HYDROSYS
Expected outcomes

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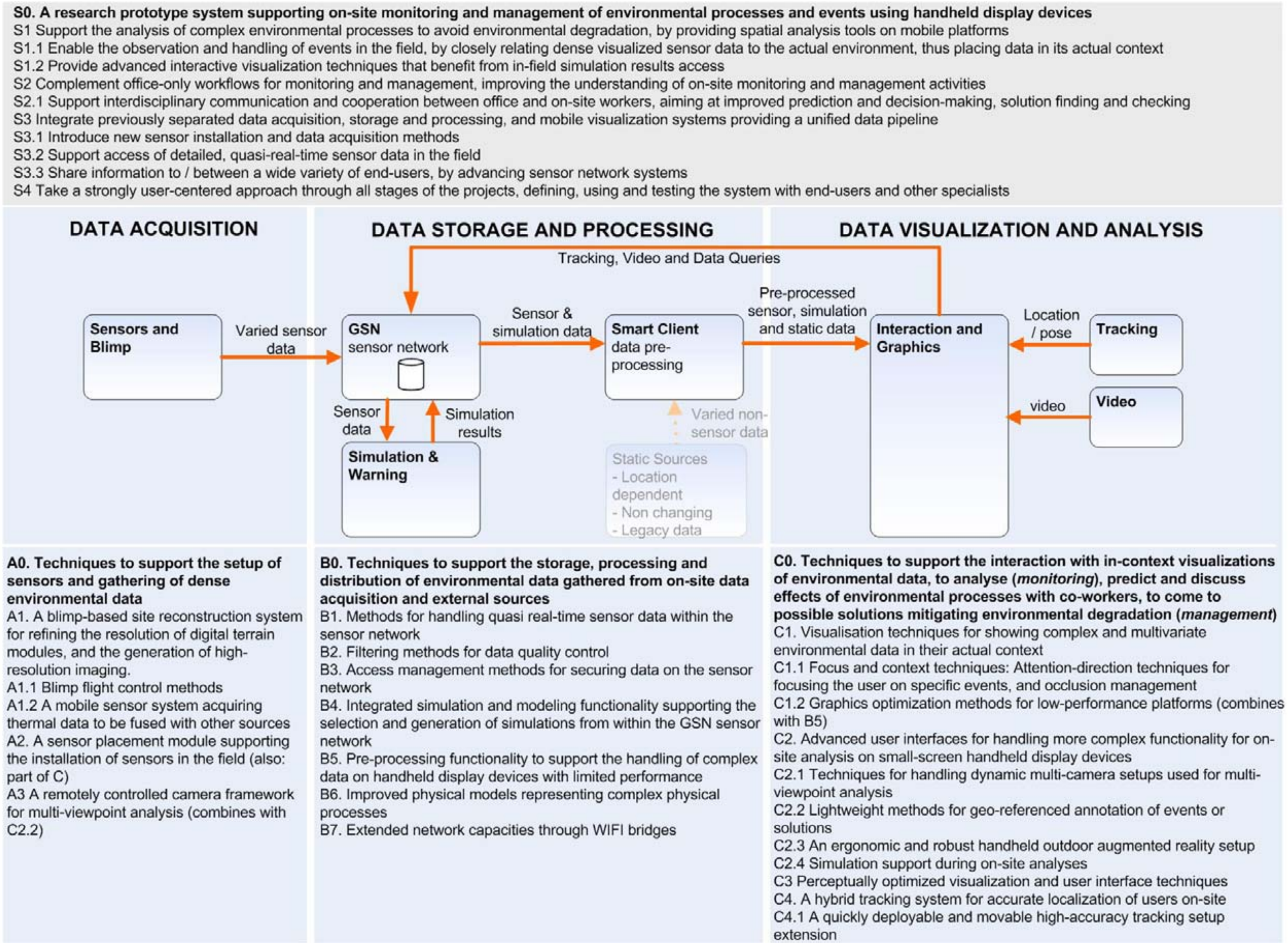
HYDROSYS is a EC funded Seventh Framework programme STREP project (grant 224416, DG INFSO) on spatial analysis tools for on-site environmental monitoring and management.



Expected project outcomes overview

Main outcomes

The following document provides a structured overview of the expected outcomes of the project. The outcomes reflect the particular innovations achieved within the project.

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

The research system will enable 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 will be 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 is 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 aims to provide the possibility of using real-time data input and visualizing the simulation results on-site. If this task works out successfully and with meaningful results such operational use of complex models might go into broader application in scientific and practical purpose.
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 static data and very limited functionality that hardly supports effective decision-making.

To confirm the usefulness of the system, multiple on-site monitoring sessions will be performed in Switzerland and Finland. These sessions will likely provide new insights in the processes being observed. That being said, the system is not only interesting for the end-users in mind in this project – there are multiple system innovations that are certainly applicable in other fields of research too. The majority of the system will be made open source and as such can also be accessed by researchers from related fields like computer graphics, human-computer interaction, database systems and robotics.

A0. Techniques to support the setup of sensors and gathering of dense environmental data

To analyse environmental processes on-site in a meaningful way, it is required to have dense and recent data sets available. Accurate data is often not available, being timely outdated or in low spatial resolution, hence, new data acquisition or refinement (update) is generally required. Next to the usage of existing sensor technologies, the project introduces and develops ways to set sensors up, and several new kinds of sensor data acquisition methods. The usage of an unmanned aerial vehicle is introduced to update and refine existing digital terrain models (DTMs), and to capture both normal and thermal images. Accurately reconstructed site data is required both for simulation and visualization purposes. Next to the cameras under the blimp, multiple other cameras are deployed that allow the user to take a look at the identified problem area, creating a better spatial awareness of the site, and the context the data is compared to. Additionally, sensor placement aids are being provided that aid in setting up sensor networks quicker and easier, especially in remote sites.

A1. A blimp-based site reconstruction system for refining the resolution of digital terrain modules, and the generation of high-resolution imaging.

Tackling the often outdated and low-resolution DTMs, a system will be created which uses the aerial imagery gathered by the blimp to refine and improve the resolution of digital terrain models. A higher resolution model of the site will improve the accuracy of simulations produced. The user will also benefit from recent high resolution imagery of the site. Part of the visualizations require textured 3D models to overlay visualizations of sensor data, which can be delivered in high quality by the blimp system. A visual reconstruction of a scene is typically done using Bundle Adjustment or SLAM algorithms. Our system will use these and take advantage of the further information provided by the low resolution digital terrain model (DTM) available and the other sensors on board the blimp. Producing a visual reconstruction requires an estimate of the camera position when each image is captured. The localisation system for the blimp (A1.1) produces such an estimate using all the available sensors on board.

