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On site environmental modeling and monitoring: the Nordic Scenario in HYDROSYS project

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Abstract: Environmental modeling represents a common method for improving the understanding of environmental phenomena and most of the times is carried out off site. The high computational requirements of environmental models coupled with large amounts of spatial data are the main causes for this situation. Conducting environmental simulations by means of environmental models on-site represents a challenge but with recent advances in Wireless Sensor Networks (WSN) and development of affordable smart hand-held devices new possibilities are opening. The work presented in this paper is related to the HYDROSYS project[1] and is linked to the Nordic scenario located in south of Finland. The goal of the project is to provide end-users with advanced on-site and on-line spatial analysis tools for the purpose of environmental modeling. Thus, we have integrated a 1D hydraulic model with WSN and environmental modeling. This allows end users to carry out environmental simulation on-site almost in real time using smart clients improving their understanding in respect to environmental phenomena. The setup has a big potential for environmental management and decision support and could be highly exploited by environmental managers and specialists.

***Keywords**:* environmental modeling; environmental simulation; on site environmental monitoring; wireless sensor networks;

1. INTRODUCTION

Environmental modeling is a widely adopted research method in environmental science as it abstracts highly uncertain and uncontrollable environmental phenomena into controllable conceptual structures by means of computer software paradigms. It is generally accepted that environmental modeling has high computational and data requirements [Erickson et al., 2008, Maier et al., 2008]. While some researchers used model reduction through system and time boundary relocation to decrease model computational requirements [Vanrollegem et al., 2004], others proposed interfacing of environmental models with relational databases to enable a simulation model to document and communicate its input parameters and receive data from distributed sources [Kokkonen et al., 2003]. Thiesselman et al. [2009] proposed a web services oriented architecture for environmental modeling to distribute modeling functionality across a network and concluded it is a conditionally viable alternative to build Environmental Information Systems (EISs). Cao et al., [2006] addressed the lack of data availability for modeling purposes in their study and indicated Wireless Sensor Networks (WSN) can impact environmental modeling positively. However, to benefit WSN, the data has to be integrated with environmental models. A

1 HYDROSYS – www.hydrosysonline.eu

good example is the SMART project[2], whose aim is to develop a distributed and inter operable geo-processing and simulation framework [Conover et al., 2009]. This short review shows that environmental modeling activities are associated with indoor environment where users benefit powerful workstations, high data storage capabilities, fast networks and access to state of the art models and related information.

It is very common for the environmental model users to observe environmental phenomena on site where they are restricted in terms of computational capabilities. During site visits or campaigns environmental scientists will use resources ranging from sophisticated domain specific measuring equipment to trivial note books but in order to validate a model-based hypothesis or scenario they have no viable alternative. On site environmental modeling addresses this particular problem; it enables users to run simulation models while on-site using mobile devices (e.g., PDA, hand-held, smart phone). subsequently assessing the feasibility of their models by comparing the simulation results with the reality.

The aim of the present work is to investigate the integration of environmental modeling, Wireless Sensor Networks, spatially enabled relational databases and web services for facilitating on-site modeling. We believe the results of this study may be of interest not only for environmental scientists and model users but also for public authorities and private sector because of the the high practical potential of on-site modeling.

1.1 HYDROSYS project

HYDROSYS is a EC funded Seventh Framework programme project whose main goal is to provide a system infrastructure to support teams of users in the on site monitoring of events and analysis of natural resources. HYDROSYS is an interdisciplinary project incorporating WSN, on site monitoring, environmental modeling and simulation, visualization and event driven campaigns. Functionally, HYDROSYS is composed of three distinct blocks: data acquisition, data processing and data visualization (see Figure 1).

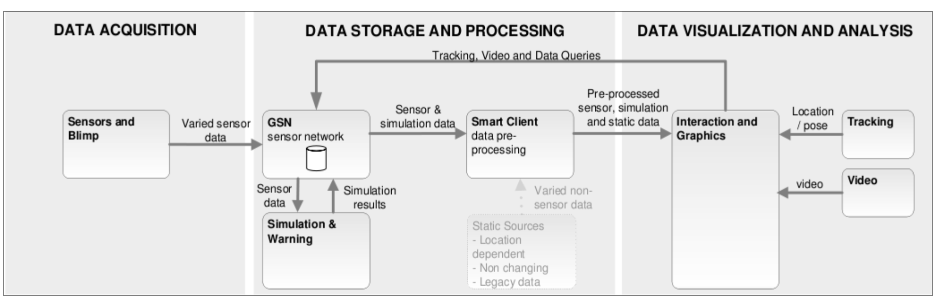

Figure 1. HYDROSYS project blocks an data flow (with permission from HYDROSYS consortium).

