INTEGRATING MOBILE GEO SENSOR INFORMATION INTO COLLABORATIVE VIRTUAL GLOBES

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Joint Workshop on Visualization and Exploration of Geospatial Data
June 27-29, 2007, Stuttgart (Germany)

KEY WORDS: Geospatial Collaboration, 3D, Visualisation, Virtual Globes, Geo Sensor Web, Mobile Sensors

ABSTRACT:

This paper describes the large potential offered by integrating mobile geo sensor data, for example georeferenced video imagery acquired from micro UAVs, into collaborative 3D geoinformation technologies. It identifies some of the key issues to be addressed in the design and implementation of such geospatial collaboration frameworks and describes the main features of a prototype system which is currently being implemented as part of the ViMo (Virtual Monitoring) research project.

1. INTRODUCTION

1.1 Status and Motivation

Virtual Globes

Current implementations of virtual globes such as Google Earth or NASA World Wind were neither primarily designed for dynamic or real-time content, such as large numbers of moving objects or mobile sensors, nor were they originally targeted at geospatial collaboration applications. However, the integration of mobile real-time geo sensor information and of collaboration functionality into high-definition virtual globes will open up yet another range of new applications in domains such as security, traffic monitoring, fire fighting or border patrol.

Geo Sensor Web

Already today, there is an abundance of georeferenced sensors collecting information about a wide range of phenomena, such as weather, water flow or road traffic. In the past, these sensors had proprietary interfaces and were typically accessed through non-standard communication channels using proprietary communication protocols. All these factors prevented a wide-spread use of such geo sensors.

However, there are a number of recent and ongoing developments which are likely to change this situation and make geo sensors and their observations an important information source, particularly in combination with Virtual Globes. Among these developments are: the establishment of standardised Internet protocols for wire-based and wireless communication channels which also address security aspects, service based architectures in general and geo sensor web standards in particular. Of particular interest to the geospatial community is the OGC Sensor Web Enablement (SWE) Initiative of the Open Geospatial Consortium (Botts et al., 2006).

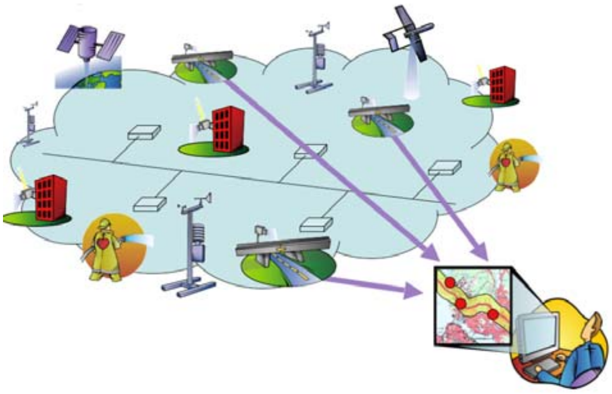


Figure 1: OGC Geo Sensor Web (Botts et al., 2006)

Micro UAVs – New Generation of Mobile Sensor Platforms

While standardisations such as those proposed by the SWE Initiative provide the necessary basis for accessing sensors and their observations, future monitoring and collaboration applications within Virtual Globes will also strongly benefit from the ongoing developments in the fields of geo sensors and platforms.

Advances in the fields of positioning and attitude control technologies in combination with high-tech materials and high-capacity batteries have, for example, led to a new generation of lightweight and autonomous airborne sensor platforms.

Figure 2 shows such a sensor platform of the type 'microdrones md4-200', one of the first operational micro UAVs (unmanned aerial vehicles) which has specifically been designed for monitoring applications. The md4-200 micro UAV is powered by 4 rotors and is designed for vertical take-off and landing (VTOL). The four gearless brushless motors are powered by a lithium polymer battery which provides a flying time of approx. 20 minutes. The UAV is controlled by GPS, barometric and magnetic sensors and can be flown interactively or in a fully autonomous mode (as of summer 2007). The maximum take-off weight of the system is approx. 900 g with a maximum payload of around 250 g. The payload can include any light-weight sensor such as an RGB, video or thermal IR camera whereby the actual field of view and the data capturing process can be controlled from the ground control station over an integrated data link.

Figure 2: Micro UAV (microdrones md4-200) with digital RGB camera (left) and portable ground control station (right).

New airborne geo sensor platforms, such as the one presented above, have a barely perceptible noise level, are environmentally friendly and can be safely operated even in built-up areas. Problems of such lightweight micro UAV are their limited stability and their susceptibility to strong wind in general and to wind gusts in particular. It is expected that further developments will significantly reduce these shortcomings.

