

A Testbed for Sensor Service Networks and the Fusion SOS: towards plug & measure in sensor networks for environmental monitoring with OGC standards

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Abstract:

Fraunhofer IITB has realized a testbed for sensors and services in order to trial the architecture and specifications developed in the EU Project SANY (Sensors Anywhere) based on going work of OGC (in particular the Sensor Web Enablement suite of standards). At the sensor network level, an ad hoc wireless network (ZigBee) is complemented by simulated sensor nodes. The nodes measure properties such as temperature, humidity, luminance and acceleration. The testbed is designed for experiments in a wide range of scenarios, such as mobile sensors traversing several networks, and in scalability.

The simulation is implemented as an application in the product LabVIEW (National Instruments) which has the dual task of configuring the ZigBee nodes. New sensor nodes (either real or simulated) are recognized automatically and registered in one of 3 OGC Sensor Observation Servers (SOS). The sensor values are then inserted into a SOS as they arise by measurement or simulation. The available network resources (observed features, sensors, services) are registered in a catalogue server along with meta-data to support resource discovery by client applications. Clients can find, for example, information sources for a given region and observable phenomenon of interest.

Fraunhofer IITB has realized a special SOS in the testbed, called a Fusion SOS. An OGC Sensor Planning Service (SPS) parameterizes and tasks the Fusion SOS to aggregate or fuse sensor data from several SOS. The fusion task queries the catalogue for available SOS of the required type and then conducts a selected procedure to produce a spatial or spatial-temporal interpolation. The interpolation result is a so-called coverage, a function defined on a space-time grid of sampling points. The procedure takes the inaccuracy of the raw sensor data into account. The spatial-temporal uncertainty of the fusion result is specified using uncertML, an XML schema developed by the INTAMAP project to describe the statistics of uncertain data. The fusion procedure is described, just as for the underlying sensors, with the OGC sensor model language SensorML. In this way, the fusion procedure can be treated as a sensor, but with the important characteristic that its result is a coverage. The coverage can be visualized using a Map & Diagram service of the SANY partner ETH Zürich.

The procedures developed to date are variants of the Bayesian Maximum Entropy method that is able to consider soft sensor data (e.g. the sensor value lies in an interval) and additional phenomenological knowledge in the form of models. If additional sensors or SOS enter the testbed, the Fusion SOS discovers these new resources with the aid of the catalogue and incorporates the new data sources automatically into the fusion procedure. The self-describing information plays an essential role in this plug & measure capability.

The Fusion SOS is implemented on the platform WebGenesis, an information management server of Fraunhofer IITB. The information management server has the information categories features of interest (sampling grids), procedures and results with associated meta-data to support searching. All intermediate files produced by the fusion procedure are uploaded together with the fusion result to the WebGenesis information management server. This ensures a reproducible trace of the processing steps.

Keywords: *Ad-hoc sensor network, fusion, OGC web services, Data Observation, Properties*

1. INTRODUCTION

Service oriented architectures (SOA) based on standards are becoming more important for the design of environmental information systems (Usländer, 2008) and systems to protect critical infrastructures (Watson et al, 2008). Relevant standards for web services and information models are being defined in the organisations Open Geospatial Consortium (OGC), ISO, OASIS and W3C. In parallel, increasing research effort in the field of sensor networks, for example in (Werner-Allen et al, 2005; Dyer et al, 2007), has made sensors and sensor networks more and more suitable for practical use. Likewise sensors and sensor networks are opening up new opportunities in environmental monitoring and infrastructure protection. These developments need to be supported by the establishment of best practices for the design and use of sensor and service networks. Aspects of robustness of sensor networks for the above application areas are considered for example in (Schimak et al, 2008). Several research projects such as the European project SANY (Sensors Anywhere) described in section 3 below are currently addressing these issues.

Fraunhofer has realized a sensor service testbed within SANY in order to experiment with various OGC services in an environmental monitoring application requiring a spatial/temporal data coverage calculated from point sensor measurements. The OGC information models Sensor Model Language (Botts, 2005) and Observation & Measurement Model (Cox, 2007) are generic specifications for which application specific usage guidelines (profiles) are required.