The system will allow users to visualize on site real time data provided by the wireless sensors deployed in the field, combine this data by means of a technique called Augmented Reality (AR) with the static visual data (2D and 3D) and run simulation models that will use the dynamic data provided by the sensors. The Nordic scenario in HYDROSYS is dealing with 1D hydraulic modeling of a small stream in a highly urbanized area in the catchment of Kylmäoja.

2 MATERIAL AND METHODS

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2 Sensor Management for Applied Research Technologies - http://smartdev.itsc.uah.edu/index.html

2.1 Study area and the monitoring campaign

The on site modeling experiment is spatially linked to the Kylmäoja catchment. The Kylmäoja stream is a tributary of Keravanjoki which drains through river Vantaanjoki into the Gulf of Finland in the middle of the Helsinki Metropolitan Area. The catchment of Kylmäoja is 22 km^2 of which approximative 75 % is within the Vantaa town and 25 % is within Tuusula. A major part of the western side of the catchment is inside the area of the Helsinki-Vantaa international airport. An on-site campaign was conducted between 1.10.2009 and 30.10.2009 with main goal to collect data using wireless sensors. The sensor stations were deployed to western branch at 1.10.2009 (Figure 2). Three of the sensor stations (West airport, West north and West Purotie) were moved from western branch to eastern branch (East upper, East lower and East Purotie) at 17.10.2009 and installed there until the end of the campaign 30.10.2009.

A typical sensor stations consists of water quality and water level sensors, data logger and battery. Temperature, turbidity and conductivity were measured with YSI 600-series water quality probe, oxygen concentration was measured with Marvet oxygen probe, and water level, which can be linked to flow and discharge functions, was measured with Keller pressure gauge. Sensors were connected to the data logger, which was operating the sensors, storing the data and transmitting data to data server via GSM network. Measurement interval of the sensors was 10 minutes.

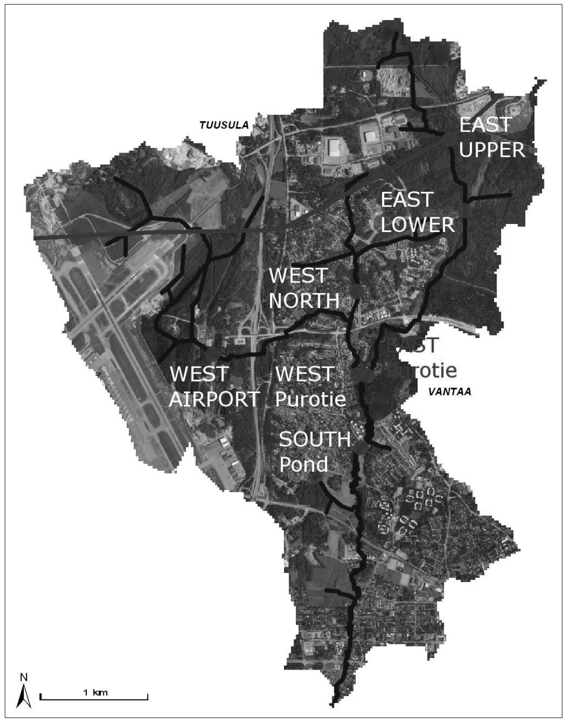

Figure 2. Locations of sensor stations 1.10-30.10.2009

2.2 Data

On site environmental modeling is highly dependent on data sources and in HYDROSYS project there are two types of data sources if viewed from the temporal perspective: static and dynamic. Dynamic data sources are provided by WSN and represent environmental variables sampled by the sensors. In the 1D hydraulic model the discharge and water level parameters are used as initial and boundary conditions, and are stored as time series in a PostGIS database. The static data sources are also residing inside the database and consist of the stream itself, its profile lines and its cross sections with cross section specific attributes (see Figure 3). The classes stream, channel, profile-line, cross-section, and hydraulic structure are abstracts from real world objects employed by the hydraulic model and are stored either as geometry tables or simple tables inside PostGIS database.

Dynamic data are published by the Global Sensor Networks (GSN) server as data streams. The structure of the data stream abstracts a table in a relational database and its individual elements abstract values in such a table. In our case the data stream contains measurements from sensors deployed to the Kylmäoja site in the 2009 campaign.