1.2 The ViMo Project

ViMo (Virtual Monitoring) is an industry and government funded research project which was initiated in 2006 with the goal of designing a software framework for the integration of distributed and mobile imaging sensors into interactive 3d geoinformation services via geo sensor networks. Key research issues of the ViMo project were:

- The design and implementation of the i3D technology, a new generation of Virtual Globe, with a specific focus on real-time and shared contents as well as maximum geometric accuracy.
- The design and development of a geospatial collaboration framework as a modular extension to the i3D technology.
- The investigation and integration of new mobile geo sensor platforms and real-time geo sensor information into the i3D technology.

While the ViMo technology is designed to be application independent, there are a number of very promising application areas. These include the autonomous and rapid mapping of disaster areas, the real-time monitoring of traffic, forest fires or large events. Particularly promising is the integration of micro UAV-based video imagery with a Virtual Globe technology such as i3D (Eugster and Nebiker, 2007). Incorporating real-time contents or various geo sensors into interactive 3d geovisualizations, such as Virtual Globes, raises a whole range of questions which are investigated in related activities (Bleisch et al., 2006).

1.3 Structure and Goals of this Paper

This paper first addresses a number of important issues which will have to be solved in order to exploit the accuracy potential offered by modern geo sensors. It then discusses current content types of Virtual Globes before investigating emerging and future content types such as georeferenced, dynamic real-time contents which might even be shared in real-time by a large number of users. The paper then points out a number of important issues to be addressed in the design of collaborative Virtual Globe environments.

The paper then illustrates the system architecture of the 3d geospatial collaboration solution which is currently being implemented as part of the ViMo project. This architecture is based on the 3rd generation 3d geovisualisation engine i3D and includes a framework from the gaming domain which is successfully used for the real-time synchronisation of actors, sensors and geospatial content alike. Subsequently, the paper explains how static and mobile geo sensors, in particular georeferenced video sensors on micro UAVs, are integrated into the ViMo collaboration framework. Finally, results from a number of real-world system trials are presented.

2. GEODETIC ISSUES

If Virtual Globes are to be extended towards monitoring, tracking, measuring or positioning real-world objects, geometric accuracy and reliability become key factors. In order to achieve the desired accuracy levels at the metre level or better, equally accurate geodetic models have to be incorporated into such Virtual Globe technologies. The following section outlines the shortcomings of some of the earlier, simpler models and the characteristics of more complex models.

2.1 Flat Earth Model – Foundation of 3D Visualizations

Computer graphics in general and 3d graphics as well as traditional 3d formats like VRML in particular are originally founded on Cartesian coordinate systems and on coordinate domains with limited resolutions of typically 32 bits per coordinate. This was – and still is – absolutely adequate for visualising the vast majority of small scale objects and for applications with no need for absolute georeferencing.

As a consequence of this Cartesian foundation, the first generation of 3d geovisualisation solutions was almost exclusively using the 'flat earth model'. This flat earth model works fine for visualising local geospatial scenes which use a single local coordinate system i.e. map projection for all spatial contents. However, 3d visualisations based on the flat earth model suffer from a number of severe limitations when extended to larger areas such as entire countries or continents.

Among the problems encountered are angular distortions introduced by the mapping of a sphere to a planar reference surface. Depending on the underlying map projection and the extent of the scene, these angular distortions can be significant and can introduce serious problems. In typical flight simulation applications covering entire countries or continents, for example, the runway directions of airports in peripheral regions of the 3d scene can be severely biased, thus leading to skewed approaches and rendering the application useless.

2.2 Spherical and Ellipsoidal Models for Virtual Globes

As implied by their name, Virtual Globes can be considered as digital versions of physical globes representing the Earth its Moon or other planets. Thus, they have to accommodate roughly spherical celestial bodies with large spatial extents in the range of thousands of kilometres. Unlike their physical counterparts of globes or maps, virtual globes also need to support much finer details i.e. higher resolutions than could ever be materialised with physical representations (see also 2.4).

Virtual Globes of the Earth are typically based on an earth-centered, earth-fixed (ECEF) coordinate system, e.g. WGS-84. Since they usually need to include detailed regional and local data sets, they must also support numerous national or regional geodetic reference systems in existence.