The testbed also acts as an experimental platform for algorithms to fuse or process sensor data. The algorithms have to be able to handle spatial/temporal gaps and overlaps in the sensor data. These scenarios arise when deploying several or even many sensors, possibly mobile and possibly of limited operation time or with unreliable communication links.

2. SENSOR SERVICE TESTBED

2.1. Overview

The functional architecture of the Fraunhofer testbed is shown in Figure 1. It uses two key services of the OGC in the area of Sensor Web Enablement (Botts et al, 2006): the Sensor Observation Service (SOS) and the Sensor Planning Service (SPS, Simonis, 2007). The related information models are the Sensor Model Language (SensorML, Botts, 2005) and the Observation & Measurement Model (Cox, 2007).

The Fraunhofer testbed offers three SOS servers delivering data into a Fusion SOS Server. One SOS server contains data originating from real sensors, whereas the other 2 SOS servers handle data generated by a sensor simulator. The testbed simulation facility allows experiments with many sensors of different types including tests with sensor data that is not uniformly distributed in space or time. Such data can arise from sensors with intermittent availability or from moving sensors. The Fusion SOS Server generates its observations as spatio-temporal coverages using a fusion algorithm that is parameterized and tasked by a Sensor Planning Service (SPS). The fusion algorithms aim to fill the spatio-temporal gaps by computing intermediate values with an associated uncertainty depending on the quality of the input data. A Semantic Catalogue contains meta-information on all available sensors, services and observations. Client applications such as a Web Map Service can access the Fusion SOS to display the fusion results as a layer on a map, for example.

Table 1. Sensors with ZigBee

The testbed functionality is explained in more detail below using a bottom-up approach from the sensor network.

2.2. Sensor Network

The real sensor network comprises a number of ZigBee nodes with sensor types as shown in Table 1. A node may carry sensors for several phenomena (observed properties). These nodes form an ad-hoc multi-hop wireless network in which all nodes communicate with a controller node. Each node must be assigned a unique ID before it enters the ad-hoc network. The controller node is connected via USB to a management PC running the Labview engineering environment of National Instruments. An application

Sensor type	Observed Properties (Units)
MTS310 (Crossbow) Wireless ZigBee sensor node with fixed location	-Temperature (C) -Illuminance (%)
MTS400 (Crossbow) Wireless ZigBee sensor node with fixed location	-Temperature (C) -Humidity (%) -Air Pressure (mbar) -Motion detection X-axis Acceleration (mg) -Motion detection Y-axis Acceleration (mg) -Illuminance (lux)
MTS420 (Crossbow) Mobile wireless ZigBee sensor node	same as MTS400 and in addition the sensor location via GPS on board (deg latitude, deg longitude)

in the Labview environment configures the sensor network and sets the measurement frequency. The observation procedure of a node measures a set of properties in parallel with a minimum frequency of 1/7 Hz.

This Labview application detects all available and new sensor nodes in the ad hoc sensor network. Each node and its type are automatically identified by its unique node ID. The observed properties delivered by all sensor nodes are processed and archived, and can be listed and displayed graphically. The sensor nodes used are not capable of processing the observed properties inside the sensor node. The application developed on the management PC allows pre-processing or filtering of the observed properties. For example, as illustrated in Figure 2, the light intensity is only registered in the right observation list and diagram if a predefined alarm threshold value has been exceeded.