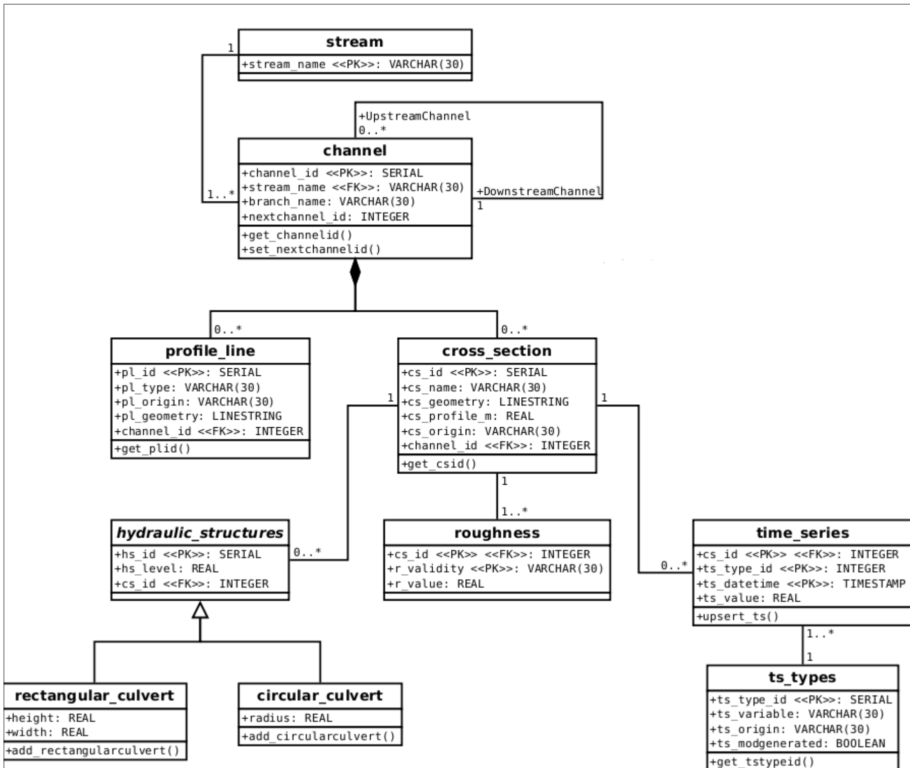

Figure 3. UML class diagram of the 1D hydraulic model database schema

2.3 Global Sensor Networks

GSN software plays a central role in the HYDROSYS structure. GSN is a Java environment running on one or more computers aiming at dynamic integration of sensor networks and produced data streams. GSN is an implementation of Dependency Injection design pattern, in its turn a materialization of inversion of control principle in Object Oriented (OO) programming [Fowler, 2004]. The main structure inside the GSN is the Virtual Sensor [Aberer et al., 2007] and represents a second level data processing inside GSN. The first level is represented by the Wrappers, blocks of software responsible for acquiring data from the wireless sensors. Together with the GSN Container object the Wrapper and VirtualSensor are the corresponding objects of the Dependency Injection design pattern. In the development version of GSN these objects have been replaced with the Pico Container framework[3]. GSN does not implements standards like OGC Sensor Web

3 PicoContainer – www.picocontainer.org

Enablement for management or data exchange purposes, rather than that it is a customized solution for real-time stream management [Aberer et al., 2007].

2.4 Web Processing Service

Open Geospatial Consortium Web Processing Service [OGC, 2007] enables the deployment of geo-spatial processes on the web in a standardized way. WPS enforces a structure and typology of input and output data types as well as meta-data describing the process. This combined with process exposing over HTPP opens the possibility to discover, bind and execute geo-processing functionality in a inter operable fashion. A WPS is suitable for environmental model encapsulation because it supports spatial data types and it allows asynchronous process execution.

2.5 1-D hydraulic model

The hydraulic model developed for the purpose of on-site simulation predicts the discharge and water level as a function of space and time in open channel flow. The model uses the principles of mass and momentum conservation expressed using St. Venant's equations for one dimensional open channel unsteady flow solved using Verwey's variant of the Preissmann discretization scheme and double sweep algorithm. The discretization scheme was proposed by Cunge et al. [1980] and the double sweep algorithm was described for example by Liggett and Cunge [1975]. In Finland, for example Forsius [1981], Forsius and Huttula [1982], Forsius [1984] and Helmiö [2002] used similar approach in their investigations.