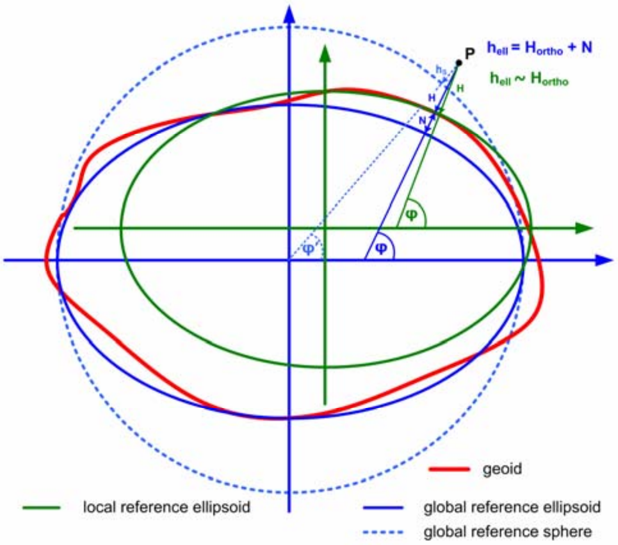


Figure 3: Geodetic reference models for Virtual Globes.

A central design issue in a Virtual Globe technology is the selection of a suitable geometric reference model. The main choice is between a spherical and an ellipsoidal model. The spherical model is considerably less complex and is sufficient for global to regional applications. However, the Earth's rotation results in a so-called flattening of the earth in the order of 1/300 of the earth radius leading to an equatorial radius which is roughly 23 km larger than the polar radius. Using a spherical instead of an ellipsoidal reference surface will introduce three-dimensional position errors in the order of 10-20 km. This error primarily affects the vertical component and can be compensated to a good part by vertically projecting 3D point coordinates to the spherical reference surface. However, with a spherical reference model, horizontal errors of up to 40 metres cannot be accounted for and need to be compensated by local transformations. As a consequence, an ellipsoidal reference model must be used if the direct horizontal georeferencing of spatial objects (e.g. 3d objects or orthoimages) should be better than 10-40 metres. This is the case in any applications involving GPS position data and/or vehicle navigation and in any application involving data sets from a local map datum.

2.3 Geoid Models for Monitoring and Collaboration

The use of a suitable geometric reference model, such as the WGS-84 ellipsoid, ensures high horizontal accuracies at the sub-metre level. This horizontal accuracy is sufficient for most visualisation and information tasks envisaged with Virtual Globes. Thus, vertical information in many cases is exclusively based on terrain model data consisting of orthometric heights, i.e. of heights relative to the geoid surface (see Figure 3).

The geoid is a physically defined reference model which is defined as the equipotential surface of the Earth's gravity field approximately coinciding with Mean Sea Level. The geoid is irregular due to the uneven distribution of mass within the physical Earth. Height differences between the geoid as a physical reference surface and a global geometric reference surface such as the WGS-84 ellipsoid are in the order of ± 100 metres.

When using the typically available orthometric heights on a reference ellipsoid, Virtual Globes are in fact neglecting these geoid separations. Thus, they are effectively introducing vertical errors of up to ± 100 metres. This effect only becomes noticeable when integrating three-dimensional real-world positions derived from GNSS (Global Navigation Satellite System) into the virtual world. This is because all GNSS are based on geometric reference systems and are consequently providing coordinates with geometric heights. It should be noted, that any application involving airborne sensors or objects is particularly affected, since it is not possible to simply map the 3d position to a 2d position on the 3d landscape. It should further be noticed, that many GNSS receivers incorporate geoid models and are capable of delivering orthometric heights as well. However, quite often the quality of these built-in geoid models is not well known.

In order to ensure good three-dimensional accuracies, Virtual Globes could employ one of the following two approaches:

- *Viewer based on geometric heights* – If the viewer is to be based on geometric heights only, then all elevation model data needs to be corrected prior to being rendered using a global geoid model.
- *Viewer based on orthometric heights* – If the Virtual Globe is to be based on a combination of orthometric heights on an ellipsoidal reference surface (see above), geoid separations need to be deducted from any GNSS-based sensor position information.

Even though the second approach is not strictly correct from a mathematical point of view, since it ignores geoid undulations when displaying the 3d scene, it has a number of advantages: all oceans can be rendered using a height of 0 m and relatively few sensor positions need to be 'corrected' – compared to correcting millions of DEM nodes. Last but not least, this approach allows the flexible use of regional geoid models with a much higher quality – if and when available.

