Summary

This report describes the result of the work package concerned with the various base system infrastructure components, visualization of sensor and simulation data, and user localization. Additionally, the report summarizes the various dependencies between the technical work packages concerned with the sensor network and user interfaces, showing how the data pipeline works, and which relationships between the various components comprising the mobile interactive visualization systems exist. Finally, we also highlight the significant results, their usefulness and likely impact.

Contents

1. Introduction

Dramatic changes in the environment are affecting the water balance, making environmental monitoring with a high resolution in space and time increasingly important. Pushed by these requirements and geared by advances in wireless networking, pervasive sensor networks for environmental monitoring (environmental sensor networks, ESN) play an important role in understanding the environment. Geoscientists, the main researchers in this field of study, are interested in capturing, manipulating and analyzing data from various sources in the field to better understand the situation under observation. Geoscientists and hydrologists divide their time between fieldwork and office or lab work. They gather large amounts of data from sensors deployed in extensive outdoor areas, and apply complex simulations to monitor the environment. Much of the field work of an environmental scientist consists of site visits to gather samples and personal observations that are later examined at the office. This workflow stems from the availability of resources and tools: while on-site, the researcher rarely has access to all sensor readings or numerical analysis tools, let alone visualization possibilities. These data and tools are the traditional domain of office applications. Nevertheless, at the office, the representation of the site under consideration is most often not timely and/or spatially accurate. There is a gap between the environment as observed on-site and its digital representation; a dissociation that the scientist must solve to comprehend the situation. Mobile technology could well be used to directly place data into its accurate spatial and temporal context. However, many challenges have restricted the deployment of mobile technology outside simplistic or artificial scenarios. Current technology either displays raw values and simple plots on a screen or is based on GIS technology designed for the desktop. Either case results in poor visualizations lacking integration with the physical environment.

Applications for environmental monitoring must deal with large, heterogeneous datasets. Geoscientists observe sites at varying scales, gathering large data sets through potentially extensive sensor networks. Recent developments in sensors networks, data gathering protocols and information filtering techniques assure high availability and fast update rates for sensors (ranging from tens of hours to milliseconds). Moreover, large spatial models that represent the environment have relatively low update rates. Finally, numerical simulations can produce spatial datasets, and their update rates depend on the complexity of the process, ranging from weeks to minutes. Applications to interact with and visualize environmental data face a serious challenge: dealing with heterogeneous, sparse, dynamic sources of data.

Bringing such applications outdoors, into potentially remote areas, only adds up to the challenge. Outdoor applications have to run on devices severely limited in terms of processing power, screen space, and network bandwidth, while at the same time deal with factors inherent to outdoor situations such as bad weather conditions or limited screen visibility. Often, research sites are located in remote areas and present difficult conditions, requiring scientists to travel by alternative transportation methods (helicopter, 4-wheel drives) or by physical means (on foot, skis, etc.), carrying all sorts of equipment needed for the task. Consequently, site observations are often a combined effort performed by interdisciplinary teams with varying requirements and experience. This results in potentially more complex collaborative work sessions that require a common understanding of the site and data under observation. However, the inclusion of mobile clients can be of great advantage to geoscientists.

Setup of Sensorscope station, Maxbotix installed in La Fouly, over the main stream

In this report we present an overview of the various technical aspects of the monitoring systems that have been developed within the project. The main components of the system build up a data pipeline, which starts with **data gathering** from sensor stations (the deployments in the project, and new developments in the area of data capturing), to **data storage and processing** (the various technical aspects of the sensor network system) to **data visualization and analysis** (comprised of the mobile systems to support monitoring in the field).

2. Requirements analysis

2.1 Requirements analysis approach

The rationale of the human-centered work underlying the developments in WP3, as well as the strongly coupled other ñpţ æœkhæŋġ æcsađ (sensors and sensor network) and WP65 (user interfaces) has followed an incremental and iterative development process using state-of the-art approaches of user-centered design and software engineering. These highly connected methodologies are based on scheduling and staging of the various parts of a system that have been developed in parallel but at different pace. The project specifically focused on developing early prototypes that can be used in the various demonstration-oriented activities (reported in WP8) and experiments (reported in the WP7 reports), in order to secure the highly user-centred

Further reading

This section introduces several of the main usability concepts. Further detailed information can be found in report D2.1 on user-centered design.

Details on user-centered design studies (in particular demonstrations and evaluations) can be found in particular in reports D7.3 and D8.4.

developments through multiple iterations. The integration of both methodologies assumes that problem definitions are not covered to its full extent in the beginning of the project: the understanding of the issues has grown as prototypes are built that generate feedback from end-users. Usability tests are an integral part of user-centered design, verifying design ideas throughout the various stages of development.

User-centred design is a design philosophy that aims at improving the overall end-user experience for a product or service by actively involving the identified user into the planning, design and development phases of the new product or service. UCD tries to optimize the designed system around how people can, want, or need to work, rather than forcing the users to change how they work to accommodate the system or function. UCD answers questions about users and their tasks and goals (reported in WP2 reports). The findings have been validated through empirical grounding and have been used to make decisions about development and design. In HYDROSYS two major gains of exercising UCD in the research process should be stated. First of all, it has acted as a mediator between different research-oriented activities and the common system development. It also helped us in providing, as a result of the project, a useful end-user mock-up sketch prototype sy
needs of the project partners and defined user groups and above all, provides additional value in the activities they perform.

Lausanne end-user meeting

One of the state of the art user-centred design process methods used within the project is called Contextual Design. This process puts emphasis on studying the worker in his/her actual working context incorporating a set of practical ethnographic methods. It is well implementable into a system development project such as HYDROSYS where the context of use has a potentially large effect on the usefulness of the system. Much of the ideas presented in the Contextual Design process are applied into the HYDROSYS research project.

Another user-centred design method that has also been applied in the project is Participatory Design, which emphasizes the role of users in development. In

HYDROSYS, end-users have taken an active role in designing the system especially by taking part in the participatory workshops (see section 5.4). In general, we regularly talked to a user group of about 65 users, through workshops, casual discussions, and on-site deployments. These two UCD models are not exclusive and both viewpoints can be expected to bring value into a research-oriented system development process. While participatory design is more of a design philosophy without formal methodology, the Contextual Design process proposes using a set of concrete methods, of which some have been directly and others more adaptively implemented into HYDROSYS. Specifically the UCD templates in the appendix have been derived from these techniques to serve the system development needs (including the tasks related to participatory workshops).

2.2 Scenarios: context of use

Where is the system deployed, and by whom?

To analyze the various users in their actual context, the project consortium has continuously included end-users through the various iterations of user and task analysis, requirements analysis and criteria statement, and system design, as well as the various evaluation stages mentioned briefly in section 1.1. As general reference, the Swiss scenarios deploy the handheld augmented reality system, whereas the Nordic scenarios make use of the cell phone 3D application.

Dorfberg wet snow avalanches

2.2.1 Swiss scenarios and end-users (handheld AR system)

The Alpine (Swiss) scenario consists of three applications, Dorfberg, Gemsstock and La Fouly. They were chosen as they represent a diversified set of natural environments, applications and sensors with complexity on different levels. The chosen environmental processes are of high importance as they are currently poorly understood, frequent and have a significant potential for damage.

Dorfberg (WSL) -- Wet-snow avalanches

Wet-snow avalanches are hazards which are frequently occurring in mountain regions. They are characterized by a large degree of potential damage to infrastructure and people. So far the processes which cause the formation and triggering of wet snow avalanches are poorly investigated. The Dorfberg (Davos, Switzerland) has been established as the preliminary field site for wet-snow avalanche research in the last years. Many different types of sensors have been installed and manual measurements were obtained regularly.

The data which have been collected in the last three years have been and are currently analysed to investigate the triggering of wet-snow avalanches. Several scientific publications have been submitted and significant advance can be reported even if it will - if ever possible - require much more efforts to get a full understanding of this highly complex topic.

Gemsstock wall inclination sensing

Gemsstock (WSL) -- Monitoring infrastructure stability

It is a well known fact that alpine permafrost has retreated in the last decades and it is expected that this trend is continuing in future. This retreat has a significant effect on human activities, especially in regions where infrastructures such as buildings, power lines or cable car pylons are located on permafrost: Thawing of ground ice can destabilize the ground and result in settling or tilting of infrastructure. The ñGemsstock-scenarioò is a case study for this impac areas. The study site is the Andermatt (Switzerland) skiing resort. Parts of the cable car infrastructure are built on frozen ground. Therefore different sensors and methods have been used to analyse the possible changes in the permafrost on the one hand, and to directly monitor the infrastructure on the other hand.

La Fouly (EPFL) ï Understanding sources of stream flow generation

La Fouly deployment focus on the **understanding and managing natural hazards such as debris flows**, **landslides and floods** because they are fairly frequent, poorly understood and could have serious economic, environmental and social impacts. The 2009 and 2010 field campaigns carried out at La Fouly took place from June to October. In October 2009 all 12 stations were removed and transferred to the EFLUM laboratory, taking care of keeping together sensors belonging to the same station to be able to reproduce the same sensor configuration for the next year campaign. During 2010 two stations were left at the field site during the winter months; the harsh winter conditions made their operation a challenge, but some data was successfully collected.

2.2.2 Nordic Scenarios (mobile 3D system)

For the Nordic scenario, the focus was on studying the hydrology and stormwater management of semi-urban catchments. Stormwater is runoff water from built-up areas. Development of the urban areas, covering ground with an artificial hard surface like asphalt, buildings and other, has a significant effect on the natural water cycle and water quality. The artificial covers on water permeable surfaces decrease infiltration, and therefore the total volume of surface runoff is substantially higher in the covered areas, than in the natural environment. Added to this surface waters flow much faster on a hard cover and channels, compared with a natural cover, and therefore the flow both arrive and pass faster. In addition, stormwater can be heavily contaminated with a range of polluting substances.

Nummela site

The Nordic scenario focused on urbanizing areas of varying sizes in southern Finland. Three sites were examined: a patch of land in Korkeasaari Zoo (in Helsinki), along Ridalinpuro creek (in the Nummela neighborhood of Vihti municipality), and Kylmäoja catchment (mostly in Vantaa municipality). The patch in Korkeasaari is a micro site, interesting from the point of view of heavy wear by strollers and occasional heavy showers. Ridalinpuro creek is a site of environmentally sensitive hydraulic engineering and it exhibits the impact of typical sub-urbanizing neighborhood and construction. The main focus in Ridalinpuro was a stretch of the channel. The Kylmäoja site is a 20.84 sq-km more complex semi-urban catchment and channel system exhibiting pressures from increasing imperviousness, construction, chemical use on Helsinki-Vantaa airport, traffic and others.The end-users in the Nordic scenario have been environmental engineering contractors, environmental authorities, non-governmental groups and water utility representatives.

Ridalinpuro (Nummela)

The catchment of Ridalinpuro is partly urbanized and therefore subject to anthropic pressure. The creek has been heavily modified due to agriculture use and urbanization. The stream suffers from flooding and heavy foreign matter loading. The creek has been heavily modified in its history due to agriculture and urbanization. Enäjärvi is a small, eutrophic lake. The stream suffers from flooding and heavy foreign matter loading. The source of its nutrient, sediment and pollutant loading is the surrounding fields and sub-urban area of Nummela.

The goals of the measurement campaign of HYDROSYS-project on Ridalinpuro ware the impact of land-use on water quality in the stream, the impact of stream restoration projects, and development of the physical modeling of environmental hydraulics.

Kylmäoja

Kylmäoja stream has three main branches, eastern, central and western, which all unites to the main stream in the middle of the catchment area. Kylmäoja is experiencing anthropic pressure, including development of the urban areas, e.g. construction of a logistic center in Tuusula in the upper part of the catchment. Also new railway line is under construction, crossing the catchment in east-west direction. The Helsinkiï Vantaa international airport is partially located in the catchment area, and it is the main source of deicing chemicals released specially in the cold season.Specific goals in the Kylmäoja site was modeling (the application of the physical model in a complex system), and specific impact of airport and the logistics area in water quantity and quality and the interaction with a natural site downstream.Based on the context and the system design framework of HYDROSYS, the following six end-user groups were chosen to be studied in the context of the Nordic scenario: Watershed/Storm water project managers, watershed contractor, national and municipal environmental authorities, environmental activists, local habitants

2.2.3 Task analysis

Which tasks are performed and what advantages are end-users expected to gain from the (mobile) system?

As mentioned in 2.1, the rationale of developing applications for geoscientists has followed an incremental and iterative development process using a user-centered design approach (UCD). This approach is characterized by the inclusion of a large group of end-users (participatory design with around 65 users with various backgrounds) from the initiation of the project on. We have focused on careful user and task analysis and initial feedback loops with early prototypes, including paper mock-ups and initial system prototypes. This process focused on creating a thorough understanding of the context of use. It also provided an empirical grounding for the various iterations of the application and accompanied underlying system. In particular, it helped us to design various aspects of the application in a human-centered approach: the grounding provided us with insights in critical perceptual, cognitive and ergonomic issues that would be worthwhile to tackle in the various research tasks of the work being performed. The following paragraphs describe the results of UCD, in terms of users, goals, tasks and methods.

User: As we introduced in the previous section, the main user group targeted by our application comprises principally geoscientists in the widest sense, with a particular focus on hydrologists. Hydrologists in general study the continuous movement of water. They examine the form and intensity of precipitation, its rate of infiltration into the soil, its movement through the earth, and its return to the ocean and atmosphere. In this frame, the areas of interest of the target user group include permafrost degradation, wet snow avalanches, and watershed modeling. People in this user group are affiliated with research institutions companies comprising, among others, specialists in charge of managing natural hazards, watershed managers, contractors and municipalities.

Goals: The goals of the work performed by the end-users are to create a better shared understanding of the environmental processes being observed, to understand its effects, and discuss potential solutions to problems found. On-site actions should aid in more closely connecting captured process data with its actual context, the environment itself. It is expected that improving the understanding of context improves the general understanding of processes and eases solution finding.

Setting up sensors in the Kylmäoja stream

Tasks: The end-user work cycles comprise several closely interconnected tasks (*workflow*), in which different users may assume different roles. The cycles generally start with the identification of an environmental problem, and/or the finding of a suitable site for monitoring specific events. Subsequently, the work continues with sensor setup and maintenance (creating, placing and maintaining sensors or sensor stations), followed up by a preparatory stage of setting up the data pipeline. The latter consists of checking the sensor network and storage system, and gathering (legacy) data that is necessary for the forthcoming monitoring actions. Monitoring and understanding environmental processes consists of outlining the problem, gathering data on-site (manual samples), and analyzing sensor data through interactive visualizations at the office. Based on the acquired understanding, users may note down observations and ideas, and define solutions. A direct product of the solution finding stage is the management of environmental processes where plans are thought out and potentially enforced. Monitoring and management actions require communication support, whereby users with potentially various backgrounds discuss findings and potential solutions.

The **expected advantages** that are noted in the table below characterize the benefits users can achieve while using the systems. The impacts were confirmed in various user interviews that are noted down in the various reports produced in WP8.

Task	Subtasks	System components offered by HYDROSYS	HYROSYS expected impacts
Monitoring and understanding environmental processes at workplace and onsite	Outline problem. Gather data. Order and download data. Integrate, visualize and analyze data. Model environmental process. Define solutions . Supervise projects.	S t u d y t h e s i t e ô s u s i n g capabilities. Collecting new information resulting from combination of data and applied modeling. A well-outlined situation to support decision making. Associating the data seen in the system interface with the actual situation.	Better basis for outlining the problem. Ease for gathering and combining data. A single information space for integrating different information. Ability to react to flaws and mistakes based on real-time feedback.
Managing environmental processes at workplace and onsite	Design plans. Setting up plan . React (enforce plan). Quantify damages.	Using the real-time monitoring and visualization capabilities to determine the effects of the plan. Sharing of the information mounted to the system with other participants. See the changes (positive/negative) in the state of the observed situation.	Ability to enforce a plan. Shared information system. Communication channel with on-site observers. Coordinate actions.
Decision making	Study problem, situation. Generating model and possible solutions for problem, situation. Make decisions.	Communicating in real time with involved parties on-site and remote. Sharing and coordination of information. Building and evaluating optional procedures.	Ability to generate solution for situation and propose. Communicate solution to other stakeholders.

Sensor setup and maintenance	Create sensorstations. Place sensorstation in field. Maintain sensorstation.	Oversee sensor station general sanity (pictures, video). Oversee high data quality. React to malfunctions.	Information on sensor or sensorstation status (sensor data, photo or video footage).
Communication	Communication. Sharing information. Coordination.	Sharing information with partner. Seeing online information (images, ...). Delivering information on actions to interested parties.	Real time communication (image, queries, d a t a , é) wi t h o n s i t e Shared information system.

Table ï overview of tasks. The expected impacts were confirmed by experts in the various discussions reported as part of WP8.

The following table summarizes which users were envisioned, how they can use the system, and what particular advantages these users can expect.

User	Task	Advantage
Environmental scientists	Study and understand environmental degradation and its influence on hydrology	Support field work with hand-held devices that allow a better integration of known and new facts
Environmental protection agencies	Monitor and minimize degradation	More and better information from the field
Engineering and consultant companies	Make hazard maps and assess critical state of natural environment	Direct access to known material and support in own data collection
Engineering and consultant companies	Make detailed analysis of glacier extend and melt, permafrost ï infrastructure interactions and slope movements for scientists and local and cantonal authorities Make detailed analysis of construction site effects / risks on hydrological processes	Big advantage in field surveys and data processing based on direct transmission of digital data
Local and regional administration	Decision making, risk management,, landscape management and citizen information	Making a more appropriate decision based on site- a (quicker reaction, understandi Appropriate tool to inform citizens.
Citizens	Access top-level environmental data that can affect daily life (like water quality), use systems in educational scenarios to learn about environmental processes	Open access to selected environmental information sources, new educational presentation method. Sensitize children and tourists to sustainable use of natural resources. Initiate and promote environmentally-conscious behaviour.

2.2.4 Higher level functional requirements

What are the higher-level requirements for the system?

Next to the support of the before mentioned tasks, several higher-level functional requirements can be stated. These requirements form the basis for the underlying mechanisms for interactive visualization of environmental data.

Sensor data and storage

¶ **Geo-referenced data**: all data gathered must be geo-referenced to generate in-context visualizations

¶ **3D digital model**: terrain models are required for visualization, but also for simulations. The digital models used for analysis are often incomplete. For example, elevation models do not include structures.

¶ **Aggregate multiple data sources**: online and offline data sources and from different sensors at different rates have to be aggregated and be available to the useds.

¶ **Sensor data quality**: S e n s o r d a t a h a s t o b e ñ c l e a n e d ò a n d be provided to the users.

¶ **Authorized access**: data aggregated by multiple sensors may be subject to different access rights for different users

Mobile systems

¶ **Data sources**: The mobile clients should access and merge real-time heterogeneous data sources in a unified view. As a direct result, the tools should aid in the spatial analysis of potentially more complex environmental data sets

¶ **Usability**: The user interface as well as the visualization should be clearly visible, preferably show undistorted colors, support correct depth perception, and have legible text.

¶ **Accurate localization**: Embedded or attached to the device, high-quality sensors such as a camera, orientation sensor and GPS are required to define the user viewpoint and direction, and to provide video imagery.

