

APPLICATIONS FOR MIXED REALITY
Sven Wursthorn, Alexandre Hering Coelho and Guido Staub,
Institute for Photogrammetry and Remote Sensing
University of Karlsruhe (TH)
Englerstr. 7, D-76128 Karlsruhe, Germany
{wursthorn|coelho|staub}@ipf.uni-karlsruhe.de

KEY WORDS: Augmented Reality, GIS, Mobile, Application, Disaster, Floods.

ABSTRACT

Mixed or Augmented Reality (AR) systems align computer generated virtual objects and real world objects with each other to enhance the vision of the physical reality with the virtual objects in a manner, that will allow a user to interact with spatial data in his natural environment and scale (1:1). Especially when dealing with natural disasters the advantage of a user's view augmented with additional supporting data is apparent. Activities like preventive protective measures, effective reaction and reconstruction need to be assisted by a technology that improves the operators efficiency and performance. This approach deals with a system that serves particular needs regarding earth science and disaster management. We will present our work developing an AR-System (ARS) and its components with examples of practical applications. The crucial point of this implementation is the use of laser scanning models with adequate accuracy, reliability, actuality and completeness. VRML tiles produced from the laser scanning data are displayed in the operator's field of view together with additional water surface models or simple features like points and lines. These geometrical objects are visualised and controlled using scene graph parent-child relationship of Java3D. In this paper, flood disasters are used to illustrate possible applications in a typical four-phased disaster management process. Additionally, several examples representing the virtual water surface for flood damage prediction are discussed. Results of virtual water models are used by applying digital image processing techniques to laser scanning data in order to provide tactical information for disaster management.

1 INTRODUCTION AND RELATED WORK

The "Reality-Virtuality Continuum" (Milgram, 1994) (fig. 1) defines mixed reality as a generic term being in-between the real world and complete virtual environments. Mixed or augmented reality (AR) extends a user's vision of the real world with additional information of computer generated objects with the user being in the real world. This is in contrast to virtual reality where the physical world is totally replaced by computer generated environment. Although vision is not the only sense that can be augmented, it is the strongest one (visual capture) - what we see is "true" (Welch, 1978).



Figure 1: The Reality-Virtuality Continuum

If augmented objects are derived from spatial data which represent real features like buildings or streets, an exact overlay of these objects with the real objects is a fundamental requirement. Additionally this overlay has to happen in real time (Azuma et al., 2001) to let the user's vision keep the impression of the augmentation during movements.

With augmented reality systems, the user can interact with spatial data in his own natural scale, 1:1. Spatial features and meta data can be queried by position and view direction and can be interactively manipulated in the viewed scene. In contrast to handheld computers with 2D map displays, the user is unburdened from the task of comparing

the results of a spatial query shown on the display with the environment on site. Another possibility is to show objects covered beneath the surface to see underground features like tubes (Roberts et al., 2002).

The MARS Project (Höllerer et al., 1999) experimented with AR solutions for pedestrian navigation, both indoors and outdoors. (Livingston et al., 2002) provide a mobile outdoor system for military operations. The Australian "Tinmith" project has developed an indoor and outdoor capable system with a solution for interactive data manipulation e.g. with gloves which are typically utilized in VR applications (Piekarski and Thomas, 2001).

All of these projects have some typical hardware components in common that are needed for an ARS. These configuration affected our hardware selection which is described in the following section.

2 HARDWARE

The head mounted display (HMD) system, Nomad from Microvision, projects an SVGA (800x600) image with a semi-transparent mirror directly on the retina, overlaying see-through information on the user's vision. The advantage of this solution is bright "display" that can be used outdoors, the disadvantage is a lack of colors. The monochrome display supports 32 shades, covering a field of view of 23°x17° which equals a 17" Display at arm's length. Furthermore our system is monocular. There is no need for a stereo display, because human vision is able to combine the three dimensional impression of the real world with the augmented objects from the HMD.

Digital video cameras are used to augment video image streams. A camera based ARS is easier to implement and experiment with than the combination of human and HMD because the calibration of head mounted displays is more complicated and time consuming than camera calibration (Leebmann, 2003). The results of calibration and tracking are better controllable by measurements than the visual impression of a human wearing a HMD which cannot be measured objectively.