Refining a coarse Digital Elevation Model (DEM in the followings) and delivering a DEM (DTM) with a higher resolution. is extremely relevant for 3-dimensional numerical modelling, where the topography of the study area is the basis for all the computation; in fact equations

describing physical processes are discretized over a 3-dimensional grid and solved iteratively. The values obtained by solving the equations are associated with a grid cell, therefore, the finer the grid resolution the more accurate and smother the process mimic. Scientists, studying natural process dynamics, and technicians from municipalities, who need to locate hazardous areas on the municipal lands, will strongly benefit from the improved DEM resolution, the firsts being able to investigate small scale phenomena with higher accuracy, the seconds being more precise in taking actions when needed. On the other hand, high resolution DEM could slow down the entire system due to the large amount of data that needs to be transmitted and elaborated. This aspect has been accounted for and tacked using the state-of-the-art techniques available in this field. Once produced, high resolution DEM can be useful for several other applications, including engineering designs, water resource management, leisure activities, such as hiking, skiing and mountaineering.
Any new algorithms developed for the aerial visual reconstruction will be of interest in the computer vision and robotics communities.

A1.1 Blimp flight control methods

In relation to A1, a control system is needed to allow the blimp to perform its tasks of producing a high resolution DEM and gathering real-time thermal imagery: hence, a system will be created to control the actual movement of the blimp in the field.
This system will use the sensors available on board the blimp to track its position within the environment. Several possible modes are possible for this control system. The most direct will allow the user to manually control the blimp. Other possible modes will allow the user to specify a region of interest that the blimp can direct its cameras to focus on or the blimp can be sent on a sensor sweep to autonomously gather the data needed to produce a visual reconstruction of an area of the test site. When using the blimp, the user will need to take into account the weather conditions. In strong winds, the blimp could be lost if the control algorithm is unable to maintain a high enough speed into the wind. In such a situation, it is advisable not to launch the blimp– in emergency situations though, the blimp can be flown, though, since it holds some safety mechanisms that will land the blimp when needed.

Apart from their key use in controlling the blimp in this project, the navigation algorithms developed will be of interest to the robotics community.

A1.2 A mobile sensor system acquiring thermal data to be fused with other sources

The blimp payload will include a thermal camera. Thermal data from this camera will be recorded and made available to the user on the ground. Since the system knows the position of the blimp (A1.1) and has a 3D model of the terrain (A1), it will be possible to register the thermal data onto the 3D model to observe live temperature measurements for locations of the site currently being monitored. These temperature readings can also be recorded and fused (validated) with other data to provide measurements for simulations of the site (B7).

It is also possible that new computer vision algorithms can be developed using the thermal imagery. These could provide useful information for the 3D reconstruction process (A1) or the blimp localisation (A1.1) since the thermal camera could observe features which are not visible to the optical camera. Since thermal imagery has very rarely been used in the field of computer vision, and thus will be a challenging task. However, the results for visual reconstruction and blimp localisation will be sufficient even if the thermal imagery is not used. Also, the registration of the thermal imagery onto the terrain model will be accomplished even if new computer vision algorithms are not developed for the thermal camera.

The dense thermal imagery obtained from the aerial vehicle will provide far richer thermal measurements across a site than was previously available using discreet ground sensors, improving interpretation of thermal data and potentially providing input for actual simulation (which requires pre-processing). In addition, any new vision algorithms developed for the thermal camera will be of interest to the computer vision community.

A2 A sensor placement module supporting the installation of sensors in the field

In order to get dense information from sites under observation, it is often required to set up larger sets of sensors or sensor stations. Depending on the site at hand, this can become a more tedious task. Some sites are not very well accessible or at remote locations, and previously defined sensor placement positions (based on data available in the office) might be inaccurate due to changes in the environment. Furthermore, in order to get sensor readings over the network, an actual network / telephone connection needs to be available, which is not always the case. All these issues may require additional setup time and potentially multiple trips to modify sensor placement. Next to the setup of static sensors, users may want to take manual probes with a mobile sensor while in the field, for which initial feedback on the readings is useful.

Both the setup of static sensors and the taking of manual probes can benefit from feedback on where to put a sensor, and the actual readings being produced. Once a sensor placement position is provided (planned in the office), a user can be directed towards its location in the field by providing directional cues on the handheld display. Once arrived at the location, the user will need to evaluate if the location is still useful to install a sensor, hence checking the physical characteristics of the place: the environment might have changed in comparison to the information available in the latest digital terrain model used for planning. In case the sensor is directly connected to the sensor network system, the data provided can be checked on the handheld. For the site at hand, network coverage maps are available that can be accessed to secure a position that has actual network access. Furthermore, a sensor placement module is provided that ties the manual sensing with direct feedback.

These techniques are particularly useful for those users (including companies) that install sensors at less accessible sites, or want to quickly deploy a sensor in the field, for example with the purpose to get an initial and rough overview of the processes on site: The methods will allow users to more quickly deploy sensors in the field at meaningful positions.

A3 A remotely controlled camera framework for multi-viewpoint analysis

See C2.1

B0. Techniques to support the storage, processing and distribution of environmental data gathered from on-site data acquisition and external sources

Once data is received from the sensors onsite, it will need to be stored, processed and distributed to the end-user display devices. Based on an existing sensor network system, several extensions will be developed that provide for specific functionality required for the on-site monitoring campaigns. The methods introduced will handle the quasi-real time data from the sensors, check the data through advanced filtering methods and prepare the data for the mobile devices by pre-processing it. Furthermore, access management is introduced to cover for possibly private (or sensitive) data access.
To advance the analysis in the field, an important aspect is the integration of simulation functionality from within GSN, advancing the prediction possibilities of the user. In relation, physical models will be advanced to improve the mentioned prediction capacities.
Finally, to both gather and distribute data from and to the site, the project introduces the usage of self-powered WIFI bridges, enabling fast access to the data storage at those sites that normally exhibit network coverage problems.