¶ **Understanding of visualization**: data should be visualized in an understandable format, which means that different approaches need to be taken for different end-users: citizens have a different understanding, for example, than specialists in the field.

¶ **Network access**: although a single user deployment is imaginable and possible using prerecorded data, the main potential of the application is achieved when it can access sensor/simulation updates in real-time as well as communicate with other users.

¶ **Robust mobile system**: The mobile system used for interactive visualization needs to be robust, ergonomic and ultimately have an outdoor readable display. The interface must allow usage under extreme conditions (e.g., wearing gloves).

¶ **Linking users at different locations**: It should be possible to link mobile clients to a user located at a remote desktop, linking users in the office and the field

¶ **Mobile sensor**: It is of advantage if a mobile sensor can connect directly to a mobile client to get direct feedback

¶ **Sharing understanding**: the mobile clients should afford methods that aid in sharing observations and understanding of environmental processes

3. System architecture

The HYDROSYS platform is a heterogeneous system, combining devices varying from mobile devices to desktop, with specialized data acquisition methods and simulations, providing highly graphical mixed reality clients as the system highlight. Figure 1 presents an overview of the main components. The system aims at providing means for on-location observation and analysis of environmental data, supporting also office work and collaboration. Each developed component progresses and contributes toward that goal.

Building on existing know-how of the partners, the architecture was already envisioned in the Technical Annex, and implementation broken down to tasks accordingly. With a research project aiming toward a system that has not existed before, there can always be surprises and issues that arise during the research. However, HYDROSYS proceeded quite well according to the original plan, and the final architecture quite closely resembles the foreseen one. From left to right in the figure, environmental data is captured (ñSensorsò), tra
and warningò) and transcoding (ñSmart Clientò), a
(ñInteraction a-location Generated data (ò)emerg iOmg from, for exam
instruments) is collected and visualized at the clients on the spot, and transmitted back to the main system, where applicable. For example, it was deemed feasible to develop a mobile sensor to allow on-demand measurements of oxygen content, moisture level and temperature. This sensor data is collected by the mixed reality clients and transmitted to Smart Client for distribution. The Clients are networked and facilitate collaboration between office and on-site.

The HYDROSYS architecture has been implemented and is functional. The system has been demonstrated in public, with the Final Event at ACM CHI 2011 conference as a highlight.

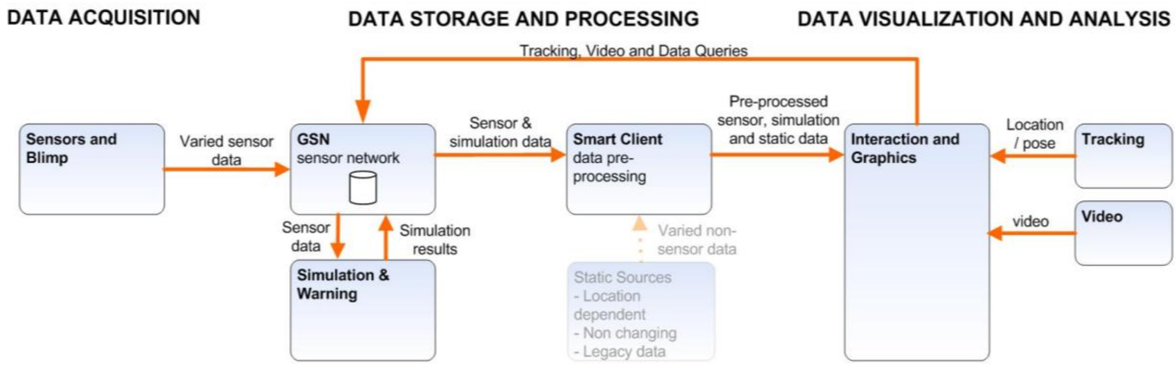


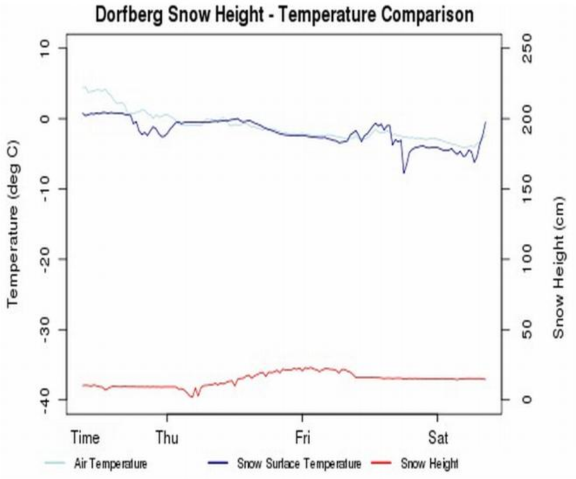
Figure 1. The high level overview of HYDROSYS main components.

3.1 Methods

What are the underlying methods?

Hydrologists use sophisticated techniques and instruments. For example, they combine automatic sensor stations, data gathering, and numerical modeling to monitor the change in regional and global water cycles. In this section, we introduce the underlying system methods that are covered by the system architecture, matching the general workflow of a end-user.

Data gathering. To study the environment, processes need to be captured by sensors that provide the required density, update rate and sensing characteristics to provide for a correct representation.



A combined plot to compare measurements of snow height vs temperature over time.

Sensors may need to be installed ad-hoc, but generally they are placed at a site for longer periods. As an example, the sensorscope station used throughout our deployments can be configured and equipped with various sensors. A sensorscope station can be set up within an hour and is self powered. Beside storing data in dataloggers, the stations form a network, whereby measurements can be routed to a station with outbound connection to a sensor network.

Data storage. Sensor data is stored and indexed by a global sensor network, allowing seamless gathering of data from stations. To ensure data validity, data is filtered using automatic or manual data quality mechanisms. Data may underlie privacy restrictions, hence, in most cases security mechanisms and user management is required.

Data visualization and analysis. After filtering and validation, the numeric data is converted to visualizations for analysis. These visualizations serve the purpose to analyze and understand the data. Based on perceptual abilities of people, visualizations provide an advantage to detect patterns, differences, connections or similarities in numerical data. Typical visualizations for environmental data include simple and combined plots for point data (**Error! Reference source not found.**). In order to get a better overview of variation over large areas, measurements coming from several sensors are interpolated and visualized as color coded 2D diagrams or maps. Sensor data is not only necessary for point-data analysis, but also provides input to simulations. Thus, numerical modeling is applied to large datasets to output simulations of the current situation and to attempt prediction of future ones. Complex simulations require potentially powerful servers to ensure regular updates of simulation results. Simulations often run on dedicated servers each requiring different ways to specify input and access to results.

3.2 Higher level system services

How are the methods matched by services?

The overall system follows a ubiquitous services organization, where the mobile application acts as client to a number of services, particularly those connected to the sensor network.

Sensor data service: The main service is GSN, a ubiquitous interface to a large deployment of sensors. Even measurements from manual sensors are uploaded to GSN. GSN also processes plot queries, which result in 2D graphical content. One advantage of generating plots in the sensor network is in avoiding the transfer of a high volume of data over potentially expensive network links.

Simulation service: The MeteoIO library presents a uniform, format independent library to access numerical simulations from simple spatial interpolations to complex physical models. Simulations can output 1D, 2D results, in which case they can be treated as a sensor. They can also output 3D data as a result of interpolations.

On-site campaign service: An on-site campaign service is deployed to support on-site activities in particular collaboration. During campaigns, this service runs on a mobile computer at the site of study and provides access to shared information such as remote views and annotations.

All these services contribute data to different layers that the application processes to generate a comprehensive visualization. The mobile application uses graphics primitives to generate visualizations. Therefore, all data needs to be transcoded and interpreted. Transcoding takes place both in offline and online stages. Offline transcoding is performed to convert large 3D models that remain unchanged during campaigns, while online transcoding is performed on data upon its retrieval from the corresponding service (sensor data or simulation data).

3.3 The data pipeline and integration

How are these services integrated in the *data pipeline?*

HYDROSYS involves static, raw external data, on-line sensor information and simulations. The raw data requires preprocessing to convert it to a form suited for visualization in the mixed reality platforms. These processing stages have been finalized and are operational. They include triangle mesh and contour line generation from digital terrain models, visibility predetermination of 3D data for mobile 3D visualization, LIDAR data categorization and transformation into renderable 3D meshes, etc. The results are either placed on databases or installed directly on the mobile clients.

To integrate our components and to distribute sensor data, we needed suitable middleware. The Global Sensor Network, GSN, was foreseen as the best solution for connecting the various systems together. While needs arose, GSN itself was modified and improved to match the new requirements. GSN wrappers were built to parse and integrate proprietary data formats, and GSN nodes modified to deal with the new data types. In general, GSN delivers what was initially expected: the sensor data from semi-permanent sensor stations is transmitted via GSN for processing and compression. On some cases, the details of the underlying systems and their results diverged slightly from what was tentatively planned. For example, the hydraulic simulation results from the Nordic scenario were seen useful for only the environmental specialists, to allow observation and improvement of existing environmental models, but without a need to provide a specialized visualization of the results to on-site. In this case, simultaneously, the Nordic scenario mixed reality clients were tuned towards direct visualization of environmental data, aimed at the environmentally aware public, involving for example support for user-created annotations and discussions. This work yielded another, GSN independent integration result: regarding user-created content, both the Nordic and Alpine scenarios now utilize a similar data structure and content transmission system between Smart Clients and mixed reality clients.

3.3.1 Components

The data pipeline principally consists of the following stages and components: **1) Data acquisition, 2) Data storage and processing** and **3) Data visualization and analysis.** Raw data is seldom in a useful form, and further processing is needed. In the pipeline, data suited for simulation, transmission, visualization and analysis.

Data acquisition

Off-line processes to manage static data necessary for visualizations or simulations were developed and have been finalized. Data was obtained mainly from national and communal sources.

On-line sensor data is collected via sensor stations, the blimp, mobile sensors and stationary cameras. Data emerging from sensor stations is transmitted via GSN as input for simulations, or for the mixed reality clients. In the case of the handheld system, the data is directly transmitted via Wi-Fi, but for the cell phone platform, it is cached on a Smart Client and transcoded prior to transmitting to the clients.

Data storage and processing

Data emerging from sensor stations and mobile sensors is cached at Smart Clients hosting a database. The data can be retrieved and observed based on sensor station IDs and sensor names, associated entities such as lakes and rivers. These queries can also be limited by dates.

HYDROSYS online sensor data gathering and transmissions via GSN are functional and finalized. In Nordic scenario, the data updates from the semi-permanent sensor stations have been increased from daily updates to a rate matching the maximum measurement rate, typically one update per 10 minutes. In addition, a pipeline from mobile sensors is established via cell phones and is functional. Similar, for the Swiss scenarios the data pipeline is fully functional, serving sensor networks from around 4 to 15 stations with each around 10 sensors, which are updated and processed on regular time intervals (typically every 10 minutes). The data is pulled into the handheld by using the Smart Clientôs update mechanism.

For the handheld platform, digital terrain models are preprocessed to triangle strips and contour lines, and stored locally for rendering. For the cell phone platform, preprocesses for 3D model optimization have been implemented, along with a process to convert raw LIDAR data to a 3D model.
Simulation data is mostly based on static digital terrain or river data sets, and is processed according to the requirements of the specific environmental model.

Data visualization and analysis

GSN acts as the main component for transmitting and caching sensor data. It also provides rudimentary sensor data cleaning features. However, Smart Clients also provide case-dependent data storage and services. Especially the cell phone platform, due to its progressive data transfer policy and application level features (such as historical queries to sensor data), utilizes and is dependent on Smart Client services. 3D scenes are stored and can be streamed from Smart Clients and all near real time updates are channeled via Smart Clients. User annotations are stored and transmitted with Smart Clients for both cell phone and handheld platforms.

Simulations use their own specific processes, inputting sensor data via GSN and caching the results locally. In the Alpine scenario, the data is forwarded via GSN to the handheld platform.

Data acquisition Acquiring data from the monitored site by means of sensors, including the generation of a detailed visual model of the site.

Data acquisition may occur through the following components specific to HYDROSYS (see D4.2 WP4 final report for details):

- Sensors and sensor stations accessible through a wireless sensor network
- A remotely controlled zeppelin that acquires thermal data and refines terrain models
- A mobile sensor for sensing of temperature and oxygen levels
- Camera footage for observing the site from multiple perspectives

Data storage and processing Storing the data from the on-site sensors and other acquired data, quality checking and securing data, performing continuous or on demand simulations on the data, integrating static/legacy data, and providing ways of pre-processing and distributing the data to the handhelds.

Components that have been specifically developed for HYDROSYS include (see D4.2 WP4 final report for details)

- Integrated simulation functionality
- User management
- Data cleaning methods and online tool
- Data querying support
- Data client functionality for data access on mobile systems

Data visualization and analysis The usage of interactive visualizations and associated functionality (including data selection, annotation, communication) to monitor and manage a particular site under observation.

Specific components have been developed for HYDROSYS, regarding visualization (see this report for details) and interaction (see D5.1 WP5 final report for details):

- Perceptually optimized visualization techniques for showing sensor and simulation data
- User interfaces supporting the guided exploration of complex data sets
- Collaboration techniques for sharing ideas (notes) and viewpoints
- Experimental techniques that can be used for attention direction in complex data / environments, through unobtrusive filtering/modulation of screen content

3.3.2 Integration aspects: the link between sensors, sensor network and mobile client

To integrate the sensors, sensor network and mobi have been defined that result into the data pipeline mentioned in the previous section. These links represent integration aspects that support uniformity in the various components developed in the project, towards the integrated research prototype system provided at the end of the project. Below, we describe the main mechanisms to bind the three major steps in the data pipeline, as well as the binding of an external system (simulations).

- ***From sensor to sensor network***

  The GSN wrappers are the essential components that feed data to GSN from sensor stations. Wrappers fetch data in a pull- or push-based mode from different sensors with different communication protocols according to the sensor type. Various wrappers already existed, such as ZigBee-, or TinyOS-Wrapper that pull sensor data from TinyOS or ZigBee mote etc, but new ones have been built for the purposes of Hydrosys for fetching images, raster data, or for receiving sensor data from SensorScope stations and via UDP, TCP from arbitrary nodes. Wrappers are pre-configured as input to the vari GSN that represent the physical sensor stations. Data is generally sent over network, using a GPRS connection, or a specially set up WiFi bridge (project outcome)

- ***From sensor data stored in sensor network to simulation system***

  Environmental models (e.g. GEOtop, Alpine3D) are very useful for understanding complex physical processes and predict potential natural hazards. *However,* running a model simulation based on field sensor data needs several steps, namely data sensing, aggregation, retrieval, cleaning, interpolation, formatting, model execution and model output visualization. This process is time-consuming (e.g. only the data preparation for a single simulation typically takes 3-4 days) and highly error-prone, as it involves many manual or semi-automated steps. Furthermore, the scientists need to employ many different software tools for the various data processing steps, and often manually import data and export the results from them.

In Hydrosys, we have defined and implemented a data processing pipeline that makes simulation process completely automated, fast and transparent to the scientist. Furthermore, our automated simulation tool is fault-tolerance and limits the space for introducing errors. A scientist can visualize or download sensor data, or run a simulation and obtain the results in the same web-based GUI.

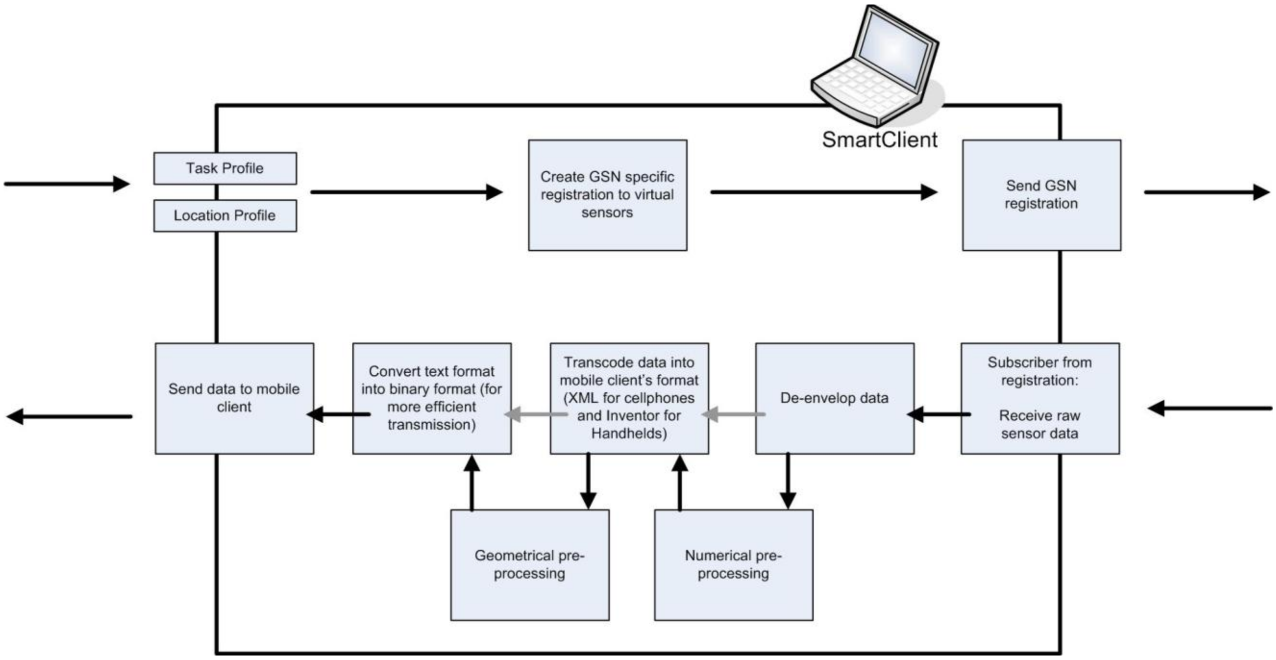
The basic framework for the implementation of the simulation pipeline is provided by GSN Its key abstraction, namely ñvirtual sensorò (VS), is an atomi
one or more input historical or real-time sensor data streams and provides one output stream. Our simulation tool pipelines several ordinary VSs with special-purpose ones. The environmental models employed are GEOtop, which *is a distributed model of the mass and energy balance of the hydrological cycle for simulations in continuum in small catchments,* and Alpine3D, which is *a new hydro-meteorological model for alpine and subalpine areas.* However, our approach is generic-enough to be include arbitrary environmental models.

Č ***From sensor and simulation data to mobile client***

To connect the GSN sensor data storage to the handhelds, we developed a component called the *SmartClient.* The SmartClient component includes all the steps related to accessing data for HYDROSYS applications. These steps are divided into a set of components for convenience. Data services define the data that HYDROSYS applications can handle and their format by providing a metadata definition. These services include mechanisms to convert data from external formats (preprocessing/ transcoding) to the formats required by HYDROSYS applications. These components are divided into data querying components, data conversion components, storage and data indexing components. As an example, a normal session of HYDROSYS application is as follows. The SmartClient registers queries according to a user profile. Before the query is actually registered, a service checks whether this data has already being retrieved (saving processing time by avoiding repetition of expensive conversions). If the query can not be handled locally, it is registered
with (if it is a query for streaming data), o
When the data is available from GSN, it goes through a preprocessor to perform necessary conversions (to convert to the format specified by metadata, to perform certain platform specific conversions, etc). The data is then stored. A Data Retriever in the client manager is notified of the arrival of data, and it forwards the data to the SmartClient. In the SmartClient the data goes through more conversions, resulting in data ready for visualization.