The orientation of head or camera movement is tracked with a low-cost, strapped down inertial measurement unit (IMU) from Xsens, model MT-9B, that provides static orientation accuracy $< 1^\circ$ with a resolution of 0.05° at 512Hz output rate. Typically such sensors make use of additional magnetic field sensors together with inclinometers to provide absolute orientation values without the need for initialisation at startup but the magnetic sensors make the IMUs vulnerable to magnetic distortions. The small size and low weight makes the sensor suitable for head mounted operation.

For positioning, a differential GPS solution with high 2-frequency receivers is deployed. In real time kinematic (RTK) mode the system provides an accuracy of 1cm for the location at an update rate of 1Hz.

The development of new, wearable augmented reality systems is beyond the scope of our projects that use the technology. All hardware components are off-the-shelf, connected over USB or serial lines to a notebook. All components are mounted on a backpack with a fixed frame together with the notebook (fig. 2). IMU(s) are mounted on the display solutions currently deployed, HMD or camera. The system can be controlled with a wrist worn keyboard. The notebook's display can be exported over bluetooth based network to an handheld computer for debugging tasks, but during development and testing it is not fixed to the backpack for more comfortable work.

3 PROBLEMS AND SOLUTIONS

The real time requirement causes the biggest error for augmented reality systems (Holloway, 1995). The system delay (latency) can cause a misalignment of real and virtual objects. The impression of augmentation is lost, virtual and real part of the vision are showing different scenes. Moderate head movements of $50^\circ/s$ can cause a misalignment of 1mm every ms in an indoor environment (Holloway, 1995). Head movements can reach a rate of up to $300^\circ/s$, about 1° with 4ms. The rotation of 1° causes an alignment error of about 11 Pixel in a calibrated video image with a camera resolution of 640×480 pixel (You et al., 1999). Generally, an augmented reality system has to be able to update display or video image information at least with 15Hz for the impression of movement in human vision.

The low (1Hz–10Hz) update rate of the GPS position causes problems, too. A pedestrian, e.g. is able to move on 1,7m within one second at a given speed of 6km/h, making the

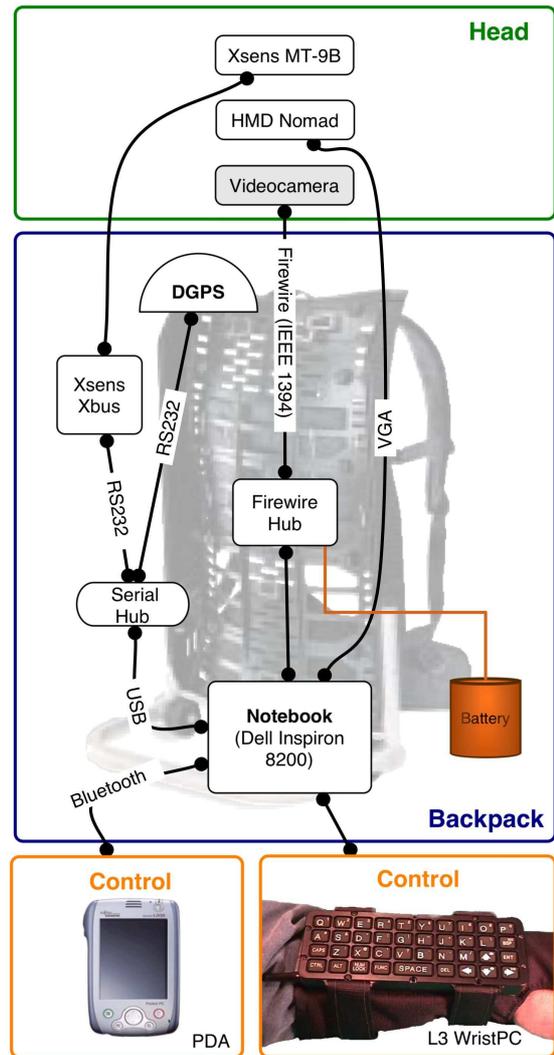


Figure 2: Backpack AR Setup

high accuracy of $1\text{cm} \pm 1\text{ppm}$ of our receiver useless during the user's movement. Another serious problem is the fact that GPS isn't reliable in urban environments due to shadowing effects of tall buildings that cause outages due to satellite signal loss. One solution to this problem is a combination of the complementary features of INS and GPS: The double integration of acceleration values together with the orientation will theoretically give the covered route. But the error will increase exponentially over time due to the incremental integration (drift). This effect can be compensated by GPS measurements. GPS/INS combination as a flight navigation solution has been introduced in late 1980s and is offered for sale since 1996 (Scherzinger, 2001).