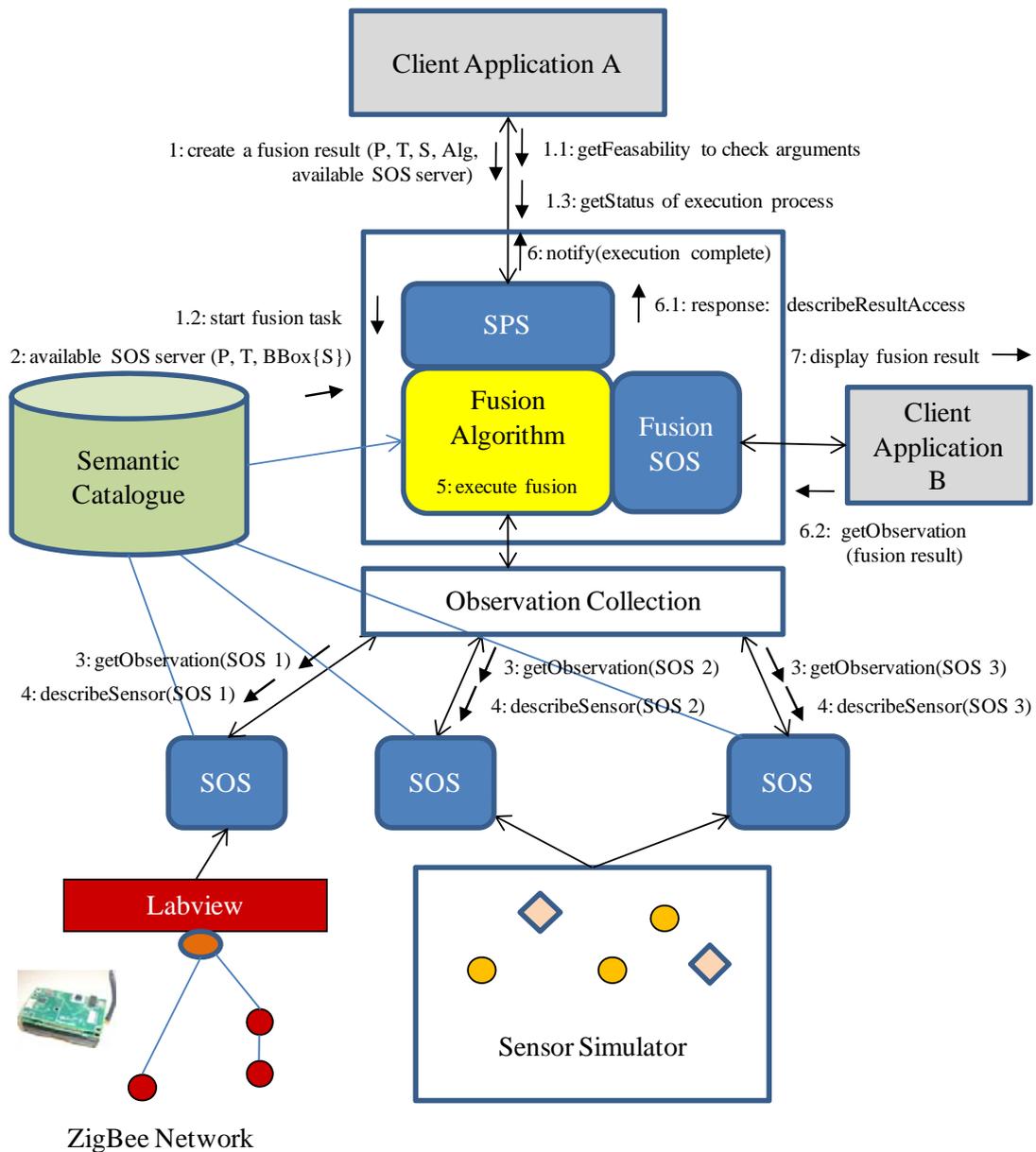


Figure 1: Schematic architecture of the testbed (detailed explanation in 2.5)