2.4 Support for Large Coordinate Spaces

The conversion from longitude, latitude and ellipsoid height to geocentric cartesian coordinates must be evaluated using 64-bit floating point numbers, otherwise it wouldn't be possible to represent geometry of the entire globe with millimetre accuracy.

Common graphics hardware (video cards) only support 32-bit floating point accuracy in the rendering pipeline. This imprecision leads to small cracks between neighbouring terrain cells. It is possible to avoid this by using a virtual camera system which defines a local origin for visible cells. This way 32-bit values are sufficient in this relative representation and it is possible to have millimetre accuracy over a range of 40'000 km.

3. GEOSPATIAL CONTENT

3.1 Current Spatial Content Types

Cartographic Base Model

The typical cartographic base model of Virtual Globes includes the following main data types:

- *Digital elevation models (DEM)* – The vast majority of DEM data in Virtual Globes is incorporated as regular grids i.e. in raster form. However, with the increasing demand for highly detailed applications such as city models, these regular DEMs will more and more be complemented by irregular DEM data.
- *Orthoimagery* – This second data type obtained from aerial or satellite imagery or from any type of maps serves as texture data to be draped over the terrain model. Virtual Globes will always consist of at least one global set of orthoimagery and of numerous sets of higher resolution regional orthoimagery at different resolutions.

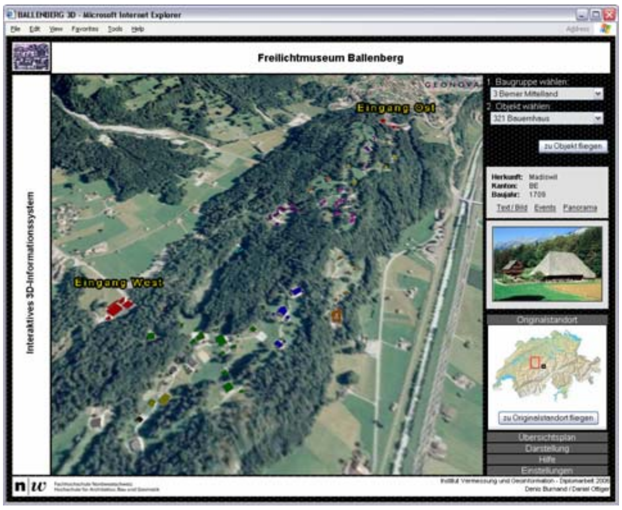
Among the typical characteristics of the base model data types are: enormous data quantities in the range of hundreds of Gigabytes to Terabytes and the imperative requirement for multiple resolutions, spatial partitioning and spatial access structures in order to ensure an efficient data access by large numbers of users. In order to fulfil these requirements, these huge base data sets need to undergo extensive pre-processing steps which typically require highly efficient parallel processing.

While the above mentioned base data sets appear to be generally quite 'simple', there are a number of issues to be addressed in real-world applications. These include aspects such as numerous local coordinate systems, irregular boundaries, holes or islands within the data sets and the need to overlay different data sets with different resolutions.

Spatial Content (Base Model Extensions)

There are an increasing number of papers in different scientific fields investigating data types for representing spatial or spatially related information in multidimensional environments. In the domain of information visualisation, for example, Shneidermann in (Shneidermann, 1996) distinguishes the following 7 data types: 1-, 2-, 3-dimensional data, temporal and multi-dimensional data as well as tree and network data. In the cartographic domain, Häberling outlines typical map object types of 3d maps and interactive 3d geovisualizations (Häberling, 2003). In contrast to the cartographic base model which can generally be considered as generic, the spatial contents representing the model extensions, are typically application- or domain-specific (Nebiker et al., 2005). Among these spatial content types are:

- *POI (points of interest)* – a point-oriented content object type consisting of a text label or a billboard with various spatial, thematic, graphical and behavioural properties. Examples include place names, landmarks or location indicators for persons or other tracked object. POI are often used in combination with multimedia-objects (see below).
- *2d objects* – a linear or areal vector object type. Examples include: hiking tracks, danger zones or ski slopes etc.
- *3d objects* – a volume- or surface-based object type with a potentially very complex geometry and with graphical properties such as photorealistic textures. Examples include: 3d models of buildings, traffic infrastructure or vehicles.
- *Multimedia objects* – various multimedia types typically supported by HTML and web browsers, such as hypertext, images, sound, and video. In Virtual Globes multimedia content is either supported by means of a built-in browser, capable of rendering multimedia objects on a POI billboard within the 3d scene, or by means of an external browser (see Figure 4).