In the case of pedestrian navigation the situation is different. The human movement causes accelerations in all directions. The vertical and longitudinal accelerations (see fig. 3 for raw vertical and longitudinal accelerations with an Xsens MT9-B fixed at the lower backside) can be used for an analysis of a person's step acceleration patterns in order to extract the covered distance (Talkenberg, 1999). DGPS can be used to calibrate the step pattern in situ.

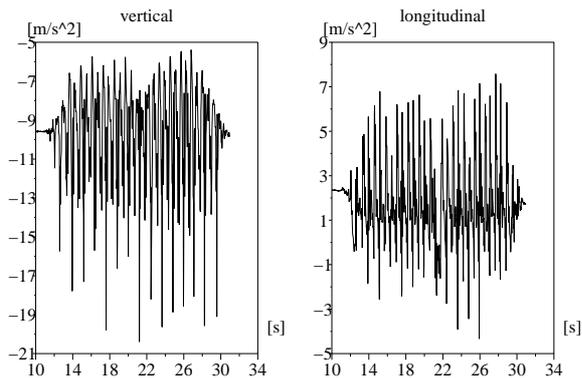


Figure 3: Accelerations during human walking

Different types of hard or soft underground cause different step pattern. This patterns change completely with a slope $> 10^\circ$. Taking the wrong time intervals will result in wrong number of steps. This can cause travelled distance errors of 10m or more meters in dead reckoning mode (Ladetto et al., 2000). (Ladetto and Merminod, 2002) present a combination of GPS, INS, electronic compass and barometer in a small wearable system that is used in a pedestrian navigation system for the blind. The system is capable of detecting several walking patterns including up and down stairs movement. It can track the person's path even indoors with several navigation algorithms that compare the information of the output of all sensors and using different strategies in case of sensor outages or conflicting information.

A wealth of research deals with fusion of several sensors in order to overcome the weaknesses. Vision based methods e.g. are used in combination with INS to improve head motion tracking accuracy (Ribo et al., 2002, You et al., 1999) with the computer vision algorithms providing information of low frequency movements and INS for fast movements.

3.1 Occlusion

An unprocessed overlay of virtual objects in a video stream or on a head mounted display system will not result in a realistic impression of the fusion of real and virtual scene. Without any further processing virtual objects behind a real object like a building will be displayed in front of that building instead of being occluded by it.

In order to solve the occlusion problem in computer graphics we can use depth information (z-buffer) of objects to be displayed. A matrix is used to store distances from the projection center to the object models for each pixel. The object with a smaller distance to the projection center occludes the one with a greater distance.

In augmented reality the depth information of the augmented, virtual objects can be calculated because the geometry about these objects is accessible. But for the real objects on the video stream there is in principle no information about the geometry. Additional data acquisition is necessary in order to generate the depth information for real objects. Other