B1. Methods for handling quasi real-time sensor data within the sensor network

Environmental monitoring is becoming important for analyzing the processes involved with the creation of hazardous events. Understanding these processes is a complex task requiring dense and real-time monitoring of the environment. Quasi real-time sensor data streams submitted from multiple mobile sensors that monitor an area of interest have to be continuously combined, processed, analyzed and visualized. Moreover, scientists may require to compare or combine real-time streams with archived ones and apply on them some complex processing. The methods developed in HYDROSYS aim to efficiently collect and combine real-time data coming from multiple mobile sensor stations through connectionless communication channels with archived data. This process has an important trade-off between the freshness of sensor data and the latency introduced by synchronizing sensor data sources that may have different rates or different update time. HYDROSYS will also provide the methods to support complex spatial, temporal and value-based querying of this data in real-time. For this purpose, time-based and space-based indices will have to be dynamically constructed and maintained. The research output of this task will be also useful for the developers of data stream processing middleware systems.

B2. Filtering methods for data quality control

Inherently sensing devices introduce some measurement error within a manufacturer bound. Furthermore, the accuracy of these devices is very sensitive to their positioning and their interaction with the environmental heterogeneity, changes and processes. Moreover, the wireless medium, through which the sensor measurements may be transmitted, is highly error-prone inducing packet loss, packet reordering and latency. As a result, sensor data streams may contain outlier measurements and data holes (i.e. missing values). HYDROSYS will develop data filtering and quality improvement methods to improve the quality of sensor data streams by removing outlier values and filling missing ones based on regression models and employing long-term historical data. Also, HYDROSYS will investigate methods for monitoring the confidence on sensor data based on probabilistic models. This feature will be of particular interest for environmental scientists that employ these data in physical models that assess the probability of hazardous environmental phenomena. It will also facilitate monitoring of the “health” of sensor data and sensors in real-time against failures. The research outputs of this task will be useful for database developers to enhance the quality of the data stored. One potential risk is that scientists will not trust the output from automated data quality improvement methods. This problem could be alleviated by extensive verification of the proposed approach, comparing its output for older SwissExperiment data traces to the data cleaned manually by the scientists for the same traces. Another risk is that the quality monitoring of sensor data is an innovative research topic. To this end, the research conducted to this area will be published to high-end conferences in database systems.

B3. Access management methods for securing data on the sensor network

Several sensor network deployments exist and more are expected to occur in the near future. Environmental scientists that collaborate and belong to different institution want to have a unified interface for accessing multiple sensor deployments. However, the access rights of different scientists to the data provided by the different deployments are different. Proper authorization of data access is of crucial importance for environmental scientists but also for other end-user, such as municipalities. HYDROSYS will provide the mechanisms for fine-grained control for data stream access supporting ACL rights. The underline mechanisms will implemented based on existing database access control approaches.

B4. Integrated simulation and modeling functionality supporting the selection and generation of simulations from within the GSN sensor network

Environmental physical models, such as Geotop and Alpine3D, assess the probability of hazardous environmental phenomena based on environmental data. Currently, environmental data are downloaded through web interfaces (in the best case) or even manually collected from the flash disks of the sensors using portable storage media. Moreover, data has to be properly formatted and then inserted to the physical models for processing. However, this procedure is time-consuming and costly.

Similar cases occur when environmental scientists want to evaluate some assumptions through simulations or analyze the data with complex visualizations. HYDROSYS will fully integrate physical models and simulation functionality with GSN. Therefore, not only the above procedures will be fully automated, but also they will be able to employ real-time sensor data. HYDROSYS will provide the functionality so that arbitrary R simulation scripts can be applied to combinations of real-time or archived data. The impact of this task will be important both for scientists, who can build several scenarios and understanding complex environmental dynamics, and technicians supporting decision-makers in decision-making processes. The system, which represents a prototype, can be extended to any other contexts where the process under investigation has to be studied through a model that needs to be fed in real-time with field data. The output of this task will be of particular interest for the e-science community, but also for the developers of data stream processing middleware. Problems might arise from pore network coverage, likely to happen in remote areas, or from a black-out during harsh weather conditions. Tampon batteries and WIFI bridges will be installed to minimize this risk. Also, problems may arise due to the inherent complexity of physical models (that may lead to non-determinism) and the complex path of sensor data for executing simulations on-demand. Proper code-verification to the physical models, induction of fault-tolerance to GSN for interacting with them, and extensive experimentation will be performed to minimize these risks.

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

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 needs 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 (GML) 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).

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 user’s location is sent to the mobile clients. The amount of filtering (patch sizes) can be 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 will be an optimization step. This involves converting the data to a binary format that reduces the network consumption, 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 tightly couple with the user’s intrinsic information and decisions such as viewing angle, occlusions and current task. Level of detail techniques (LOD) 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 we're based: OpenGL. By fitting our graphical data structures to the specific needs of OpenGL (such as by using Vertex Buffer Objects, and by minimizing state changes) we will increase the performance of our application.
The developed techniques are generally useful for low-performance platform developers and computer graphics scientists.

B6. Improved physical models representing complex physical processes

Within the complex structural framework HYDROSYS encompasses sophisticated physical models able to mimic physical processes such as avalanche triggering, rainfall run-off and infiltration, surface and subsurface flows, flood generation, etc. These models are 3D, distributed, dynamical and physically based, meaning they contains equations that describe, at every time step, physical process for every cell in which the study area is divided into. These models are poor in tuning parameters, (which are usually difficult to be given a physical meaning), but eager for "real" data. That is the reason why they can be implemented in such a system, because they can be fed with data and take advantage of the different type of data available to deliver reliable results. In essence, HYDROSYS framework allows the use complex physical models thanks to its capability of providing in real-time several data from field sensors. The understanding of natural phenomena will benefit from such an approach, where "black boxes" are removed and processes are described by mathematic equations. The high computational load is the paid off. Appropriate machines and clusters with an adequate number of processors will be used for such a task to avoid too long processing time.

B7. Extended network capacities through WIFI bridges

HYDROSYS necessitates the handling of a multitude of sensors combined with model results, which means that the HYDROSYS mobile devices will be dealing with relatively large data sources. The insertion of this data into the field requires high bandwidth to function effectively, otherwise, the frustrated scientist/practitioner is left waiting for their data to download and in the worst case, this data is then outdated.

Some of the sites in the project have good mobile coverage, meaning that for many tasks the UMTS/HSPA networks can be used for data transfer. The speed of this system varies according to the area, but is up to 3.5 Mbits/s download and 1 Mbits/s upload. Though 3.5 Mbits/s is relatively high speed, it will be beneficial to cover these areas with a 2.4GHz wireless network, or at least hotspots where the user could retire to in order to quickly download to download large volumes of data: extremely high network speeds could be provided and data costs could be cut.