The next figure exemplifies a typical connection diagram of how data is retrieved from GSN and delivered to the mobile client. First, the Task and Location profiles are sent to the SmartClient, these profiles were previously set during campaign planning (section **Error! Reference source not found.**). The SmartClient receives the profiles and converts them into registration queries that can be understand by the GSN server (the server may be locally in the same machine or remote depending on network availability, for an example of a local GSN server see section **Error! Reference source not found.**). The GSN server will respond with sensor data specific to the requested registration (publisher/subscriber pattern) to the

SmartClient. This will in turn pre process the information before delivering it to the mobile device.



3.3.3 Data acquisition: the data producers

To gather data from the sites described in section 2.2, dense sensor networks have been set up that cover the relatively small sites with carefully defined grids of sensors. The sensors produce data that is fed into the sensor network system data storage, to be further processed and browsed by the mobile clients. The density of sensors can be several sensors on a site like Nummela (a part of the stream of about 200 meter length), to about 20 sensor stations (totaling around 200 sensors) covering an area of about a couple of km2. However, these are not the only data producers in the HYDROSYS project. More specifically, we can identify the following data producers and other sources:

¶ **Sensor stations:** sensor stations are a bundle of sensors connected to single station, which forms a data hub to the sensor network. Generally, a sensor station holds sensor that capture various weather data attributes, but they may also connect to specific sensors (see next point). An example of a sensor station deployed in HYDROSYS is the *SensorScope,* which has been developed at EPFL.

¶ **Specialized sensors:** next to general weather data, specialized sensors are deployed that sense a particular modality. An example is the turbidity sensor deployed within the Nordic scenarios.

¶ **Blimp**: within the HYDROSYS project, a blimp-based system has been developed that can be used to gather thermal imaging and create updated, detailed terrain models.

¶ **Mobile sensors:** appropriate mobile sensors should be selected as supporting measurement units and for searching for local anomalies in the watershed. Pairing the sensor with cell phones intended to be used via Bluetooth.

¶ **Legacy data**: next to dynamically generated data, geoscientist generally fall back on legacy data such as terrain models, land usage coverage schemes or topographical data

The following table provides an overview of the data captured in the various scenarios.

Data type	**Sensing method and purpose** ***Nordic scenarios***	**Sensing method and purpose** ***Swiss scenarios***
Nutrient (phosphorus)	Based on real-time turbidity measurement; Nutrient load analysis/control	
Nutrient (nitrogen)	Laboratory analysis (spectrometer) from field samples; Nutrient load analysis/control	
Water level	Pressure gage; Hydrologic and hydraulic modelling	Conventional gauges and test different type of radar ultrasonic devices
Water flow	Same as water level, flow and level are linked with a discharge function	Conventional gauges and test different type of radar ultrasonic devices
Turbidity	Optical measurement with a water quality sonde; correlates with phosphorus concentration, indicates erosion	
Soil moisture		Decagon Sensor on Sensorscope station to measure and model one part of the evaporation process, the runoff process, slope stability and soil-atmosphere interactions and understand their spatial and temporal distributions.
Soil pressure		Decagon Sensor on Sensorscope station to measure and model the runoff process, slope stability and understand their spatial and temporal distribution
Water temperature	Thermistor in a water quality sonde; water quality modelling	aerial imaging to measure, understand and quantify the exchanges between surface water and groundwater.
Air temperature	Thermistor sensor / From National Weather Service; Hydrologic modelling	Sensirion Sensor on Sensorscope station, LIDAR
Humidity	RH sensor / From National Weather Service; Hydrologic modelling	Sensirion Sensor on Sensorscope station to measure and model one part of the evaporation process and understand its spatial and temporal distribution
Skin temperature		Zytemp Sensor on Sensorscope station to measure and model one part of the evaporation process and understand its spatial and temporal distribution
Precipitation	Rain gage / From National Weather Service; Hydrologic modelling	Davis Sensor on Sensorscope station to measure and model hydrological Input and understand its spatial and temporal distribution
Solar radiation		Davis Sensor on Sensorscope station to measure and model one part of the evaporation process and understand its spatial and temporal distribution

Wind speed		Davis Sensor on Sensorscope station to measure and model one part of the evaporation process and understand its spatial and temporal distribution
Cartographic data	Municipalities, National land survey; Background data, hydrologic modeling	Maps obtained via BLIMP (SLAM), general map data. Used for overlay of data / analysis
Elevation data	Municipalities, National land survey; Background data, hydrologic modeling	Obtained via LIDAR, Blimp/SLAM methods, combined with cartographic data

3.3.4 Data storage and processing: sensor network and simulation

Global Sensor Network (GSN) middleware was developed by EPFL during SwissEx project and is continuously extended since then. The Global Sensor Networks (GSN) platform aims at providing a flexible middleware to accomplish these goals. GSN assumes the simple model shown in Figure 1: A sensor network internally may use arbitrary multi-hop, ad-hoc routing algorithms to deliver sensor readings to one or more sink node(s). A sink node is a node which is connected to a more powerful base computer which in turn runs the GSN middleware and may participate in a (large-scale) network of base computers, each running GSN and serving one or more sensor networks.

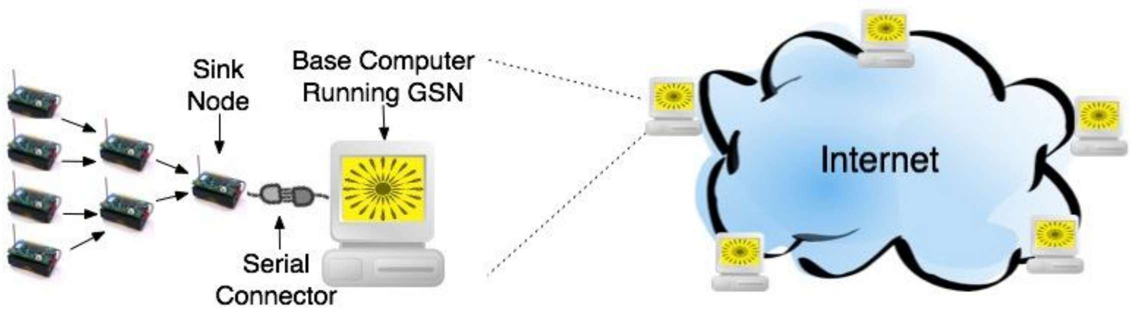
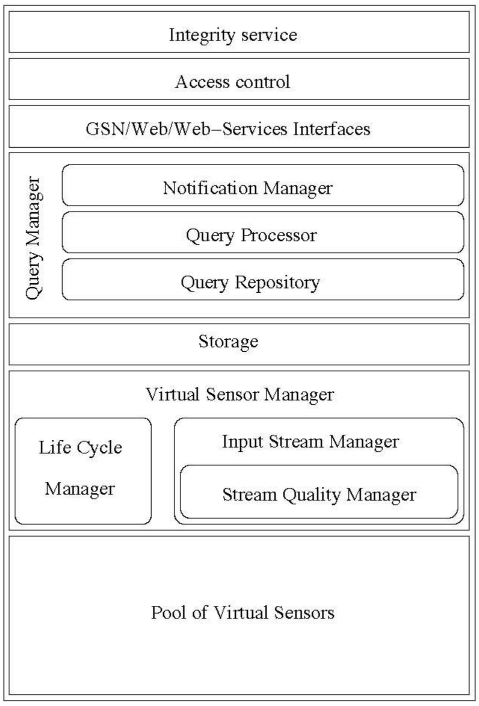


Figure 2: Global Sensor Network

GSN makes no assumptions on the internals of a sensor network other than that the sink node is connected to the base computer via a software wrapper conforming to the GSN API. On top of this physical access layer GSN provides so-called *virtual sensors* that abstract from implementation details of access to sensor data and define the data stream processing to be performed. Local and remote virtual sensors, their data streams and the associated query processing can be combined in arbitrary ways and thus enable the user to build a data-o r i e n t e d ñ S e n s o r I n t e r sensor networks connected via GSN.



A GSN server consists of the following subcomponents, shown in Figure 2:

- The virtual sensor manager (VSM) is responsible for providing access to the virtual sensors, managing the delivery of sensor data (through local and remote wrappers), and providing the necessary administrative infrastructure. The VSM has two main subcomponents:
  - The life-cycle manager (LCM) provides and manages the resources provided to a virtual sensor and manages the interactions with a virtual sensor such as sensor readings.
  - The input stream manager (ISM) is responsible for ensuring stream quality of service via the included stream quality manager (SQM), yet in a simplified way until now, i.e. by dropping outlier values. The data from/to the VSM passes through the storage layer which is in charge of providing and managing persistent storage for data streams.
- The query manager (QM) is responsible for query processing. QM includes the query processor being in charge of SQL parsing, query planning, and execution of queries (using an adaptive query execution plan). The query repository manages all registered queries (subscriptions) and defines and maintains the set of currently active queries for the query processor. The notification manager deals with the delivery of events and query results to the registered clients. The notification manager has an extensible architecture which allows the user to customize its functionality, for example, having results mailed or being notified via SMS.

The GSN has been significantly enhanced to offer new functionality regarding access control, access rights management, simulation management, virtual sensor management, temporal-range querying of sensor data and spatial querying of sensor data. Overall, the use cases diagram of the existing system is provided in Fig. 1 below.

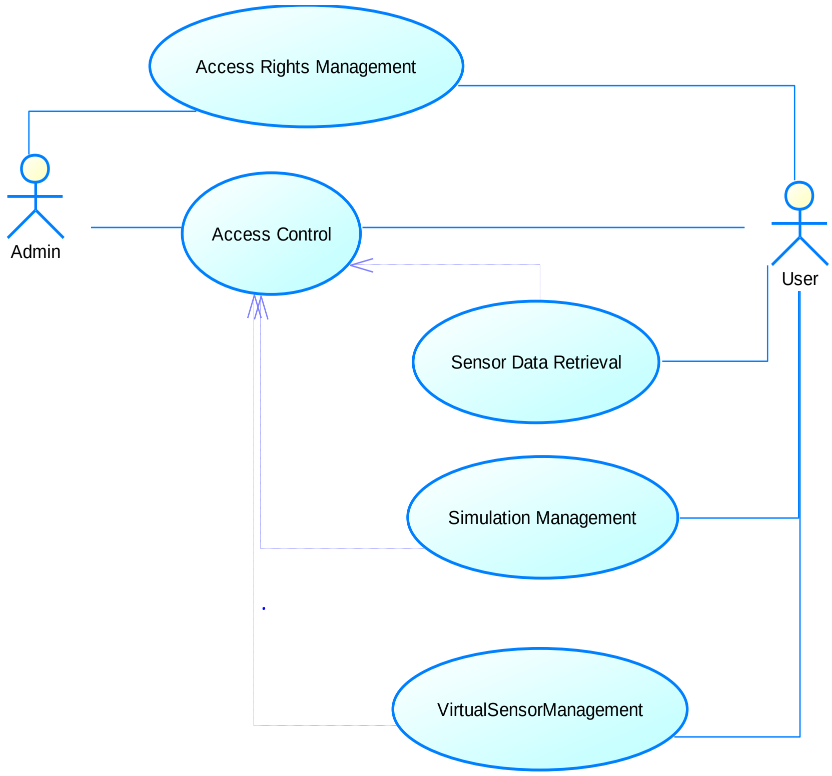


Fig. 1: GSN Use Cases

A number of newly developed GSN interfaces are utilized by other components (described in report D4.2 WP4 final report), specifically:

Interfaces

- HTTP GSN Interface for Temporal - Range Queries
- HTTP Interface for Spatial Queries
- Interface for Managing Simulations
- Web Service Interface for Data Retrieval

Wrappers

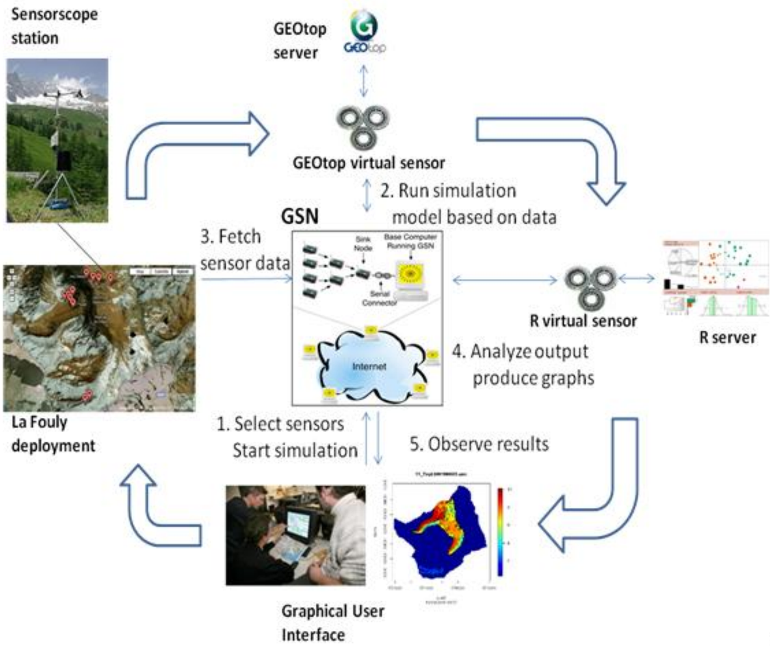
- Metadata Merging (SparqlWrapper)
- Image Support (ImageWrapper, GridWrapper)
- SensorScopeWrapper
- UDPWrapper, push data into GSN through UDP
- CSVWrapper, for importing data from CSV files
- RasterWrapper, importing/exporting raster data from GSN

Virtual Sensors

- Clock synchronization and joining of mobile data sources (UDPVirtualSensor)
- Scriplet virtual sensor
- ScheduledBridge virtual sensor
- ClockedBridge virtual sensor
- DataClean virtual sensor
- GEOtop virtual sensor

Simulation Pipeline

We developed a simulation pipeline for the integration of arbitrary physical models with GSN, as illustrated in the figure below. For example. for GEOtop, we developed a ñ interaction with the specific environmental model that R server (http://www.r-project.org/). Also, a web-based front-end simulation GUI is included in the GSN portal.



The simulation process happens as follows: Initially, the scientist selects the sensors over a geographical region, their sensing period and sets the most important simulation parameters of the model (the rest of the parameters have their default values).Then, GEOtopVS starts the execution of the simulation at a remote server where the physical model resides.The environmental model employs MeteoIO library (http://slfsmm.indefero.net/p/meteoio/) to retrieve sensor data from GSN, filter and complete a certain segment of the sensor data of interest. When simulation is completed, GEOtop VS retrieves the simulation results, stores them and forwards them to R VS that interacts with a R server to execute a visualization R script for producing graphs of the simulation output. These graphs are then stored to GSN, and finally, the graphs of the simulation output appear in the web-based GUI of the scientist. A similar process happens for Alpine3D simulation by replacing GEOtopVS with Alpine3DVS.

3.3.5 Data analysis and visualization: the mobile clients

The mobile clients are described in detail in section 5 and 6. Here, we offer a brief overview of the differences and similarities of the mobile clients.

Similarities

- Data retrieval (Smartclient concept) is similar, though data transfer is optimized for cell phone (network protocol)
- Both systems need to perform pre-processing of data in order to display the content
- The graphics systems in both systems have about the same specifications, leading to a similar graphical/visualization approach based on OpenGL
- Both systems have 3D navigation methods to move through the environments dynamically, even though the augmented reality system is largely laid out for first-person perspective
- Both systems can make use of an orientation sensor to orient a view in a scene (navigation of viewpoint)
- A similar annotation approach is used at both platforms, with a similar protocol

Differences

- Both platforms use 1D/2D/3D visualization, but the handheld additionally has augmented reality visualization, to overlay content over the real environment (video footage)
- Both platforms have a quite different functional approach, structuring the workflow in different ways. This also includes the way the data exploration works.
- Screen management is quite different between systems, due to the size difference of the screens
- The cell phone system has a more restrict resource management to cope with the more complex data sets
- The cell phone holds more environmental details in the model, whereas the handheld depends on seeing these aspects through the video image on which the data is overlaid
- There is a notable difference in the form factor of the mobile devices
- Data handling for sensor data retrieval is quite different between both platforms, offering direct streaming or pull-based data on demand mechanisms.

3.4 Alternative technologies

How does the HYDROSYS system compare to alternative technologies?

This section provides a brief overview of the state of the art (alternative technologies) and how we compare to these technologies with our final outcomes.

3.4.1.1 Sensors and sensor networks

Baseline: Many different systems exist for query planning and query optimization for processing data streams. All of them support receiving data from distributed stream producing sources such as wireless sensor networks. The Aurora[1] and STREAM[2] projects, are based on a centralized model where all processing take place at a single system. In distributed stream producing environment, moving some processing to the sources instead of moving all data to a central system may lead to more efficient set of processing and network resources. The TelegraphCQ [3] achieves this goal by running several TelegraphCQ instances in different machines and each machine, receive the streaming element from stream producers and does the filtering and forwards the results to the other TelegraphCQ node. Therefore, a TelegraphCQ can node receive several filtered streaming data and do the processing on them and produce the output data stream. There is another version of Aurora called Aurora* and Medusa [5] which is aimed to design the distributed version of the centralized stream processor of Aurora[1]. The HiFi [6] system is based on the Telegraph-CQ [3] stream processing system for enabling disparate, widely distributed organizations to continuously monitor, manage and optimize their operations. The HiFi system doesn't address *different type* of streaming data produced by different sensor networks, while GSN [9] does. The Cougar[7] and TinyDB [8] projects both are design for facilitate this process and hide the underlying details by providing declarative query languages for getting the data from a sensor network, and generate an optimized and efficient (in term of communication cost and energy) query execution plan for in network query processing. In GSN [9], they have a different goal: they want to integrate several heterogeneous sensor networks and issue complex queries on them. On the other hand, Cougar and TinyDB projects can be used for efficiently getting the data from the sensor network and delivering it to the seed node which in turn delivers it to the listening wrapper. Therefore, Cougar and TinyDB projects are complementary to GSN.

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Technological advancements and advantages:

As opposed to related systems, GSN open source middleware is a mature technology that is vastly employed for data acquisition throughout the world. Hydrosys has greatly improved the robustness and the functionality of the system. Currently, various different types of data, such as raster, images, etc., from almost arbitrary sensors can be aggregated into GSN and it can be efficiently retrieved by means of temporal or spatial range and aggregate queries. Multiple real-time data sources and historical ones can be fused together and processed in real-time. Also, we have developed support for fine-grained data access control and for enhancing data quality. Moreover, we have defined and implemented a data processing pipeline that makes simulation process completely automated, fast and transparent to the scientist. Our automated simulation tool is fault-tolerant, it limits the space for introducing errors and reduces the data preparation time for simulation from days to minutes. The aforementioned characteristics take GSN way beyond the state-of-the-art.

