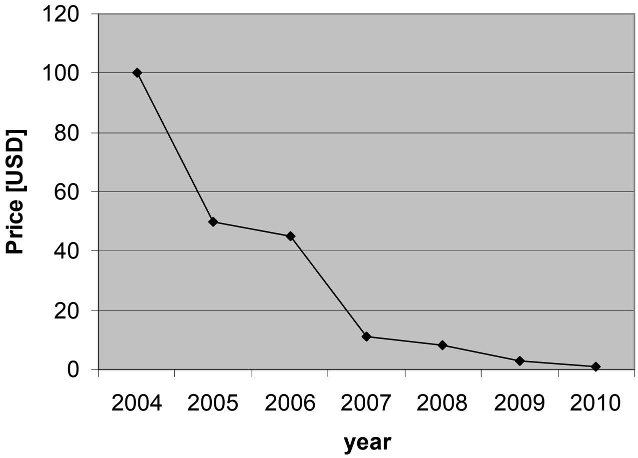

Figure 2. Mote price forecast.

Even in the near past observations were made using relatively small number of sensors and the sensors typically targeted only one or few physical domains (e.g. temperature, pressure, etc.). The advance in technology as described above makes it possible to create cheap, small, easily deployable sensor systems, which can cover wide spatial areas and can collect data about various physical and chemical domains (Figure 3). In the - hopefully near - future we will be able to create extremely small sized, very cheap, self-sustained, disposable wireless sensors capable of observing wide variety of physical domains. These 'smart dust' particles will redefine the way we observe our environment, but also elevate the challenges ahead to a higher level.

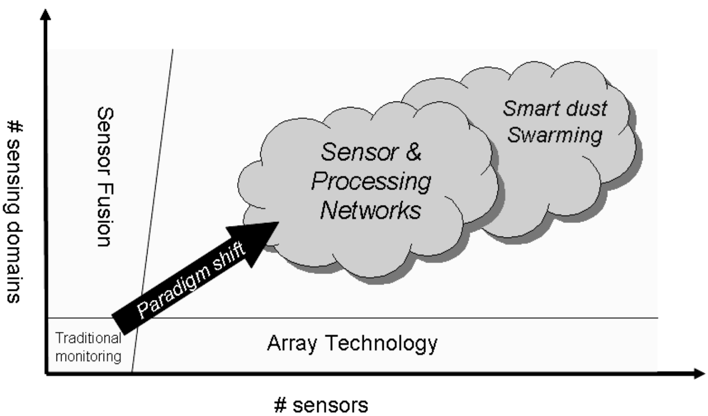

Fig. 3. Trends in observation.

The development is not at this stage yet, but the path it is taking already goes into this direction and giving straight answers to the mounting questions cannot be postponed. The sensor web changes the sensing landscape in a number of ways.

Amount of data
This is the most obvious consequence of the sensor web technology. As the unit cost is decreasing and the connectivity is wide-spread available more and more sensor nodes are deployed resulting in higher spatial resolution, wider coverage and increased observation frequency. These factors manifest themselves in rapid surge in the amount of data. On one hand this is good news (i.e. as set of observations become bigger we can have deeper insight into the process), on the other hand the receiver side should also be prepared because otherwise the raw data never become information. In some cases the currently used models are able to 'consume' and make use of the extended data set, but in other cases new models should be developed to adequately process the high resolution data stream. Consequently a computing infrastructure should also be in place to run these complex, high-dimensional models. 'Scaling up' the existing models and moving them to distributed computing platforms may not be straightforward: to assure high performance significant restructuring and reimplementation of the models may be necessary[4].

Diversity of data
The development in sensory technology in combination with the highly improved and affordable sensor web infrastructure makes deployment of sensory systems economically feasible, which can cover multiple physical domains. 'Imaging type sensors', which normally deliver large output data sets and were prohibitively expensive to deploy at remote locations in the past, are becoming mainstream. The data collected from the area (process) to be observed delivers multiple 'views' on the governing phenomena thus allowing deeper understanding of its behaviour. But again, in order to make use of this potential the 'receiver side' of the data stream should properly be prepared (see details later).

Openness
The sensor web also transforms the way the data processing is associated with sensors. The sensor web can be considered as a 'data provider infrastructure'. The 'user' of the data typically does not 'own' the data source anymore. Depending on the problem in hand the user can determine what data are needed (coverage, resolution, other data acquisition parameters) and the data can be requested from the infrastructure (provided enough suppliers are available). Consequently the data interpretation stage should not depend on a fixed set of sensors always, but the sensor set becomes easily customizable resulting in a problem matched data acquisition scheme. Obviously, this openness again has impact on the data processing; it should be able to cope with sensor reconfiguration.

Dynamism
The dynamism in part is a consequence of openness. The availability of the sensors and the quality of the data depends on circumstances, which cannot be controlled by the

[4] Certain model classes do not lend themselves to efficient distributed implementation. In these cases the development of structurally new models is the key for up-scaling.

'user', e.g. temporary communication failures can disturb the operation, the accuracy of the sensory data can be provider dependent, etc. The data interpretation should 'do its best' under varying conditions because the total isolation of the data processing from these external circumstances is either expensive or not feasible at all. Another type of dynamism is brought in by new family of sensors. Due to the miniaturization, power efficiency and ubiquitous communication sensors can easily be installed on mobile platforms (e.g. ships, road vehicles). These mobile platforms can visit difficult to reach areas, can serve as temporarily deployed sensor systems or can traverse areas where permanent installation would be prohibitively expensive. Degradable 'smart dusts' deployed from e.g. airplane or ship, constitute the extreme of sensor mobility. In the near future this may become one of the common ways of sensor deployment. Mobile sensors – beside the measured values of the observed physical quantity – should report their position (with given uncertainty), because this is part of the characterization of the phenomena monitored. Again, the data interpretation should be prepared to incorporate observations of varying spatial locations.

The following sections investigate what is the impact of these characteristics on the monitoring and control process and what Sensor Web Enablement (SWE) can offer to overcome certain difficulties. Modeling plays crucial role in monitoring and control, so before the interaction between SWE and data interpretation is considered the use of models in the data interpretation process will be detailed.

About the role of models

There is no one single definition for what a 'model' is. For our purposes the model can be briefly defined as 'formal representation of knowledge'. The model is the means to look into and describe the operation of a system (or phenomenon) from a certain aspect [3]. A few remarks should be made here:

- The model does not give the full description of the system: certain aspects are covered, some others are not. It is the problem in hand (i.e. the question to answer), which defines what are the important aspects. For example, when a control system is designed the dynamical model of the process to be controlled is of concern, other aspects, like assembly, manufacturability of components, aesthetics, etc., are out of scope[5].
- Even from one aspect the description is not complete: certain features are neglected, others are emphasized. Again, it is the problem in hand, which determines what features are necessary to consider. E.g. if we know that the process to be controlled always will be used around a well defined operational point certain non-linear effects in the dynamics can be omitted. Consequently it may turn out that a linear

[5] In complex cases the independence of the aspects cannot be maintained and the interaction among the aspects makes both the modeling and the application of the model difficult. In the same way, as the selection of the features to model is crucial, finding out the sufficiently accurate but still manageable interaction scheme is the key for the success.

differential equation describes the system accurately enough to design the control system.

– What is the 'system' and what is the 'environment': The 'system' is a collection of interconnected objects, where the interconnection is purpose-directed. Consequently, everything, which is not part of the system, is part of the environment. The border of the system is defined by the scope of the problem investigated and the possibility to influence behaviour.

Depending on the approach to formalization, various model types exist. Models can be physical, conceptual or mathematical. The purpose of the modeling, the preferred model building process and the amount of available knowledge determine which model type is reasonable and/or possible to use. Mathematical models have overwhelming advantages above the others: there are formal methods to transform models and to prove properties, the computers serve as the ultimate (and very flexible) way of making models working, just to name a few important features. In the following mathematical models are assumed, i.e. when we refer to 'models' always 'mathematical models' are meant.

When 'measurements' or 'observations' are mentioned not only the mere values are considered. The values by themselves are meaningless. Measurement is always about validating an underlying system model and/or determining certain parameters or states of the system (i.e. model matching). By measurement our understanding of the system can be extended as formalized in the model. As an example consider 'checking the fever' on a human being. We use a thermometer to determine the body temperature. What we have to realize is that we are not interested in the temperature per se: the real consideration is to establish certain insight to the health state of the human under test. Consequently a particular reading in itself (e.g. 37.8) does not tell too much. In order to answer the real question about the health state we use models unconsciously. On the sensing side we know the thermometer shows the reading in ºC and assume that it operates correctly. On the data interpretation side a simple behavioural model is used as shown in Figure 4. The health state of the human is modeled as a finite state machine with two states and the state transitions are controlled by body temperature. Using these two models simple decisions can be made about the health state of the

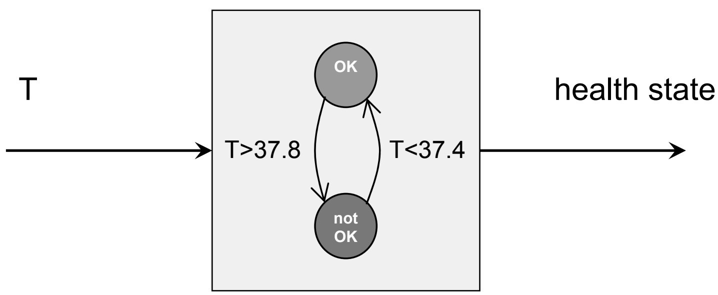

Figure 4. Interpreting body temperature.

human under test. These models do not capture the dynamics of the system. In real life actually an extended model is applied, which takes into consideration the evolution in time: the thermometer is not read out immediately after placing it, because there is a not negligible settling time (which depends on the measurement principle used by the sensor and its implementation features). The read-out should not be made until the reading reaches the steady-state value. Similarly, the body temperature is not monitored continuously (even not too frequently), because the human body has its own dynamics and it is enough to 'sample' the temperature on hourly basis or so.

Generally speaking every element of the monitoring or control process contains the models of the system under consideration including the sensors and actuators (Figure 5). Sometimes these models are explicitly represented, sometimes they are implemented implicitly in the data interpretation, decision making and control algorithms. The models code the relevant characteristics of the system, the characteristic of the sensing (incl. its possible interaction with the process to be observed), the dynamics and constraints of the actuators, etc. The algorithms used depend on the model available about the process [3] (e.g. without sufficient statistical insight certain type estimators cannot be derived for system parameters)[6]. The applied modeling formalism also defines how we can express the 'goals', i.e. purpose of monitoring and control.

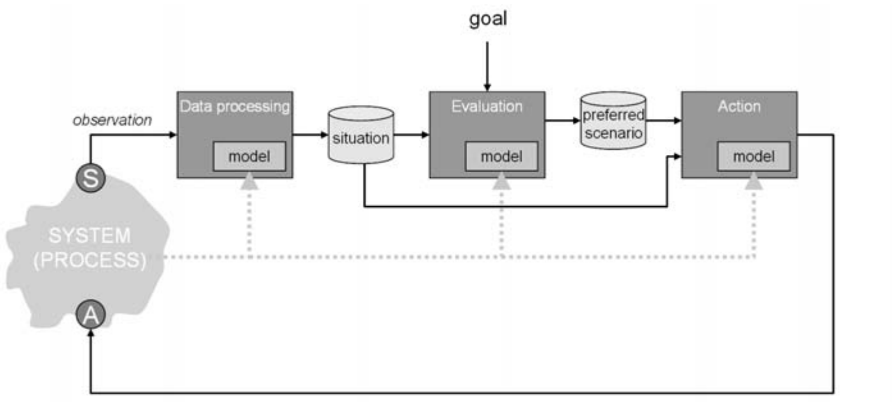

Figure 5. Models in monitoring and control.

Figure 6 details this picture from sensing point of view. The conceptual scheme is very simple: sensors are mounted on the process to be observed and collect the observations. In reality the scheme is more complex. The sensor is attached to the process. The

[6] In sophisticated cases the characteristics/constraints of the implementation of the algorithms may have significant impact on the algorithm itself (e.g. the accuracy of the representation of parameter values, the accuracy of the calculations due to the finite word length of the digital computing hardware, the resolution of the analogue-digital conversion, the temporal uncertainties introduced by the networked implementation, etc.). In these cases the implementation characteristics/constraints should also be modeled and taken into consideration when deriving the data interpretation algorithm.