Using this technology, even at sites that have no network connection, a limited bandwidth can be achieved (covering R1). In this case, there are two possibilities: a multi-hop (more expensive) WIFI network can be used to transport traffic between either a fixed connection in the village or the high speed mobile coverage and the site; alternatively, the WiFi bridge device may be placed in an area of GPRS coverage for a single hop (cheaper), though slow network connection. The project will particularly focus on optimizing the hotspots at such kind of sites. These hotspots can be made large (though close to the GPRS coverage), with a sector antenna or small and further reaching with a directional antenna. Positions for this equipment will be modelled to select optimal positions and then tested in the area for practical use of the connection before a decision is made on whether further equipment is required.

The risks exists that only lower bandwidth connections can be guaranteed. Still, these kinds of connections will make a big difference in data access on-site – hereby, the data transmission can be further optimized by using more strict pre-processing methods, as suggested in outcome B5.

WiFi links are a rapidly 'up-and-coming' technology in the mountain regions. Previously, 900MHz radio links have been used for data transfer, but the data rate on these is slow. Low power computing technology has now made autonomous WIFI nodes a real possibility. SWITCH (the Swiss university network company) are currently doing research in this area and are in close contact with SLF for knowledge transfer in both directions. Knowledge on this area of technology development will be integrated into this rapidly developing industry and will be of particular significance for research institutions throughout Switzerland. Further distribution of this infrastructure within Europe is also possible.

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 can be adapted to for example direct the attention of the user to a specific area or event. 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.

The functionality to support the user's actions consists of several modules that are 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 will be 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.

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 will 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 will provide to the user a concrete representation of the abstract data delivered by the sensors and simulation. This visualization aims at helping the user understand the data that typically comes just as a collection of numbers. The final techniques will have to be optimized to run in the low-powered mobile outdoor devices for this project. At the end of the which, users will be able to 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, which will likely be a performance bottle neck for the mobile clients (risk R8). Furthermore, data may not always be physically visible and might be occluded (such as sub-surface soil moisture) which will require extra tools for visualization. Data to be visualized may not always be fast changing as is the case of sensors, but it may be roughly static, as in the case of Digital Elevation Models. Methods will be developed to cover these limitations.

Data visualization is a large area of research. It typically is a slow process of high quality image generation from an abstract data source, such as in volume visualization of MRI data. Our work focuses on a fast generation of a highly representative image from abstract data. The limitations of this type of visualization are higher, as images have to be generated within 0.06 seconds after data is available. This includes not only incoming sensor and simulation data, but also tracking and video information. 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.

Labeling generation is a promising solution for single sensor data visualization. However, this incurs in a problematic situation when multiple sensors are in the field of view of the user. Labels are typically thought of as containing textual information on the sensor values, but this is not the only type. Graph-like representations can also be placed inside labels or annotations, further techniques such as glyphs with color codings (e.g. red circle means damaged sensor, green means healthy) will also be investigated throughout the course of the project. Overlapping, cluttering are just some examples of the possible issues we will face. Visualization of simulation data can be done by mesh generation of a DTM overlaid with textures representing simulation values. This is a useful technique but limited, as overlaid information can only be uni-dimensional. Three dimensional simulation data visualization is more complex as it cannot be simply overlaid as a texture in which case 3D primitives generation will be explored. Comparison of data will also be in the HYDROSYS toolset, to help the user contrast information coming from different simulation results (see C1.1).

The generation of images from abstract data is dependent in multiple factors, many of which are related to the users themselves. Appropriate techniques of visualization need to consider the cognitive load imposed on the users. For example, lagging effects from low refresh rates may cause motion sickness, as the imaging device (camera) might physically move faster than the presented graphics on the screen. Inaccurate overlay of tracked information may cause a misunderstanding on the scene, where sensor data is presented in the wrong physical position on the screen. This and many other perceptual problems are tackled by HYDROSYS (see C3).

The developments being made can be very useful for computer graphics scientists and developers that develop for limited performance platforms.

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

Attention direction techniques are used to guide the user's eye sight to areas that the system has detected as being of interest. For example, sensor health reports, location of other users in the environment, and user defined metrics. Users could tell the system to direct their attention to sensors that exceed certain threshold; this could be useful to explore areas with potential landslides or patches in a river where pollution is above healthy levels. Attention direction techniques will provide HYDROSYS with a tool to let the user know of important areas in the image.

The final techniques developed by HYDROSYS will deal with the limitations imposed by the low-powered mobile devices. The performance of the attention direction techniques will also be tested on real outdoor environments in order to steer their development. The techniques will not only focus on the underlying digital data being observed, but they will deal also with environmental factors (e.g. Contrast of snow) to better direct the user's attention. During the first year of the project, we have already tested a set of techniques for attention direction based on Visual Saliency.

The field of human attention based on visual graphics, however, is vast and other techniques will be investigated for HYDROSYS. Humans' attention is a complex process rooted in physiology (such as the cones and rods in our eyes) and in culture and experience (such as fears). Naive techniques for attention direction would consider simple overlays to be sufficient to solve the task, but this would ignore the problematic of visual cluttering and of the complex background information provided by the camera feed. Sound is often cited as another source for attention direction, but its potential is limited as direction itself is hard to achieve (i.e. one can generate a sound coming from the computer, but one cannot easily direct the user to a particular location of the environment exocentric from the computer itself). These problems are exacerbated when one considers the limited computational resources at hand and the difficult environmental situations in which the users will use the system. HYDROSYS will propose solutions for these situations mainly based on management of colour (and visual saliency) but will also explore further techniques throughout the project.

C1.2 Graphics optimization methods for low-performance platforms

See B5.

C2. Advanced interfaces for handling more complex functionality for on-site analysis on small-screen handheld display devices

Two different kinds of handheld devices are used during monitoring and management of environmental processes: a handheld computer with additional sensors, and a cell phone. These devices are kept small due their need to be mobile (portable) – users need to take them in the field without being limited by the weight or ergonomics of the device. However, the size of the devices implies that users can only view and interact with content on small screens. Typically, small handheld computers have a screen of around 5 inch, mobile phones more or less just 3 inch. In addition, users have to use either small controls (like a mini keyboard and joystick) or a pen to interact with the content, which is quite different from interacting with normal desktop computers. At the same time, the HYDROSYS system provides quite some functionality to support the different actions. As a result, the functional depth is not always visible to the user: most of the functionality is not directly seen by the user, but needs to be learned or communicated by other means. Hereby, different users access different amounts of functionality, based on the purpose the system has to perform for the end-users task set (see C0).