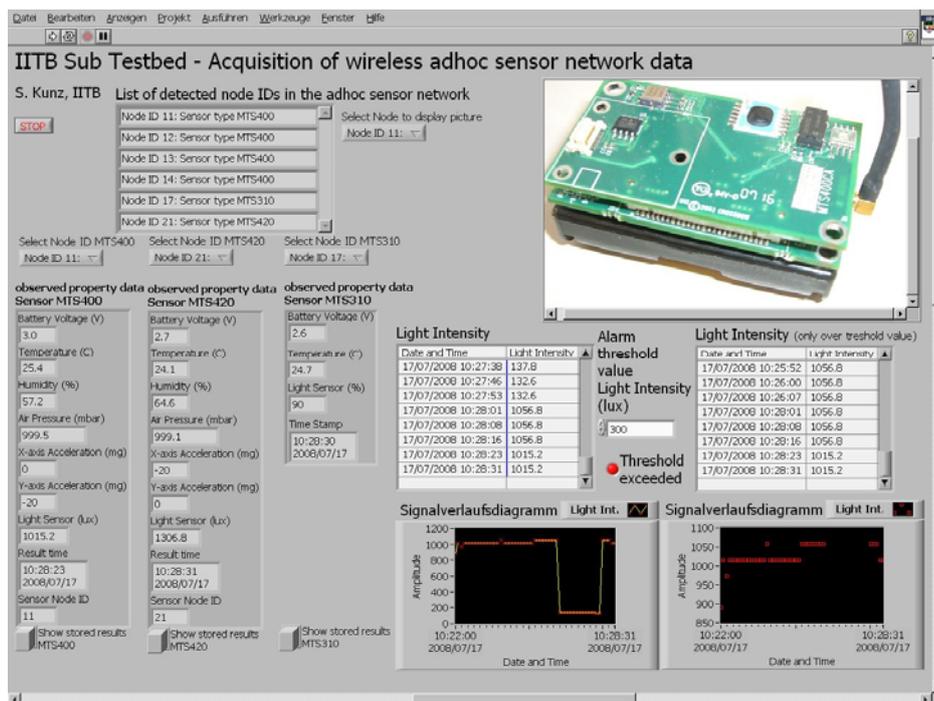


Figure 2: Acquisition of ad-hoc sensor network data in the testbed

The sensor simulator (cf. Figure 1) is realized as a Labview application running on the management PC. Since the simulator is capable of generating hundreds of virtual sensor nodes of several known types, it can be used as a tool for preparing scalability tests. Such experiments with so many real sensors of different types would otherwise be very expensive and less flexible.

The simulation of observations can be based on a random number generated from a distribution over a configurable interval (e.g. uniform in an interval between low and high limit values). The sampling time of the observations can also be set or randomized. Thus different data qualities (frequency, accuracy) can be simulated. Sets of observation data can be generated according to a spatial field with measurement noise especially for testing fusion procedures. Moreover, the location of the sensor can be varied to simulate sensors moving along a pre-configured path.

A further simulation application was designed to simulate missing sensor values due to possible sensor failures (value out of range etc.). This event is represented and coded by the NaN (not a number) value. It is possible to generate comparable data sets with different proportions of missing data to test fusion procedures.

2.3. Sensor Observation Acquisition

A separate interface application transforms and uploads the sensor observation data with all observed properties and sensor descriptions to a SOS server based on a 52° North open source implementation via transactional SOS operations (SOS-T). The real sensor data is uploaded automatically to a fixed SOS server. The simulated sensor data is uploaded to one or both of two other SOS servers. This simulates the scenario of mobile sensors moving between sensor networks connected to different SOS servers.

First a RegisterSensor SOS-T operation adds a new sensor type associated with its unique sensor node ID and other sensor metadata (type, observed properties, units, location etc.) as described in SensorML to the SOS server database. After registration the corresponding sensor observations are inserted individually by an InsertObservation SOS-T operation.

2.4. Registration in the Semantic Catalogue

The Semantic Catalogue can harvest the SOS servers for available sensors and further metadata. The describeSensor operation is used to read in the sensor metadata contained in SensorML. The Catalogue also allows clients to register new sensors on request. The Semantic Catalogue can respond to client queries on

SOS servers for a given observed property and geographical area. Further details on the Fraunhofer Catalogue may be found in Hilbring and Usländer, (2006).

2.5. Fusion of SOS data

The overall fusion process is illustrated in Figure 1 with the following possible sequence of service operations.