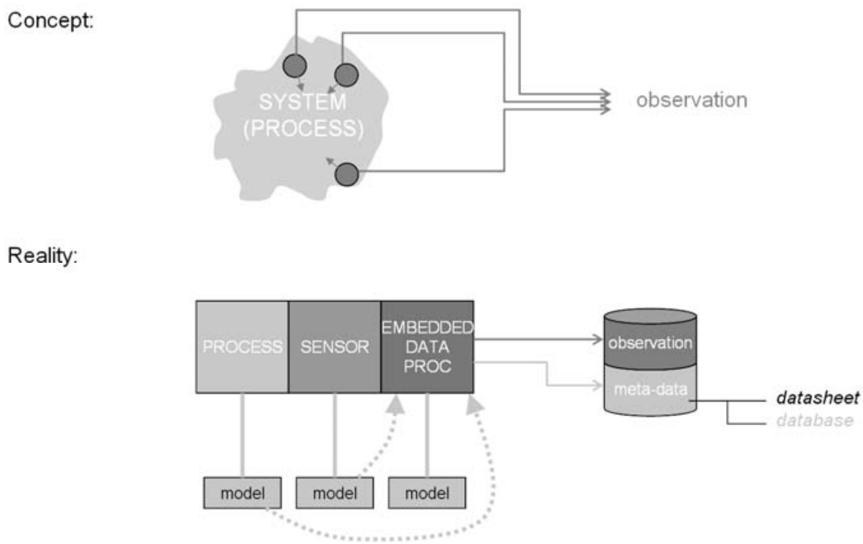

Figure 6. Models in sensing.

underlying process and sensor models have to be known in order to interpret the sensor reading properly. Nowadays most sensors are attached to an embedded data processing stage ('smart sensors') which carries out additional data processing such as filtering, information extraction (data reduction). Obviously the embedded data processing algorithm depends on the process and sensor characteristics (coded in the models). In many cases the embedded data processing can be parameterized from outside to match the processing to the properties of the process observed. Consequently, when a smart sensor is attached to the monitoring/control process it is important to know what the embedded data (pre)processing does, how it is parameterized, etc. This information is usually available in the data sheets (manuals) and the designer of the data interpretation can take it into consideration in the design.

The data interpretation side (representing by the Data Processing, Evaluation and Action blocks in Figure 5) is typically decomposed to connected functional blocks, each responsible for implementing a particular transformation on the input data set. In a more detailed view Figure 7 shows the 'interfaces' of a functional block. The 'main

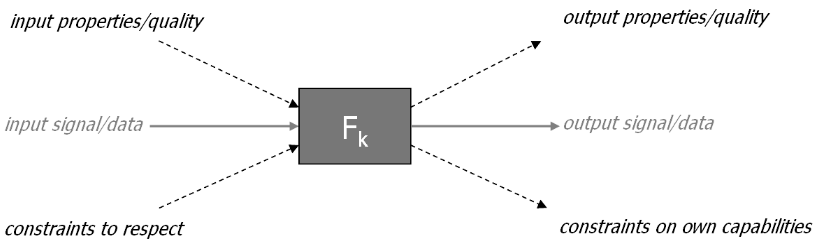

Figure 7. A functional element of the data processing.

data path' is between the input and output terminals: the transformation associated with the block is applied to its input and the output data is generated. Beside the main data path the block should serve other inputs, too. The properties of the input data stream (e.g. uncertainty, temporal jitter, etc.) should also be provided by the data source and the block should take them into consideration when applying the transformation. The properties of the output data stream have to be calculated, which depend on the properties of the incoming data and the transformation itself. The connected function blocks are also interconnected by their capabilities. In a way a block has to take into consideration what the requirements of the block connected are and similarly it should inform its predecessor about its own constraints.

Figure 8 shows the interconnection between a series of processing blocks interacting both through the main data path and through the 'quality/capability' interfaces. It should be noted that this is a conceptual scheme, i.e. the arrows do not necessarily represent data exchange in execution time. The main data path is always implemented by the monitoring/control system. The interactions through quality/capability interfaces may or may not exist in execution time: if the properties of the input data stream are known in advance and can be considered stationary, the quality/capability interactions are handled in design time, i.e. a dedicated design is created, which is customized to this well-defined circumstance. In this case only the main data path exists in the operational system. In a more 'dynamic environment', where either the quality of the input data or the capabilities of system components may change, the quality/capability interactions exist in execution time. This is managed via a higher level coordinator, which is responsible for the reconfiguration of the data processing according to the changing environment.

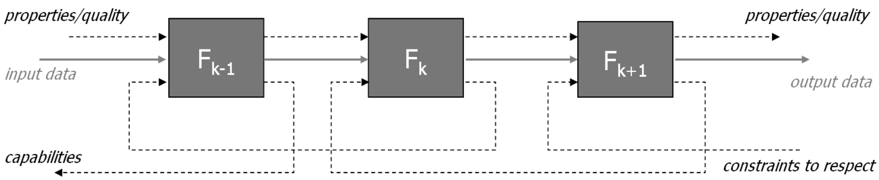

Figure 8. Compound transformation.

The use of models: sensor web context

As summarized above the sensor web based data acquisition has a few distinctive features, which influence substantially the data interpretation stages connected. The 'sensor web style' interconnection between the system/process to be monitored/controlled and the data interpretation functionalities can be drawn as Figure 9 shows. Though the scheme is simplified (and some current day applications reflect certain similarities) it wants to emphasize a trend: with the spread of the sensor web based observations the data interpretation stages (D) will be connected to a variable set of sensors (S, typically managed outside of the institution involved with the data interpretation). The process (P) is richly instrumented with sensors delivering a multi-aspect view on the operation of the process.

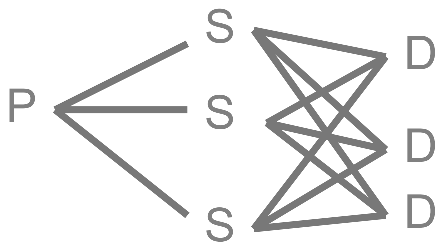

Figure 9. Process (P), sensor (S), data interpretation (D).

Due to the openness and dynamism (as described in the previous sections) the same (type of) sensor may not be available all the time, the sensor parameters may change, etc. This creates an inherently time variant environment for the data interpretation. Consequently, on the data interpretation side it is not sufficient if the quality/capability path of Figure 8 only in design time exists: the handling of these characteristics – to a well defined extent – should be moved from design time to execution time. Figure 10 details the internals of a data processing block prepared to work in this type of dynamic environment. A processing block (F_k) may encapsulate multiple and/or reparameterizable variants of the functionality useable under different conditions. The operational conditions of the block are defined via the 'secondary path'. The selection of the proper variant and/or the parameterization is controlled by the internal 'Monitor-Evaluate-Act' (MEA) component, which decides about the proper strategy and communicates this with the adjacent blocks. Each variant of F_k is designed to work under predefined operational conditions (e.g. available observation set, constrained noise levels, predefined environmental conditions, etc.) and under these conditions F_k is capable of delivering the output data of predefined quality. Differently stated F_k operates under a given 'contract', which defines its 'rights' and 'responsibilities'. If the conditions defined in the contract are violated F_k is not able to deliver its output as specified. One of the most important functions of the MEA component is to check the operational conditions and

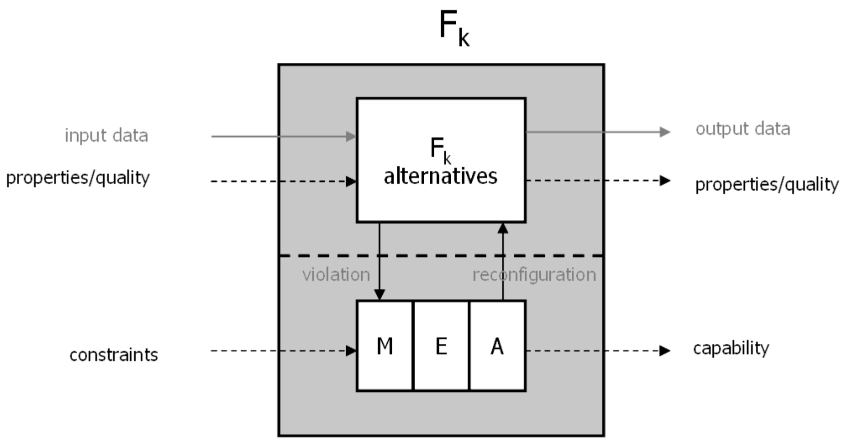

Figure 10. Inside a data processing block.

assure that no variant works outside the valid operational region. Though complex inside, on the interfaces F_k manifests itself as 'normal' processing block – but with a very powerful feature: it can operate effectively under various operational conditions and it is able communicate its capabilities with its environment [7].

The sensor web style of use has impact also on the sensing side. In order to enable the data interpretation stage to operate in an 'open data acquisition' environment the sensor systems should feed in the necessary 'background information', denoted as metadata in Figure 6. The metadata describes the 'meaning' of the primary data (i.e. the observations) by specifying the unit, the accuracy, the properties of the data pre-processing stage, etc. Consequently in this dynamic environment the static 'data sheet' style solution is not sufficient. Instead, proper descriptors should be attached to the observation data and provided to the data processing stage 'electronically'.

Sensor Web Enablement: What does it offer?

The Sensor Web Enablement (SWE) effort of the Open GIS Consortium targets making various sensors, instruments and sensory data repositories discoverable and accessible remotely – more specifically via the World Wide Web [4][5]. The effort was initiated by various large-scale remote and in-situ observation projects and enabled by the technological development mentioned before. Consequently SWE addresses a number of issues arising from the open and dynamic nature of sensor web and maps the solutions to web protocols and XML (eXtensible Markup Language). Information about capabilities of the sensor and its control interface is provided in standardized form and accessible by the data interpretation applications as sensor metadata in XML form. By bringing the sensor web to world scale, SWE has extraordinary impact on environmental monitoring, transportation, safety/security, disaster management, etc.

Before overviewing to what extent SWE answers the challenges of sensor web based monitoring and control, the main components and features of the SWE is summarized. (For deeper insight, for the content of the different standards and the status of the standardization process see [6].)

SWE covers the following functionalities [4]:

- Discovery of sensor systems and observation sources according to user specifications;
- Access to sensor capabilities and quality characteristics;

[7] Many times it is not necessary to implement a 'full-blown' reconfiguration scheme behind the processing blocks. In a number of cases it is an acceptable level of robustness if the data processing is blocked of applying the transformation under circumstances, which invalidate the 'contract' (i.e. at least incorrect conclusion will not be drawn from data). In these cases the MEA block becomes ME, i.e. M checks the conditions of the 'contract', E evaluates the findings and aborts the operation (informs users) if the conditions are not met. This is a manifestation of the 'doing nothing is better than doing incorrect things' principle.

– Access to sensor parameters;
– Retrieval of real-time or stored time series data;
– Tasking of sensors to execute observation and data preprocessing procedures;
– Definition of alert criteria and subscription to alerts to be issued by sensors.

These functionalities are mapped to encodings, interface definitions and services controlled by a number of SWE standards (or pending standards as at the time of writing).

Observations and Measurement Schema (O&M)
O&M defines a standard for representing and exchanging observations. One of the main considerations is to assure an efficient exchange mechanism for large amount of data. O&M binds the observation to the feature of interest as modeled in the ISO/OGC Feature Model [7].

Sensor Model Language (SensorML)
SensorML defines an information model that enables discovery and tasking of sensors and usage of observations. This includes the description of measurement and data (pre)processing processes. SensorML gives the functional description of the sensor system (rather than a detailed hardware description). Every component is described as a process model. A process model is given by defining the inputs, outputs, parameters and method of the process. SensorML description of a sensor is available as meta-data.

Transducer Markup Language (TML)
Sensors and actuators are jointly called transducers. TML defines the way to efficiently capture, transport and archive transducer data in a unified form. TML defines (1) a set of models describing the hardware characteristics of a transducer, and (2) an efficient method for transporting data and preparing them for temporal and spatial data fusion. TML is harmonized with O&M and SensorML.

Sensor Observation Services (SOS)
SOS is basically an API [8] for managing sensors and retrieving sensory data. SOS is an intermediate 'layer' between the data interpretation ('application program' or 'client program') and the real-time sensor (or sensory data repository). Through SOS also the sensor meta-data can be retrieved.

Sensor Planning Service (SPS)
SPS defines the way of requesting information about a sensor for determining the feasibility of an intended sensor usage request (plan), submitting such a request, modifying the request and requesting information of other sensor web related services.

[8] API: Application Programming Interface.

Sensor Alert Service (SAS)
SAS specifies interfaces for requesting information describing the capabilities of SAS, determining the features of the defined alerts and subscribing to specific alerts [9]. It also allows for nodes to advertise and publish observation data (with meta-data). SAS serves as a registry rather than a notification system, consequently SAS implementations rely on notification standards (e.g. OASIS Common Alert Protocol).

Web Notification Services (WNS)
WNS specifies an interface through which clients can conduct asynchronous message exchanges with multiple services.

Example: Measurement of water discharge in waterways [10]
In order to manage both the safety of the Dutch inhabitants and the efficient transportation over water, measurements of water characteristics are performed on a regular basis at several locations throughout the country. For instance the changing water levels are monitored at a number of places along rivers like the Meuse and the Rhine. Various models require the water throughput in m^3/s as an input and this parameter is difficult to measure. In general a varying throughput would lead also to a varying water level, however the relation between these two parameters is complex and different for every location. Nonetheless this water level measurement used to be the bases for estimating the water throughput. Higher accuracy can be obtained by combining the water level measurement with a measurement of the speed of the water flow. Complex installations were introduced to measure the time of flight of an acoustic pulse through two diagonal paths across the waterway. This way the mean flow velocity in a horizontal plane in the waterway can be measured. Deriving the water throughput from this mean water speed at a certain plane in combination with the measured water level is still not a straightforward calculation because the flow speed distribution is not uniform (it decreases as the edge of the water body is approached).