The model is written in FORTRAN95, and the original source code is from the model presented in Helmiö [2002]. The model was modified to meet HYDROSYS project requirements. The original model was able to compute discharge and water levels in a single trapezoid channel with cross sections in regular distances from each other. The new model works with irregularly placed cross sections and in addition is able to compute flow in branching channels too. To account for culverts, additional head loss computation was introduced in the channel. Likewise, friction losses are estimated through single Manning roughness coefficient per cross section in comparison to the original version where friction coefficients were handled through three separate Darcy-Weissbach coefficients.

2.6 The simulation client

The conceptualization of on-site environmental modeling includes the smart client. The smart client is an application capable of consuming services provided by GSN, including running simulation models, in a spatial 2D or 3D context. In this form, the smart client is comprised only of soft components. However, if the smart client is to support Augmented Reality(AR) capabilities it will be tight also to the hardware, i.e. custom hand held device. Augmented Reality superimposes or composites virtual 3-D objects upon the users view of the real world, in real time [Azuma, 1997]. As a result, users, depending on their interests, might use different versions of the smart client, each version offering slightly different capabilities. gvSIG Mini[4] is an open source map viewer for mobile devices developed by ProDevelop[5] and constitutes the framework smart client is built upon. The smart client assumes mobile and wireless capabilities. A device is known to be mobile if it is usable on the move, while wireless capabilities are related transmitting data and information without being physically connected to a network (iAnywhere, 2006). The smart client application supports simple geo-spatial data types resembling OGC' s Simple Features For SQL. The very same components will be incorporated into GSN simulation modeling capabilities to facilitates geo-spatial data transmission.

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4 GvSIG Mini - https://confluence.prodevelop.es/display/GVMN/Home

5 ProDevelop – www.prodevelop.es

The aforementioned features define a minimum set of capabilities the smart client needs to provide. In addition, the smart client application should be user friendly and robust so the user has a constant feeling of spatial awareness.

3 IMPLEMENTATION

3.1 Architecture

A typical smart client application is commonly tailored to the characteristics of the supporting device [iAnywhere, 2006]. In the case of mobile computing there are presumable limitations in terms of area coverage, bandwidth, connectivity and costs [iAnywhere, 2006]. Consequently, the proposed design is attempting to limit the interaction between the simulation model and the client by incorporating a WPS client inside GSN. As a result, the mobile client interacts only with GSN (see Figure 4), all the other heavy interaction is delegated to the GSN. The main advantage of this architecture is the reduced amount of meta-data exchanged in the client-server OGC service discovery and binding between the smart client and the GSN. By encapsulating a WPS compliant client inside GSN the smart client application uses indirectly the WPS client in a less restricted, faster network. Secondly, simulation objects inside GSN are responsible for casting between WPS types and the smart client spatial types. Thus, the simulation results can be even serialized and this can impact significantly the amount of data transferred between GSN and the smart client. Not at last, publishing new models becomes relatively simple task, the only requirement is to identify a WPS server that publishes the model and point a GSN simulation model to it.