The project specifically focuses at providing all the needed functionality in an apt way – ignoring the limitations of the system would likely lead to only partly usable systems. Approaches taken include the usage of different interaction modes and associated structuring of functionality, the definition of functional sets by using user profiles, and the structuring of functionality according to the workflow of the user. Hereby, the user interfaces particularly take care of using methods that match the used input control method at hand. The development of the techniques is supported by a range of human factors studies and user evaluations. These techniques relate to C3 perceptual optimization, which tackles optimizing the integration of visualization and user interfaces. Furthermore, several innovative modules will be made available that allow for multi-viewpoint analysis, simulation support in the field, and making geo-tagged, sharable notes. Additionally, specific focus is put on providing a robust platform for outdoor analysis with mobile devices, by creating a new kind of handheld augmented reality construction.

The lessons learned from developing the techniques, and the techniques themselves can be useful for any developer making more complex mobile applications for small-screen devices, and as such affect among others cell-phone, MID (mobile internet device) and UMPC (Ultra mobile PC) developers. Furthermore, several of the techniques we will develop will be applicable in general for augmented reality applications.

C2.1 Techniques for handling dynamic multi-camera setups used for multi-viewpoint analysis and A3 A remotely controlled camera framework for multi-viewpoint analysis

The HYDROSYS system deploys a number of static and dynamic cameras. Mounted under the blimp, at the sensor stations, at a quickly deployable pan-tilt unit, and at the handheld devices, multiple cameras can be accessed while users observe the site at hand. The camera footage will allow the users (especially those using the handheld computers) to get a good overview of the identified problem area: by viewing from different angles, and possibly controlling the camera itself (blimp, pan-tilt), the problem area can be observed from different sites, avoiding possible object occlusions and creating a better understanding of the spatial relationships between all objects in the scene.

In order to use the different camera footages, users need to create an understanding of where the cameras are in relation to the user, and what possible common objects are interested can be seen. Basically, the user needs to understand the relationship between herself, the cameras, and the site being observed. Apt techniques aiding that understanding will be developed to avoid that users get confused while accessing the different cameras: the user may have limited knowledge on the site and location of the cameras. The consortium will develop techniques that provide spatial cues communicating the spatial relationships between the user, camera and site. These techniques can be both aimed at providing a general overview (like map-related techniques), or by integrating location and directional cues while switching between ("travelling") different cameras. The development of techniques is supported by several human factors studies and user evaluations that specifically focus on spatial awareness.

The development of these techniques is also beneficial for other researchers: relating to surveillance systems used for a diversity of purposes, the techniques extend the generally used system techniques for "static" setups and users that know their setup well through experience. Currently, there is much interest for mobile camera setups, especially in the field of robotics, that may profit from our techniques.

C2.2 Lightweight methods for geo-referenced annotation of events or solutions

One of the potentials of visualizing data on site is the collaboration among users. Having many users on site browsing the simulation and sensor data in their surroundings can generate large amounts of useful logging of events. HYDROSYS will enable users to easily create content on site about current events. This takes place in many levels, from image capturing of the scene to text comments for later analysis. The mobile devices for on-site analysis will all be equipped with a tracking device and an image capturing device. This enables the creation of geo-referenced visual logs by the users. Each image will not only be a snapshot of the current view of the camera but will possibly include contextual information about its position, viewing direction, tracking quality, user who took it, and current viewed profile. Be it to record damaged sensors or potentially interesting climatic events, the advantages of image capturing are clear. But the recording of images is not always sufficient; users may find the need for a more explicit logging method. For that purpose HYDROSYS will include a tool for the recording of text annotations. The annotation will be in the form of simple text boxes in which the user records geo tagged information. This tool will allow collaboration among users and more detailed information on events. Furthermore, it will enable the sharing of ideas and revisiting of details while back at the office.

C2.3 An ergonomic and robust handheld outdoor augmented reality setup

The sites under observation by the HYDROSYS end-users are often at remote locations with possibly harsh conditions. Whereas most observations tend to take place during "normal" weather conditions, the devices used for on-site monitoring and management potentially still need to cope with lower temperatures, dirt, and water (snow, rain). In addition, to improve the user acceptance, device setups need to be robust to be taken around. In particular the device setup for augmented reality visualization (the handheld computer setup) needs to be protected by these external influences. The setup requires the connection of additional sensors (such as a camera, and location/orientation sensors) to provide high-quality in-context graphics visualization. The project will develop prototype casings that will integrate and protect the computer and the sensors. The encasing will allow for ergonomic pose during operation and a good weight distribution, to avoid strain. Additionally, the encasing will be portable to be taken around easily, or stashed away.

Due to the rather specific combination of hardware, such a construction is currently not available either at research institutions or commercially. Nevertheless, outdoor augmented reality applications is increasingly focused upon – both researchers, but also professional field workers from other application areas (such as engineering) have shown interest and may profit from the knowledge gathered.

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 aims to provide near-real time simulation-results to be available for the user while being in the field.
A simulation can be triggered either from a desktop in advance of a field trip or remotely, with a handheld device while being on-site. This supports scientists and technicians on-site who need to check the ground-truth against model results to follow the evolution of the current scenario.
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 can be updated with the most recent input data coming from the sensing stations in the area. It therefore should be possible to get near real time data when being on-site. Simulation results can than be visualized on the handhelds. 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.
If the task works out as successfully as expected, and with meaningful results such operational use of complex models might go into broader application in scientific and practical purpose

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 will provide tailored visualization and interface methods that filter and structure the content and functionality at hand: the techniques will be perceptually optimized to avoid confusion and cognitive overload; hence, the techniques will 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.

Throughout the project the development of graphics will be steered by user tests that hint at the better ways of presenting information. End visual graphics need to pay attention to basic elements such as colour, brightness and depth of field in order to present a coherent data view: a typical failure of similar projects is to heavily enhance the virtual graphics overlaid on the real world. This presents a disconnected view of real and virtual and may deviate the attention of the user from the important areas, a problem known as the transparency of the media. Within the development of the techniques, particular attention will be given on how to relate the sensor data to its actual context, balancing the communication of visual features of both sources to create a coherent view. The usage of the visualization techniques directly depends on the screen management associated with the display of the user interface. The user interface may occlude specific visual information that is associated with performing a certain task, or users may want to adapt perceptual qualities of the visualization itself based on personal preference.