3.4.1.2 Mobile clients:

Baseline: Mobile GIS extends Geographic Information Systems from the office to the field by incorporating technologies such as mobile devices, wireless communication and positioning systems. Mobile GIS enables on-site capturing, storing, manipulating, analysing and displaying of geographical data. The coupling of real time measurements from a distributed sensor network and Mobile GIS opens up the possibility of mobile environmental information system. Early on, researchers identified the potential of location based services as a means to increase awareness in the general public. Services developed for such purposes provide information on the spot, basically including text and sometimes images, about the environmental situation, i.e. bathing water quality. As an extension, the ability to interact with location based information was added to mobile GIS applications and services. Such services play an important role for on-site analysis, aiding critical decision making with information about environmental processes. They are suited for data collection with online monitoring purposes. Industrial Mobile GIS can already be deployed in low end computing systems like PDA. The current commercial mobile GIS products include, for example, FieldWorker, GPSPilot, Fugawi, Todarmal, ESRI ArcPad, and MapInfo MapXmobile. FieldWorker is used for exchanging information with mobile workers. GPSPilot and Fugawi are examples of traditional 2D maps intended for navigation, although there are nowadays plenty of similar products. Todarmal provides the possibility to create map content (points, lines and 2D polygons) online in a layered manner. ESRI ArcPad is intended for managing point type GIS data, where digital photos can be attached to point information. The ArcPad comes with a support for routing with street map data. MapInfo MapXmobile is a development tool similar to ArcPad, intended for creating map applications.

The presented commercial mobile GIS software and SDK's are based upon **largely static map views**, with **traditional raster or vector map representations**, with overlaid point information and **GPS support.** For map content, the most advanced dynamic feature is that of Todarmal's, allowing run time map creation. In addition, some packages like ArcPad allow creation of point data, and modification of their attributes. The point data is stored onto two-dimensional coordinates, or sometimes to street addresses. These features are supported on PDA's, while their deployment in mobile phones is still limited, or exist only in research project.

Several drawbacks have been identified when deploying Mobile GIS/Location Based Environmental Services for purposes of field-based management of environmental resources. These drawbacks are related to connectivity and visualization issues. Previously, none of the available products supports real-time data feeds, such as input from sensor networks. Also, the data cannot be tied to other elements in the environment; At least currently, limited network access can update the data viewed (see ArcPad), but still, visualization is limited to simple values registered to a map.

Of the non-mobile GIS applications, GoogleEarth has gained a lot of popularity. It presents the environment with orthocorrected aerial or satellite photographs on a 3D terrain. Nowadays, it is also possible to register sensor data to maps or models, such as provided through the SwissEx binding to VirtualEarth. Nonetheless, functionality in these systems us mostly confined to passive viewing of data, with limited interactivity, and potential visibility and performance issues on small devices.

Mobile 3D maps have faced severe technical obstacles, and are still a new field of research. Due to the limited resources of mobile devices, direct porting of desktop applications, or straightforward 3D GIS visualization in general, is not very feasible. Previous work on mobile guides applying client-rendered 3D graphics encountered these problems, where rendering speed was the most visible limitation. Most approaches for client-side rendering have applied direct model viewing, either with PocketCortona or JSR-184.

Finally, existing common mobile GIS systems is slowly starting to support multivariate data, but campring various data types is still limited. Research on complex multivariate data is conducted mostly in the area of Visual Analytics (VA). In the context of geoinformation, the related field is GeoAnalytics visualization (GAV). In addition to the GIS systems in use by professionals or researchers, quite a few services are available for citizens that deal with the sharing of environmental data ï Apple appstore offers a range of weather forecast or other simple environmental data viewers, but limited interactivity.

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Technological advancements and advantages:

The handheld and cell phone platform present several important advancements and advantages over the current state of the art:

¶ **Comparative analysis between 1D, 2D and 3D data**: the systems offer far more advanced ways of comparing spatiotemporal data, by ways of multivariate comparative visualization. Even when mobile GIS systems nowadays offer multiple data layers, comparison of data is often more difficult than with our systems.

¶ **GIS layers**: the way data is dealt with in the handheld system is oriented towards GIS layers. We are able to optimize visibility of layers, and perform advanced exploration. However, traditional GIS layers are more powerful by ways of metadata and set/changing attributes of layers on the fly: This kind of functionality is more bound to desktop systems.

¶ **In-context visualization using video overlay**: the handheld system is likely the first augmented reality system that can handle more complex sensor data sets for environmental monitoring, with improved capacities for understanding data in their real context.

¶ **Perceptually optimized graphics:** the handheld system optimizes some of the visual content to improve visibility, which is especially useful in more complex data sets. Mobile GIS tools, as well as many other 3D systems (and AR) normally do not have these optimizations. In addition, we are able to use methods that emphasize specific elements in the environment, which may be used to direct or aid focus.

¶ **Mobile sensing**: the usage of the mobile sensor allows users to obtain direct feedback while taking manual probes, in a directly integrated manner: data can be fed directly in the 3D representation of the environment shown on the cell phone.

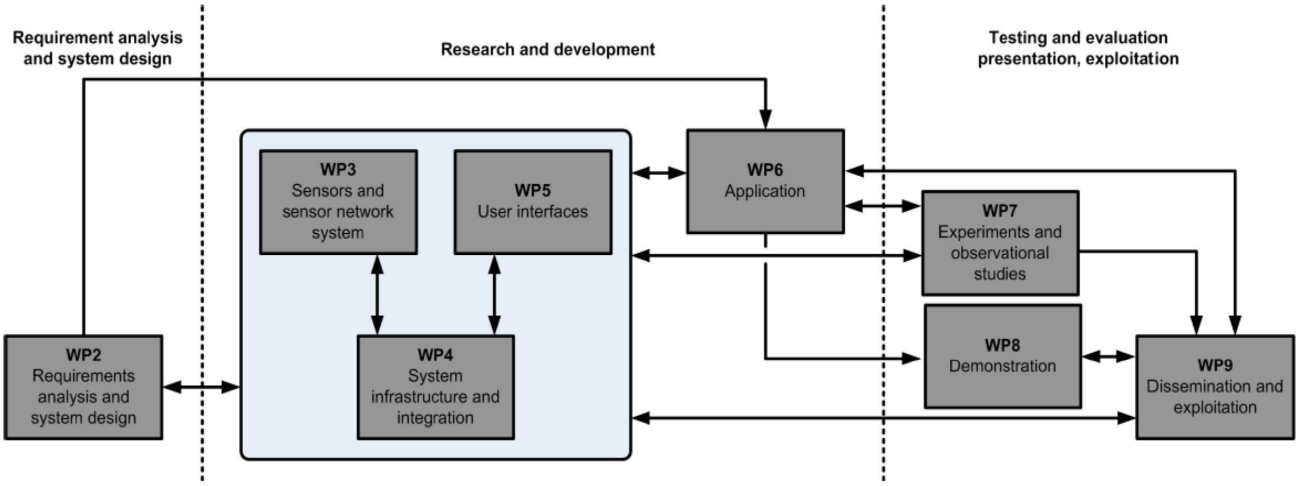
¶ **ñSmarterò and improved collaboration**: the cell phone system makes use of topology based annotations, which binds annotations In a logical way to the environment. Normally, annotations done in mobile GIS systems (as well as general systems) are just bound to location, instead of the underlying structure. In addition, the unified collaborative system in the handheld represents a completely new approach to collaboration, in mobile GIS as well as general mobile systems.

¶ **Ability to handle real-time sensor data**: the platforms are able to handle real-time sensor data streaming, whereas most current mobile GIS are limited in their data update: the majority of mobile GIS systems is based mostly on static data, even when nowadays limited data updates can be provided. The cell phone system additionally is scalable well with regards to data communication, due to their data subscription methods.

¶ **Support for simulation results**: the systems have a far better support for almost real-time simulation results, which is normally not foreseen in mobile GIS systems, that largely use static data (like land usage, etc.).

3.5 Relationships with other tasks and reports

The system components development presented in the document has strong relationships with work in other work packages: the graphics systems in particular closely connect to the user interface which is the higher-level system component binding several other lower level components, in particular the components dealing with visualization (WP3, describe here) and the sensor network (WP4). The user interface framework is described in detail in the WP5 final report. In addition, the work on visualization was driven by end-user involvement throughout all stages of development. This included various demonstration oriented activities that took place in WP8, as well as a number of validations performed in WP7.



Throughout this report, multiple reports are referred to that are useful to read for further reference. These reports include:

- D2.2 Application specifications: the various scenarios and users the system is developed for
- D3.4.1 WP3 second project year report: this report includes an updated and detailed system definition
- D4.2 WP4 final report: developments on the various sensor and sensor network components
- D5.2 WP5 final report: developments and ñappli
- D7.3 Final stage validation report: all the validations performed on technical components
- D8.4 System usability report: various end-user orientation demonstrations to asses higher-level opinions on system directions / results by experts and non-experts

3.6 Guidelines for deployment

What needs to be taken into account to deploy the system?

In order to run the HYDROSYS system, multiple assumptions do need to take into account. Most importantly, the final result of the project is a ***research system prototype**,* not a product. Hence, it holds many prototypical components that have been produced out of a research perspective, however, with a strong connection to the user community, due to the projects significant user-centered approach. As such, its operation depends on several variables, and should under no circumstances be used in mission-critical situations.

The prerequisites can be clearly related to the stages the system is being deployed: there is a need for a campaign planning phase before the actual deployment on-site, which is needed for preparatory actions: the system does not offer ad-hoc usage at an unprepared site. This section lists the major prerequisites in both phases.

Campaign preparation

- **Known possible problem:** a possible problem that needs to be monitored should be known to select the right data / sensor types.

- **Data**
  For the site under observation, data needs to be gathered and prepared. This data includes:
  - **A detailed digital terrain model (DTM):** for detailed monitoring, a recent (hence, up to date) terrain model of around 5m. accuracy is preferable. Depending on the usage of a blimp system that can refine a DTM, this accuracy should already be available or generated by the blimp.
  - **Textures:** for the 3D models being used, up to date geo-referenced textures of the environments are required. If the textures are not correctly references, geo-referencing needs to be manually provided for.
  - **Manmade objects.** For proper visualization for the cell phone platform, manmade structures need to be 3D modeled and textured onto a VRML or CityGML file format, with JPEG or PNG textures.
  - **Sensors:** sensors are required that measure the needed environmental aspects. It should be assumed that these sensors send data by network. The sensor network system should include filters that can automatically handle the received data. Sensors need to be setup and checked that its sending data over the network, and that power is supplied for.. Likely, a sensor company or specialist provides the data pipeline up the storage, whereas the mobile client specialist connects to the storage and transcodes the data in apt formats.
  - **Legacy data:** legacy data often needs to be prepared manually to be included in the sensor network system
  - **Simulation:** If data needs to be processed by simulations, apt models should be available. If the integrated models in GSN are not apt, a new integration should be take care off. Apt computing power needs to be available and serviced once more complex models are used. Simulations need to be prepared / started before the on-site monitoring action takes place.
    - **Fast servers:** it is often required to have fast servers available to run the simulations. External services may need to be hired if these servers can not be maintained internally.

- **Data handling**
  For the handling of complex data sets, several issues need to be taken into regard:
  - **Data naming conventions**: Data should keep itself to naming conventions.
  - **Data transcoding;** it should be checked if the data sent by GSN can be processed by the preprocessing system. If this is not the case, new transcoding / data preparation schemes should be provided for.

¶ **Mobile system preparations:** the handheld system software needs to be prepared, which may overlap with the profiles, but may also include adding icons for data selection once the current set does not hold the new data type.
  - **Profiles**: profiles may need to be defined which state, for example, the location of servers and other technical parameters
  - **Localization accuracy:** the mobile systems depend on localization of the user. It should be checked if enough satellites can be seen by the GPS system or if an alternative system needs to be used to correctly localize users with handheld computers.
  - **Cameras:** a d d i t i o n a l ñ r e m o t e ò c a m e r a s n e e d t o b e into the system. They may also require specific setup procedures (for example, related to network and power provision)

General preparations: several general preparations (or issues) need to be taken intro regard:
  - **Network coverage:** a network coverage indication is required, both for sensor communication and the usage of all mobile devices. If only low-bandwidth network is available, an alternative network system (such as a WiFi bridge) should be set up. The setup of these kind of connections may require an external service provider.
  - **Transportation:** some equipment, such as the blimp and the tracking system, requires transportation planning and possible extra storage
  - **Setup time:** the blimp requires a setup time before it can be used
  - **Weather:** weather forecasts should be monitored, since some equipment cannot be used under bad weather conditions (particularly the blimp)

On-site monitoring

¶ **Sensor-display devices:** mobile systems need to be available with apt sensors (camera, tracking equipment) to show the visualized sensor and simulation data. Computers need to be powerful enough to

¶ **Additional tracking devices:** when needed, additional tracking devices may need to be taken

How long does it take the setup the data pipeline?

Setting up a complete data pipeline, especially using simulation functionality can be a more complex process and may require specialists. There is a good level of configurability and automation in the sensor network and the mobile clients, but parameters need to be set /adjusted to get the whole pipeline to work. For a simple pipeline, this may take just a few days, whereas for complex systems, this can easily take weeks, or even longer. We offer configuration tools to aid in this process, but, as said, it may require a specialist to aid in the process.

What are the hardware costs?

If we look at the data pipeline, we can identify several cost categories, of which we can roughly claim the various costs. However, it is almost impossible to give a complete picture, since it largely depends on available hardware and personnel ï in particular support services may be needed that can absorb finances quickly if no local support is available

¶ Sensor-stations: sensor stations such as the sensor scope cost roughly 8000-10000 Euro. Hence, for larger sites with a dense network, costs for setting up a network of several stations can cost roughly 50.000 Euro and upwards. Specialized sensors may be much more expensive, which differs from case by case.

¶ Servers: servers for storing data are a common modality and can be bought from 2000 euro on. Support for larger data sets, and/or integrated back-up solutions may run up to 10.000 Euro for simpler systems. With regards to simulation, fast servers might be needed that can range anywhere from a simple server of around 2000 Euro up to a cluster of computers that may skyrocket in costs. For the latter, specialized services (expert personnel) is likely needed.

¶ Mobile clients: whereas the cell phones are a likely affordable modality for most users (a smart phone costs around 500 Euro), the handheld augmented reality setup is more aimed towards specialists, with a total price around 4500 Euro per setup. It is expected that in the future, with industrial involvement, prices will drop to around 3000 Euro. Still, these prices reflect usage by specialists.

Is it difficult to maintain?

To maintain the complete data pipeline, specialists with different backgrounds are likely needed to team up: specialists for setting up sensors, server maintenance, and networking are the most likely persons that need to be involved. In research institutions, support is likely available, but for other users (government, etc.) specific services may be needed provided by external provides. Depending on the complexity of the maintenance and the kind of service, the costs may run in thousands, up to tens of thousands of Euro. It is very difficult to estimate costs, since it largely depends on a case by case basis.

3.6.1 Limitations

The system presented in this document is the outcome of a research project, and as such should be regarded as a research system prototype: it is a solid proof of concept which has run in real usage, but naturally, the system is prone to limitations that are inherent to this kind of system. Below we list the main limitations and, where possible, directions on how these limitations can be coped with, or even solved in the future. We also list general limitations here which are not in direct relation to the limits of a research prototype, but are seen more from a requirement point of view that may not be matched by any potential end-users.

Data gathering

¶ The systems are laid out for monitoring of small sites, which also requires that a more dense sensor network needs to be deployed. End-users may not have the capacities to maintain (or even afford) such a more dense sensor network.

¶ Sensor networks need to be checked regularly ï they depend on network connections and power, which may drop away. It may happen that remote sensors cannot be corrected when areas are not well accessible, leading to po
sensors networks are less prone to this problem.

¶ Some sensors cannot be deployed under all conditions ï this includes in particular the blimp (wind) or the vehicle setup (accessibility of the vehicle, blocking of roads).

¶ Sensors may need frequent physical maintenance (such as cleaning).

Data pipeline

- The data pipeline, though working remarkably well, requires regular check-ups to guarantee data delivery. Most of our sensor network systems are under general usage, but also are changed by updates or other manual changes. Changes may disrupt the pipeline, and may for example require changing profiles at the mobile clients. The maintenance of a complete data pipeline likely requires experienced users for administration. At current, the system is not intended and useful in any mission-critical system situation, since stability could not be guaranteed for these situations. It needs to be noted that the system was not intended to aid in critical missions, but would rather be useful before and after such situations (flooding, avalanches, etc.).
- Whereas the data pipeline offers a great improvement in partial automation, some data still needs to be handled manually, or may not be directly available when, for example, a user forgets to start a process (simulation data update, plot generation). Though transcoding aids are available, data handling still requires a manual step, for example to put simulation and plot results in a predefined directory.
- In our current system, we also optimized our pipeline through preferred file formats of data type (Arc Info Grid for DTM, GSN for Sensors). Extending the system to more directly support other standards (such as SHP for vectorial data or OGC SWE for sensors) will deliver a more efficient pipeline, more portable solution and extend the applicability of our solution to other areas.
- The simulation extensions offer a good basis for performing various simulations and can well be extended over time to support other simulations/physical models. Due to the nature of simulations, though, it cannot be guaranteed that every process can be simulated ño box Exploring more complex and hybrid solution of a three-tiers architecture (storage, processing, presentation) will leverage a more robust solution, handle more complex solution and will help to further analysis of datasets on site.
- The data pipeline depends on networks. By nature of networks, in particular in more remote areas, disturbances in communication may occur that affect data communication from sensors to sensor network (storage) or from storage to mobile client. Similar, general problems that limit accessibility (like those associated with firewalls or other network security) may occur.
- The unified annotation and multi-camera system has been tested with smaller numbers of cameras and notes. It is likely that network protocols need to be optimized if larger numbers of cameras (multiple sites) or large number of notes (example: tourists taking notes) since it may not be digested by the current system.

Mobile clients

- The mobile clients are low-performance devices. As such, only models / sites of limited size and density may be included. Larger sites that have to be loaded with a lower resolution accuracy (resolution of the grid of the terrain model) automatically result also in lower accurate registration of information. Generally, we can load models for small sites that have a 1-2 meter resolution, but for large sites (like long valleys of around 10km), resolution may drop to around 10 meter accuracy. It would be beneficial to have a mechanism for dynamic loading of different resolutions (a sort of level of detail on the terrain model), but this has not been included in the handheld system since it involves complex memory management. Similarly, if the resolution of a underlying DTM drops down, localization of users is of limited use in the field, though may be useful for recording data (notes, video, manual samples) for use in the office. Here, likely a more detailed model can be used for registration due to computationally more powerful systems. For the cell phone platform, the preprocess automatically takes care of the level-of-detail management of the underlying model and detail. It is not limited by model size due to its out-of-core rendering scheme, but the 3D models need to be preprocessed.