1. A client application A wishes to create a new fusion result for observed property P in a time interval T and a set of sampling points S (e.g. a rectified grid) by applying the fusion algorithm Alg to raw data from available SOS servers. The algorithm Alg takes several configuration parameters as additional arguments. This fusion task is described in SensorML for submission to the Sensor Planning Service (SPS). A prior *getFeasibility* operation can be executed to check if the arguments are correct and acceptable. The SPS launches the fusion task. Its execution can take up to several minutes depending on the amount of data to be processed and the computational cost of the algorithm. The client may inquire about the execution progress with a *getStatus* operation.
2. The fusion task queries the Semantic Catalogue for SOS servers with observations of property P in time interval T and in the area of a bounding box $BBox\{S\}$ around the sampling point set. In addition, the Catalogue could have been queried in the previous step for suitable algorithms and SPS servers.
3. The fusion task applies the *getObservations* operation to each SOS server to obtain the available observations of property P . Duplicates are recognized as observations taken by the same procedure (sensor) at the same sampling time; duplicates are deleted from the observation collection.
4. The fusion task determines the accuracy of the measurements. In the case of the testbed, this meta-information is in the SensorML of the related procedure. So the fusion task executes a *describeSensor* operation at the relevant SOS server to acquire this information. In general, the accuracy metadata could alternatively be in the observation result. The descriptive model language *uncertML* developed by the INTAMAP project (INTAMAP, 2007) is used to encode the accuracy information into the XML file containing the result of the observation collection.
5. Now the fusion algorithm itself can be executed with the arguments a) fusion parameters, b) the observation collection including (if available) the uncertainty of the observations, expressed as accuracy intervals, c) the sampling points at which the fusion is to estimate a value of the property. The result of the fusion algorithm is a coverage, i.e. a set of estimated property values for the sampling points together with a quantified description of their uncertainty. The uncertainty is described as a statistic (such as variance) or a probability distribution. The descriptive model language *uncertML* is used once again to encode the uncertainty information into the XML fusion result file.
6. The completion of execution of the fusion task is recorded by the SPS which can issue a notification to the client (or other notification broker). The SPS responds to the operation *describeResultAccess* with the XML file argument required by a client when executing a *getObservations* request to the Fusion SOS server to retrieve the fusion result.
7. Application Client B can, for example, display the fusion results geo-referenced on a map as in Figure 3. The coverage can also be visualized using a Map & Diagram service of the SANY partner ETH Zürich, for example as a contour map.

The fusion procedures developed to date are variants of the Bayesian Maximum Entropy method (Christakos et al, 2002) that is able to consider soft sensor data (e.g. the sensor value lies in an interval) and additional phenomenological knowledge in the form of models. The results are statistics encompassing the uncertainty of the spatial/temporal interpolation given the uncertainty of the available information.

If additional sensors or SOS enter the testbed, the fusion task discovers these new resources with the aid of the catalogue and incorporates the new data sources automatically into the fusion procedure. The self-describing information in the SOS *getObservations* result file plays an essential role in this plug & measure capability.

2.6. Implementation platform

The Fusion SOS and SPS are implemented on the platform WebGenesis®, an information management server of Fraunhofer IITB. The information management server has the information categories features of interest (sampling points or grids), procedures (sensors) and results with associated meta-data to support searching. All intermediate files produced by the fusion task are optionally uploaded together with the fusion

result to the WebGenesis® information management server. This ensures a reproducible trace of the processing steps for provenance. The fusion algorithms are developed in MATLAB® and then compiled to run in the Java implementation environment of WebGenesis®.