A more sophisticated solution is to use an instrument called an Acoustic Doppler Current Profiler (ADCP) which can measure the speed of particles in water as a function of distance from the sensor head by measuring the Doppler shift of a reflected signal. By using multiple beams the speed can be measured as a two or even three dimensional vector and a speed profile can be obtained. The ADCP can therefore be used to measure the speed at multiple locations across a water way compared to the single mean water speed value that was produced with the time of flight measurement. Another advantage over the 'time of flight' setup is that the ADCP does not need multiple locations for instrumentation (separate transmitters and receivers). The ADCP can therefore easily be mounted on a moving platform like a ship. The detailed information about the flow speed distribution provided by an ADCP has to be combined with the cross section profile and the actual water level to derive the actual water throughput.

[9] Alert is defined as a notification of event occurring at an object of interest.

[10] This example is based on a concrete measuring problem of the Dutch the Ministry of Transport, Public Works and Water Management.

The measurement of water throughput in waterways as described above is used as an illustration for the possibilities of SWE. In Figure 11 the information flow to obtain water throughput measurements is presented. It is assumed that an ADCP and a floatation (water level) sensor are available as SWE compliant sensors on the net (the figure shows both the ADCP and the 'time of flight' configurations). The 'throughput sensor' is implemented as a 'virtual sensor' (SWE sensor 3) that provides water throughput measurements by combining the measurements from the water level and the flow speed sensors with a model of the cross section of the water way. The water throughput sensor could even use flow speed measurement data from moving platforms (e.g. ships equipped with an ADCP) because the (SWE compliant) sensor output contains – in addition to the observation data – information also about the time the measurement was performed, geospatial information, information about the sensor type and the quality of the data (as metadata, see Figure 6).

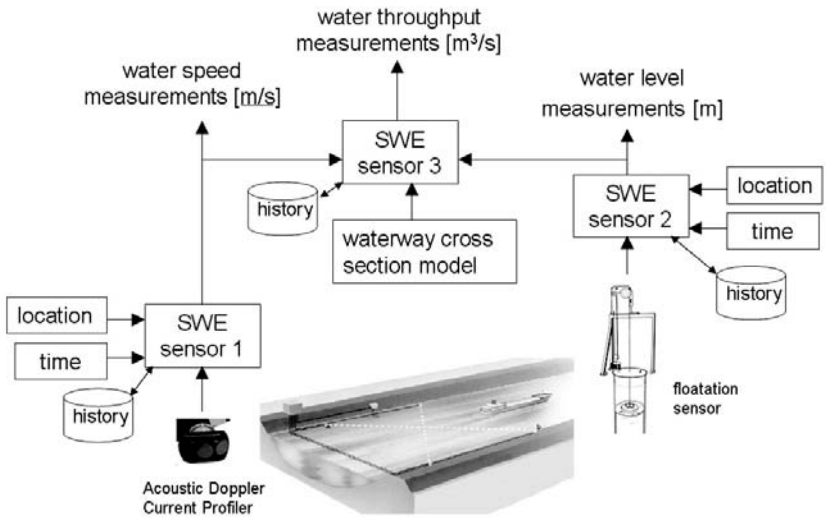

Figure 11. A 'virtual' SWE sensor using data from other SWE sensors.

Although at the time of writing the described sensors are not yet available in a SWE compliant form, an impression can be given about what information could be available in the SWE interface definitions and services for such sensors. For the ADCP the Transducer Markup Language (TML) would describe (among others) the frequency of the measurement signal, the repetition speed, the excitation signal strength, etc. With the Sensor Model Language (SensorML) the internal signal processing of the ADCP can be described: typical functions may be Kalman filtering and auto correlation, but also the compensation for the water temperature dependence of the sound propagation. Of course the description of the floatation sensor would be much simpler, but for this sensor it would be important to now in what way salinity would effect the measurement and whether measurements are still accurate when the temperature is around the freezing point. For the 'virtual' water throughput sensor, the SensorML would typically describe the way water throughput measurements are derived from the combination of other sensors.

The importance of the SWE standard and consequently the emerging family of intelligent, discoverable and 'self-explaining' sensors are overwhelming. These developments really have the potential to reshape environmental monitoring. Considering the promises SWE offers and the new challenges the data interpretation side is facing in the networked sensor world, the following conclusions can be drawn.

SWE offers crucial functionalities in a standardized way covering unified sensor interfaces, access to sensor capability descriptions, access to sensor parameters and process models. The O&M, SensorML and TML components of the standard have conceptual importance: they enable the design and implementation of robust and reconfigurable data interpretation schemes, which are capable of 'surviving' in the open and dynamic sensor web environment. These components (if thoroughly setup) provide exactly the metadata the data interpretation stage needs (see Figure 6). The other four SWE service types (SOS, SPS, SAS, WNS) are substantial from implementation point of view (actually making large-scale, practical implementations possible) but these services do not extend the conceptual limits. SPS, SAS and WNS allow the switch from pure data-driven execution to event based control of the data interpretation, which, besides making the implementation task easier, helps preserving system resources (battery, communication bandwidth, etc.) [11].

SWE can be considered as an 'enabler': it defines a proper starting point for sensor web based data interpretation, but it 'cannot do magic'. In order to make use of the potentials hidden in the sensor web the data interpretation stages have to be prepared to accept and adequately process the data stream reflecting the changing availability of sensors, communication infrastructure, etc.

SWE in practice: step-by-step

Fully utilizing the potentials of the SWE demands a lot from the data interpretation, but it does not mean that positive effects of the SWE infrastructure cannot be felt before the full 'retrofit' of the processing stages.

SWE sensing infrastructure can be 'introduced' gradually, coexisting and jointly used with the 'classic' sensor installations. Aging/broken sensors can be replaced with SWE sensors gradually simplifying management and maintenance. On the receiver side only straightforward interfacing work should be done: an interfacing block should be built, which carries out the initialization of the sensors as the data interpretation requires (i.e. command the new sensor to 'imitate' the operation of the old one) and converts the sensory data to the old format. Obviously, the new, SWE sensors can serve other

[11] Though important, the control of execution of the components of the data interpretation is not covered in this paper. Interested readers are referred to [8].

applications too (eventually with different settings) without disturbing the legacy applications.

After a while – at least it is expected – a 'data economy' emerges on SWE infrastructure. The deployment of sensors, the maintenance of those and the services offered may be provided by different entities. This creates a distance between the 'real-world sensors' and the data interpretation. The entities, responsible for data interpretation, monitoring and management may not own the sensors anymore, but simply buy data according to their needs. This brings in enormous flexibility into the system and can significantly reduce costs as the parties involved can specialize their activities and the costs of installation, operation and maintenance of sensor systems can be shared among the 'data consumers'. On the receiver side the model shown in the previous paragraph is still applicable (Figure 5).

SWE can also pave the road for easy and cost effective following of technological development in sensing, embedded systems (data processing) and communication. SWE shields the application side from the implementation specific details, consequently applications interact with sensor systems on a higher abstraction level. This isolation through the configurable interfaces speeds up the evolution of systems both on the sensing and data interpretation side.

The widespread introduction of mobile or randomly deployed sensors will be a push for SWE. A unified and standardized interface to georeferencing – in itself a great value – will be highly appreciated by application developers. In the mobile setup the dynamism of the sensor systems (incl. availability, communication) really asks for most of the support SWE can provide. From this point on the burden is on the data interpretation side to develop new models, which are able to cope with the challenging data stream.

Inevitably, SWE is a great driver to create a truly data rich environment. It is not difficult to predict that this will trigger new thoughts about modeling and data interpretation and analysis resulting in new approaches for monitoring and control.

Conclusions

SWE is a crucial step in the development of networked, world-wide sensor infrastructures. Its importance cannot be overestimated, because it will be the vehicle to create a data rich environment containing virtually limitless quantitative observations about various aspects of the world around us. On the other hand, it should also be emphasized, it merely opens up possibilities and it is the 'receiver side', which should be prepared and ready to make use of these possibilities. The openness, the finer temporal and spatial resolution, the deployment of mobile sensing platforms bear great promises, but also create new challenges for the data interpretation stages. These challenges cannot be answered without thoroughly restructuring and renewing the data interpretation stages of the monitoring, decision making and control processes. Even further, the new possibilities will trigger 'out of the box' thinking, possibly new breads of applications will emerge. New models capable of absorbing the bigger, finer, more accurate observation streams should be developed and implemented. Distributed implementation of systems becomes common not just on the sensing but also on the data processing side.

The robustness of the data interpretation processes will have even higher importance as coping with continuously and 'wildly' changing measurement and communication conditions are inherent in sensor web based sensing. The analysis of the role of models in data processing clearly showed the weaknesses of the implicit use of models, thus the model-based design and implementation paradigms for monitoring, decision making and control should become mainstream. Nowadays the model-based [9] approach seems to be the single most promising way to tackle these problems even in distributed environments.

It should be emphasized that the SWE works mostly on the 'syntax level', i.e. gives only very limited support considering the 'meaning' or semantics of sensing and data processing. This is definitely a strong limitation of SWE. There are substantial research efforts to build a semantic layer above data-rich sensor systems [10]. The main aim is to define and bind ontology to data hierarchy allowing transformations of data between physical domains, optimization for queries and data processing, etc. But SWE can start small: There is a relatively easy and 'smooth' evolutionary process, which can transform the existing observation infrastructure to a virtually limitless source of real-time sensory data.

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Acknowledgements

The authors whish to thank Niels Kinneging and Martin Verlaan (RWS RIKZ) for the enlightening discussions on the current issues in sensing and modeling for water management. Peter van der Mark, Edgar Janssen and Hap Kolb (TNO Science and Industry) drew our attention to certain aspects of the applications of sensor networks. The participants of the TNO – RWS Sensor Web Enablement Workshop (May 2007) provided their views on the development directions of water monitoring. The Rijkswaterstaat Innovation Program 'Location Awareness' provided partial funding for the research and writing this paper.

Sensor Web Enablement – An overview

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Abstract

The services specified by the Sensor Web Enablement (SWE) framework shall enable the discovery, access and control of all sensors available via the World Wide Web. The standardization of access to sensors and sensor data yields considerable advantages. For example, the standardized description of observations and measurements as well as sensors in conjunction with standardized interfaces for accessing the data produced by them enables the implementation of applications which are capable of discovering and integrating available sensors and sensor data on the fly and in real-time – an important step for realizing the Sensor Web. In this article we will give an overview over the specifications constituting the SWE framework.

Introduction

Since information exhibits aside the spatial and thematic attributes also always a temporal variance, the potential of use and acceptance of Spatial Data Infrastructures (SDI) considerably depends on the possibility of supporting the access to space-time variant information [1]. The most important type of time-variant geoinformation is sensor data. In a variety of use cases the availability of data sets gathered by sensors is essential, for instance in the case of risk management.
By means of traditional services of the Open Geospatial Consortium (OGC)[1] you can request sensor data, but only in a limited manner:

1. A map of the air temperature can be requested from a Web Map Service abbreviated as WMS [2] for a certain area of interest and point in time.
2. Raster data like satellite images or results of dispersion models can be accessed via the Web Coverage Service abbreviated as WCS [3].
3. Vector data, say way points from vehicle tracking might be provided by a Web Feature Service (WFS) [4].

But a generic framework for sensor data integration into SDIs was missing. Thus it was obvious to extend the SDI specifications by a framework for integrating sensors into SDIs. Therefore the Open Geospatial Consortium (OGC) founded the *Sensor Web Enablement* (SWE) initiative which is developing standards for access to and control of sensors and sensor networks via the Internet. The goal of SWE is to enable all types of internet-accessible sensors to be accessible and, where applicable, controllable via the

[1] http://www.opengeospatial.org/.

web. The vision is to define and approve the standards foundation for 'plug-and-play' Web-based sensor networks [5].

The rest of the paper is organized as follows. In the next section we will outline the functionality which is required in the SWE framework. Afterwards we will present in the third section the two building blocks of SWE: the information model and the service model. Before summarizing (page 48), we illustrate the SWE framework by means of a scenario (page 47).

Required functionality

The current situation of sensor networks is that they are developed around different communities of sensor types and user types, with each community relying on its own stovepipe system for discovery, accessing observations, receiving alerts, and tasking sensor systems [6]. The integration of a new sensor into those systems is a highly expensive task, due to the incompatible encodings and services. In order to realize the vision of a 'plug-and-play' web-based sensor network, the following functionality is required:

- Discovery of sensors and sensor data that meet applications' or users' immediate needs;
- Determination of sensors' capabilities and quality of measurements;
- Access to sensor parameters that allow software to process observations automatically;
- Access to real-time measurements and time series in standardized encodings;
- Tasking of sensors and simulations to acquire observations of interest;
- Subscription to and publishing of alerts to be issued by sensors based upon certain criteria (Event based notification).