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Baujahr: 1709

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Figure 4: Prototype of 3d tourist information system for the Open Air Museum Ballenberg (Switzerland) with virtual globe embedded into webpage with multimedia contents (© FHNW & Ballenberg Museum)

3.2 Emerging and Future Content Types

The trends of extending Virtual Globes towards geo sensor integration and geospatial collaboration generates a series of new requirements, namely for the support of real-time and possibly kinematic contents such as geo sensors and geospatial actors as well as cartographic or graphic objects suitable for representing multidimensional and temporal information within 3d environments. Examples of such new content types include:

- *Sensors* – this content type is designed to accommodate geo sensor platforms, geo sensors and observations with their typical properties. Such sensor objects could be static or kinematic and multiple sensor objects could be assigned to the same sensor platform. Within the 3d scene, sensor objects can be represented by animated 3d objects illustrating their position, attitude and for example their field of view (FOV) as shown in Figure 5.
- *Actors* – this content type is used to represent users or viewers within collaborative 3d environments. Their properties and representation are similar to those of the sensor content type.

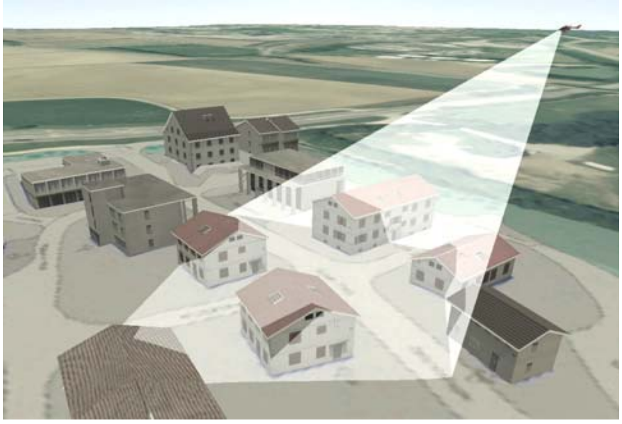

Figure 5: New 'sensor' content type: UAV-based mobile geo sensor platform with video camera, indicated with semi-transparent field of view

- *Thematic map objects* – this new type of content will be required to support efficient information visualization within Virtual Globe environments. This will be of particular importance in conjunction with supporting geo sensor data. Thematic map objects could also be considered as specialisations of more generic graphical content types, including 3d bar charts, 3d cartograms etc. As already pointed in chapter 1.2, scientific foundations for 3d cartography in general and suitable 3d representations in particular are still work in progress.

- *Georeferenced (video) imagery* – this type of geospatial content will allow the overlaying of imagery – and in particular video imagery – with the interactive 3d scene in (near) real-time. While this type of content bears an enormous potential in many application areas, it is at the same time quite demanding. First investigations and solutions for combining georeferenced video imagery with Virtual Globes are presented in the following chapters and in (Eugster and Nebiker, 2007).

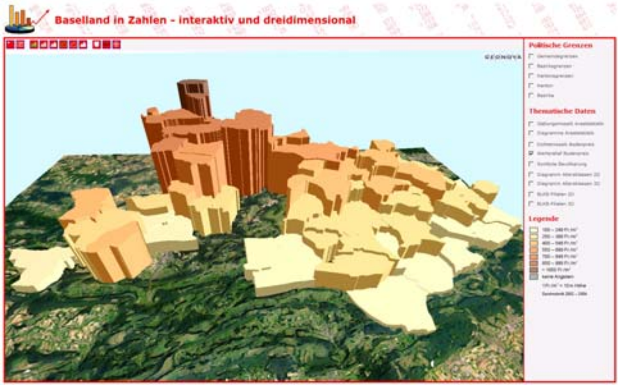

Figure 6: Thematic cartographic content integrated into an interactive 3d scene (Bertiller and Keller, 2005).