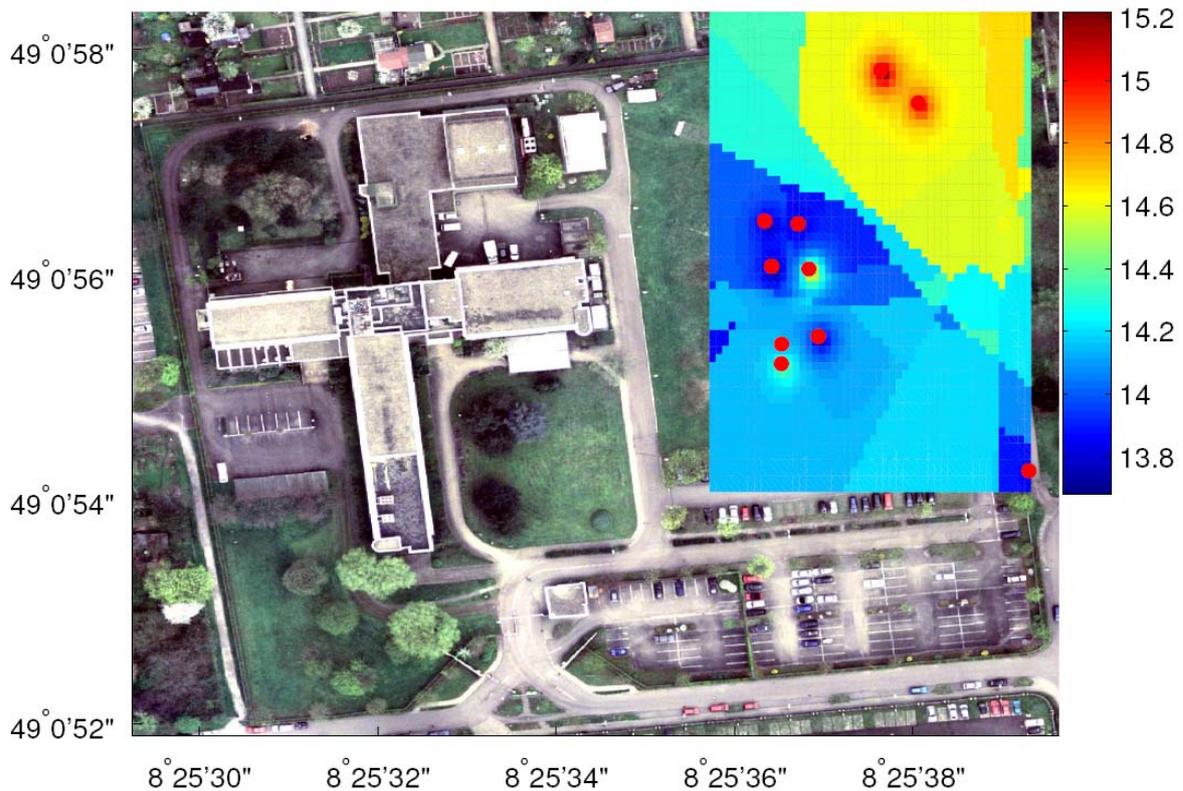


Figure 3: Example of a spatial interpolation of temperature. Red circles denote sensor locations.

3. THE SANY PROJECT

SANY (Sensors Anywhere) is an FP6 Integrated Project co-funded by the European Commission within the Thematic Priority “Information Society Technologies” in the area of ICT for environmental risk management. The SANY consortium is composed of 16 partners from eight countries. It includes the 2 research organisations Austrian Research Centers (coordinator of the consortium) and Fraunhofer, 6 companies, 3 universities, 4 public authorities and the Open Geospatial Consortium Europe. The primary objective of SANY during the project duration 2006-2009 is to specify an architecture for sensors that allow seamless “plug and measure” of sensors in applications, and sharing of information between sensor networks. The sensor service architecture and the service specifications have been made publicly available on the SANY project server (<http://www.sany-ip.eu>). The SANY specifications and best practice experience are contributed to the OGC standardization work.

The SANY project focuses on interoperability of in-situ sensors and sensor networks using standards and on-going work of OGC (in particular the Sensor Web Enablement suite of standards), OASIS and W3C. The SANY sensor service architecture provides a quick and cost-efficient way to reuse data from currently incompatible sensor and data sources. Data sources can range from live sensor data, databases of archived data to model based calculations.

4. SUMMARY AND OUTLOOK

The testbed has demonstrated the potential of the OGC services to be easily and rapidly deployed in typical environmental monitoring applications. The largely self-describing information sets (XML files in specific schemas) delivered by the services are an important step towards plug & measure of sensors and application components. The progress beyond proprietary exchange formats requiring customized processing is not to be underestimated. Environmental agencies are investigating how existing monitoring systems can be migrated or integrated into service oriented architectures based on OGC standards.

However, further standardization work is required to harmonize the formal description of resources such as observed properties (urn identifiers of phenomena) and to specify techniques to map between the resources defined in different expert communities. Accordingly, ongoing work in the testbed focuses on the semantic annotation of the sensor descriptions and observation results in order to provide a higher level of interoperability between applications.

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