In the following section we present the architecture that was developed to achieve the above mentioned requirements.

SWE building blocks

The SWE architecture comprises of two major blocks: the information model and the service model. The former consists of the underlying conceptual models and encodings and the latter is the specification of services. The separation into these two blocks represents a logical view point on the SWE architecture, but does not imply that there are no links between both blocks (see Figure 1).

In the following sections we will have a closer look on each of the building blocks and the constituting elements.

Information Model

The Information Model (see Figure 1) comprises of the conceptual components of the framework, by name: transducer, process, system, and observation.

Transducers represent the interface between the real and the digital world; thus they form the basic elements of a sensor network. Transducers that translate phenomenon to data are typically referred to as sensors, and transducers that translate data to phenomenon are called transmitters or actuators.

Based on pre-defined methods and parameters a *process* creates one or more outputs out of one or more inputs.

A *system* transforms one or more inputs based on a given methodology to one or more outputs. It consists of a set of transducers, for which the relative positions to an internal coordinate system is defined. By relating the internal coordinate system to a geographic reference system, the system, its components as well as the produced measurements can be georeferenced.

The act of observing a phenomenon is called an *observation*. It contains information concerning the lineage of the measurement, the resulting value, time of measurement, and the observed phenomenon.

The amount of information contained by the above mentioned elements increases from raw data (transducer) to processed data (observation). Each logical layer of the information model forms the basis of another layer. For example the information served by transducers form the input of processes. Applications have access to all of these layers, but they should use the information of the higher layers to guarantee a higher level of interoperability. The components of each layer use elements from SweCommon, a data format defined for SWE which contains common elements and which is based upon the Geography Markup Language (GML) [7].

In the following the specifications that form the basis of the Information Model are presented.

Transducer Markup Language

The Transducer Markup Language (TML) provides the description of sensor data and the information necessary for understanding the data gathering process. It is also used for archiving and exchanging sensor data. The TML specification [8] defines a model with which sensor data can be streamed, archived, aggregated and analyzed efficiently in a common manner. The format of the raw data provided by the sensors is not prescribed, TML rather defines a structure for describing both the data format used and the sensor metadata. The latter contains – among others – information that allows the application

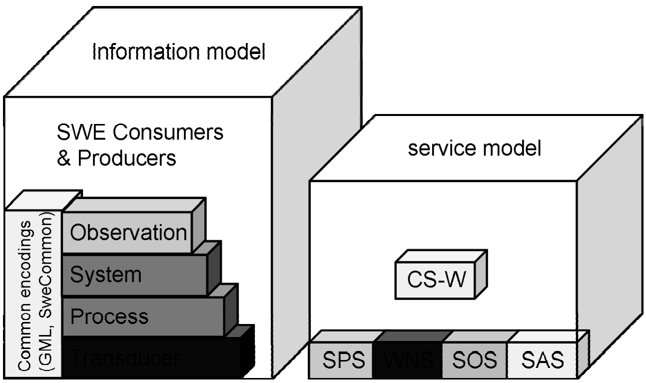

Figure 1. Building blocks of the SWE architecture.

to determine the time and location of a measurement. TML enables decoding, processing and analysing of sensor data without a need for accessing further information from other sources.
TML is well suited for transmitting data streams, e.g. video streams. Data can be streamed from an archive or directly from the sensor. Nevertheless, in the context of SWE, TML is mainly used for delivering live data directly from the sensor to the client.

Sensor Model Language
The Sensor Model Language (SensorML) [9] defines a common format for the description of sensors and sensor systems which facilitates sensor discovery as well as the analysis and processing of sensor data. The basic concept of SensorML is that sensors can be modelled as processes. GPS devices are a good example herefore. They are providing a position value based upon measurements of GPS signal run time and subsequent complex computations. Process models define the in- and outputs, the reference system being used, available parameters and the method of a process. In addition, metadata for a process can be defined. This metadata for example contains general information used for identification and classification of a process – and therefore also a sensor – and also contains information about the properties and capabilities of a process. A process either describes the actual measurement procedure or a method to analyse the data and generate further information.

SensorML enables:
- The *description* of information which is required for the exploration of sensors, sensor systems, and processes.
- The *archival* of the sensor parameters relevant for a measurement.
- The *processing and analysis* of sensor data on demand. By means of SensorML processes the necessary processing steps – like for example georeferencing and rectification of a satellite image – can be performed on the fly based upon the description of the sensor and additional process definitions. Failures possibly introduced during processing can therefore be corrected every time. SensorML strives for the development of process libraries which can be used by clients for sensor data processing.

Observation and Measurements
The Observation and Measurements (O&M) specification [10] provides a standard model for representing and exchanging observation results. O&M is primarily a conceptual model describing the relationship between different aspects of the data-capture process to one another.
According to O&M an *observation* is an event which occurs at a certain point in time and that generates a value for the observed phenomenon. Besides the time and value of a measurement, O&M is capable of describing other measurement properties, e.g. the process used to generate the measurement value as well as the location and quality of the measurement. O&M considers a measurement value to be an approximation of an attribute of the observed feature of interest (FOI), additional information is regarded as metadata for further analysis and interpretation of the data.

The O&M schemata not only enable the definition of observations but also of phenomena. Based upon these definitions dictionaries can be designed which defines the phenomena used in a certain application domain. Such a dictionary forms the basis for a general understanding of sensor data.

SweCommon

Elements for describing time, phenomena, positions, data and parameters are required within different parts of the SWE framework. Thus they are defined as a set of basic types in the SweCommon specification[2]. SweCommon lays down the basis for the information model and is used in the service model, too. An example is the *InputDescriptor* that is used by the Sensor Planning Service (see page 46) for defining the parameters for a sensor. The *InputDescriptor* element uses the *DataDefinition* element, which is used also within O&M (see above) for the encoding of observation results.

Service Model

Within the service model the services of the SWE framework are described (see Figure 1). In the following sections we will give a short overview of the SWE services.

Sensor Observation Service

The goal of the Sensor Observation Service (SOS) [11] is to provide access to observations from sensors and sensor systems in a standard way that is consistent for all sensor systems including remote, in-situ, fixed and mobile sensors. SOS leverages the O&M specification (see page 44) for modeling sensor observations and the SensorML specification (see page 44) for modeling sensors and sensor systems (sensor metadata).

An SOS organizes collections of related sensor system observations into Observation Offerings. An *Observation Offering* is also analogous to a 'layer' in Web Map Service because each offering is intended to be a spatially and/or thematically non-overlapping group of related observations.

In contrast to a Web Feature Service the format of documents provided by a SOS can only be O&M and SensorML. SOS implementations are therefore independent of specific user domains and can be used by each SWE compliant client without special previous knowledge.

The specification arranges the SOS operations into several profiles: core profile, transactional profile, enhanced profile and entire profile. The operations of the core profile have to be implemented by each SOS whereas the other profiles are optional. A SOS which supports all operations implements the entire profile. The operations of the core profile form the fundamental functionality of a SOS: identification of available sensor data and filter parameters (*GetCapabilities*) as well as access to sensor data (*GetObservation*) and sensor descriptions (*DescribeSensor*). Operations for the registration of new sensors (*RegisterSensor*) and the insertion of new sensor data (*InsertObservation*) are assigned to the transactional profile. The enhanced profile offers additional operations which provide an efficient mechanism to repeatedly request sensor data (*GetResult*), a

[2] Right now no separate specification exists for SweCommon. The elements available this far are described in the specifications for O&M and SensorML.

detailed description of the FOI associated with a measurement (*GetFeatureOfInterest*) and the time where measurements are available for this FOI (*GetFeatureOfInterest-Time*). In addition, operations for requesting the XML schemata which define the format of the FOIs, observations and the contained measurements (*DescribeFeatureOfInterest*, *DescribeObservationType* and *DescribeResultModel*).

Sensor Alert Service

The Sensor Alert Service (SAS) [12] can be compared with an event notification system (see Figure 2). A *producer* can advertise new event types at the event notification system and afterwards he can publish new events. On the other side, the *consumer* can subscribe at the service for available events. The consumer will be automatically notified once an event that matches his subscription condition occurs. Various event types can be identified, e.g. a single measurement can be considered as an event as well as the exceedance of a threshold defined by the client or a status message from a sensor (e.g. concerning the current battery status).

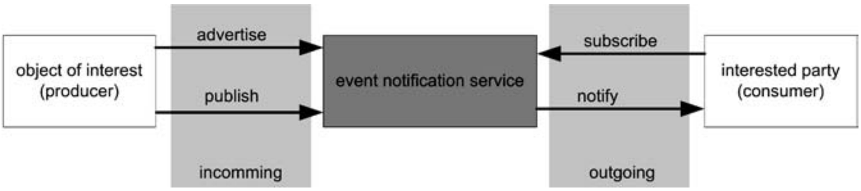

Figure 2. Event notification system.

The SAS specification defines operations only for the management of the event notification service. A messaging server is used for the delivery of notifications to the client. As this service is not part of the SAS specification, the implementation of that service is up to the SAS provider.

Traditional OGC web services are not suitable for implementing this alert service. Instead of regular request/response protocols such as HTTP, the XMPP[3] protocol is used as the standard transport protocol for notifications, but a client may also subscribe to be notified via the Web Notification Service (see below).

Sensor Planning Service

The Sensor Planning Service (SPS) [13] offers a standardized interface for the control of sensors. Therefore the interface contains operations for accessing service metadata (*GetCapabilities*), for retrieving the taskable parameters of a sensor (*DescribeTasking*), for inspecting the feasibility of a task (*GetFeasibility*), for submitting (*Submit*), modifying (*Update*) and cancelling (*Cancel*) tasks. For retieving the current status for a certain task the SPS interface offers the GetStatus operation. Since the time for the completion of the task is not known a priori, the SPS can use the WNS (see page 47) for communicating with the client in asynchronous manner. The storage of the gathered data is out

[3] XMPP = Extensible Messaging and Presence Protocol [18]

of scope of the SPS. In order to enable a client to discover the data gathered in his task, the SPS offers the *DescribeResultAccess* operation.

Web Notification Service

The Web Notification Service (WNS) [14] provides an interface for the asynchronous communication with a user or web service. In general, web services support synchronous communication with a client. Let's assume we submitted a task to the SPS that will last some time for completion (e.g. gathering satellite images). In this case we need a way to be informed that our task was completed. Therefore the WNS can be used.
The WNS supports the transmission of notifications via various transport protocols. Messages can be delivered via HTTP, instant messaging (e.g. XMPP), email, sms, fax and phone. Which protocols a WNS instance supports is given in its Capabilities.
The specification differentiates two communication patterns: one-way- and two-way-notification. A *one-way-notification* represents a simple notification – the caller does not expect an answer from the recipient. This is different for the *two-way-notification*: here the recipient has to create a reply message and send it back to the caller.

Catalogue Service Web

The OGC Catalogue Services for the Web (CSW) Specification [15] defines an abstract model of a service for the management of and the search for metadata. The model consists of the OGC Common Catalogue Query Language and the General Catalogue Interface Model. The former defines a minimal, abstract query language for metadata which has to be supported by all OGC compliant catalogue services. The latter defines interfaces for the management of catalogues, the search for metadata, session handling and the mediation of metadata which cannot be accessed directly. These interfaces can be realised via various protocols[4]. Catalogue Application Profiles (CSW AP) define which protocol has to be used and which interfaces from the General Catalogue Interface Model have to be implemented. A CSW AP thereby extends the model according to the needs of the user domain where it is going to be used[5].
During a search for metadata, catalogues access their own or foreign sets of metadata, access to other CSWs is also possible. This enables a distributed search over several catalogues. OGC catalogues are therefore essential components of the OGC Web Service infrastructure. In the SWE context catalogues enable spatial and temporal searches for measurements and for sensors which measure a certain phenomenon.

A SWE scenario

Imagine the following scenario to illustrate how SWE could help in several use cases, for instance in the field of flood management: Chris works in an environmental agency. His task is to monitor the discharge of a water catchment during a flood event. He has to find answers to questions like the following ones: Which parcels will be affected? What provisions have to be implemented? The answers to these questions are based on real

[4] The specification currently supports CORBA, Z39.50 und HTTP.

[5] Currently there are two CS-W-APs, based upon ebRIM [16] on the one hand and on ISO19115/ ISO19119 [17] on the other hand.

time sensor data and possibly on run-off simulations. In order to improve the decision process one needs the following information:

- Amount of precipitation in the last 5 days (input for a run off simulation model);
- Hydrograph curve of the last month, and of past flood events for visual comparison;
- Actual information concerning the water level and current velocity;
- Real time notification if a certain water level or current velocity threshold value is crossed.