3.3 Content Delivery and Exchange

Extending Virtual Globes towards collaboration and real-time contents will also affect the mechanisms for delivering contents to the viewer clients. In the future, the following four types of content and their corresponding *content channels* can be distinguished:

- *Static / fixed content* – is loaded during the initialisation of the 3d scene or at run-time when opening and adding a new content file, such as a KMZ file in the case of Google Earth. This content channel typically does not support streaming and is thus not suitable for large amounts of data.
- *Streamed content* – is typically pre-processed and is used to deliver the cartographic base model with its enormous amounts of data to large numbers of clients. Streamed content inherently supports object partitioning and multiple resolutions in order to ensure a progressive and smooth content delivery.
- *Content services* – enable the access to the increasing number of standardised geospatial web services such as OGC Web Map Services (WMS) or Web Feature Services (WFS). Since these services do not yet provide streaming support, they need to be treated like static content with a certain risk of slowing down the application in the case of large result sets.
- *Synchronised content* – enables the automatic delivery and updating of geospatial objects between server and client but also the sharing of geospatial contents among multiple users. This type of content channel is particularly interesting for collaborative geospatial environments.

The comparison of these content mechanisms reveals that the first three mechanisms are all 'pull' mechanisms whereby clients request data from a web server, from a file system or from a web service. The content synchronisation introduces a paradigm change by employing both 'pull' and 'push' to distribute geospatial content. The push paradigm becomes particularly important when dealing with time-critical content in general and in collaboration environments in particular.

4. THE VIMO ARCHITECTURE

4.1 i3D Viewer Technology

The i3D Viewer is a 3rd generation 3d geovisualisation engine developed at the University of Applied Sciences Northwestern Switzerland (FHNW). The viewer uses spherical rendering using the WGS-84 Ellipsoid. The engine is highly optimized for current generation GPUs (Graphics Processing Units). The engine uses the OpenGL Graphics API and is cross platform (Windows, MacOS X and Linux).

The virtual 3d terrain can hold several terabytes of aerial imagery and elevation data. This data can be streamed over a network or can be loaded from a local hard drive. There are also channels for 3d objects, including city models, POI, and 2d vectors.

Data must be pre-processed to be streamed efficiently for real time rendering. During pre-processing coordinate transformations from a local system to WGS-84 are performed, and data tiles are generated. These tiles are stored either on a web server or in an archive on the user's hard drive. Data pre-processing is implemented using parallel algorithms. It is highly optimized for dual or quad core processors. For fastest processing, data can also be processed using distributed computing.

Because of the streaming capability, limited memory, and rendering speed, a level of detail approach must be used. A built-in error metric helps to decide which level of detail is actually required. Lindstrom introduced an error metric which switches the terrain LOD level according to the visible pixel size (Lindstrom et al., 1996). This screen space error metric has been widely adapted by various terrain algorithms using "flat earth"-rendering. For the i3D engine the screen space error metric had to be modified for spherical rendering and is now calculated considering ellipsoid segments.

Different levels of detail neighbours have different numbers of vertices and do not fit together without modification. This results in cracks. To eliminate cracks, neighbouring cell borders must be modified – possibly each frame. To avoid overloading the graphics card bus, the cells are changed using different index buffers which are preloaded on the graphics card.

4.2 Collaboration Framework

In (MacEachren, 2005) and (Brodlie, 2005) a valuable overview and classification of different types of geospatial collaboration are provided. When designing the ViMo collaboration framework, it was decided that it should support all four combinations of spatial-temporal group work proposed in (MacEachren, 2005), i.e. same place as well as different place collaboration from a spatial perspective on the one hand and same time as well as different time collaboration from a temporal perspective.

The main requirements to be fulfilled by the ViMo collaboration framework included:

- Support for the authentification of users and for their connection to a collaboration session
- Secure communication over the Internet between a large number of users in real-time
- Support a collaborative geospatial environment, i.e. for the shared use of a Virtual Globe
- Provision of multiple additional communication channels between users such as chat, video or voice

Below the selected communication framework and the geospatial collaboration functionality are outline in more detail.

Communication Framework

Based on the above mentioned requirements, the RakNet network engine (Rakkarsoft, 2007) was chosen as basis for the ViMo collaboration framework. RakNet is a cross platform C++ UDP network library designed to allow programmers to add response time-critical network capabilities to their applications. It is mostly used for multi-user games, but is application independent.

The ViMo collaboration environment consists of the following three types of components:

- ViMo Session Server
- ViMo Connection Server
- ViMo Client

The ViMo Session Server is responsible for synchronising shared geospatial objects among all Clients which a) are logged into a specific collaboration session and b) have the objects within their field of view. Objects outside the field of view of a current user are not synchronised in order to optimise the synchronisation process and network traffic.