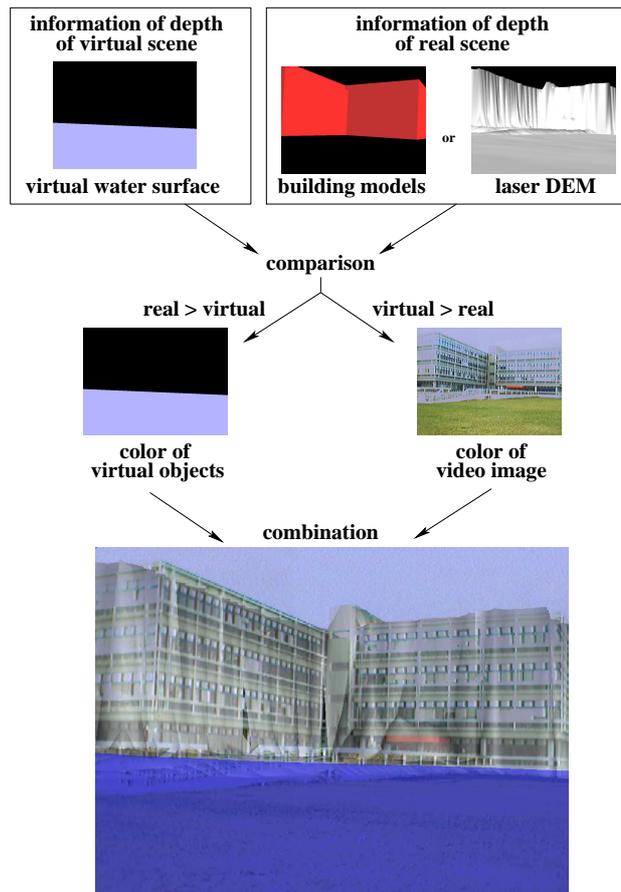


Figure 4: Schema of occlusion processing

possibilities are the use of image processing (Simon and Berger, 1999) or probabilistic models of form and position (Fuhrmann et al., 1999). The virtual objects that are used to provide the depth information about the real objects are not displayed. They are called "phantoms" (Grohs and Maestri, 2002, Fuhrmann et al., 1999). The used occlusion solution in this work is shown in figure 4. Here the depth information (phantoms) is extracted from a digital elevation model derived from laser scanning or, if available, from building models. These models are used to continuously calculate the depth information according to the camera movements. The phantoms used for the depth information are not visible, they are replaced by pixels from the video image. The depth information for the real and the virtual scene are compared, pixel by pixel. A real object that is more distant from the projection center than a virtual object at a distinct pixel will occlude the real one, and vice versa.

4 AR FOR DISASTER RELIEF: HIGH WATER

4.1 Motivation

In 2002, 30% of all damaging events, 42% fatalities, 50% economic and 37% insured losses are due to high water worldwide (Rückversicherungs-Gesellschaft, 2002). Apart from storms, high water causes the most damage in comparison to other natural disasters. Disaster management

tries to reduce damages with preventive protective measures before any high water event and effective disaster reaction while fighting the high water. The disaster management cycle consists of four phases illustrated in figure 5: Mitigation is the ongoing effort to lessen the impact disasters may have on people and property, preparedness means the measures before the occurrence of an emergency. Simulations, training situations and information visualisation can be done during the first two phases. Response refers to the immediate actions during the emergency. It is important to make adequate decisions during this time-critical third phase. And finally, recovery is the process of going back to normal.

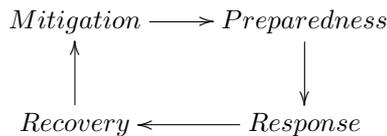


Figure 5: Cycle of disaster management

Flood simulations basically rely on calculations based on measurements of rain and topography. In literature several different solutions for flood simulation are presented. (UNESCO Training Module on GIS-Module H-2, 1999) and (Casper, M. and Ihringer, J., 1998) e.g. describe tools for simulating flood using a digital elevation model.

4.2 System, Data and Results

Results of high water simulations can be used as a basis for planning disaster response measures. Visualisation of results is needed in order to help the local forces interpreting them. The 3D visualisation with AR can be useful to expand the comprehension of the situation during the disaster (fig. 6).

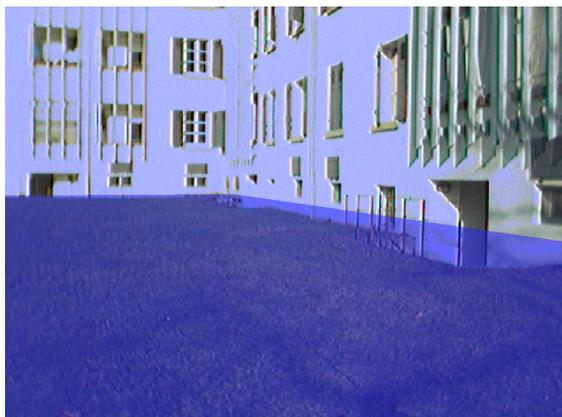


Figure 6: Virtual water surface nearby a real building, result of occlusion processing

In the city of Cologne authorities installed a mobile flood protection wall, shown in figure 7, to protect the old town against flooding from the river Rhine.