In order to get time series of the precipitation and water level, Chris will use a CS-W in order to find those SOS instances that serve the desired information. Chris sends a GetObservation request to the SOS to access the required observation data; his client feeds the precipitation data into the simulation model and presents the water level information in a nice hydrograph. Its Chris' task to stay tuned about the water level information. In this situation the SOS is not the right service; it would require to poll the information periodically. Thus Chris subscribes for the desired information at the SAS. In the case the subscription condition is met, he gets a notification.
After receiving a notification, that the water level exceeded the public warning level Chris releases a warning and searches for sensors providing stream flow information. Unfortunately, there is no SOS available that serves this information, but Chris found a sensor, which is taskable via a SPS. He checks if the sensor is feasible and defines the task. After the successful submission of the task he receives an SMS from the WNS informing him that the sensor is configured and new data is available. He invokes the *DescribeResultAccess* operation of the SPS in order to get access to the observed data. Chris has luck; he can access the observation via a SAS for the real time access and via a SOS. Thus he is able to access the observations in the future for documentation purposes.

Summary

The standardization of access to sensors and sensor data yields considerable advantages, as shown in the scenario. Based on the interoperability of SWE we are able to 'plug and play' sensors into our systems in order to analyze observations. The SWE framework enables the integration of time-variant information into SDIs. After the long period of evolution and testing it is now the time to start applications based on the SWE 1.0 framework.

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A testbed for SWE technology

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Abstract
This paper details how Sensor Web Enablement (SWE) technology has been exploited in a number of projects financed by the European Space Agency (ESA).

Introduction
In this paper the requirements and approach for the use of Sensor Web Enablement (SWE) technology in a number of ESA projects are presented. SWE technology becomes increasingly relevant as interoperable interfaces and information models and encodings are defined by the Open Geospatial Consortium (OGC) and its members. These items make feasible the incorporation of diverse sensor webs -- connecting devices, such as flood monitors and air pollution monitors -- into infrastructures. The projects presented in this paper have in common that they use the ESA Service Support Environment [1] as the interoperability Testbed.

Scope
This paper concentrates on the use of SWE technology within the following ESA and OGC projects:

- Heterogeneous Missions Accessibility (HMA - ESA);
- HMA-T (HMA Testbed - ESA);
- Web Services Phase 4 (OWS 4) Sensor Web Enablement (SWE Thread - OGC);
- Mission Planning for Constellations and Multi Use (CoMu - ESA);
- Cooperating Earth Observation Sensors (COPS-B - ESA);
- Federated Earth Observation Interoperability Pilot (FEDEO – OGC).

The ESA HMA and CoMu projects are concerned with Earth Observation from satellites and the benefits of SWE technology are investigated as applied to this context. The COPS-B project investigates and demonstrates synergies between earth observation and in situ data, heavily applying SWE technology and in particular the Sensor Planning Service Earth Observation (SPS EO) profile [2] interface derived and proven in HMA, OWS 4 and CoMu. The use of SWE technology within each of the above projects will be further described in this paper.

Interoperability Testbed

The ESA Service Support Environment (SSE) is used as the interoperability platform. It was developed for the Ground Segment Department at ESA-ESRIN and implements an open service-oriented and distributed environment providing a reusable architecture for the integration of services in the Earth Observation (EO) and Geography Information Systems (GIS) domains. The projects described in the following sections introduce enhancements to this infrastructure such as SWE services and clients.

Heterogeneous Missions Accessibility (HMA) and CoMu

The Data Access Layer defined in the HMA project will enable GMES Service Providers to access data from the European EO satellite missions (TerraSAR-X, SPOT, Pleiades, Cosmo-Skymed, ENVISAT, etc.) contributing to the data provision. GMES services will have standardised access through a common interface. The standard interface is defined in the HMA and COMU projects concerning programming of the space-born sensor.

Among the main results of these projects is the Sensor Planning Service Earth Observation profile [2], based on the OGC SPS implementation specification. This specifies the interface and input/output parameters of a Sensor Planning Service (SPS), dedicated to the mission planning or programming interface in an Earth Observation Sensor domain. The proposed document [2] has been approved as an OGC Best Practice.

The profile was implemented in the CoMu prototype which demonstrated the *getFeasibility* and the *submit* operations for optical sensors from ESA and Spot Image satellite missions. Figures 1 and 2 show the client interface to this service as implemented in the SSE Portal. The pseudo-scenes returned by the Sensor Planning Services from ESA and Spot Image are depicted as footprints on a map background.

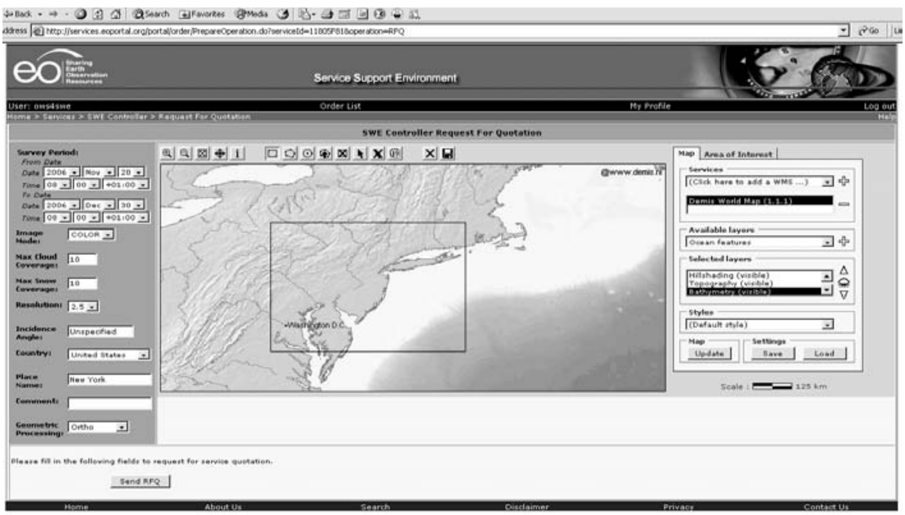

Figure 1. GetFeasibility Request Page.

Figure 2. GetFeasibility Response list of scenes for multi mission (Spot and Envisat).

The user can evaluate information and choose the most feasible scenes to submit his planning to the sensor.

OWS 4

The authors have worked together with ESA on OGC OWS-4 Testbed activities concluding with a demonstration in December 2006. This activity uses the SPS interface deployed at Spot Image as part of the COMU project. This work is fully documented in [7]. The demonstration scenario is shown in Figure 3.

The Business Process Execution Language (BPEL) Engine is used for chaining the SPS and other services into a composite service (SWE Controller) on SSE. The SWE control-

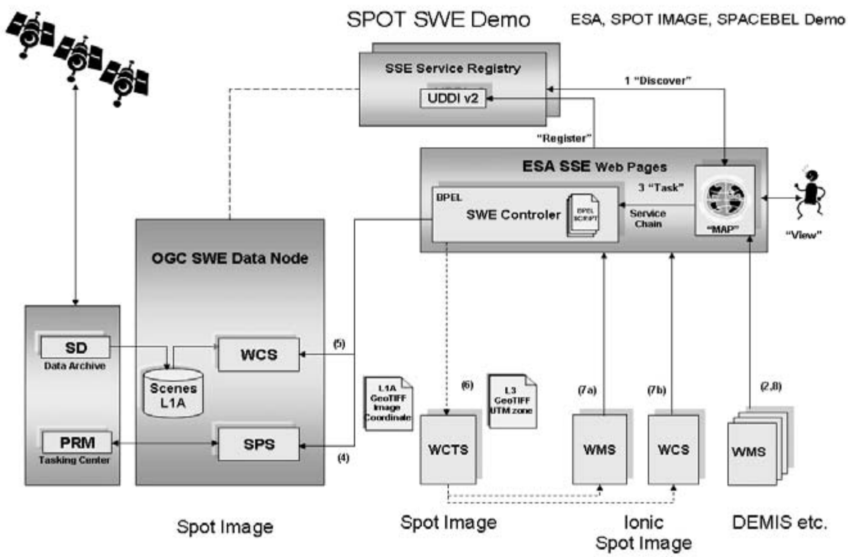

Figure 3. OWS-4 SWE Demo Scenario (see [7]).

ler is accessible via a SPS interface, thus referred to sometimes as a Virtual SPS (Figure 4); the client sees the SWE Controller as a SPS and can access directly to the Spot Image SPS (for raw images) or to the SWE Controller (for ortho images) through the same interface.

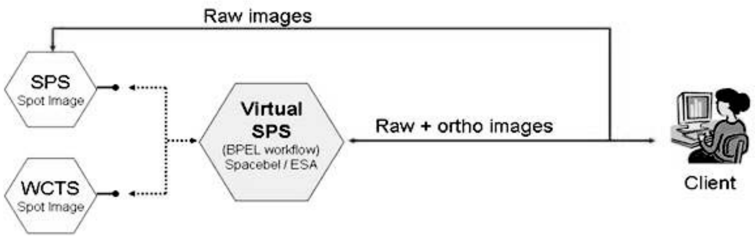

Figure 4. The virtual SPS is a composite service.

WS-Addressing standards were successfully used to implement both asynchronous and synchronous communication. The ESA SSE Portal is used as an SPS client to make requests to the SPS and SWE Controller services (Figure 5).

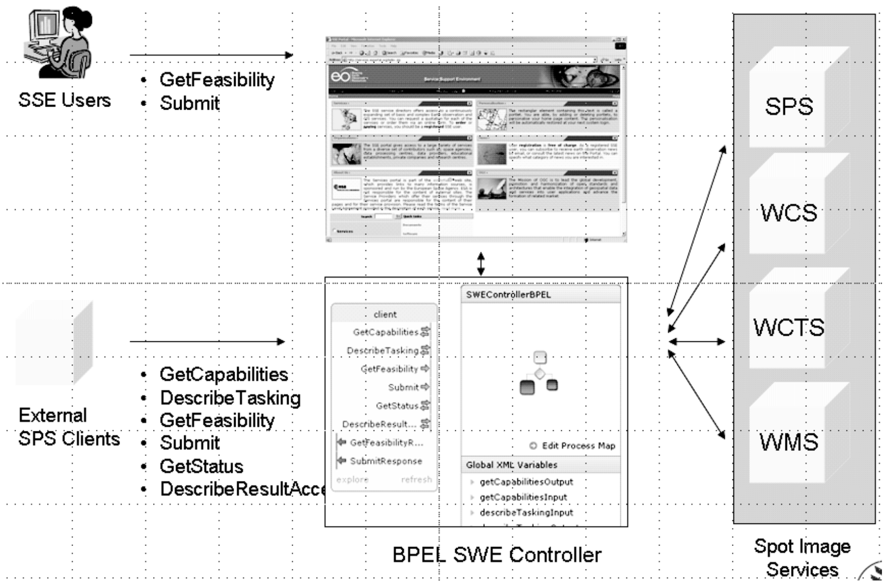

Figure 5. SWE Controller Composite Service Deployment Architecture.

The composite service SWE Controller is made with a set of BPEL processes which are deployed on the SSE BPEL Engine. The SWEControllerBPEL BPEL process works as the access point of the controller. The BPEL process after being deployed on the BPEL engine is a web service and is accessible via the SOAP binding interface.
The SPS was a prototype based on version 0.0.30 of the SPS specification allowing the user to interact with the Spot Image programming system internal to Spot Image's ground segment. For the purposes of the demo the internal system was simulated.

Cooperating Earth Observation Sensors (COPS-B)

COPS-B is an ESA project aimed at exploiting synergies between earth observation and in-situ data enabling the creation of value added services in areas such as pollution monitoring and flood monitoring. A first phase of this project identified the technologies and services that are to be demonstrated in the second phase of the project finishing end 2007. The SSE is used as the integration platform for the following COPS-B services:

- OVL (Operational Forecast Model for Air Quality) Rio;
- Wind and Wave;
- Flood Monitoring / Synthetic Aperture Radar (SAR) Tasking;
- EO supported ground based Topography.

The core of the SSE Portal is the workflow engine which is the component executing the workflows within a Service-Oriented Architecture. It executes business processes based on the Business Process Execution Language for Web Services (BPEL) standard. It is this workflow engine which is used to exercise the interfaces and orchestrate the various COPS-B services.

The COPS-B portal is an evolution and an instantiation of the SSE with an additional Sensor Observation Service (SOS) [5] client and web services notification client conforming to WS-BrokeredNotification [4]. It will deploy the COPS-B demonstration services. This work is currently ongoing.

OVL Rio

PM10 is considered as one of the major air pollutants. This service allows the client to order high quality PM10 concentration maps over Belgium, for forecast, real-time or historic concentrations. The service has been improved in COPS-B through adaptation of the model to take account of Aerosol Optical Depth (AOD) maps derived from EO data (ENVISAT/MERIS level 2B).

The OVL-RIO Service is aimed at producing better PM10 (fine dust) forecast maps for the Belgian territory. IRCEL, the organization responsible for the day by day communication of the ambient air quality in Belgium, currently publishes daily forecasts of PM10 concentrations up to four days in advance. Input into the forecast model are the observations sampled by the real-time telemetric network of the three Belgian regions (Flanders, Walloon and Brussels).