The primary role of the ViMo Connection Server is to provide a list of all available collaboration sessions and to enable the subsequent communication between a Client and a Session Server even if they are both behind an NAT (network address translation) and are not able to directly connect to each other. The Connection Server serves as so called non-NAT intermediary and thus enables a NAT punch-through allowing the Client to subsequently establish a direct and secure connection with the Session Server.

Geospatial Collaboration

The above mentioned collaboration framework enables the communication between Client and Session Server, it is also used for automatically delivering shared geospatial content to the client and for sharing and synchronising geospatial content between all clients within a session. Thus, once a geospatial object is classified as 'shared', it is automatically synchronised between a client, which is for example modifying this specific object, and the Session Server and from there on with all other clients.

5. APPLICATIONS AND RESULTS

The ViMo research project is still under way. However, most of the concepts outlined in this paper have already been implemented and successfully evaluated using early prototypes and prototype applications. The following examples illustrate some of these tests and their results.

Integration of Geo Sensor Web Services

Based on early versions of the OGC specifications and on the open source implementation of the Sensor Observation Service (SOS) by 52°North (www.52north.org), a Geo Sensor Web Service could be successfully integrated into the ViMo architecture. Figure 7 illustrates colour coded temperature readings at the Euroairport in Basel/Mulhouse over a period of 6 observation epochs.

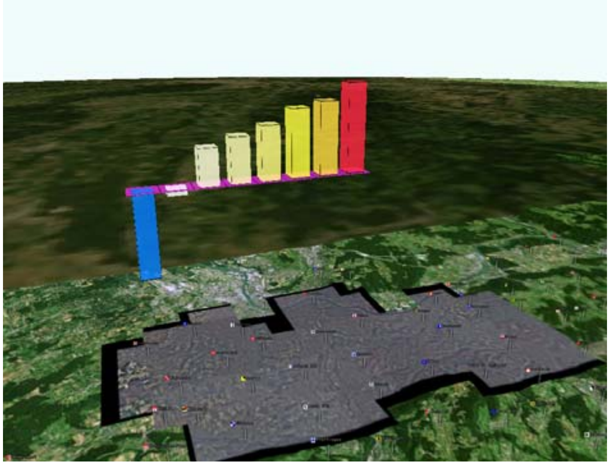

Figure 7: Integration of an OGC Geo Sensor Web Service with meteorological data into the i3D viewer.

Virtual Monitoring – Monitoring Real-World Objects in a Virtual Environment

One of the main goals of the ViMo project was to enable the monitoring and tracking of real-world objects, i.e. of geo sensors, in the virtual environment. For this purpose two different types of geo sensors were investigated: a GPS logger with a GSM data link and a georeferenced video stream acquired from an autonomous mini UAV with GPS/INS positioning. This integration of georeferenced imagery is documented in (Eugster and Nebiker, 2007) and has been tested on a number of test flights. Figure 8 shows a frame of the airborne video stream on the left and a screenshot of the i3D

Virtual Globe showing the position of the geo sensor and its FOV on the right.

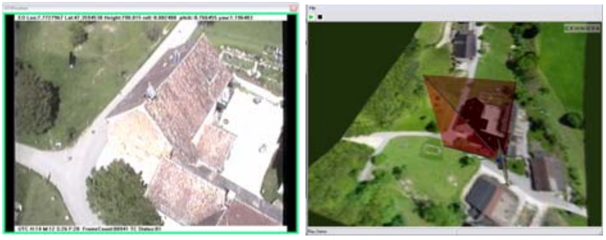

Figure 8: Virtual Monitoring: Real-world view (UAV based georeferenced video) (left) and linked virtual world view (right)

Augmented Monitoring – Monitoring Real-World Objects in a Mixed Reality Environment

Ongoing investigations within the ViMo project aim at integrating real-time video imagery into a Virtual Globe environment. One approach would be the draping of the georeferenced real-time video stream over a detailed 3D landscape model. Another, equally promising approach, focuses on overlaying the video stream with selected content types, e.g. 3d building models, from the 3D landscape model. Figure 9 illustrates such an augmented video view which was acquired during a test flight over the Open Air Museum Ballenberg. The video view also contains the GPS time together with the estimated position and attitude information of the sensor platform.

Figure 9: Augmented Monitoring – UAV based georeferenced video overlaid with 3d objects from digital landscape model

6. CONCLUSIONS AND OUTLOOK

In this paper we provided an overview of the current status and trends in Virtual Globe technologies on the one hand and in mobile sensor platforms and geo sensors on the other. The paper also showed some of the benefits of integrating mobile geo sensors into future Virtual Globe technologies. It was also outlined that this integration introduces new requirements, namely in terms of accurate geodetic reference models and new geospatial content types such as real-time geo sensor data.