- As a result of the limited capacities of the mobile clients, we currently do not offer switching between local and remote sites, since the data handling would become extremely difficult. This function was not directly intended to be supported by the system, but would be a useful extension – it is likely feasible and useful in particular for a desktop system.
- Mobilie clients are also limited in term of graphics capabilities which will allow more complex visualization techniques. For example, offering more complex way to mix the virtual content with the real one needs advanced algorithms -time performance on not current devices.
- This even more truthfully regarding time-varying datasets: offering for example simulation of snow falls using animated 3D mesh may be relevant for the end-users but difficult to handle through the devices used along this project. A trade-off between benefit of more recent state-of-the-art devices and implementation of efficient rendering algorithms will help in this matter.
- The sensors attached to the handheld system may be affected by external conditions, even when generally this is not the case. The cameras have a limited range of operation - for example, very bright or dark areas result in limitations in visibility. Orientation sensors may be affected by large metal constructions that would lower its accuracy, whereas GPS sensors require enough satellites in view to work properly (which may be covered by mountains, cloudy sky, etc.). The project offers alternate tracking methods that are intended to offer for a more robust tracking by using additional sensors, but the system is still a research prototype, even when it significantly aids localization. For example the horizon tracker is still prototypical and needs to be optimized to work on the handheld.
- The hardware of mobile clients, in particular the size and quality of the screens, as well as the overall size of the handheld computer setup, limits field usage. On very bright days, screens are almost unreadable outside, even though partially "outdoor di With regards to the handheld setup, we have minimized the size of the setup over time to the best possible extend within our current limitations (sensor sizes/housing and cabling in particular), but it is still large due to the external sensors. Some users will find the setup too large to take into the field. Both issues require further industrial efforts to be solved – in particular better outdoor screens are expected to emerge soon, under pressure of the usage of smart phones and tablets in outdoor situations. Finally, screen size limits readability and visibility of information. The more complex data sets are, the more difficult it will be to make a comparative analysis. The current mobile clients offer several ways of dealing with more complex data sets and their inherent issues (such as clutter), but there are simply limits caused by the dependency of screen size and the human visual system capacities that is likely to differ between users.

4 Achievements

4.1 Overall achievements

HYDROSYS has produced a number of highly advanced system components that have been integrated into research prototypes that have actively been used in the

> **Further reading**
>
> This section introduces the higher level outcomes, which are detailed further in section 4.2, as well as reports D4.2 and D5.2.

office as well as in the field. Whereas this report highlights the various outcomes of WP3, we would like to start with a general overview of the main outcomes of the project, to place the more detailed outcomes in a ñframe of referenceò.

The overall outcome of the HYDROSYS project can be described as **a research system prototype supporting on-site monitoring and management of environmental processes using handheld display devices.** This system builds atop the notion **of a shared information system fusing heterogeneous data sources that supports teams of stakeholders to monitor environmental processes on-site, complementing remote monitoring and management in the office.** This outcome can be seen from various perspectives, holding components that enable new ways of gathering data, methods to support the handling and processing of data in the field, as well as ñsystemsò that aid user field. As such, we can describe the following higher-level project outcomes, and other main issues that have been important to achieve these outcomes. The identified outcomes are detailed in this report (see section 4.2) as well as in reports D4.2 WP4 final report, and D5.2 WP5 final report.

¶ **Data pipeline:** though this project did not focus on a *fully automated* pipeline between sensors and mobile clients, we ended up with a prototypical but well working pipeline: the level of integration between the various components can be considered high, if one takes into account that the outcomes of the project are directed more towards proof of concept. In particular the sensor network system / extensions are regularly used, as a result of the longer availability of GSN throughout the years: some partners have been using GSN in various projects, hence the usage of the new GSN components has been quite a smooth introduction. As such, the new tools developed within the project are gradually improved and introduced to end-users, with generally very positive feedback.

¶ **New data acquisition methods:** we developed several novel data acquisition methods that have received positive feedback from geoscientists as well as technical specialists in the field of aeronautics and human-computer interaction. Both the blimp-based reconstruction and thermal imaging methods and the mobile sensor where seen by end-users and specialists as useful extensions to the project that could be well applicable in many situations.

¶ **Advances in sensor network:** the GSN sensor network has been a stable platform for sensor deployments. In particular in the Swiss scenarios, the deployments build atop previous experiences with the sensor network system, which has been successfully extended to tailor special needs from HYDROSYS, as well as provide components that are very useful for other projects deploying GSN sensor network. Next to new and useful components such as the access management and the data cleaning functionality, in particular the new simulation framework is big step forward. Most end-users have confirmed the usefulness of the data pipeline improvements.

¶ **Advanced mobile systems:** the cell phone and handheld system application represent the forefront of mobile interactive visualization and aid the spatial analysis of environmental processes through context-sensitive methods, aiding in real-time decision making processes. The prototypes represent novelties in what is generally possible with interaction and visualization-wise, but also in particular when comparing with mobile GIS. The systems represent functionally extensive and well structured clients with, for the small platforms optimized visualization and interaction techniques. Additionally, we offer improved localization for users, of which the spatial registration of information benefits. The systems have been tailored towards *improving the analysis of environmental processes*, which has been positively confirmed by end-users.

¶ **Systems applied in real-life scenarios:** The overall system architecture provided actually *works outside the lab,* which is a very good feature for a research system prototype. From the start of the project on, various test deployments and monitoring exercises have been performed to test and demonstrate the systems

¶ **Important validations:** The validations we performed have been basis for multiple developments and publications ï most validations have been extremely useful and discovered, in some cases, state of the art research results. Examples are the various visualization-centered (perceptual) tests, as well as the multi-view cognitive validations.

¶ **Positive feedback on impact:** the outcomes have been largely reacted positively on. Whereas some results are tailored towards usage by specialists, we received in general positive feedback on usefulness, technical soundness and usability.

¶ **Great outreach:** The outreach we generated in the project has been quite extensive and has found a lot of positive resonance. In general, we surpassed the initially set quantity and quality of outreach, varying from the number of high-quality publications and presentations, up to the number and size of high-quality public and research events.

The systems provided by HYDROSYS can positively affect (impact) environmental monitoring by offering a more advanced mobile GIS tool than is currently available, but it also affects positively the various technical sciences that have contributed to the development of the systems. In the detailed achievement sections available in this report (section 4.2) as well as in reports D4.2 (sensor network achievements) and 5.2 (user interface achievements), we go into detail on how the results are useful and could impact future work and activities.

4.1.1 Overall technical usability and usefulness

Further reading

This section summarizes the technical usability, which is detailed in report D8.4 System usability report.

As a result of the various system usability assessments, we can report positively on the usability of the applications and underlying technologies: we could show that the applications could be a practical tool for many end-users, even though the applications are still research prototypes. The applications are, however, not a tool for every end-user per se: not every geoscientist will find benefit in using the system, since its task domain is quite focused.

What has been a continuous issue in the evaluation of the applications is the general comparison to applications on smart phones: for the handheld platform, it is often difficult to compete with simpler but ñfancierò applications. Additionally, users cannot compare to any other mobile tool, hence, do compare mostly on a functional and usability level to desktop tools: of course, this is difficult to assess. In the future, it would be interesting to compare the tools side by side to a similar mobile GIS application ï unfortunately, such a comparison is difficult to achieve at the moment, since approaches and functionality differ too much.

General usability: the general usability spanned from good to excellent. Most system concepts were very much appreciated and were well usable, though often users require more time to use the system. Currently, the systems are very well usable by expert end-users, but still research prototypes: even though the applications are powerful, it would require modifications or services to truly use the systems in long-term usage scenarios by themselves. As such, we can only make assumptions on the numerous short-term assessments we have made. Also, the handheld system seems less useful for less-specialized end-users: this is more the domain of the cell phone application. Specialists in the field of human-computer interaction acted positively on the implemented user interface methods and workflow structure.

The effects of user background: user background often has an effect on the ratings we achieved. Users that were going more often to the field generally reacted very positively to the demonstrated systems, whereas office-workers did see the applications positively, but mostly rated them good but not excellent. As such, it can be stated that the applications are very good for most (but not all) specialized users: it really depends on the users activities. In the long run, some effects (such as smaller hardware) are expected to lead to further interest by also the more skeptical users. Nonetheless, users at all levels (from field worker to governmental decision makers) have expressed that the usage of these kinds of tools are the way for the future.

Sensor setup and maintenance: using the system during sensor network setup and maintenance is generally seen very positively, in particular with respect to metadata that can be retrieved, as well as the (mentioned during monitoring) way of annotating problems when they occur. A side effect which was also noted positively is the ability to communicate with remote users, for example to be able to fix a station.

On-site monitoring: for those users that have a generally positive stance to on-site monitoring, the systems / approaches are generally seen positive on. Often, users express they would like to use the systems, though in general, some modifications would need to be made (modular software, smaller hardware). Almost all users could see some benefit of using the system.

Management tasks: using the applications for management-oriented tasks was seen with mixed perspectives. Users expressed themselves positiv scenariosò, but did not see the -critical systems. Whereas the ap collaborative aspects of the applications, such as annotations, were reacted very positively on, the applications were not seen as useful in mission-critical assessments: users could not imagine using the systems in real urgencies, such as emergencies in avalanches situations or floodings. It should be clearly stated that from the start of the project on, this was also not seen as goal or priority, even though we believe that the next level of more mature applications could potentially be useful in these situations.

Data pipeline: the data pipeline was seen positively on, even though it would require a long-term assessment to really understand its full effects. Some users also are already using advanced systems, for which reason it is often difficult to assess the step forward. The sensor network system in general is used widely by now, but the full data pipeline and its effects (from sensor data to storage and simulation to usage on mobile devices) is mostly understood well by the developers, and can be understood by end-users, but would require more -users to al us see its true advantages.

Visualization approach: the usage of mixed representations was seen very positively. Many users reported that using the mix of 1D, 2D and 3D representations was very useful, and comparing between them seen as advantage. Augmented Reality was seen positive on in general, but sometimes users also reported they could do without. 3D in general obtained a more positive stance upon over time, even though there are still users that do not see its advantage. Some issues in readability/visibility were noted ï they improved over time due to new methods we applied, however, there are still some technical limitations in outdoor situations (see below). Specialists in the field of computer graphics confirmed the usefulness and novelty of perceptual optimization approaches.

Learning curve: in particular the handheld computer platform requires some experience: the application is quite complex and tuned more towards usage by experts. The application generally has good to excellent usability, but there are numerous functions that are seen as useful, but require some training. Most users reported they expect to either be able to learn them quickly and/or see the good potential for applications that have just the func
event.

Technical issues devices: many users still noted the form factor of the handheld system. Even though the reduction of size was reacted positively on, in general users prefer small devices to take in the field. In many cases users would not take the big setup, even though informed on the technical requirements (sensor quality) which need to be guaranteed. Within the project, this project can not be solved, since it requires a more industrial approach to create truly small devices with high-quality sensors. A second issue that often played a dominant role is the quality of the screens. In outdoor situations, especially at bright days, most displays are hardly usable. Fortunately for both issues, we still a fast-paced industry taking up: more and better sensors are being put in smaller devices, and screens improve considerably. As such, these problems are expected to be solved over time, likely within the next few years.

4.2 Significant outcomes particular for WP3

The HYDROSYS project has produced a range of outcomes that are unified in what can be called *a research system prototype supporting on-site monitoring and management of environmental processes using handheld display devices.* There are a multitude of components that contribute to this system, of which a number are described in this report. In one of our earlier reports we structured the various outcomes. The outcomes that describe the various components that have fully met their objectives. We describe how the components can positively affect future developments and usage, and provide limitations were necessary.

S0. A research system prototype supporting on-site monitoring and management of environmental processes using handheld display devices.

> **Further reading**
>
> This section includes a general summary of outcomes according to the structure provided in document D9.2 addendum. It is recommended to read this document, or the publicly available document (website) called

The research system enables end-users to analyse environmental processes and their effects in their actual context, by providing interactive visualizations of quasi real-time sensor data shown at mobile display devices. A dense information space is built up: the system binds sensor data and the actual environment in a unified manner, thus creating the actual context for the data. The methods, the *spatial analysis tools,* allow end-users to analyse in particular those processes and events that cause environmental degradation. Till date, many of the processes are not well understood because of the complexity involved. The system is expected to aid in better understanding these processes. Of particular advantage is system mobility and usage of multiple cameras dispersed at the observed site: users can analyse the data from multiple perspectives, getting a better understanding of the outlined problem area.

To develop these methods, a deep understanding has been created on the actual principles of on-site monitoring and management, in relation to the work normally performed in the office. The system is meant to complement office work, not to replace it. This understanding of the work principles has been strengthened by continuously involving end-users in the different stages of the project, in particular in the on-site applications (campaigns) of the system, by taking a strongly user-centred design approach. On-site monitoring and management encompasses several activities related to prediction and decision making in the field. Users can analyse environmental processes, and make predictions of its effects based on both simulation results shown by the system and the knowledge acquired by seeing the quasi real-time sensor data in its actual context. Hereby, a very useful outcome is the testing of on-site modelling in practical use: HYDROSYS provides the possibility of both accessing simulation results from the field and visualizing the simulation results, or even perform simple simulations ad hoc, while in the field.

Based on the acquired knowledge, interdisciplinary teams of users can cooperatively discuss their interpretation of the processes, and possibly come up with solutions or plans that may limit environmental degradation. Assumptions and possible mitigation plans may be checked by visiting the site in regular time intervals. Hereby, the system complements office work, by allowing interplay between activities in the office and in the field. The premise of the system consists of a common platform that integrates data acquisition from static and mobile sensors in the field, data storage and processing of the sensor data, and the final data visualization and analysis functionality provided at the mobile devices, being either handheld computers or cell phones. The two display platforms represent both a functionally more straightforward approach, but therefore more mobile approach using the cellphones, and a more functionally encompassing and complex approach using the handheld computers. The platforms are tuned to the varying end-users needs regarding functionality / tasks in the field. The system binds different data sources and can share the data among many users. The system as envisioned in this project does not exist to this extent: at current, the most advanced mobile systems used for on-site work predominantly make use of non-contextual visualizations of mostly static data and very limited functionality that hardly supports effective decision-making. Nonetheless, the project outcome should be seen as a *research prototype,* not as a fully operational ñproductò with associated ser

S3 A unified data pipeline

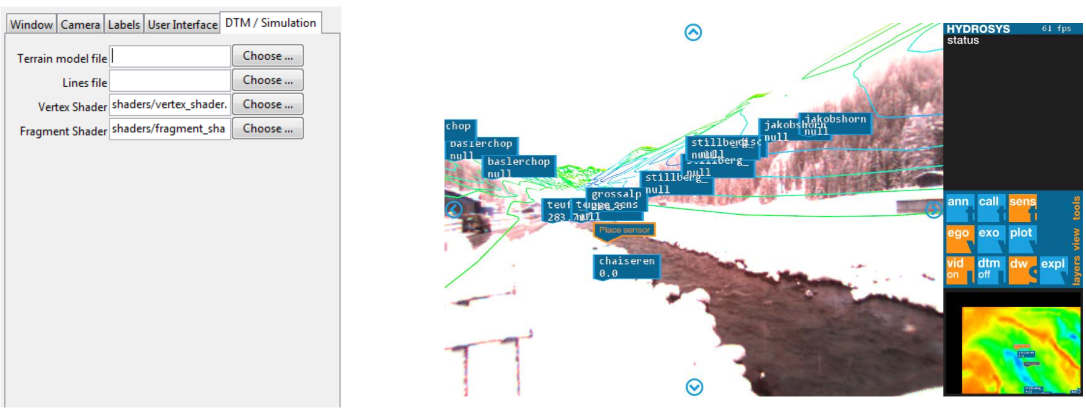
Aalto planned to incorporate Microstation CAD data sets, often used in municipalities, to the HYDROSYS data pipeline. Unfortunately, this was not deemed useful. The data sets now include a pipe from 3D models in VRML and CityGML formats to the binary formats used in the cell phone. In addition, a pipeline was established from national LIDAR data sets, where rudimentary data categorization has already taken place. These sets can now be transformed to the mobile platform. The system needs to deal with noisy data, where both accuracy and categorization are insufficient and filled with errors. This pipeline was implemented using Computational Geometry Algorithm Library (CGAL). Unfortunately, CGAL was not well documented and did not support necessary data types. These were created, and CGAL was improved significantly to support LIDAR data. This tool set was released as open software, conformant with CGAL licencing.

> **Impact:** the provided data pipeline eases the set up of services considerably, easing the management of data sources.

B5. Pre-processing functionality to support the handling of complex data on handheld display devices with limited performance, and C1.2 Graphics optimization methods for low-performance platforms

Handheld: HYDROSYS makes use of different kinds of mobile devices that only have limited processing capacities , both for processing data (CPU) and graphics. In order to interact with the graphics on the mobile platforms, sensor data needed to be optimized at two stages: the data is pre-processed before it is sent over the network, and optimized during display time.

Pre-processing optimization takes place at different levels, from the moment the data is received on the SmartClient till it is sent to the mobile devices. Once the data is queried and received at the SmartClient the first step is to transcode the information from the exchange format onto the graphics specific format. This allows us to reduce unnecessary transport information to a more compact display specific format such as Open Inventor. During the generation of graphical primitives the data may be further filtered, for example, the density of a DEM point cloud can be reduced to lower resolution sampling (e.g. from a 10cm LiDAR DEM sampling to a more manageable 20 meters display DTM model with the associated simulation results). To aid in the process of optimizing some of the data, in particular the terrain models and simulation data, we offer a tool for the handheld platform that automatically produces optimized data for the system. This includes optimized simulation overlays, among others for improved visibility (example: usage of isophotes, which improves visibility even with more limited size textures)



Data production tools for handheld system, optimized visualization using limited size textures

Data filtering does not always infer a quality loss (as in the case of data reduction) but it may also involve a partitioning of data depending on user location, i.e. only the data associated with the current userôs location is sent to the mobile cl configurable depending on the location and current task.

The final step for pre-processing is the transmission of the data to the mobile devices. Here too, there is an optimization step. This involves converting the data to a binary format that reduces the network consumption on the cell phone, although it does not directly affect the graphics performance.

After data has been successfully received at the mobile devices, further optimization is necessary. These techniques are characterized by being tight and decisions such as viewing angle, occlusions and current task. Level of detail techniques (LOD) on the cell phone allow the system to use the graphics resources unevenly, by reducing the quality of lower important data patches. Possessing heavily occluding features, such as the DTM, allow the system to determine the visibility of objects and whether or not they can be excluded from the display.

The rendering of graphics is also tightly coupled with the hardware restrictions of the mobile devices. In the case of both the UMPC and mobile phones, a special care has to be taken on the management of texture units. Typically, the usage of textures enables the system to boost performance by mimicking more complex data, in reality, however, this heavily depends on the capabilities of the graphics devices. In general, this level of optimization is based on the graphics API upon which weôre based: OpenGL. By fitting ou of OpenGL (such as by using Vertex Buffer Objects, and by minimizing state changes) we increased the performance of our application.

Cellphone: Raw data sets are not suitable for direct use on mobile devices, and need to be optimized and arranged to device friendly ways aimed for optimization of data. Aaltoôs mobile and data representation. The HYDROSYS data sets are incorporated to this *in-house*

development with a possible *software release* (**S2.1**). Aaltoôs approach here is standard for digital 3D assets, where a standard defines the form of raw data sets, but which are processed to useful formats suited and optimized for each application. Aalto *demonstrates* and leverages this view actively in other standardization bodies such as the Web3D Consortium, which oversees the development of the X3D standard.Management and optimization of raw data sets was improved throughout the span of HYDROSYS.

Aaltoôs processing phases were improved throughout the HYDROSYS. Optimization and compression of 3D models for mobile use was improved beyond state-of-the-art level. A stage for including LIDAR scan data sets was implemented to facilitate scalability, where very large areas can be input and processed for use in HYDROSYS. A data set from the Kylmäoja site was acquired from a national data bank and used as a test case.

> **Impact:** The developed techniques aid significantl basedö data sets in the site access and analysis of environmental data. The developed techniques are generally useful for low-performance platform developers and computer graphics scientists. However, the current transcoding tools are tailored to our specific data sets and may need to be extended to be fully functional for other data sets too.