A drawback of the current forecast application OVL is the fact that the output is only valid for given point locations (measurement stations). To obtain full coverage over Belgium with a sufficient spatial resolution, the RIO interpolation technique was developed by VITO that uses a spatial pattern of an explaining variable that is related to the pollutant concentrations for improving the spatial resolution. Aerosol Optical Depth (AOD) is a product derived from EO MERIS data and provides a good explaining variable for PM10. The results of the OVL-RIO service are daily PM10 forecasts maps, with a forecast up to two days in advance. Sensor Observation Services gives access to the raw PM10 sensor data stored in the Air database (IRCEL) and to the forecast PM10

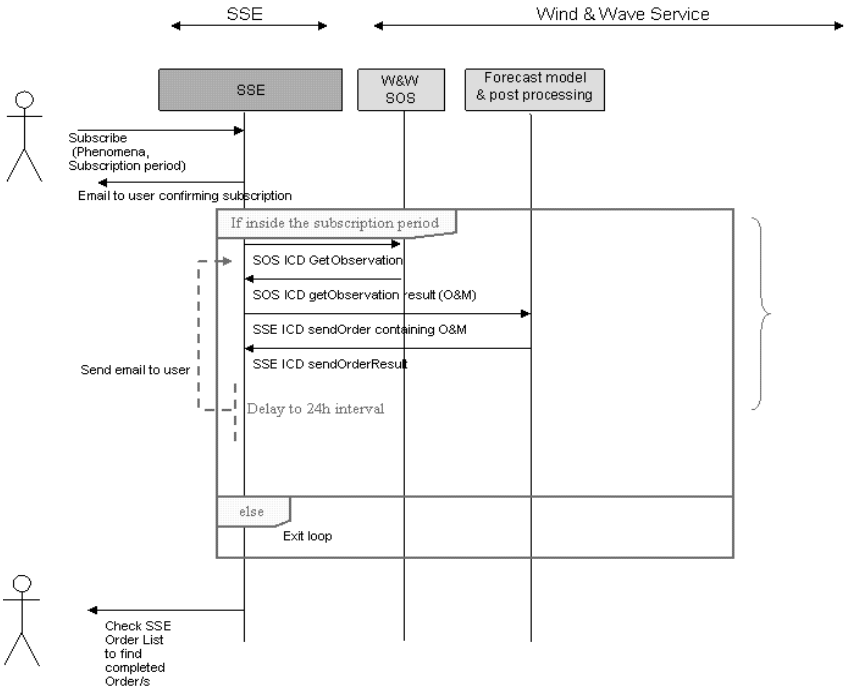

Figure 6. COPS-B Wind and Wave Workflow.

sensor data stored in a new database (IRCEL). The client provides a set of Web pages to capture the various parameters for the request and to display the results.

The RIO-OVL service chain is built using Web Services with Open Standard based interfaces. The following OGC Web Service standards are put to use:

- The in-situ sensor measurements of 25 measurement stations are opened up to the workflow in near-real-time by a Sensor Observation Service that delivers the PM10 measurement values in O&M encoding. This SOS is one of the Web Services that is called from the workflow. In addition this SOS can be interrogated from the SOS client that is integrated within the WebMapViewer of the SSE portal. This OGC Web Service client allows the interactive visualisation of the SOS Features of Interest on a map and the display of graphs and tables of user-defined sets of observations.
- The AOD rasters are delivered to the RIO interpolation service by Web Coverage Services implemented with the Open Source UMN MapServer product.
- The resulting OVL-RIO maps are offered as interactive maps through Web Map Services that are deployed using the Open Source GeoServer product.

Wind and Wave

The objective of the Wind & Wave forecast service is to improve an operational wind and wave forecasting model that is based on a worldwide statistical database of EO measurements by incorporation of in situ measurements and a local wave model.

This service allows the client to order five-day wave and wind forecasts for the near-shore area of the Flemish banks (Belgian Coast). The Wind & Wave Forecast application is an enhancement over the GeoID/Argoss existing wind & wave forecasting services (using EO data and an historical archive) by incorporating in-situ measurements into the forecasting model. A sequence diagram depicting the workflow to orchestrate this service is show in Figure 6.

The in situ sensor network that provides near real time wind and wave information on the Belgian continental shelf is Web Service enabled by the implementation of an SOS service. This SOS service is called from the workflow to obtain the required in-situ measurements, Discrete Time Series Observations in O&M encoding, that are required in the forecasting process. The resulting forecasts are stored in a database that itself is exposed as an SOS service that delivers data in the same O&M encoding and that can hence be queried to compare forecasts of the past with the actual measured wind and wave conditions (Figure 7). The implementations of the SOS services within the COPS-B project are done with the SOS Services developed within the 52° North Open Source Software Project.

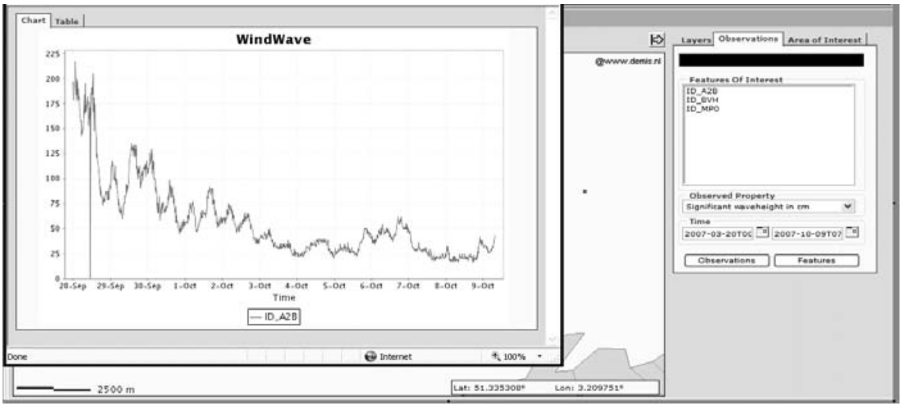

Figure 7. COPS-B Wind and Wave Result presentation in Client.

Flood Monitoring / SAR Tasking

The objective of this service is to reduce the time that is required for acquiring SAR imagery over flooded zones, by implementing a workflow that – triggered by in-situ measurements or a flooding model – starts a complex process that leads to requesting the feasibility for EO imagery acquisition over the effected area. Eventually this workflow could be extended to also include the actual tasking of the satellite.

A user can automatically receive an indication of the possibilities for acquiring a SAR satellite image for a defined area of interest in response to an alert generated by a SensorWeb. For COPS-B the regions of interest are Morecambe Bay in the UK and Flanders (the IJzer Basin)) in Belgium.

The Flood Monitoring service implements two BPEL processes, one dedicated to the flood monitoring service, the other a more generic notification consumer to receive notifications about flooding (Figure 8).

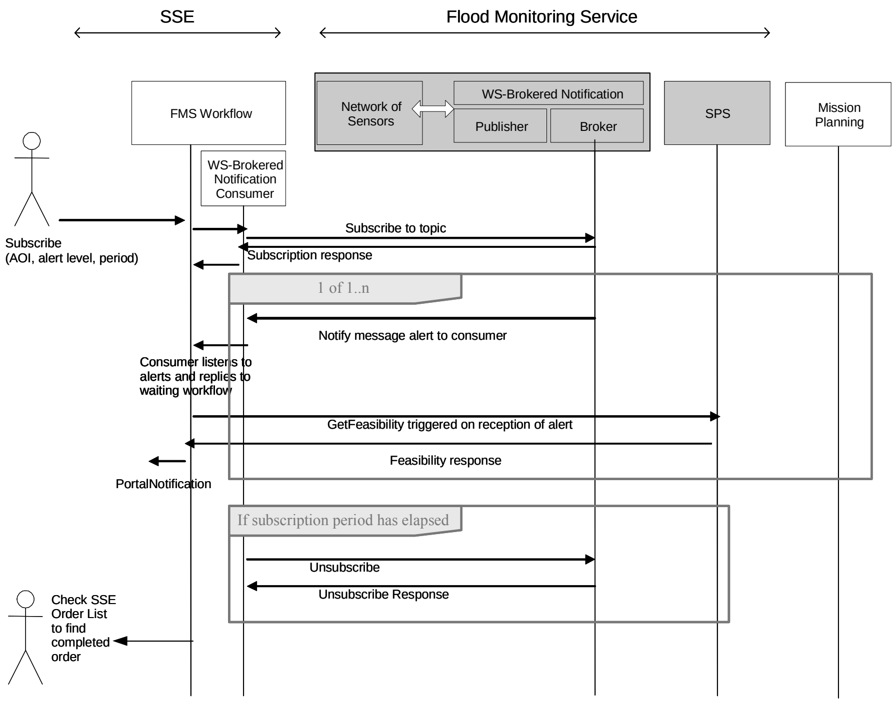

Figure 8. COPS-B Flood Monitoring Service.

WS-Brokered Notification from OASIS [4] was used as the notification standard in preference to the Sensor Alert Service (SAS). This was for a number of reasons:

- It was considered to be a more widely used and mature standard.
- The XMPP protocol used in the SAS implementations available did not fit easily with the BPEL workflow.

The alert levels to which a user subscribes are described by topics in the subscription request. On reception of a notification from the notification broker the listening notification consumer passes the trigger to the flood monitoring workflow which constructs the EO Profile *getFeasibility* [2] request to determine the feasible scenes for the area of interest and the SAR acquisition parameters requested.

Conclusion

The design for the above projects is based on platform neutral standards in order to meet common design objectives of being open, extensible and scalable. In the described projects, we used a large set of the OGC SWE specification, including:

- OGC Observations & Measurements (O&M) – Standard models and XML Schema for encoding observations and measurements [8] from a sensor;
- Sensor Observations Service (SOS) – Standard Web Service interface for requesting, filtering, and retrieving observations and sensor system information;

– Sensor Planning Service (SPS) - Standard web service interface for requesting user-driven acquisitions and observations.

SWE technology and the OGC standards describing the use of that technology are in the main part sufficiently mature in order to make successful implementations. Open Source software conforming to those standards is available and has been demonstrated in the above projects.

The major problem encountered during all of the above projects was missing SOAP bindings for SWE specifications. The provision of SOAP bindings for SWE services will be required for the introduction of authentication.

The work done in the COPS-B project identified a necessary alignment of the Web Notification Services (WNS) with the OASIS notification services.

Future Work

The following areas are expected to be the subject of future work:

– Service ordering beside or in front of the SPS for real satellite tasking;
– Final version of the SPS EO profile to be published and implemented;
– Authentication & security issues;
– On-line compliance test scripts for EO profile of SPS according to the Compliance & Interoperability Testing & Evaluation Initiative (CITE).

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Acknowledgements

The authors are grateful to the colleagues of the HMA, HMA-T, CoMu, OWS4 and COPS-B projects that have provided input to this paper.

Sensor Networks, basis for the Dutch geo-infrastructure

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Abstract
The wish for more recent dynamic maps requires the combination of sensors in the field, with remote observation and forecasting models. The introduction of a new communication protocol for sensor data, accommodating web-based dissemination is studied and evaluated.

Introduction
Maps are usually based on data collected years ago. This has never been a problem for relative stable geographical objects like river-alignments, rail infrastructure or highways, but the modern society increasingly demands near real-time data. Clear examples of continuously changing and updated maps are weather prediction and indications of traffic jams. In case of major threats like flooding or chemical plant disasters, it is necessary to instantly produce maps with threatened areas or evacuation plans.
In day-to-day life farmers need daily updates on the local temperature drop at night or a camping owner needs timely warnings about high wind velocity or potential flooding of the lower lying fields. These use-cases prove the necessity of easily accessible and continuously updated maps, based on high-density data collection.

This paper is organized as follows. First, new trends are identified. Then the expected difficulties and pitfalls are investigated, which provides the outline of a field test. The article closes with the evaluation results and recommendations for the future.

Intelligent Sensors
Sensors are getting more and more versatile. They are becoming smaller and smaller, sending their data continuously into networks. They could even have their own IP-address, so they can receive messages and orders as well. Clever sensors will perform their own processing and include a memory for a small database. They can also send a warning signal in case a threshold is surpassed. It is possible to instruct the sensor remotely to step up the measuring frequency in case of dangerous circumstances.
Actual sensor information is essential to feed prediction models to warn for future high water (Figure 1), for night frost or to start sprinklers for additional irrigation.

Figure 1. Prediction of flooded area.

Democratization of sensor information

Nowadays the common civilian has the possibility to purchase weather stations or other sensors cheaply. If these sensors are connected to the Internet, dense sensor networks may evolve which for instance can be used to follow the downpour of thunderstorms. See for example the American 'WeatherBug' community (http://weather.weatherbug.com/). Here a user-community is formed outside the regular institutes. Farmers connect their weather stations and are able to follow the weather very precisely in their neighbourhood.

Also in the Netherlands there is a strong demand for up-to-date environmental information. After validation, Rijkswaterstaat (the National and Regional Water Authority) places the actual water level and water quality of the large rivers on the Internet. More and more water boards (Local Water Boards) provide their farmers public insight in the

Figure 2. Measurement stations water level and water quality river Rhine.

levels at pumping stations and weirs (Figure 2). Provinces inform their inhabitants about groundwater quality and outdoor swimming water quality.