The paper particularly addressed suitable geodetic reference models which need to be implemented in Virtual Globe technologies in order to achieve 3d accuracies at the metre level or better. These accuracy levels will be required for local monitoring, tracking or even measuring applications using modern geo sensors. The paper then provided an overview of existing geospatial content types and proposed a number of new content types which would be suitable to support real-time geo sensor data as well as geospatial collaboration within Virtual Globes.

Many of these requirements have been addressed in the design and implementation of the new Virtual Globe technology i3D and the ViMo collaboration framework. This collaboration framework makes use of a high-performance network engine which originates from the gaming industry. The ViMo collaboration framework not only provides efficient communication among large numbers of concurrent users it is also used for synchronising the geospatial contents in real-time.

Finally, the paper presented test cases for three different application scenarios. The integration of OGC Geo Sensor Web Services was successfully implemented and demonstrated. However, the implementation of the OGC SOS interface revealed some serious shortcomings of the underlying specifications. As an example, it turned out that the SOS specification currently does not support spatial properties, which inhibits its use for mobile sensors. The following test cases for Virtual Monitoring and Augmented Monitoring clearly demonstrated the enormous potential offered by combining real-world sensor data with the seamless virtual environments offered by modern Virtual Globes.

Ongoing and future work at FHNW includes further development and completion of the i3D Virtual Globe technology and of the ViMo collaboration framework. A special focus will be placed on further investigating and developing the Augmented Monitoring scenario with integrated georeferencing of real-time video imagery obtained from low-weight, low-cost micro UAV platforms.

7. REFERENCES

Bertiller, A. and Keller, D., 2005. Baselland in Zahlen - interaktiv und dreidimensional. Diploma Thesis, FHNW University of Applied Sciences Northwestern Switzerland, Muttenz.

Bleisch, S., Dykes, J. and Nebiker, S., 2006. How are we to Represent Abstract Information in 'Realistic' 3D Environments?, GIScience, Münster (D).

Botts, M., Percivall, G., Reed, C. and Davidson, J., 2006. OGC® Sensor Web Enablement: Overview And High Level Architecture (OGC 06-050r2), OGC White Paper, Open Geospatial Consortium Inc.

Brodlie, K., 2005. Models of Collaborative Visualization. In: J. Dykes, A.M. MacEachren and M.-J. Kraak (Editors), Exploring Geovisualizations. Elsevier Science, Amsterdam, pp. 463-475.

Eugster, H. and Nebiker, S., 2007. Geo-Registration of Video Sequences Captured from Mini UAVs - Approaches and Accuracy Assessment, Mobile Mapping Technologies Symposium MMT 2007, Padua.

Häberling, C., 2003. Topografische 3D-Karten - Thesen für kartografische Gestaltungsgrundsätze. ETH Nr. 15379. Dissertation Thesis, Institut für Kartographie, ETH Zürich.

Lindstrom, P. et al., 1996. Real-Time, Continuous Level of Detail Rendering of Height Fields. In: H. Rushmeier, T.-M. Rhyne and Association for Computing Machinery (United States) Special Interest Group on Graphics (Editors), SIGGRAPH 96 conference proceedings August 4-9, 1996. Association for Computing Machinery, New York, NY, pp. 109-118.

MacEachren, A.M., 2005. Moving Geovisualization toward Support for Group Work. In: J. Dykes, A.M. MacEachren and M.-J. Kraak (Editors), Exploring Geovisualizations. Elsevier Science, Amsterdam, pp. 445-461.

Nebiker, S., Schütz, S. and Wüst, T., 2005. Geo-Roaming: Model-Driven Content Management for Web-based 3D Geoinformation Services, XXII International Cartographic Conference (ICC2005). The International Cartographic Association (ICA-ACI), La Coruna, Spain, 11-16 July 2005 (accepted paper).

Rakkarsoft, 2007. Raknet - UDP game network library. URL: http://www.rakkarsoft.com/.

Shneidermann, B., 1996. The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations, Visual Languages 96.

8. ACKNOWLEDGMENTS

The authors would like to thank the Commission of Technology and Innovation (CTI) of the Swiss Federal Office for Professional Education and Technology for the support of this project[1].

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[1] CTI Project Nr. 8012.1 ESPP-ES ViMo (Virtual Monitoring)