The techniques that will be developed are not only useful for the particular application framework at hand, but beneficial for developers in the field of augmented reality in general. Supported by the planned validation outcomes, we expect that people interested in computer graphics, perception and user interfaces will also benefit from the results.

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 will be developed to track the pose of the user's hand-held augmented reality setup. This pose information is crucial 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 will be able to easily note their own location within the site when making observations.

This hybrid tracking system will fuse measurements from a variety of sensors within the hand-held unit. These sensors include gyroscopes and accelerometers providing inertial measurements, a GPS sensor, and a camera. This camera will 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 produced in A1. Additionally, the tracking system will benefit from the ultra wide band position sensing developed in C4.1. When fused, all of these measurements will provide an estimate of the unit's pose accurate to roughly 1m.

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.

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

In order to extend the tracking accuracy, a mobile ultrawide-band tracking system will be deployed that can potentially localize users at high accuracy within a limited range. 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.

It should be stated that the tracking presents some issues, which will be carefully tackled. On the one hand, due to the terrain relief, the physical readjustment of the sensors angles and their software calibration should be performed after each movement on the site. On the other hand, the localisation performance remains, by physics, limited due mainly to the small number of sensors seeing the tag and to the small sensors inter-distance. In order to improve the overall performance, we propose to:

- Increase the height of the sensors, so that angle of arrival errors would have smaller impact on the location accuracy
- Average over several sighting locations in order to reduce the deviation from the real physical positions.
- Combine the ultra wideband tracking results with the GPS and inertial positioning ones will be deeply investigated.

The final outcome would be very interesting also for people safety on construction sites. Other applications of the outcome may consider problems faced by police, fire and rescue, and other services.

Publications and open source outcomes

This section provides an overview of the publications and presentations presenting the work performed in HYDROSYS, including external cooperation, as well as the components that are, or will be soon released as open-source.

S1 Support for analysis of complex environmental processes to mitigating environmental degradation by spatial analysis tools on mobile platforms.

Accepted publications:

Dawes N., Lehning M., Aberer K., Parlange M., Bavay M., Berne M.: Swiss Experiment: Providing diverse snow research data sets when and where they are required; Proc. International Snow Science Workshop (ISSW 09 Europe), Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland, September 2009.

Kruijff, E., Mendez, E., Veas, E., Gruenewald, T., Simoni, S., Luyet, V., Salminen, O., Nurminen, A., Lehtinen, V. HYDROSYS: on-site monitoring and management of environmental processes using handheld devices. To appear in: GeoHydroinformatics: Integrating GIS and Water Engineering. Anand, S., Ware, M., Jackson, M., Vairavamoorthy, K., Abrahart, R. (eds). Published by CRC Press (to appear in 2010).

Kuonen, P., Bavay, M., Lehning, M., POP-C++ and Alpine3D: petition for a new HPC approach. In: Advanced ICTs for Disaster Management and Threat Detection: Collaborative and Distributed Frameworks, in press.

Conference presentations:

Aberer K.: Infrastructures for a smart earth; ASUT Seminar at SWISS TELECOMMUNICATION SUMMIT, Bern, June 2009

Juliette Blanchet and Michael Lehning. 2010. Spatial models for climate extremes. Application to extreme snow depth in the Swiss Alps. Presentation at the European Geophysical Union General Assembly, May 2nd to May 7th 2010, Vienna, Austria.

Ari Jolma et al. HYDROSYS: spatial analysis tools for on-site environmental monitoring and management. Poster presented at the 4th GEO European Projects Workshop, 29-30 April 2010, Athens, Greece.

Tero Niemi. 2010. Modelling the hydraulics of a small suburban stream. Presentation in a conference ”Kansallinen mallinnusseminaari”. 8.2.2010. Helsinki, Finland.

Mitterer, C.; Mott, R.; Schweizer, J., 2009: Observations and analysis of two large wet-snow avalanche cycles. Presentation at the International Snow Science Workshop 27 September to 2 October 2009, Davos, Switzerland.

Rebecca Mott, Thomas Grünewald, Michael Schirmer, Vanessa Wirz, and Michael Lehning. 2010. Understanding snow deposition on mountain slopes Presentation at the European Geophysical Union General Assembly, May 2nd to May 7th 2010, Vienna, Austria.

S2 Office-only workflows complemented for monitoring and management, improving the understanding of on-site monitoring and management activities.

Conference presentations:

Antti Nurminen. 2009. Maps in Mobile Services. Presentation at the Cartographic Society of Finland (SKS) and ProGIS Autumn Seminar 29.9.2009, Helsinki.

Antti Nurminen. 2009. Mobile 3D Maps. Keynote at SIGGRAPH Finland Autumn Event "Syysgraph 2009", 27.10.2009.

S3 An integrated and unified data pipeline for data acquisition, storage and processing, and mobile visualization

Accepted publication:

Mathias Bavay, Thomas Egger, Laurent Winkler. 2010. MeteoIO: A Meteorological Data Pre-Processing Library for Numerical Models. Presentation at the European Geophysical Union General Assembly, May 2nd to May 7th 2010, Vienna, Austria.

Conference presentations:

Aberer K.: Swiss Experiment - From Wireless Sensor Networks to Sensor Data Management; Invited Talk at DMSN Workshop, July 2009.

Simoni, S., Egger, .T. and Bavay, M. the HYDROSYS toolchain GSN-MeteoIO-GEOtop. 2009. A presentation in joint EPFL TUG meeting.

A0 Techniques to support the setup of sensors and gathering of dense environmental data:

Accepted publication:

Jeung H., Sarni S., Paparrizos I., Sathe S., Aberer K., Dawes N., Papaioannou T. G., Lehning M.: Effective Metadata Management in Federated Sensor Networks; SUTC, Newport Beach, CA, March 2010. Presented at SUTC 2010 by H. Jeung.

A3/C2.1 remotely controlled camera framework:

The module will be *released* as part of the open source software architecture.

Accepted publication:

Veas, E., Mulloni, A., Kruijff, E., Regenbrecht, H., Schmalstieg, D. Techniques for View Transition in Multi-Camera Outdoor Environments. In Proceedings of Graphics Interface 2010 (GI2010), 2010.