Infrastructures

We see also a shift towards infrastructure. In the past an expert or an institute was responsible for one phenomenon, put out sensors in the field and had intrinsic knowledge of the apparatus and signals he received. The outcome was presented as a report. Nowadays data are stored in large institutional databases and outsiders are sometimes permitted to have a glance inside these databases. But every database has its own terminology, its own protocols and protection procedures. If data policies become more open, a future could be envisaged where sensors may report directly to the Internet. This will allow many users to access various information sources which might stimulate new applications.

The Open Geospatial Consortium (OGC) foresees such a future, where sensors are always ready to inform the outside world on its existence, location, capabilities, monitoring regime and observed phenomena [1].

The OGC has therefore developed a new set of protocols under the title 'Sensor Web Enablement' (SWE). The most recent one is 'SensorML' for describing the metadata and 'Observations and Measurements' for the data itself [2]. These protocols have been approved in 2007 [3] and this will certainly stimulate the cooperation and development of cooperative use of sensors [4].

Reliability of data

The publication on the Internet of near real-time, not yet quality-checked data requires also a different view on the reliability. Three types of data are distinguishable:

1. Data from historic databases are quality checked and considered reliable.
2. The data coming directly from the sensor in the field cannot be trusted completely as calibration and validation are not yet performed, but they are necessary to have a good idea of the actual situation.
3. Data coming from forecast models may propagate the uncertainty of sensors, but their spatial and temporal coverage typically provide valuable information for decision makers, e.g. to start safety measures or evacuation in case of emergencies.

Improvement of model results

Traditionally, simulation models had to be fed with boundary conditions which originated from point sources, e.g. rainfall gauges; (see Figure 3).

Nowadays, an increasing amount of remotely sensed information (e.g. radar images) is becoming available. In combination with in-situ monitored data from multiple sources (see Figure 4), algorithms can be improved to provide more frequent updates of boundary conditions with high spatial resolution, e.g. rainfall distribution patterns. This increased resolution will improve the reliability of the forecasts conducted by simulation models. While data exchange standards may enhance technological devel-

Figure 3. Rain gauge.

opments, it is essential that data policies on real-time data availability do not hinder such innovation.

Trends

Resuming the following trends are visible:

- Larger presence of sensors in our society;
- Steadily improvement of the intelligence of sensors [5];
- The real-time availability of sensor data on the Internet increases fast;
- The public wants better and actual information on the quality of their environment;
- A general need for more actual and higher density in space and time;
- Access to more diverse input variables to improve the reliability of models.

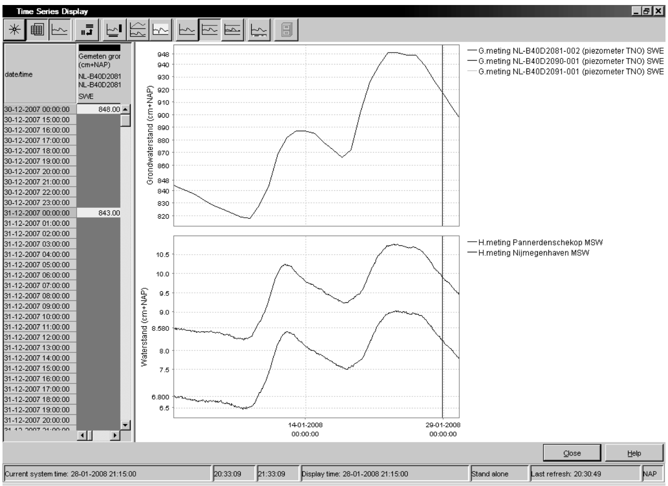

Figure 4. Combined observations of groundwater levels adjacent a river and associated upstream and downstream river levels.

Pitfalls and problems

During a field test to evaluate the Sensor Web Enablement protocol of the OGC (see section 'Project scope'), the following issues and pitfalls were identified. They require careful consideration when deciding on the future adoption of sensor communication protocols.

1. Wireless communication from sensors in the field is only possible with a minimum on energy consumption. This necessitates very tiny sensors, small compact messages for the telemetry and large intervals between the messages. This trend prevents the development of field sensors with more processing power, memory and frequent messaging. Also it opposes the introduction of the new, bulky XML-protocols.
2. Maintenance on sensors is a costly and responsible job. If the data becomes public directly, the relation between maintenance and the institution budget is lost. It becomes difficult to request and allocate a maintenance budget.
3. Full insight in raw data may easily lead to misinterpretation or even to unfounded public scandals in newspaper. For example, wrong interpretations may mislead evacuation procedures during disasters. Many authorities are therefore careful to put data directly on the Internet, without internal evaluation and interpretation.
4. Generic formulated protocols, such as the SWE-protocol, as formulated by the OGC, may have the advantage of wide application opportunities. However for automated data processing especially in forecasting systems, its generic nature necessitates the development of additional domain specific profiles, to enable proper interpretation of the messages communicated.

Project organization

'Space for Geo-Information', a governmental initiative in the Netherlands, supports the new standardization developments. A consortium of major scientific institutes and sensor suppliers is now exploring the new OGC SWE-protocols and testing the advantages and disadvantages. The partners are:

- TNO B&O Built Environment and Geosciences, research for groundwater and geology;
- Alterra, responsible for studies on agricultural and environmental data;
- WU, Wageningen University, is concentrating on Remote Sensing in the framework of this project;
- KNMI, acquiring, processing and predicting meteorological data;
- GeoDelft, especially interested in geo-mechanical sensors;
- Eijkelkamp, supplier of sensors for water, weather and environment;
- KPN, developing a new market for communication with sensors;
- LOFAR, The astronomical and geophysical network for the Netherlands;
- Rivierenland, local waterboard, the water authority mostly confronted with potential river flooding and droughts;
- Deltares - Delft Hydraulics, expert on real-time data collection for operational flow forecasting systems;

Figure 5. Layer with weather stations, rain gauges and webcam sensors.

– The University of Münster, in special the IFGI, gives special support in developing the SWE services.

Project scope

The project focuses on a polder in the Betuwe, named 'Gendtse Waard'. In this polder the water management is measured in all aspects. Sensors are placed for groundwater, soil-humidity, surface water level, dike measurement and all meteorological data (see Figure 5). Next to that, the river water data, received from 'Rijkswaterstaat', is used to feed prediction models. Also environmental data are accessible, but will not be converted in this project. It is the intention that in the end of this project the partner insti-

Figure 6 - Location of groundwater level measurements in study area.

tutes are able to provide a better support to all users like waterboards, municipalities, farmers and local inhabitants.
The information layers with actual data may seamlessly integrate in existing GIS-systems with administrative layers, project boundaries, traffic infrastructure and other static information.
Presently a prototype in Google Earth is available (Figure 6). This prototype portrays the installed sensors with their actual data.

However the publication of data remains the responsibility of each organization and is not a responsibility of this project.

Suggested applications of sensor networks

Agricultural models for growth prediction can receive data from sun-radiation, local rain showers, atmospheric humidity, soil humidity, remote sensing and other parameters to improve the detailed local support to farmers. Flood prediction may be improved by more detailed precipitation data of the upstream surface and the absorption capacity of the soil. Advanced groundwater models can be fed with actual data to provide a spatial overview of groundwater levels and the prediction of future change. A dense net of groundwater sensors in and behind dikes to monitor the water pressure, in order to detect and predict: seepage, upwelling of water behind the dike (see Figure 7), or even an impending collapse.
Networks with intelligent sensors may independently warn control rooms or officials at home for dangerous levels of variables, then increase themselves the measurement frequency and send data every 15 minutes, instead of forwarding a daily summary. Several of these applications are now tested by the partners.

Figure 7. Riverdike in the Betuwe area.

Conclusion

An improved spatial and temporal coverage of sensor networks is increasingly becoming valuable for society. Although both authorities and public appreciate up-to-date information, the former are hesitant to open their real-time data collection networks as the data interpretation step is considered crucial before releasing the data into society. While technology is progressing to facilitate direct availability of sensor data on the Internet, the real challenge is in the data policy, where many institutes and civilians measure and may share data with each other to reach better, localized predictions and more insight in the environment.

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Research topics for the Sensor Web

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Abstract
It is necessary to gain more experience with SWE in practice and perform further applied research before one can exploit the concept to its full extent. That is the main conclusion of seminar discussions as well as of a general reconnaissance of the potential of SWE for water management in the Netherlands. The discussion touched upon issues like the value of metadata in the interpretation of raw data, the scalability, the ownership and the distribution of costs. The reconnaissance dealt with topics like the meaning of SWE for measurement requirements on short and long term, maintenance and innovation of sensor networks, guiding of operational and incidental processes, controllability and measurement results, and finally the level of costs of SWE in comparison with traditional solutions. Although these are all serious issues, the potential of SWE was estimated very high.

Introduction
Little experience has been gained with operational use of SWE as part of spatial data infrastructures. There is a need for more applied research and development regarding the actual use of SWE. This was the conclusion of a lively discussion during the seminar 'Sensor Web Enablement' of the Netherlands Geodetic Commission (NCG) the 1st of February 2007 in Utrecht.

Seminar discussion topics
– When SWE is generally used and sensors are exploited by more than only the initiating organization, the owner, how is data transformed to information? Is the concept of metadata such a powerful aid that data always can be interpreted well and is that possible from any domain?
– What happens if suddenly a sensor or part of the sensor network gets requests from all over the area e.g. as consequence of a calamity? This scalability issue is seen a problem area that requires still quite some research. The same type of questions arise for cases where large data volumes have to flow through the network would many sensors in an area simultaneously be put on high frequency schedule.
– Application of SWE raises the question if in future sensors belong to either the public or the private domain. Those authorities that from the character of their primary task install sensors and that have to make data accessible according to INSPIRE might

do so as well directly from the sensor to the public. However, also companies and institutes can from their objectives or duties and private persons from their interests make sensors available on the Internet, 'sensor casting', e.g. weather stations. Connected questions are, at one side whether a kind of core sensor network owned by the authorities, only needing expansion for special cases is desirable or, the other side, whether installing and maintaining sensor networks and offering them as SWE services can be expected from the private sector

– Following questions about the costs and distribution of costs, it was remarked that billing mechanisms are available on Internet. More important is the notion that in a public sensor network costs and benefits do not necessarily fall with the same stakeholders. So, what is needed here is not so much technological solutions as for billing as well a business model in which costs and benefits are properly distributed. For many authorities this touches the discussion about what part of the costs of geo-information may be billed to users. The statement that costs billed have to bear a reasonable relation to the added value the data have for the user, does not seam to offer a solution, as that could lead to negotiations for each data request. Although, with intelligent agents coming soon ...

A closing remark of one of the participants was that the point of view to be taken from the application side is the most desirable. From there it can be determined what way is the most beneficial for incorporation of SWE in the various business processes. Certainly an issue that needs further thought at coming seminars and demonstration projects.

Reconnaissance by RWS and TNO of the potential of SWE for the water management observation networks

With RWS, the national water management authority of the Netherlands, the introduction to SWE gave rise to take SWE in consideration as a powerful option for the modernization of the water monitoring system. It was subject of a brainstorming between representatives of RWS and TNO in May 2007. The tens of questions and suggestions the ones most important in the light of SWE have been categorized in 5 groups described and commented upon below.

Measurement requirements on the short and long run

Measurement needs on the long run should be derived form the operational and strategic planning of an organization. Uncertainty in these needs in case SWE is the leading principal in the design of the networks, can simply be taken care of by e.g. adapting the sensors' observation schedule or, if that does not offer sufficient extra capability, by adding sensors to the network. The latter can be done without having to change the other parts of the infrastructure.

Once networks are installed, on the short run, one can accommodate ad hoc measurement requests thanks to the direct control one has over the sensors. Ad hoc request can be generated as well manually e.g. through a GIS interface as under full software control by offering different settings for the planning of the observation processes.

Maintenance and innovation of sensor networks

By modularization and separation of concerns that are introduced by SWE into sensor networks, it is possible to replace components without any influence of the results. This holds for the sensors and the communication network. If a sensor is replaced by one with more capabilities, this is reflected by the metadata of its services so the user can take account of it immediately.

Guiding of operational and incidental processes

Here SWE can facilitate needs to a high degree. Only where absolute real-time availability of sensor data is requested, SWE may not perform well enough. On the other end, SWE does offer a high degree of flexibility, also as part of automated processes e.g. in warning system in which alternative sensors are looked for by the software. Stated more generally: when demand is put on the aspect of 'real-time', SWE on public networks can not always meet the demand. For the rest SWE can be very well put to work for the guidance of operational processes and the dealing with incidents.

Dynamic environments and places difficult to access

Here is valid what holds for sensors in general, it stays hard. However, also here SWE can have additional value over traditional solutions. On hard to access places it is all the more important that sensors are put to work selectively, have low energy use and that the sensor condition can be determined from a distance. SWE offers facilities to those demands by way of all the control options e.g. by the possibilities to program master-slave relations so that the 'slave' only is activated once the control program determines it necessary on the basis of the observations of one more 'masters'. Also in very dynamic environments, for example in coastal flats like the Waddenzee in the North of the Netherlands, where space and time aspects of systems and processes continuously change, the observation schedule of the sensor network can be adapted to also continuously optimize the observations of systems and processes.