C0. Techniques to support the interaction with in-context visualizations of environmental data, to analyse (monitoring), predict and discuss effects of environmental processes with co-workers, to come to possible solutions mitigating environmental degradation (management).

The research prototype system encompasses a range of functionality to support the tasks involved in monitoring and managing environmental processes. This functionality is centred on the interaction with in-context data visualizations, that is, the data representations that are directly related visually to the locations they refer to. Different kinds of visualizations can be generated, based on sensor type and visualization method (numerical, graphs and overlays/maps), and are optimized to for example direct the attention of the user to a specific area or event (desktop-only). The visualization is optimized to support the limited graphics possibilities of the hardware platforms.

The dependency on in-context visualization requires accurate localization of users using the handheld computer (around 1m accuracy), which is provided through a hybrid tracking system that can rely on an additional support vehicle holding a high-accuracy localization system (see WP3 final report). The functionality to support the userôs actions consist integrated into a single user interface. Depending on the handheld platform (handheld computer or cellphone), the user accesses the full or a more limited set of functions. These modules support the **selection of data and visualization formats, and allow the access to simulation services**. The data can be **viewed from different angles**, by either walking around the site and receiving data visualizations adapted to the users viewpoint, view a 3D model from different sites, or observe videos from remote video cameras. The functionality enables to analyse the data, outline its problems, make predictions, and possibly find solutions. These processes can occur in a **cooperative** manner, by supporting communication and data exchange between different users in the field and in the office. Users can thereby note down their results in an effective way using geo-referenced notes. Both user interfaces and graphics representations have been perceptually optimized to ease the potential load on the user to deal with complex data and quite some functionality, all displayed and used on a small display.

> **Impact:** The interactive visualization systems have been positively received by end-users, confirming their usefulness and technical approaches. Both user interface and visualization techniques developed in the project represent the state of the art of what is possible, and have resulted in a number of very well accepted publications. In general the methods are of use for any mobile device developer that has to deal with more complex data sets, and potentially outdoor situations.

C1. Visualization techniques for showing complex and multivariate environmental data in their actual context

Within the context of HYDROSYS, around 25 different sensor data types can be visualized that may differ both in representational method, and complexity. The sensor data is varied and comes at different frame rates, in different formats, and in multiple dimensions, for example, temperature readings are uni-dimensional and come at roughly 0.1hz, while wind direction is three-dimensional and comes at roughly 20hz, while some sensors are of proprietary technology and come encoded in special formats ranging from text outputs to voltage readings.

The visualization techniques developed for HYDROSYS provide to the user a concrete representation of the abstract data delivered by the sensors and simulation. This visualization aids the user to understand the data that typically comes just as a collection of numbers. The final techniques have been optimized to run in the low-powered mobile outdoor devices for this project.

Users can see the data delivered by sensors and simulation in a near real time fashion while they are on the field. While on the one hand sensor data can be seen as a single geo-referenced label, simulation on the other hand is a point cloud dispersed around a large area. Simulation data is far more complex and dense, but nevertheless can be shown in real time, and even is perceptually optimized. For example, at the handheld system we offer various other techniques, such as isophotes or the usage of transparency. The limitations of this type of visualization may be higher, as images might need to be generated immediately after data is available. This includes not only incoming sensor and simulation data, but also tracking and video information (for the handheld system). Such fast generation of graphics allows the system to present to the user an augmented view of the world that closely relates its current physical state, called **in-context visualization**. This kind of data visualization allows contrasting digital information coming from sensors with the current real state on site.

At the handheld, labeling generation is a solution provided for single sensor data visualization. Labels are typically thought of as containing textual information on the sensor values, but this is not the only type of information that is available. Next to textual labels, we also offer numeric overviews of sensor data by station or type, graphs or plots. The latter two are not sensitive to the environment, but coupled to the station as directly linked information or can be browsed by sensor data type. Furthermore, we include notes (annotations) and cameras, that can be browsed too within the view. The potential problem for dense ñoverlappingò, ñclutteringò are data just some examples of the possible issues users will face when exploring more complex data sets. We offer several methods to get around this issue, being **spatial filtering** or the usage of **various viewpoints** that ñpull apartò the data.

> **Impact:** The visualization techniques developed for the environmental monitoring applications have been found very applicable for doing on-site monitoring, by supporting the comparison of data in 1D, 2D and 3D formats: end-users reacted very positively on their availability and format.The developments being made can be very useful for computer graphics scientists and developers that develop for limited performance platforms such as cell phones, tablets, and ultra-mobile computers. Often, applications ate these platforms are limited by the complexity of their data sets one can explore. We offer various methods that could be useful for systems, in particular those systems that deploy **location-based services**. Still, there is a limit of what is possible in complexity of data sets in the mobile devices.

C1.1 Focus and context techniques: Attention-direction techniques for focusing the user on specific events, and occlusion management

Handheld: Within the mobile systems, we experimented with several so-called focus and context techniques. At first instance, we worked on several attention direction techniques. Attention direction techniques are used to guide the userôs eye sight to areas t interest. For example, users can be pointed in an unobtrusive way to a specific part of a scene that may hold a specific problem.

Techniques have been developed that can direct attention by using saliency modulation. This method can best be understood as a unnoticeable modification to certain aspects of a scene to make a specific part more prominent in view, without the user actively noting it. Throughout the project, we have performed a range of experiments, thereby also deploying eye tracking mechanisms to assess in detail the workings of the techniques. As a result, we have developed techniques that have been successfully used on video-based systems to either draw attention of a user in general, or specifically modify scenes to improve memory recall. The latter, for example, is of high interest to navigation systems. We produced several important papers that address the various issues in the framework for augmented reality (video-based system), which have been received well by the community, showing visualization techniques at the forefront in the field. We defined useful methods that can be used by the community, and clearly showed the perceptual and cognitive factors involved. We also included multi-pass rendering functionality in our system, building atop the methods developed for focus+context techniques. The multi-pass rendering is used for various perceptual optimizations (see C3). The major drawback, however, is the computational need: the focus + context techniques work mainly on the desktop, since the mobile devices are simply not up to par due to the lack of a GPU (graphics processing unit) that could take over the calculations at real-time (an implementation of the latter is available, as provided through another cooperating project that continued our work). As such, techniques can readily be applied when more mobile devices are available with an acceptable GPU, which is expected within a year after ending of this project.

The initially intended occlusion management techniques have also been triggered ï we already described these methods as part of C1.

Cellphone: With HYDROSYS focusing on water eco-systems and hydrological phenomena, it was deemed suitable to focus on emphasizing related visualizations. In the cell phone application, attention is now directed towards water in the environment. Furthermore, using lightmaps, areas of high curvature in the underlying geometry can be emphasized.

Impact: whereas at the moment, no direct connection between sensor warnings and the attention direction techniques was provided, the techniques could be very useful for warning signals or any other urgent messaging. Unfortunately, the currently available techniques will only run on a specific breed of GPU-enabled devices. Nonetheless, the developed and validated techniques present the forefront of possibilities, as is confirmed by specialists and a number of very well accepted papers. The studies provide a solid perceptual and technical framework for further work by notably computer graphics researchers and developers.

Attention direction using the focus + context techniques.

C1.2 Graphics optimization

The HYDROSYS cell phone platform supports a texture stack for multi-texturing with transparent or partially transparent textures, billboards, level-of-details, lightmaps, visibility optimizations and several tricks to speed up rendering. The most essential component is perhaps the caching mechanism and memory management related to out-of-core rendering, where the size of the initial data set does not affect the rendering speed. Already at the pre-process time, it is deemed which parts of the scene are visible and contribute sufficiently to be included.

C2.4 Simulation support during on-site analyses

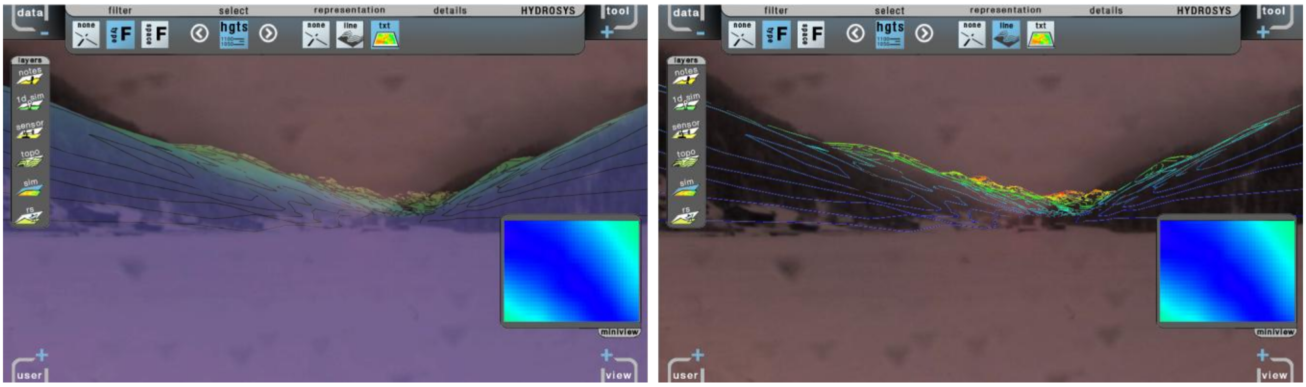
An important outcome of the project is the testing of on-site simulation in practical use: HYDROSYS provides near-real time simulation-results to be available for the user while being in the field (WP3 visualization task, see WP3 final report).

Usually a simulation will be started in advance (e.g. the day before you plan to go to the field). While the simulation is running and while being on-site the simulation-runs are permanently updated with the most recent input data coming from the sensing stations in the area. It therefore is possible to get near real time data when being on-site. The information obtained from the model output can now help the user to decide weather and which spots might be interesting for further (more detailed) analysis (e.g. manual measurements) or sensor placement. Since distributed models are in general computationally demanding, and the data load required is large, the use of such models in operational context is still restricted in terms of calculation effort and time. Nonetheless, we have come up with a solution using METEOIO to also allow **ad hoc simulations** in the field using the handheld AR platform.

Impact: the level of simulation support, both from pre-processed and ad-hoc methods, is truly novel and has found very positive feedback on usefulness and re-usability in other projects. The techniques are extremely useful for environmental scientists, or geoscientists in general, but also has the potential to push forward new work that truly looks at *in-field* triggering of simple simulations. Whereas this contradicts with the current workflow of many scientists that work in the field, the initially developed techniques show potential that it certainly can be useful for selected tasks such as quick manual sensing and feedback loops. For mobile platforms, the access and performance of simulations is at the forefront of what is possible. It is difficult to compare, but the only comparable simulation level is provided by mobile gaming engines that make use of very simple physical simulations, which in complexity are not to par with our methods.

C3. Perceptually optimized visualization and user interface techniques

While using the handheld devices, users need to interpret complex data sets, and simultaneously use a potentially larger set of functions. Users need to interpret different kinds of visualised data, and possible compare different sets to come to a conclusion (interpretation or prediction). With the limited display size of the handheld devices, handling both the visual data and the functions may cause cognitive load that limit the usefulness of the system. As a result, the project provides tailored visualization and interface methods that filter and structure the content and functionality at hand: the techniques are perceptually optimized to avoid confusion and cognitive overload; hence, the techniques actively tackle visual data management of both the visualizations and the user interface. This specifically counts for the augmented reality system, inhabiting a wide functional set and more complex visualizations than the cellphone platform.



Perceptually optimized simulation data using transparency and isophotes

To solve perceptual issues, we performed a large study to **categorize issues** and identify directions for solving, coupling visualization (WP3) with user interface efforts. More details on the visualization efforts is written down in the WP3 final report. Regarding the user interface for the handheld system, we performed several steps to optimize for perceptual issues. This includes strong **screen management** using collapsible menus, the usage of **higher-contrast color schemes**, and provision of **spatial filtering methods** and **multi-perspective** views to optimize for **visual clutter**.

Impact: the perceptual optimization of graphics for mobile platforms is still a very much open field of research, with little attention but a large number of unsolved issues. The classification of issues particular to augmented reality, as well as our first attempts of optimization affect positively the visibility of graphics to improve usability by end-users, but also gives directions for researchers and developers to ñattackò the

C4. A hybrid tracking system for accurate localization of users on-site

In order to create in-context visualizations, apt localization of users needs to be guaranteed. A hybrid tracking system has been developed to track the pose of the user's hand-held augmented reality setup. This pose information is important for correctly rendering the augmented reality data on the screen: the in-context visualization methods are depending on accurate localization of the user. Furthermore, the user depends on localization noting down annotations during observations.

This hybrid tracking system fuses measurements from a variety of sensors within the hand-held unit. These sensors include gyroscopes and accelerometers providing inertial measurements, a GPS sensor, an ultra-wideband unit, and a camera. While fusing the various sensors, we can estimate the userôs location roughly accurate to 1 meter, wi user gets further away, the resolution decreases (up to 70 meter) but still is significantly better than GPS-only solutions.

This camera was also intended to provide information on the pose of the device by tracking the horizon in the image and matching it to that provided by the terrain model. An initial system has been provided which, however, does not run at real-time. Nevertheless, the system forms an important step forward, and a solid base for further work.

Impact: The offered techniques improve the spatial registration of information on the display, thus improving the ñtruthfulnessò of the [illegible] is [illegible] to the underlying terrain model. In general, accurate real-time tracking systems are useful in a number of different applications. In particular, our system will be of interest in the fields of augmented reality and robotics. The source code for the hybrid tracking system will be released making all new techniques developed available to the wider community.

Vehicle setup

C4.1 A quickly deployable and movable high-accuracy tracking setup extension

In order to extend the tracking accuracy, a mobile ultra-wideband tracking system has been deployed that can potentially localize users at high accuracy within a limited range. The system deploys a quickly mountable solution on vehicle (set up time around one hour), which alternatively can also be covered on difficult to assess locations by using tripods. The tracking system setup is an important extension in the HYDROSYS framework since it enables the real time tracking of people on a given area around the vehicle while taking measurements on the site. In conjunction with the location engine running on a station onboard the vehicle, the sensors mounted on a fixed setup compute an accurate position. Depending on the terrain and on the required time and accuracy of the on-site measurements, there are three kinds of setups.

The vehicle-only setup will be used for a quick deployment in order to increase the accuracy of the GPS and inertial positioning. This setup is especially advantageous for the application when a frequent or quick change of the operation area is required.
Furthermore, detailed investigation of the terrain requiring a higher accuracy will be achieved through an extension of the vehicle setup with movable tripods. This heterogeneous setup offers also the advantage in increasing the flexibility of the vehicle setup for difficult terrain relief, where the movement of the vehicle is rather limited. For rough terrains, which are not easily accessible by the vehicle, the tripod-only setup offers a great advantage of flexibility and coverage, as the sensors could be moved freely on the site.

Impact: In general, we offer a far quicker deployable system than, for example, differential GPS. As such, we can better react to more ad-hoc situations, even though differential GPS offers a higher accuracy: the mobile setups are very well suitable for unprepared and unstructured, natural environments.

4.3 Publications

As part of the research and development efforts, a number of publications has been submitted/accepted, and several under preparation that will be submitted after th

¶ Veas,E., Kruijff, E., Grasset, R., Schmalstieg. Mobile interfaces for environmental sensor networks. Publication under submission.

¶ Kruijff, E. Swan II, E. Jr., Feiner, S. Perceptual Issues for Augmented Reality Revisited. In Proceedings of the The IEEE International Symposium on Mixed and Augmented Reality 2010, Seoul, South-Korea, 2010.

¶ Veas Eduardo, Mendez Erick, Steven K. Feiner, Schmalstieg Dieter. Directing Attention and Influencing Memory with Visual Saliency Modulation. In Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI2011)

¶ Mendez, E., Feiner, S., Schmalstieg, D. Focus and Context in Mixed Reality by Modulating First Order Salient Features. In Proceedings of the ACM International Symposium on Smart Graphics, 2010.

¶ Mendez, E., Schmalstieg, D., Feiner, S. Experiences on Attention Direction through Manipulation of Salient Features. In Proceedings of the IEEE Virtual Reality Workshop on Perceptual Illusions in Virtual Environments (IEEE VR 2010), 2010

¶ Nurminen, A. Smart and Scalable Communications Between Dynamic Entities. Proceedings of Parallel and Distributed Computing and Systems, Acta Press, 2009.

¶ Nurminen, A. Mobile Three-Dimensional City Maps. A doctoral dissertation. 2009. TKK, Dept. of Media Technology.

¶ Partala, T., Nurminen, A., Vainio, T., Laaksonen, J., Laine,M. and Väänänen, J. Salience of visual cues in 3D city maps. 24th BCS Conference on Human Computer Interaction - HCI 2010.

- Froehlich, P., Oulasvirta, A., Baldauf, M and Nurminen, A. On the Move and Wired to the World.. Communications of the ACM, 2011.
- Nurminen, A., Kruijff, E. and Veas, E. HYDROSYS -A mixed reality platform for on-site visualization of environmental data In Proceedings of the 10th International Symposium on Web and Wireless Geographical Information Systems, 2011.
- Oulasvirta, A., Nurminen, A. and Suomalainen, T. How Real is Real Enough? Optimal Reality Sampling for Mobile Imagery. Submitted to IEEE Multimedia, 2011.
- Duenser, A., Billinghurst, M., Lehtinen, V., and Nurminen. A. Handheld AR for Outdoor Navigation. Accepted to Mobile HCI 2011 (Mobile Augmented Reality Workshop).

5 Handheld computer platform components

5.1 Overview

The ultimate goal of our mobile interface for environmental monitoring is to visualize abstract data, such as sensor measurements, simulation results, etc. in the context of their occurrence. One advantage of on-site monitoring is the fact that the actual site, not some probably outdated model of it, is available to the user. The challenge is to exploit this fact, relating synthetic data to the real world and attempting to convey as much information as possible without losing the real world context. The method of choice, augmented reality, strives to render computer generated artifacts correctly registered with the real world in real time. The appear in the appropriate position relative to the point of view of the user. We propose a mobile AR application for visualization of digital content in the context of the real world. This in-context visualization and interaction supports the scientist across all tasks described above, from displaying sensor position for deployment or current readings for maintenance, integrating representations for multivariate data and complex simulations. All this must happen in a collaborative framework whereby users can interact, communicate and discuss findings and potential solutions. The proposed solution contributes innovations in the following areas:

- *Real-time access to complex data*. Users in the field obtain the latest sensor data without manual intervention. Data handling is carried out by automation stages in the sensor network, in our case GSN. GSN outputs data at higher refresh rates, offering a timely accurate representation of events. In addition, simulation services are closely integrated to support extended analysis.
- *In-context visualization*. Complex data sets are brought into direct context with the environment it originates, by using AR techniques. Similar to a multi-layer approach, multivariate data can be compared and analyzed through a combination of representations (mixed dimensionality).
- *Situation awareness support*. The in-context capacities of the system are extended by offering multiple perspectives on the site, by leveraging the deployment of multiple imaging devices. This multiview infrastructure improves understanding of spatial relationships and provides a solid basis for cooperative work.