[†]Source: Sabine Möwes, An der Schutzmauer, <http://www.stadt-koeln.de/hochwasserschutz/bilder/03808/index.html>



Figure 7: Mobile wall in the city of Cologne [†]

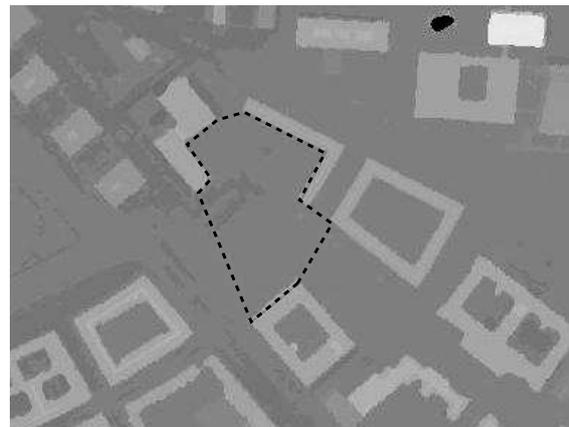


Figure 8: 2D view of polygon representing an area protected with mobile walls

In order to simulate the effect of such mobile walls, the user can draw a polygon in a 2D view of the flood zone which represents the virtual position of a mobile wall (fig. 8). In the 3D view of the area (fig. 9) the user can see the water surface around the protected area.

This approach overlays virtual objects on a video stream that can be viewed live on a laptop's screen. The GPS receiver and the inertial sensor provide necessary information about position and orientation of the camera's view in order to overlay the vision of the real world with virtual buildings and water surface models.

The data used are building models, a digital elevation model derived from airborne laser scanning and hydrological data like the amount of rainfall in a region. The laser scanner data is used in different ways. The last pulse data provides elevation information of the surface with buildings but roughly without vegetation. A filter algorithm that uses an image pyramid method extracts the digital terrain model out of the laser scanner data (Coelho et al., 2002). Flood water simulation models use hydrological data together with digital elevation models in order to estimate the water surface at a given time. The simulation models and the hydrological data are provided by the Institut für Wasserwirtschaft und Kulturtechnik (IWK) at the University of Karlsruhe. The project scheme is shown in figure 10.

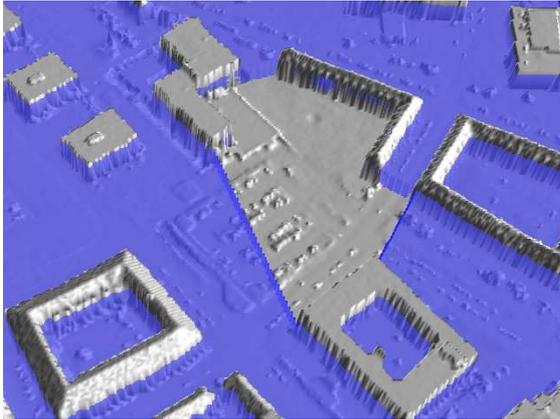


Figure 9: The effect of the protected area in the 3D view of the flood zone

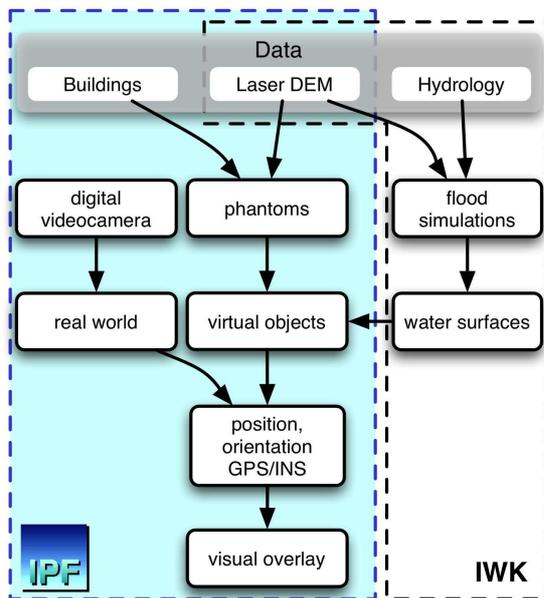


Figure 10: Project structure

5 AR IN GEO SCIENCES

The project "Advancement of Geoservices[‡]" aims at developing an overall concept for acquisition, management, usage and visualisation of geodata for mobile geoservices (Breunig et al., 2003a, Breunig et al., 2003b). The project is subdivided into four working groups. The database group is developing web based GIS components for online access of spatio-temporal objects. Others do research on mobile data acquisition, usage and analysis and the definition of standardized interfaces for geoservices. Our group is developing an "Augmented Reality GIS Client" for online visualisation, processing and acquisition of 3D datasets.