Controllability and measurement results

From the brainstorm it appeared that a need exists for controllability of the monitoring frequency. That is only one of the obvious advantages of SWE. Individual measurements are initiated by the 'Sensor Planning Service'. That means one has control over the measurement frequency as far as offered by the sensor and at the low end even more. Regarding the measurement results one also has more control because with SWE one can request for the sensor's condition, one can request additional measurements to be done by the same sensor or by different sensors in the area, etc. An alert can be generated the moment a sensor gets into a condition it is not reliable any more so one has maximum time to take corrective measures.

An important advantage of SWE is the uniform way in which the data capturing and processing chain can be organized. This makes management of monitoring programs easier to master and in that way increases the quality and availability of observations from sensor networks.

What does it cost?

Of course many questions and even scepticism exists with respect to the costs of large scale application of SWE. Hardly any experience is available on that aspect. The only statements that can be made now are that also other large scale solutions are costly and that SWE offers a tremendous lot of advantages in the way of flexibility, modularity, controllability an uniformity of the capturing and processing chain over other alternative approaches, not to mention seamless integration in spatial data infrastructures. This is advantageous for an organization like RWS that has to operate properly on the short run but in an adaptable way seeing the changing environment it has to control or to take account of, also on the long run. High value for money can be expected.

The risk that mega investments are done in inflexible systems that eventually do not live up to expectations is much smaller than in a situation of diverse co-existing sensor networks each developed for one purpose only. In those cases one had to go through a learning cycle for each subsystem separately before and after the installation. With SWE one has one concept to master. Small but expensive material adaptations will occur much less thanks to the flexibility inherent to the SWE concept. If, for whatever reason one has to replace modules of the sensor network one does not have to alter the entire system or ones mode of operation.

Closing remark

SWE has the potential to gain significance by assuring 'accessibility' and 'controllability' of dynamic geo-information through Internet in the context of Spatial Data Infrastructures. Integration of dynamic geo-information, acquired by sensors with static geo-information is enabled by the framework of international geographical and web services standards. In that context the SWE standards have also found a place in the 'Framework of geo standards for the Netherlands' (www.geonovum.nl).

Nevertheless still a lot of development and experience is needed before the SWE concept can be exploited to its full extent. SWE is not a new trick to measure something. Still domain and sensor experts are needed to determine what should be observed and how. SWE opens up a new world in which measurements of all kinds are brought under the common denominator of the spatial data infrastructures. The value of turning sensors and sensor information into a new dimension of geo-information infrastructure cannot be overestimated.

About the authors

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Euro Beinat has an extensive experience in consulting and management. He combines a strong academic curriculum with knowledge of the IT industry and of the natural resources sector. As a recognized expert in these fields, he advises public and private organizations on emerging technologies – such as RFID, location services or pervasive computing – from an operational and a strategic long-term perspective. He is a skilled decision analyst and facilitator, able to position innovative technologies within the business and culture of organizations and their evolution. He is a regular speaker at conferences and events and maintains a strong affiliation to academia and research. At present Euro Beinat is:

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Yves Coene currently works for SpaceBel SA in Brussels as Business Unit Manager. He has 15 years of experience in aerospace software projects such as Ariane 5, the International Space Station, F16 MLU, and various other projects for the European Space Agency. Since 2001, he and his team have been responsible for the SSE project for ESA in Frascati, Italy. Yves is also member of the OGC TC.

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Since 2001, Didier Giacobbo has been working at the Direction of Sales and Marketing at Spot Image, as an Engineer in charge of the development of new products and as project manager. He has been in charge of the technical support of the DIMAP format developed by Spot Image. He is currently managing several projects with international and national institutions (ESA, European Commission, CNES). He is involved in several project with ESA (HMA, CoMu, NSI). He is the business representative at OGC and mainly he is involved on the Interoperability Program. Moreover he was nominated as

expert level in the liaison group with ISO TC 211 for imagery and metadata domain. He was involved on the pass OWS3 Testbed and testbed OWS4. He has a MSc's degree in Remote Sensing from Paris VI university. From 1995 to 2001 Didier Giacobbo was head of training department of GDTA (Groupement pour le Développement de la Télédetection Aérospatiale) and was in charge of the coordination and organisation of Remote Sensing and GIS activities and of the energization of products supply development at scientific and technical level. His main skills are space-mapping, urban planning and Remote Sensing and Geographic Information Systems.

Peter Gijsbers

Mr. Gijsbers graduate as civil engineer (Delft University of Technology), in hydrology, operational water management and integrated water resource management. Research conducted on decision support systems for water allocation in international river basins during periods of low flows resulted in a PhD degree. Dr. Gijsbers joined WL | Delft Hydraulics in 1999 and contributed as a modeller to various integrated river basin management projects. Since 2002, Dr. Gijsbers is an active participant in wide variety of EU-research projects, amongst others HarmonIT, HarmoniCOP, HarmoniQuA, BMW, Aquastress, Scenes and OpenMI-Life. Dr. Gijsbers has been leading various software development projects, amongst others the architectural design of the OpenMI, a standardized protocol for model linking which is shared and applied among a range of key players in the water software domain. He is a founding father of the OpenMI Association, a body responsible for the sustainable future of OpenMI. As Deltares representative, Mr. Gijsbers is treasurer in the OpenMI Association Executive Committee. In 2005, Dr. Gijsbers took the lead in the National Groundwater Modelling System-project for the Environment Agency of England and Wales, aiming at a centralized modelling system to conduct scenario analysis using large regional groundwater models. After a positive advice on the feasibility of DelftFEWS as the IT-backbone, While DelftFEWS is designed as a software system for real time data collection and operational forecasting, Dr. Gijsbers turned this client-server technology into a suitable application concept for groundwater modelling which is implemented by a team of Deltares - Delft Hydraulics in co-operation with UK groundwater consultants. Within the BSIK project on Sensors as data sources, Dr. Gijsbers combined his experiences of IT-standards with state-of-the art technology in real-time operational systems.

Michel Grothe

Michel Grothe has a Doctors (PhD) degree in Spatial Computer Science, Department of Regional Economics, Free University Amsterdam. From 1988 until 2001 he worked in different positions as GIS-developer, researcher, lecturer and consultant in government, university and the private sector. Since 2001 he is senior consultant and projectmanager Geo-ICT at the Data and ICT Department, Ministry of Transport, Public Works and Water management in the Netherlands. He worked the last years on the development and implementation of the Geo Data Infrastructure (GDI) of Rijkswaterstaat and the Enterprise Architecture of Rijkswaterstaat.

Since 2007 he has also joined Geonovum, the Dutch organisation for the development of the national Spatial Data Infrastructure, where he is working on the national geoportal.
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Henk Hakkesteegt (1962) received his MSc degree at the Technical University Delft in 1987 in electrical engineering. From 1984 until 1990 he worked as a consultant in the area of operational management of information systems for Pink Elephant. From 1990 he is within TNO Institute of Applied Physics (TPD), now TNO Science and Industry, Business Unit Monitoring Systems. He served as the project manager for the design of various electronic instruments often including embedded software. Currently as a senior systems engineer he is responsible for the technical result in complex multidisciplinary technical projects.

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Caroline Heylen is managing director and chief technical officer of GIM nv. She has over 15 year of experience working with EO and geographic information, in data management, spatial analysis and software development. She has headed projects for international organisations such as the European Space Agency, NATO and the European Commission. Currently she focuses on building Spatial Data Infrastructures and interoperability, using open geospatial standards.

Jan Jellema
Jan Jellema (1948) started his academic education at a Technical Academy with a degree in applied civil engineering. Hereafter he completed a study as Civil Engineer at the Technical University in Delft, with a specialisation in environmental and sanitary engineering. During the study he worked at the Ministry of Public works, Traffic Dep. and the Hydraulic Laboratory of Delft (DeltaWorks). From 1976 till 1986 he was responsible as project-leader for the design and installation of large urban drinking water systems in South-east Asia.
From 1986 he specialised on the IT-aspects of environmental and civil engineering, and was subsequently responsible for the IT-section at the Spatial Planning Department of the Ministry of Housing, and the IT department of the Geological Survey of the Netherlands. Since the merger of the latter institute into TNO-NITG a specialisation is taken up as advisor for new technologies, in special: geo-knowledge systems, XML and SVG. He participated in large European projects on harmonisation of metadata, user-interfaces and meta-data (GEIXS and eEarth). In his career he developed a broad knowledge of international terminology on geology, hydrology, civil engineering and environment. Therefore he is responsible for the official Multi-lingual Thesaurus for the geo-sciences and participates in several international standardisation groups.

Jan Kooijman

Jan Kooijman: MsC in Irrigation and Drainage and control theory. Joined TNO in 1978. Consecutive assignments as head of departments for ground water monitoring, mapping and research and marketing manager for in situ soil remediation research. From 1997 till 2007 team leader of a group of 20 ICT developers. In that period the most important task was to develop the information system for Data and Information of the Netherlands' Subsurface (DINO) for the Geological Survey in the Netherlands. From 2005 onward he was heavily involved in the Space for Geo-Information Program, a state financed program to improve the national spatial data infrastructure (SDI). He initiated a project under this program to integrate web enabled sensors in the SDI. At present he is strategic advisor Geo-ICT for the development of DINO with special attention to positioning it in the SDI. His special interests are in efficient data collection and optimal accessibility of data, information and knowledge for a wide variety of user groups.

Philippe Merigot

Philippe Merigot joined Spot Image in 2003 as a software architect. He worked on several projects related to R&D in ISO / OGC standardizations and Web Services for image handling over the Internet. He participated to the OGC testbed OWS-2 by providing a WCS (Web Coverage Service) and a tool for automatic conversion from DIMAP to iso19139 format. He participated to the GMLJP2 (GML in JPEG 2000 for Geographic Imagery) and OWS-3 testbeds by developing an asynchronous WCTS (Web Coordinate Transform Service, linked with a Web Notification Service). Editor of the Sensor Planning Service for Earth Observation profile (SPS EO) specification, he developed a SPS EO for the OWS-4/5 testbed.
Graduated in computer science in 1995 he has worked for 4 years as a project manager in software development before joining Spot Image.

Zoltan Papp

Zoltan Papp received his MSc and doctoral degree at Technical University Budapest, Hungary in 1978 and 1982, respectively, all in electrical engineering. Until 1991 he served as a faculty member at the Department of Measurement and Instrument Engineering of Technical University of Budapest, Hungary. From 1991 he is with TNO Institute of Applied Physics (TPD), now TNO Science and Industry, Business Unit Monitoring Systems.
On leave from TNO he spent two semesters as visiting professor at Vanderbilt University, School of Engineering in the USA covering real-time programming for model-based distributed systems. His professional interest covers model-based signal processing and control, distributed real-time systems, multi-agent systems and sensor networks.
During the recent years he was involved in projects as system architect and/or project leader covering applications like training simulator for see port logistics, space robot arm path planning, real-time simulator for multi-agent systems, control of intelligent transportation systems and wireless sensor network based corrosion monitoring.

Rowena Smilie
Rowena Smillie currently works as a Project Manager for SpaceBel SA in Brussels. She has more than 15 years of experience in mainly in aerospace software projects for the European Space Agency. Most recently she has been involved in the SSE platform and Heterogeneous Missions Accessibility projects for ESA in Frascati, Italy.

Steven Smolders
Steven Smolders works as GeoICT Project Manager for GIM nv. He has 10 years of experience in designing and project managing complex GeoSpatial software systems.
He is responsible for a number of projects that are built with SOA architectures and Open Standards. He is GIMs project manager on the SSE project for the European Space Agency.

John Steenbruggen
John Steenbruggen received his MSc degree at the Technical University Eindhoven Delft in innovation Management on information and communication technology. He also graduate at the Hogeschool Utrecht (bachelors degree) on Geodesie and Geo-information technology. At this moment he finalizes his Doctors (PhD) degree in Spatial Computer Science, Department of Regional Economics, Free University Amsterdam on context-aware information systems.
Form 1988 till 1993 he worked in the private sector for ingenieursbureau 'Oranjewoud' in the field of Geo-information technology. Since 1993 he is senior consultant Geo-ICT at the Data and ICT Department, Ministry of Transport, Public Works and Water management in the Netherlands. He worked the last years on the development and implementation of mobile location aware information solutions within the Ministry. He also is responsible for organising international conferences on this subject.

Alexander C. Walkowski
Mr. Alexander C. Walkowski holds a degree in Geography, with minor subject in Geoinformatics, from the University of Münster (Germany). Since 2005, he is research associate in the working group of Prof. Dr. Ulrich Streit at the Institute for Geoinformatics of the University of Münster. He has broad experience in the design and specification of interoperable Geoinformation Services, the general concepts behind Spatial Data Infrastructures (SDI) and especially in the context of Sensor Web Enablement (SWE). He was involved in Sensor Web Enablement thread of the OGC Open Web Service Testbed phase 3 and phase 4. In the open source software initiative 52°North he is leading the development of the Sensor Observation Service within the SWE community. In his dissertation he works on an approach for the model based optimization of mobile geosensornetworks for spatio-temporal phenomena.