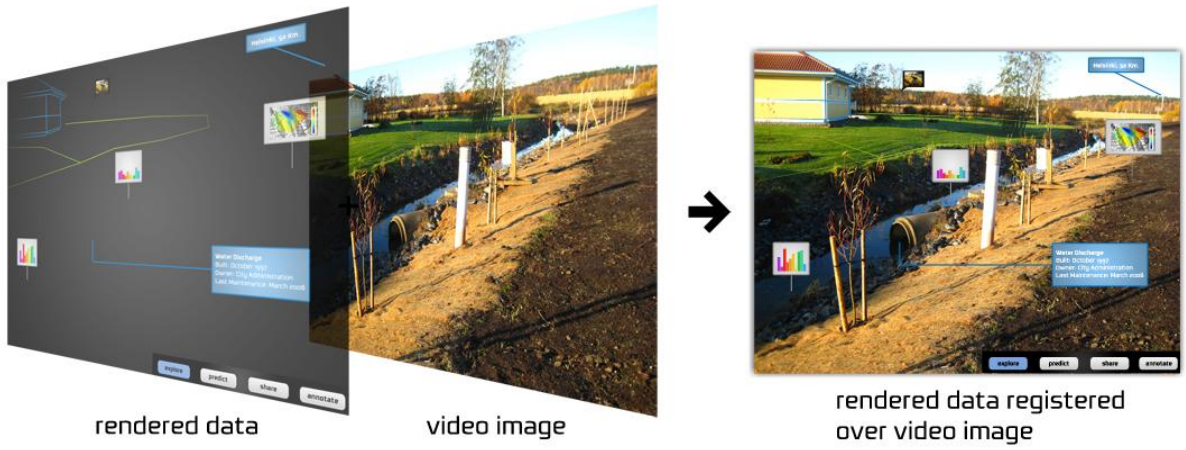
The ñcontrolò of the appli... ed i... report, even when some references to basic techniques are made in the following sections. To read more about the control of the application, it is recommended to read report D5.2 on user interfaces.

Further reading

Read more on the user interfaces for the handheld computer in report D5.2 WP5 final report.

5.1.1 Augmented reality

Augmented reality (AR) is the registration of computer-generated imaging over a physical world. The registration is achieved by sensing technology (like GPS and orientation sensors). The view on the physical world is captured by one of the possible cameras. With the extra information presented to the user, the physical world can be enhanced beyond the userôs normal experien... located relative to the handheld computer (or other camera being accessed) can help to improve their understanding of it. The information is, as previously noted on this proposal, retrieved from a sensor network. The processed visual information can take different forms, from structural elements like water pipes, up to pollution levels or temperature distribution graphs. One of the particular advantages of AR is that also subsurface structures can be visualized, which can be extremely useful for monitoring in the field.



The principle of Augmented Reality (photomontage)

5.1.2 The notions of context and situation

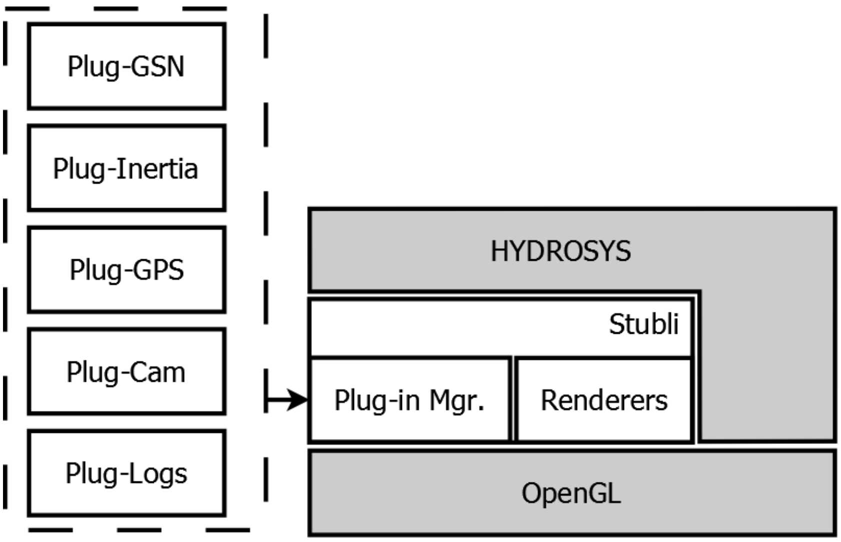
While monitoring events on-site, users operate within a certain context. This context entangles the various users that may cooperate, the actual environment with its artifacts, and other high-level conditions of the action space (situation), such as weather or noise. Context and situation are two overlapping concepts that refer in general to the action space within which a user operates. In our application, we are foremost interested in the relationship between user and environment, and in-between user understanding. These constructs have gained much attention over decades, and can be represented through formalized methods such as situated action (user-environment) or distributed cognition (in-between users) models.

We are interested in what is called *situation awareness,* which encompasses user understanding of the current action space. This concept can be seen as underlying mechanism for the previously mentioned notion of shared understanding. Context is important if one considers the characteristics of the action space in which users operate: physical processes are being observed, that originate in an environment, which may be heavily under change.

As such, the spatiotemporal characteristics of the environment are of utmost importance for creating a correct understanding: Bringing representations of physical processes in relation to spatiotemporally outdated or only partial representations of the physical environment may well lead to the wrong interpretation of the situation. This notion is also the crux behind the application presented within this article: as we will see in the next section, visual representations of environmental data are brought into direct context of the actual environment, thus, it always refers to the latest spatiotemporal stage of development of this environment. Assuming that the office is not in the direct vicinity of the environment being observed, this separation may well lead to misinterpretations when environments are under heavy change, or only limited representations exist. Hence, with our application we want to create (a) a correct per-user understanding of the data representations in relation to actual environment in its latest spatiotemporal state, as well as (b) a shared understanding of the knowledge gained by different users with potentially different backgrounds and different perspectives on the site. The latter is a very interesting concept: how can we share different pieces of knowledge gained by different users to improve the overall understanding of a potentially complex situation? Within our application we offer two mechanisms that focus on these issues: in-context visualization and a multi-view system for sharing different perspectives on a site.

5.1.3 Handheld augmented reality platform

The software platform for handheld AR was initially based on Studierstube. During the course of the project, however, several parts of it had to be reengineered to cope with the ever increasing requirements on graphical features for a poor graphics hardware and worse graphics drivers of the Panasonic CF-U1, our main deployment unit. The idea behind the new software was to lose all dependencies on components that did not provide a particular advantage, and to reimplement those critical for performance. Stubli, (short for studierstube-light), leverages a plug-in manager to deal with sensor input (see figure below). Sensors input plug-ins are self contained components, that can be hot-loaded, or unloaded in necessary. This means that they are not linked together with the application, but are separate modules. They require the application to provide a callback, which is executed whenever new data is available from the sensor. Based on this, we were able to isolate problems with sensors, exchange sensors for other types providing similar input, or simulate their input without having to even link the application again. This step alone removed lots of dependencies from the application and simplified the task of isolating problems with input. On the graphics side, we took a minimal approach to directly use openGL, which enabled us to manage the openGL context and connection to the graphics hardware directly. We created implementations of specific renderers to handle geometry (e.g., elevation models), and the user interface (e.g., tiles, text). These were based on the openGL vertex buffer objects (VBO) extensions, that organizes and reduces the number of communications between CPU and GPU. The speed ups in this implementation immediately allowed to reach interactive framerates even on the slow tablet PC when running the full fledged application.



Plugin based AR architecture

An application using Stubli is mostly datadriven, as is often the case for AR applications. The main application loop takes care first updating the input, then updating all the visual representations according to the input (including the user interface and the visuals), and finally rendering. This separates three important parts, gathering input data, updating visual data (where all the CPU-GPU communication takes place), rendering (where visualizations are generated). The separation has no impact from the userôs perspective, but has adv performance, and isolate what steps are causing an application to slow down. The application is organized following the model-view-control design pattern.

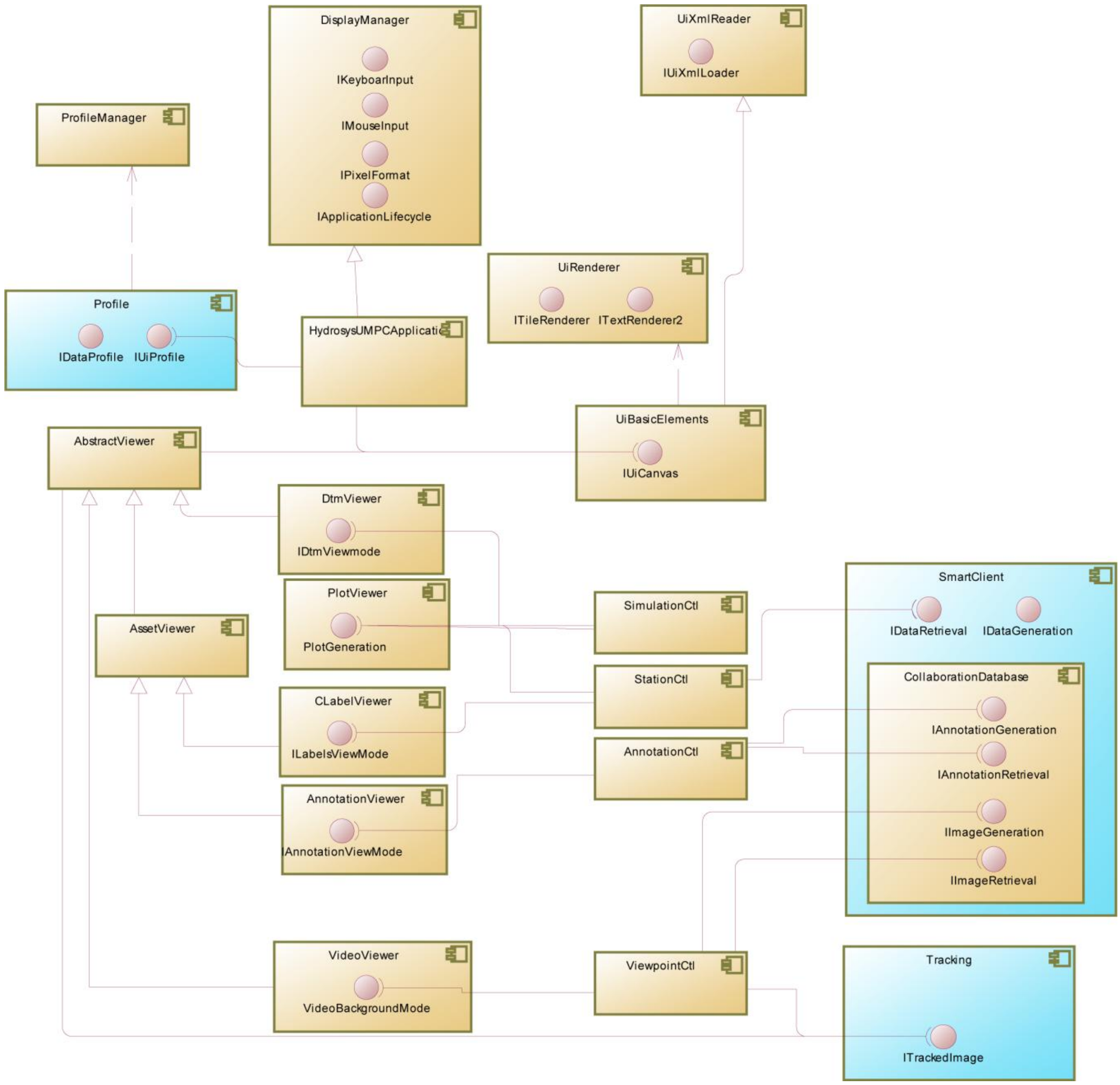
Display Hardware

During the project HYDROSYS we will use a Panasonic Toughbook UMPC (CF-U1) ruggedized for outdoor use. It has been chosen because it fulfills all of our requirements including: Ruggedized form-factor for outdoor use, anti-reflective screen and a USB interface for attaching the external sensors. The Toughbook is MIL-STD-810F and IP54 compliant ð four-foot drop, rain-, spill- and dust-resistant, thus usable in rougher outdoor conditions like will occur in HYDROSYS.

Hydrosys overview

The latest version of the HYDROSYS handheld AR system builds on the simple interfaces afforded by Stubli. The figure at the next pages **Error! Reference source not found.** illustrates the main features of the handheld AR system. The main application serves as event system gathering data from standard input (e.g., keyboard, mouse, touchscreen) and managing the display settings for rendering. To manage the presentation of multivariate datatypes with different complexities, their presentation has been divided in *viewers* that encapsulate the operations needed for each case. These represent the views in the mvc pattern. The data is obtained and preprocessed by the *SmartClient* component, and the user interface is provided by *controllers*. In a sense, this structure gives complete control over what is visualized and how it is presented. The user interface including all the controllers are defined using xml files. The settings include all data that defines a ui element, like its position and appearance properties on the screen, the states is can take, and how it changes from one state to the other. The application, upon startup, instantiates the ui from an xml description and then it finds handles to all controllers and connects them together with the controlled objects (views, models). One main aspect to account for in augmented reality applications is the tracking. In our case the tracking is associated with a viewpoint (together with the video), thus it is handled by a viewpoint control or view manager.

The view manager deals with viewpoints from different, remote cameras, as well as the local video background and virtual cameras to explore the 3D model. All the viewers mentioned above require details about the viewpoint used to render their data. This takes the form of a modelview matrix and a projection matrix, which are the ones that define a viewpoint. The viewmanager gives the user full control over these matrices, by allowing control over virtual cameras, or switching to remote cameras. At the same time, the view manager provides all the viewers with the matrices for rendering.



Hydrosys handheld AR system overview

Profiles handling user preferences

In order to deal with the high volume of data and its complexity, HYDROSYS relies on the notion of profiles. The application stores profiles containing information about required data and how to retrieve it. Profile management also includes other tasks and information that are not date specific, like storing the device's hardware setup, and user interface preferences. The latter also includes stripping down the functionality of the UI, for example to offer a personalized interfaces for people with different roles.

In reality, the profile includes several user preferences. One of the goals of profiles is to associate them with user roles. This allows a user to view different data depending on which profile is currently activated. An advanced feature that depends on processing power and network bandwidth, would allow a user to activate more than one profile at the same time, switching profiles to observe different aspects. This feature that could be regarded as layered augmentation optimizes the screen space usage, and it is not implemented by the current system.

User interfaces for profile management including creation, update, deletion and comparison are considered. Profiles are stored as xml files. They are not created, nor updated, automatically. Profiles are complex enough, storing preferences and information about different tasks, so that their automatic generation would entail a complex process that is out of the scope of this project. However, part of the profile management user interface, is the creation of profile templates. Profiles can be thought of as representing roles that users assume when using the system, thus they cover different needs for example of data. Profile management may include templates for roles (sensor specialist, hydrologist, geologist, etc) that are required in a certain campaign or site. An administrator for a campaign may have considered different roles and created profiles for each. The actual users can download those profiles and modify them, or use profiles that they already have in their setups. Profile switching becomes an important task when used for collaboration purposes, where a user may want to share her viewpoint together with augmentations. In that case, another user, to whom this viewpoint is remote, needs to switch viewpoints and profiles momentarily.

Graphics pre-processing for handheld computers

The Handheld devices are small full featured computers with limited processing and graphical power. They are capable of displaying graphics at a high speed, provided that they are not excessively large. Therefore, the SmartClient component needs to pre process the incoming sensor data before deploying it to the mobile devices. The pre processing takes place in several levels such as level of detail and polygon reduction. Furthermore the SmartClient is also in charge to deliver the data in a form that is understandable by the Handheld device.

Level of detail optimization refers to the decrease of the detail of objects depending on their distance to the viewer. This is, objects far away have less detail than those closer. This is a common optimization technique that HYDROSYS employs to minimize network transmissions. Information coming from sensors is not directly understandable by the Handheld client, it needs to first be transcoded (previous section). In order to properly display information from sensors, the Handheld client needs to convert this information into geometrical primitives, or polygons. These traditionally receive input from point clouds (such as DEMs or Simulation interpolations) and generate a series of triangular polygons. The polygon reduction technique tries to find a minimal representation where the number of polygons is reduced but the visual quality is not adversely affected. These and other techniques are implemented by HYDROSYS as part of the SmartClient component.

The SmartClient component includes all the steps related to accessing data for HYDROSYS applications. These steps are divided into a set of components for convenience. Data services define the data that HYDROSYS applications can handle and their format by providing a metadata definition. These services include mechanisms to convert data from external formats (preprocessing/ transcoding) to the formats required by HYDROSYS applications. These components are divided into data querying components, data conversion components, storage and data indexing components. As an example, a normal session of HYDROSYS application is as follows. The SmartClient registers queries according to the current user profile. Before the query is actually registered, a service checks whether this data has already being retrieved (saving processing time by avoiding repetition of expensive conversions). If the query can not be handled locally, it is registered with (if it is a query for streaming data), or just sent (if i t ô s a q u e r y f o r p a s When the data is available from GSN, it goes through a preprocessor to perform necessary conversions (to convert to the format specified by metadata, to perform certain platform specific conversions, etc). The data is then stored. A Data Retriever in the client manager is notified of the arrival of data, and it forwards the data to the SmartClient. In the SmartClient the data goes through more conversions, resulting in data ready for visualization. The following figure exemplifies a typical connection diagram of how data is retrieved from GSN and delivered to the mobile client. First, the Task and Location profiles are sent to the SmartClient, these profiles were previously set during campaign planning. The SmartClient receives the profiles and converts them into registration queries that can be understand by the GSN server (the server may be locally in the same machine or remote depending on network availability. The GSN server will respond with sensor data specific to the requested registration (publisher/subscriber pattern) to the SmartClient. This will in turn pre process the information before delivering it to the mobile device.