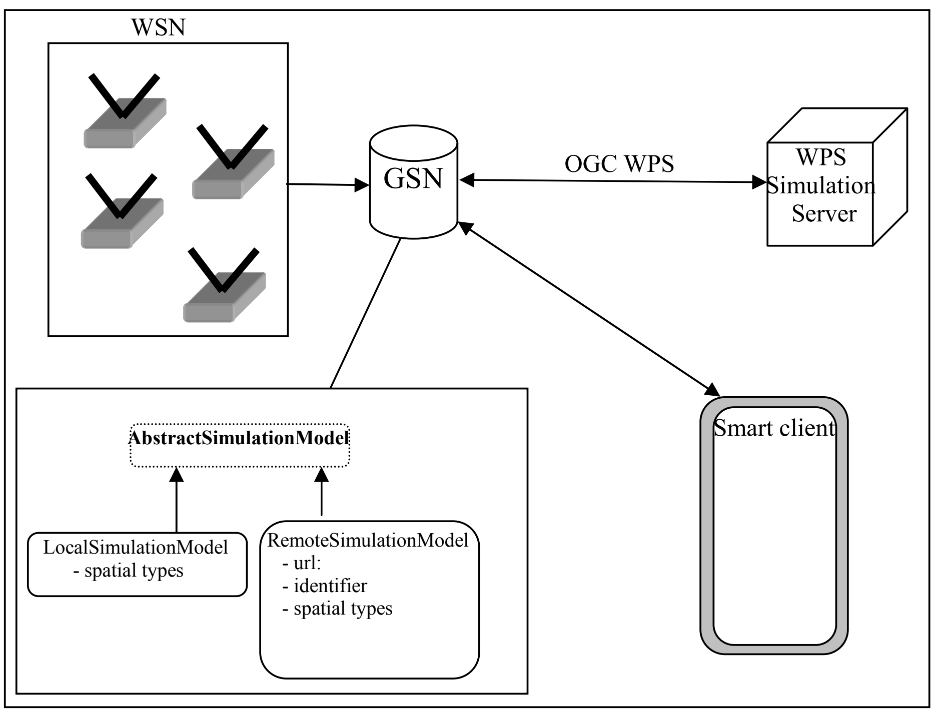

Figure 4. Proposed architecture for on-site modeling middle-ware

3.2 GSN simulation modeling capabilities

The simulation-modeling capabilities inside GSN consist of a series of software components developed to support distinct and specific functionalities. Simulation-models abstract environmental models and can be executed locally or remote. A VirtualSensor can have zero or more simulation models. Simulation models are create at runtime by the GSN container from parsing the corresponding VirtualSensor's configuration file. A simulation-models passes through a series of steps of which the most important is the initialization. If a simulation model fails to initialize, it will not be deployed. However, the VitualSensor will not fail to start, it will just not publish the simulation-model so the client will not be able to use it. This last feature induces a loose coupling between the simulation-model and VirtualSensor maintaining in this way the GSN robustness.

The capabilities developed can be separated into specific functions performed by different objects. The communication with the WPS server is carried out by the 52North WPS client[6]. The data type casting and translation between WPS and smart client spatial types is assured by utility classes. These components are responsible for casting Literal and Complex data types used by the WPS client into the simple geometry model supported by the gvSIG Mini application. The communication between GSN and smart client is handled by customized Java servlets deployed into the embedded Jetty[7] web server.

3.3 Hydraulic model as web processing service

The characteristics and capabilities of web processing services make them valuable candidates for exposing environmental models over HTTP. In this particular case the 1D hydraulic model is published using open source pyWPS software[8]. For this purpose a Python extension module was created that exposes FORTRAN routines to the pyWPS. The model was wrapped inside a pyWPS Process object and exposed it as an OGC Web Processing Service.

3.4 Simulation client

The simulation client developed on top of gvSIG Mini would support WSN data displaying as well as execution of simulation models, whilst fetching input parameters from WSN, all of these in a spatial two dimensional context while on-site. Additionally, it offers users a spatial awareness feeling by displaying sensors location on top of a map together with the position of the mobile device. The simulation client enables users to interact with simulation models at various complexity levels by allowing them to manipulate input parameters values in sense of setting them directly of fetching them from a WSN. These features make the simulation client an important component of on-site simulation middle-ware.

The development of the simulation modeling capabilities inside the simulation client consists of software components with specific functionalities targeting displaying WSN data in a spatial context and issuing simulation-modeling requests and displaying the results returned by the server wrapped inside Graphical User Interfaces(GUI). Hence, the user-simulation model interaction is much simplified. However, the users are not limited by the GUI, in case it is desirable a user can input specific values for initial and boundary conditions or alter spatial extent of the computational domain.

4 CONCLUSIONS AND RECOMMENDATIONS

On-site environmental modeling requires a generic architecture to support execution of environmental simulations. In its essence, it is a middle-ware, a integrated system of

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6 52 North WPS client - http://52north.org/maven/project-sites/wps/52n-wps-client-lib/
7 Jetty Web Server – www.mortbay.org
8 PyWPS - http://pywps.wald.intevation.org/

components not necessarily implementing legacy industrial standards following web service oriented paradigm designed to minimize the information and data exchange between the simulation client and simulation server. The main benefit is it enables users to run simulation models while on-site, a somehow simple accomplishment but relatively difficult to implement due to constraints imposed by the network environment and limited by mobile devices hardware capabilities. Additionally, the setup allows visualization of WSN data in a 2D spatial context. The benefits of using standards, e.g. OGC WPS, are counter-balanced by the high cost of data transmission over the wireless networks. Attention must be paid to the robustness of the design. If the middle-ware is not perceived as robust it can jeopardize users confidence in the value of such an approach towards environmental modeling.

On-site simulation has a high potential in so far it can support environmental decision process in a timely manner. Future work related to this subject should investigate the role of geo spatial semantics in linking environmental models and WSN data, the effects of using OGC compliant data transmission protocols on data transmission over wireless networks, the integration of environmental simulation frameworks with WSN middle-wares and not at last the usability of such concepts when applied to practical problems.

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