B0: Techniques to support the storage, processing and distribution of environmental data gathered from on-site data acquisition and external sources

Accepted publications

N. Bonvin, T. G. Papaioannou, and K. Aberer. An economic approach for scalable and highly-available distributed applications. In Proc. of the 3rd IEEE International Conference on Cloud Computing, Miami, FL, July 2010. Presented at CLOUD 2010 by N. Bonvin.

Zhou Y., Salehi A., Aberer K.: Scalable Delivery of Stream Query Result; In proceedings of the 35th International Conference on Very Large Data Bases (VLDB), July 2009.

Wu J., Zhou Y., Aberer K., and Tan L.: Towards Integrated and Efficient Scientific Sensor Data Processing: A Database Approach; In proceedings of the 12th International Conference on Extending Database Technology, 2009

B1: Methods for handling quasi real-time sensor data within the sensor network

Accepted publications

Jurca O., Michel S., Herrmann A., Aberer K.: Processing Publish/Subscribe Queries over Distributed Data Streams; In proceedings of the 3rd ACM International Conference on Distributed Event-Based Systems, 2009

B4: Integrated simulation and modeling functionality supporting the selection and generation of simulations from within the GSN sensor network:

Several software components resulting from the project have been and/or will be published as FOSS. These include:

RemoteWrapper. This component was updated to link together multiple GSN instances and thus make the fusion of archived remote data with real-data possible.

CSVWrapper. This component was updated to read archived data from CSV files to GSN. It allows full flexibility of parameterization and it is robust against errors contained in the CSV files.

RVirtualSensor. This new component allows for the communication of GSN with an R server, so as GSN is able to apply R scripts to real-time or archived sensor data.

Web service interfaces to access sensor data from GSN instances.

GSN access control. This framework allows the fine-grained access control for the sensor data aggregated by the GSN instances.

Web service interfaces: These new interfaces allow for dynamic virtual sensor registration for arbitrary sensor data processing, dynamic query registration, temporal and spatial queries, and for simulation execution.

Accepted publication:

Ferencik, I., Niemi, T. and Jolma, A. 2010. On site environmental modeling and monitoring: the Nordic Scenario in HYDROSYS project. In Proceedings of iEMSs 2010 International Congress on Environmental Modelling and Software. Ottawa, Canada. (in press)

B6 Improved physical models representing complex physical processes:

The consortium continues to improve existing process models, e.g., by adding new features to them and making them compatible to the HYDROSYS system. (See also B4 above).

Accepted publication:

Mott, R. and Lehning, M.: Meteorological modelling of very high resolution wind fields and snow deposition for mountains, J. Hydromet., doi:10.1175/2010JHM1216.1, in press.

Niemi, T. 2010. Development of a hydraulic model and its application to a small urban stream . Master's thesis. Aalto University.

Simoni, S., Assessing of the impact of spatial heterogeneity on natural hazards for an

Alpine watershed, Newsletter of the Mountain Research Initiative, no. 4, May 2010

Papers in preparation:

Simoni, S. Porporato, A. Padoan, S., Parlange, M., Different sensitivity of streamflow components to spatial variability in complex topography, in preparation.

Conference presentations:

Michael Schirmer and Michael Lehning. Snow Surface Scaling and Roughness in Mountains. Presentation at the European Geophysical Union General Assembly, Mai, 2nd to Mai 7th 2010, Vienna, Austria.

Simoni, S., Porporato, Padoan, S. and Parlange M. Different sensitivity of streamflow components to spatial variability in complex topography. EGU 2010, Vienna, Austria

C1 Visualization techniques / C1.1 attention-direction and occlusion-management techniques:.

The techniques will be made available as *software release.*

Accepted publications:

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

Partala, T, Nurminen, A. and Vainio, T. 2010. Salience of visual cues in 3D city maps. British HCI 2010. (in press)

C2 Advanced interfaces:

Accepted publications:

Nurminen, A. 2009. Mobile 3D City Maps, Doctoral Dissertation. Helsinki University of Technology

Froechlich, P., Baldauf, M., Oulasvirta, A. and Nurminen, A. On the move and wired to the world. Communications of the ACM. (in press)

Nurminen, A. 2009. Mobile 3D City Maps, Doctoral Dissertation. Helsinki University of Technology

C2.3 Ergonomic handheld:

The ergonomic handheld is likely to be used by other projects through *collaborations*.

Publication under preparation:

Publication on different generations of handheld constructions.

C3 Perceptually optimized visualization and interaction techniques:

The techniques (integrated in the visualization and interface modules) will be made available as *software release*.

Accepted publications:

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

Outcome issues

ID	NAME	RELATED TASK	INPUT	OUTPUT	CRITERIA	RISK	VALIDATION
A0	**Techniques to support the setup of sensors and gathering of dense environmental data**						
A1	A blimp-based site reconstruction system for refining the resolution of digital terrain modules, and the generation of high-resolution imaging.	T4.2 remotely controlled blimp T4.3 GSN Real-time support	DTM, localization data (GPS/IMU), image footage	Refined DTM and surface optical and thermal texture maps	Spatial resolution of recovered terrain model and thermal overlay	R2. Weather conditions and altitude for blimp operation	T7.3 Blimp flight test
A1.1	Blimp flight control methods	T4.2 remotely controlled blimp	Localization sensor data, imaging, communication downlink	Navigation algorithms, communication uplink	Stability of flight path, navigation accuracy	R2. Weather conditions and altitude for blimp operation	T7.3 Blimp flight test
A1.2	A mobile sensor system acquiring thermal data to be fused with other sources	T4.2 remotely controlled blimp	Localization sensor data, imaging from thermal camera, communication downlink	Thermal imaging to be handled by real-time data processors (B1)	Spatial resolution of overlayed thermal data, thermal variance (accuracy)	R2. Weather conditions and altitude for blimp operation	T7.3 Blimp flight test Spot measurement and comparison
A2	A sensor placement module supporting the installation of sensors in the field	T5.3 sensor placement module	Sensor(station) data, mobile sensor	Direct sensor / installation feedback	Usability, feedback loop usefulness	R1. Poor network coverage at remote sites	T7.3 Wireless network capabilities investigation WIFI bridge tests in cooperation with SwissEx WP8 usability tests D6.1 Research results of on-site monitoring
A3	A remotely controlled camera framework for multi-viewpoint analysis	See C2.1					
B0	**Techniques to support the storage, processing and distribution of environmental data gathered from on-site data acquisition and external sources**						
B1	Methods for handling quasi real-time sensor data within the sensor network	T4.3 GSN Real-time support	Real-time sensor data	Processed data in sensor network	High data insertion throughput, High processed data extraction rate	R3 Data archiving and modelling of (live) data	T7.3 GSN performance investigation WP8 usability tests