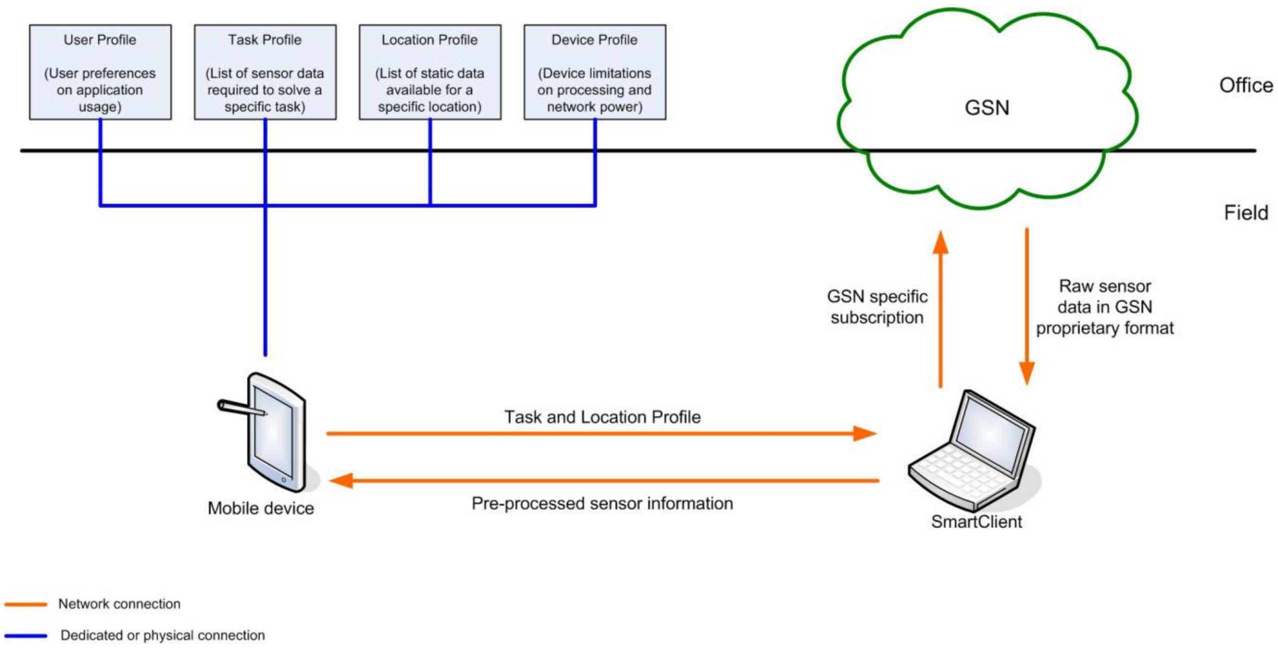
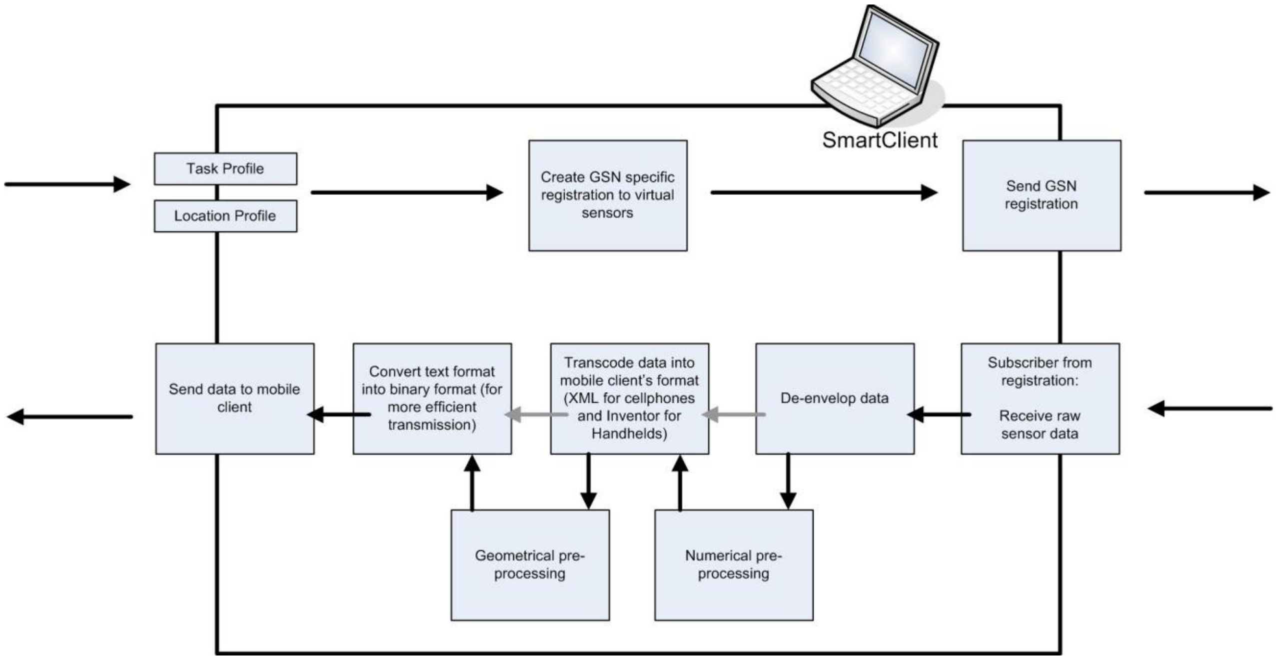


Figure 3 SmartClient data connection diagram

The following components can be identified within the SmartClient:

- *Receiver*: manages queries and retrieves data.
  - *Profile Manager*: Manages a set of profiles that the user may activate, and a current running profile storing all active queries for the user
  - *Transcoding*: converts data from network transport format to a format appropriate for the visualization component.
- *GSN Node*: gathers data for clients (campaign wide) according to the client queries. It includes conversions on the data necessary to account for platform details and data caching to provide for similar queries from different users.
  - *Client Manager*: In the case of multiple clients, it registers queries and retrieves data for each client, depending on the deployment strategy there may be more than one of these components acting at the same time in a certain machine.
    - *Query registrar*: attempts to satisfy user queries with data in the local cache, if that is not possible, queries are sent to GSN.
    - *Data Retriever*: retrieves the data from local storage and forwards it to the client.
  - *Data Preprocessor*: performs conversions on data received from GSN, adapting it for the current platform.



The above diagram presents a specific version of the internal elements of a SmartClient since there are several ways to deploy the data services components. One may consider the Local GSN Node to be running in a special server that handles several clients. It is also possible, that it runs in a handheld device, and the SmartClient in the same handheld device connects to it to retrieve the data. In the last case, most probably the data has been queried and preprocessed previously as part of the campaign preparation phase. Different platforms may require different deployment plans (information present in the Device profile): While handhelds may deploy a light preprocessor and do heavier crunching in the transcoding component, mobile phones probably require a preprocessor that does more work and offloading the work of the slim platform.

Transcoding pipeline

The information produced by sensors is not homogeneous, some sensors deliver data in binary format, others as voltage readings, text files, and so on. Moreover the information, although geo-referenced, is abstract and cannot be directly presented raw to the user. Traditionally, hydrologists use math software to produce plots of these sets of information. This is, however, not an automatic process and is unsuitable for interactive graphics. Therefore, we need a mechanism to convert the raw input information, either from sensors, simulations or even user generated into visual primitives. This process is called transcoding and it is essential for any complex system with such varied sources of information.

The transcoding pipeline refers to the process of converting data from one format to another. In the HYDROSYS project this refers to converting data from raw sensor output to visual information. The required transcoding is not simply a one-to-one conversion from one format to another but it also includes a higher level interpretation of the sensor data. The transcoding from semantic attributes from sensor data into purely visual primitives necessarily implies information loss. It is therefore important to find the right point in the pipeline for the transcoding: If the semantic information is discarded early, it cannot be used for interaction with the user at a later stage of the pipeline. If it is discarded late, this induces the overhead of a repeated interpretation of the semantics at runtime, and adversely affects performance.

The transcoding pipeline creates sensor visual models based on real world data used by researches of the hydrology community rather than on synthetic made-up data. The resulting visual data sets will be embedded with semantic markup (such as date of data collection and type of sensor), used for interactive filtering and styling of the models This allows the actual graphics primitives to be generated on-the-fly by scripts that are are included in the data sets for interactive visualization effect behavior without compromising interactive frame rates. This approach allows defining the visualization styles with relation to the semantic markup and thus independently of any actual object structures. On the other hand, for front end devices with less computational resources, the stage can be placed a step earlier.

The transcoding pipeline for the HYDROSYS project will begin from the sensors themselves and end on the mobile devices used on the field. The following diagram highlights the components involved in the transcoding of sensor data.

The transcoding pipeline in the above diagram considers only the transcode of data between the data server, data services and the presentation component. However, transcoding exists essentially in every step of the system architecture, for example: for data from sensors to be delivered up to the presentation component, the following steps are necessary:

¶ *Internally recorded*. First, the data from sensors needs to be internally recorded in the proprietary format.
¶ *GSN Delivery*. The second step is to relay this information to GS scope stations have a direct network connection to GSN but data from older sensors needs to be manually collected.
¶ *XML encoding*. The GSN is designed to distribute sensor data in a general, standardized format. It encodes all input to an XML dialect (SensorML has be chosen as the standard to be used), which is then received by any system that has subscribed onto GSN feeds.
¶ *Reception, decoding, processing*. Once the data arrives at its HYDROSYS Data Services, its fate depends on the services currently requested by the visualization front end. It may be simply forwarded, possibly in a compressed format for lightweight devices and slow networks. Or, if the visualization front end has requested further processing, such as simulation, the data may first enter a Speculative Modeling module, which then outputs the simulation results. Data Services can also bind and mix the data with HYDROSYS specific data structures. Now the data is within the HYDROSYS system and can be transmitted to the visualization front end in a proprietary format.
¶ *Display*. The visualization front end receives the data and renders it for the user.

Data processing for lightweight visualization

Mobile devices are characterized by their *thinness,* their lack of resources. Even devices equipped with 3D hardware are able to render and keep in memory only small data sets, while real world data easily exceeds their capabilities. In addition, the devices run on batteries. Running 3D visualizations at interactive frame rates strains the batteries easily. While unnecessary computations in a desktop could go unnoticed, in the mobile device this would reduce the power of the precious and limited energy source.

Developing mobile 3D applications is a demanding challenge, dominated by optimization issues especially in relation to data. One needs to consider all the aspects of this environment. First, manually built data sets intended for mobile use should be designed for lightweightness, and existing or automatically generated data sets optimized for rendering. This involves graphics designs and optimization processes that yield simpler geometry and simpler surface detail than would be possible on desktop platforms. Furthermore, *importance* could be utilized, where important data is highly detailed, while the unimportant data presented with more coarse approximations.

Second, one must consider *view dependency.* Any rendering that does not yield a visible result, such as rendering hidden or extremely small surfaces, should be avoided. In this case, the data that doesnôt contribute to the current view is culle
Similarly, a complex object consuming only a small amount of screen space could be replaced by a simpler object, or even an *impostor,* for example a billboard. Unfortunately, visibility determination or level-of-detail simplification may induce demanding run time computations. One solution is preprocessing, where static data sets are optimized as an offline process, incorporating view dependencies, where the whole space is spanned automatically to determine the visible objects and suitable representations for each view position.

Third, all resulting data sets need to be represented in an efficient, compact form, possibly involving specialized compression methods. Even a properly designed, lightweight 3D scene could still consume considerable amounts of space in a standardized model exchange format such as X3D, while a binary, more proprietary solution could reduce the size by an order of magnitude, without compromising the contents. This transcoding stage is essential for especially real time data streams (see below).

The abovementioned methods mostly deal with static data. Unfortunately, real time data feeds such as sensor data cannot be preprocessed, and may not even present directly renderable data. Other analytical means of compression, data selection and geometry generation must be applied, possibly in separate online processing servers. Alternatively, renderable geometry could be procedurally generated at the mobile client. In this case, the generating algorithms should utilize the previously mentioned optimization methods.

At the final stage, data is delivered to the devices. Mobile networks are claimed by operators to achieve higher and higher peak rates, while in real world the situation is not so simple. High speed cell network coverage does not extend outside urban areas, and even there, the theoretical transmission rates are achieved only on rare occasion. In the worst case, no networks are available. HYDROSYS attacks this problem by providing a local WLAN connection where possible, and by utilizing efficient transmission protocols for all other cases, especially for the cell phone platform. The actual transmission can adapt similar optimization schemes as in the preprocess stages: the most important and proximate data sets are transmitted first, possibly utilizing level-of-detail optimizations, sending only the currently needed representation of the data.

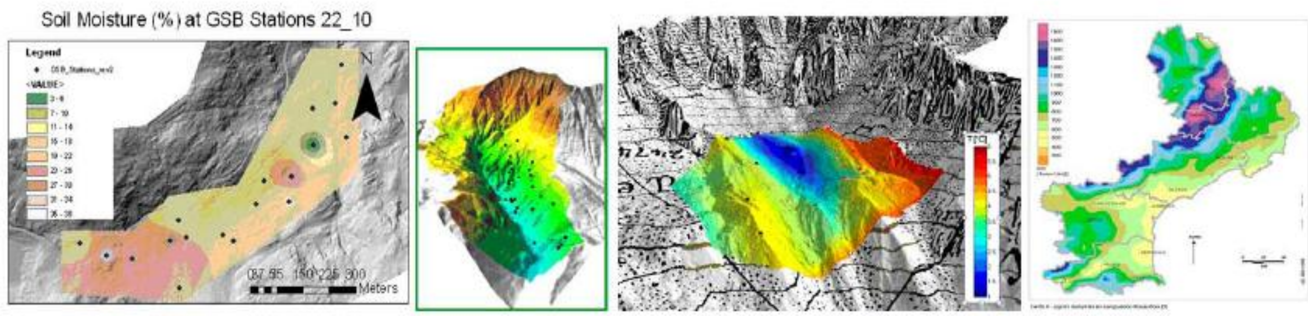
5.2 Visualization

5.2.1 Objectives

> **Work package tasks**
>
> The work mentioned in this section has been performed in T3.2 system infrastructure, T3.4 visualization techniques and T3.5 Focus + context techniques.
>
> This work was primarily performed by TU Graz.

Interactive visualization is the core of the handheld system, and basically consists of a visualization component (handled in this report) and the front-end to interact with the various visualizations (the user interface, primarily handled in the WP5 final report). Within the project, visualization techniques had to be developed that could interpret and show various **sensor and simulation data** retrieved from the sensor network and the simulation pipeline (see Wp4 final report) into direct *context* of the environment. That is, the information should be *spatially registered* to an underlying model (a digital terrain model, which should also be made visible upon request) and correctly matched to the environment representation shown as video image. The process of matching, or better said *overlaying* digital information over a video image, is called augmented reality, which forms the crux of the handheld system. However, geoscientists do not only require spatially and visually registered overlays of primarily 3D data, but also more traditional 1D and 2D formats, such as numeric data and plots. Within the visualization work, methods had to be found to unify the analysis of multi-variate visualizations controlled by the user interface. One particular aspect that had to be taken into account was the actual technical platform: both performance wise, but also from a perceptual stance, visualizations had to be optimized to be both visible and understandable on a small screen in outdoor conditions.

Next to the general sensor visualization system, an additional stand-alone visualization system had to be developed. This system primarily has to deal with measuring and showing wall inclination data (Gemsstock scenario). Though it holds also user interface aspects, it is primarily handled as part of the visualization system.



Traditional sensor and simulation data visualizations. Left: color coding of soil moisture values. Middle: interpolations for surface skin temperature. Right: color coding of land use.

The visualization work also encompassed experimental research that encompassed so-called **focus + context** techniques. Focus + context techniques represent a breed of techniques in which focus areas (a sub-set of the visible area) are brought into context of the overall scene visible within the current view. Various useful tasks can be imagined. The work performed explored various directions, with the aim to find suitable techniques that can be used for analysis of complex data sets. The primary focus was on modulation of aspects of a scene, to draw attention to sections that would desire a closer look. Hereby, it would be wishful that the techniques also run on mobile platforms ï this, however, was identified as potentially difficult to achieve from the start of the project on. The goals of this work were extended over time, streamlining developments with other useful components created within the project, as well as to solve technical issues related to performance. As a result of this, we followed up two more directions. First of all. in close relation to multi-view system, we were interested to analyse the potential of modulating video imagery, the cornerstone of augmented reality. A user watching a remote video feed from a multi-camera system may want to be reminded of the location of the viewing camera, of locations of other cameras, and of interesting objects. We would like to be able to suggest an attention shift without distracting the user from her main task. We would also like to use a complementary, lower priority channel to provide information to users without disrupting their tasks.

Secondly, as an outcome of the performance issues we experienced while testing the implemented on mobile systems, we had to explore useful other ways of using focus+context. As a product of the renewed data structuring in multiple layers, it was expressed that it would be useful to compare data from multiple layers, thus, putting data from one layer in context to another layer.

5.2.2 Task activities

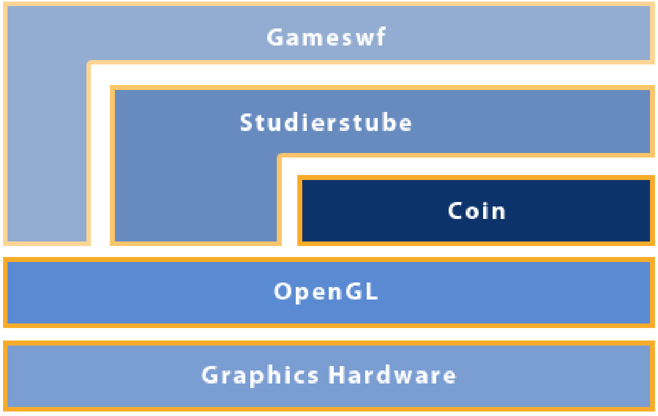
> Sensor and simulation data visualization

To show the sensor data on the screen, a basic rendering system for sensor and simulation graphics had to be created. To start with, the data needs to be received from the sensor data storage, and transcoded, to be handled on ultramobile PC: The initial system worked as a plug-in platform upon which the rest of the system would be integrated, such as video, interaction and so on. A basic connection to the GSN data source was been created, known as the *SmartClient* (see WP4 final report). This connection was done in the form of a C++ module posing as a node in the Studierstube scene graph. The node makes an HTTP connection to a GSN server, then queries the available sensor data and delivers it to the scene graph. The returned information comes in the form of an XML file which is in turn transcoded into a format that can be understood by Studierstube, the underlying software framework of the handheld system. In particular, we generated object key-value pairs (sensor-name, sensor-data pairs), to support the Flash plug-in logic (see next step).

Step 1: transcode data coming from the sensor data storage

As next step, a basic visualization system was created. To do this, we integrated an open source engine that interprets Flash files (SWF) and renders them in OpenGL as textures. This work highly coincided with the work performed on the *user interfaces,* as is explained in detail in WP5 final report. Basically, the visualization of sensor data and the user interface share specific components for displaying information. OpenGL is the lowest level rendering API used by Studierstube for displaying graphics. By integrating the Flash engine (called gameswf) we enabled an easier prototyping of user interfaces and visualization techniques in our system, but at the cost of a performance impact.. The following diagram illustrates the dependencies and communication interfaces necessary to display information.

Step 2: create an initial sensor data visualization system using Adobe Flash (cohesion with WP5)



Initial graphics systems for visualization and user interfaces

Step 3: solve coordinate system issues with transcoded data, create digital terrain models

Once the data is received and transcoded, the data needs to be interpreted to be registered correctly in the context-based visualization. These point clouds may represent either individual sensor data points or a digital terrain model (DTM). In the case of the sensor data, this is received from the GSN connection and transcoded as explained before. The first challenge to solve is that of the position of the sensor data on the screen. This is no easy task since the data comes in a different 3D coordinate system and needs to be related to the 2D limited space on the display of the device. Backend work had to be carried on the conversion of 3D points in geo-referenced format to graphics coordinate systems registered with tracking back into the screen of the device 2D coordinates. This work aids the placement of labels, ray intersection of interaction and so on.

The position of the sensor in the world is encoded as a field of the incoming sensor. This position comes in WGS84 format and needs to be converted to UTM32 in order to be usable for the system. The converted coordinate also needs to be resized to a smaller scale manageable by the system (original values range around the tenths of millions). Then, a transformation matrix that reflects the current position and orientation of the user is applied to it. After this is done another projection is performed that considers the intrinsic camera parameters (field of view, off axis projection and so on) and returns a point on the screen where the data should be displayed. The sensor data can then be sent to the Flash subsystem. The following image illustrates this process.

Point information coming from a Digital Elevation Model (DEM) is handled differently. The DEM is a collection of point information that represents a real world surface, therefore, it cannot be displayed as simply a set of points on the screen but a surface has to be created. To create this surface, or mesh, one needs to know the following: the spacing between point samples, the location of at least one sample, the orientation of the point grid, the dimensions of the grid and the height at each relevant