B2	Filtering methods for data quality control	T4.7 GSN Data quality improvement T4.3 GSN Real-time support	Real-time sensor data	Cleaned processed data in sensor network	Level of data quality (based on data confidence metric)	R3 Data archiving and modelling of (live) data	T7.3 GSN performance investigation WP8 usability tests
B3	Access management methods for securing data on the sensor network	T4.5 GSN security mechanisms	Data in sensor network, user lists	Access rights management methods	Authorized data access, confidentiality of sensor data	Data privacy	WP8 usability tests
B4	Integrated simulation and modeling functionality supporting the selection and generation of simulations from within the GSN sensor network	T4.6 GSN Simulation and modeling	Data in sensor network, physical models	Simulation result	Usability	R4. Poor accuracy of physical models output, Simulation performance time, Complex simulation data path	T7.3 GSN performance investigation WP8 usability tests
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	T3.2 System infrastructure T4.3 SmartClient	Data in sensor network	Pre-processed data, system optimizations	10-15 frames per second (cellphone) and 15 frames per second (handheld computer)	R8. Poor graphics performance of handhelds	T7.1 Reality experiments T7.1 Environment visualization experiments WP8 usability tests
B6	Improved physical models representing complex physical processes	T6.x.2 generation of physical process models	Data in sensor network	Model for simulation	Improvement of model accuracy and performance (simulation output)	R4. Poor accuracy of physical models output, Simulation performance time, Complex simulation data path	D6.1 Research results of on-site monitoring T7.3 Simulation performance investigation WP8 usability tests
B7	Extended network capacities through WIFI bridges	T3.2 System infrastructure	UMTS signal	Quickly deployable WiFi bridge setup	High-bandwidth connectivity (500kb/s and up), ease of deployment	R1. Poor network coverage at remote sites	T7.3 Wireless network capabilities investigation WIFI bridge tests in cooperation with SwissEx
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).**						
C1	Visualization techniques for showing complex and multivariate environmental data in their actual context	T3.4 Visualization techniques	Data in sensor network	Numeric data, plots, overlays, 3D models	Accessibility, visibility, interpretation, learning factors	R9. Misinterpretation of complex and possibly abstracted information on small screens of handheld devices	T7.1 Attention and saliency T7.1 Perceptual optimization test WP5 Human factors studies WP8 usability tests

C1.1	Focus and context techniques: Attention-direction techniques for focusing the user on specific events, and occlusion management	T3.5 Focus and context techniques	Data in sensor network	Visual data modifiers	Unobtrusiveness of method, success of attention direction	R9. Misinterpretation of complex and possibly abstracted information on small screens of handheld devices	T7.1 Attention and saliency
C1.2	Graphics optimization methods for low-performance platforms	See B.5					
C2	Advanced interfaces for handling more complex functionality for on-site analysis on small-screen handheld display devices	T5.x user interfaces	Sensor network connection, sensor data	User interfaces	Usability, understandability / visibility	R9. Misinterpretation of complex and possibly abstracted information on small screens of handheld devices	T7.1 Reality experiments T7.1 Attention and saliency T7.1 User interface aspects with prototypes T7.1 multi-camera navigation and cognition T7.1 Perceptual optimization test WP8 usability tests WP5 Human factors studies
C2.1	Techniques for handling dynamic multi-camera setups used for multi-viewpoint analysis and A3 A remotely controlled camera framework for multi- viewpoint analysis	T5.5 remotely controlled cameras	Camera footage from image database	User interface for observing and switching between perspectives	Cognitive load, knowledge acquisition, usability	R9. Misinterpretation of complex and possibly abstracted information on small screens of handheld devices Data loss, image quality	T7.1 multi-camera navigation and cognition
C2.2	Lightweight methods for geo-referenced annotation of events or solutions	T3.3 Collaboration methods, T5.1 on-site monitoring interface, T5.5 remotely controlled cameras	Annotations in database	Text annotation methods for input, sharing mechanisms	Ease of annotation, sharing	R9. Misinterpretation of complex and possibly abstracted information on small screens of handheld devices	T7.1 User interface aspects with prototypes WP5 Human factors studies WP8 usability tests
C2.3	An ergonomic and robust handheld outdoor augmented reality setup	T5.1 On-site monitoring interfaces	-	Robust, modular handheld platform	Protectiveness, mobility, modularity, user acceptance	R11. Adverse weather condition effects on device sensors / devices	WP8 usability tests

C2.4	Simulation support during on-site analyses	T5.4 Speculative modeling interfaces	Processed sensor data provided by GSN	User interfaces for accessing and partly adapting simulation processes and results	Potentially: feedback loop time	R4. Poor accuracy of physical models output, Simulation performance time, Complex simulation data path	T7.3 Simulation performance investigation WP8 usability tests
C3	Perceptually optimized visualization and user interface techniques	T3.4 Visualization techniques, T5.1 on-site monitoring interfaces	Sensor data visualizations, user interface elements	Adapted visuals (color schemes)	Visibility, understandability	R9. Misinterpretation of complex and possibly abstracted information on small screens of handheld devices	T7.1 Perceptual optimization test
C4	A hybrid tracking system for accurate localization of users on-site	T3.6 hybrid tracking methods	Localization and orientation sensors	Optimized fusion methods providing pose (position and orientation)	Added accuracy (~1m) against traditional methods (~5-10m), alignment of visuals	R10. Poor localization accuracy, deployment of support vehicle not possible	T7.3 Positioning and orientation precision tests
C4.1	A quickly deployable and movable high-accuracy tracking setup extension	T3.7 vehicle setup	Ultrawide-band system components	Mountable rack construction for vehicle	Added accuracy (~1m) to C4 and relative ease of deployment, alignment of visuals	R10. Poor localization accuracy, deployment of support vehicle not possible	T7.3 Positioning and orientation precision tests

Note: the exact criteria are mostly covered in detail in the associated validations. Please refer to the validation reports for more details.