A use case was chosen in the field of Geosciences as the application frame. The AR system allows for the visualisation and measurement of underground geo objects in a mobile real time environment which makes it possible to anal-

[‡]The research project "Advancement of Geoservices (Weiterentwicklung von Geodiensten)" has been funded by the German Ministry of Education and Research (BMBF)

yse geological and geomorphological processes directly in the terrain. To show the utility and feasibility of such a system, data of a project investigating landslide processes will be used. Data are made available by the Landesamt für Geologie, Rohstoffe und Bergbau (Land Office for Geology, Resources and Mining) in Freiburg i.Br., Germany. The investigation site is an area of mass movement on the Alb which has to be routinely monitored due to a road crossing the risk area. Data are available as points, lines, three-dimensional landslide bodies, DEM and attribute data. The AR system can help in data acquisition and assessment of the current state of the movement by visualising additional data like geological structures, soil parameters, border lines and textual information. The application scenario can also provide data in 4D (several epochs of data have been gathered in the past), which will be stored into the 4D database system being developed by the database group and therefore allows to "see" the landslide moving in the past. This application scenario allows to show the integrated use of the joint developments based on a common architecture, 2D real time data display and collection, AR based display and data collection based on a common 4D Geo Database.

6 CONCLUSIONS

Augmented reality is an appropriate technology for use cases, where people need additional spatial information on-site. Today's HMDs are already capable of overlaying the display information directly into the user's vision and once head tracking and navigation systems become small and affordable enough the technology will be adopted in many applications.

Disaster management is just one of these applications that benefit from AR. In the case of high water management, predictions from hydrological simulations of water surface models, directly visualised with real video images, help understanding the situation in the near future. This understanding makes it easier for disaster management to prepare preventive measures like the placement of mobile water protection walls.

REFERENCES

- Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S. and MacIntyre, B., 2001. Recent advances in augmented reality. *IEEE Computer Graphics and Applications* (6), pp. 34–47.
- Breunig, M., Malaka, R., Reinhardt, W. and Wiesel, J., 2003a. Advancement of geoservices. Technical Report 2, Geotechnologien, Hannover.
- Breunig, M., Malaka, R., Reinhardt, W. and Wiesel, J., 2003b. Entwicklung mobiler geodienste. In: L. Bernard, A. Sliwinski and K. Senkler (eds), *Geodaten- und Geodienste-Infrastrukturen - von der Forschung zur praktischen Anwendung*, IfGI, Münster, pp. 253–264.

- Casper, M. and Ihringer, J., 1998. GIS-gestützte Regionalisierung von Abflüssen in Gewässern Baden-Württembergs unter Einsatz von Arc/Info und Arc-View. <http://www-ihw.bau-verm.uni-karlsruhe.de/members/casper/region.htm>, accessed in 2003.
- Coelho, A. H., Vögtle, T., Weindorf, M. and Bähr, H.-P., 2002. Utilização do método de pirâmide de imagens para a extração de modelos digitais de terreno de imagens geradas por dados de laser scanner. In: V Congresso Brasileiro de Cadastro Técnico Multifinalitário, Florianópolis - SC - Brasil. Anais em CD.
- Fuhrmann, A., Hesian, G., Faure, F. and Gervautz, M., 1999. Occlusion in collaborative augmented environments. *Computers and graphics* 23(6), pp. 809–819. <http://www-imagis.imag.fr/Publications/1999/FHFG99>, accessed April 2004.
- Grohs, E. M. and Maestri, P. R. B., 2002. Realidade aumentada para informações geográficas. Trabalho de conclusão de curso em bacharelado em ciências da computação, Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre, Brasil. <http://grv.inf.pucrs.br/Pagina/Projetos/Augment/aug.pdf>, accessed April 2004.
- Höllerer, T., Feiner, S., Terauchi, T., Rashid, G. and Hallaway, D., 1999. Exploring mars: Developing indoor and outdoor user interfaces to a mobile augmented reality system. In: *Computers & Graphics*, Vol. 23(6).
- Holloway, R. L., 1995. Registration error analysis for augmented reality. Technical Report TR95-001, Department of Computer Science University of North Carolina, Chapel Hill, NC.
- Ladetto, Q. and Merminod, B., 2002. In step with gps. *GPS World*.
- Ladetto, Q., Gabaglio, V., Merminod, B., Terrier, P. and Schutz, Y., 2000. Human walking analysis assisted by dgps. In: *Proceedings of GNSS 2000*, Edinburgh, Scotland.
- Leebmann, J., 2003. A stochastic analysis of the calibration problem for augmented reality systems with see-through head-mounted displays. In: *ISPRS Journal of Photogrammetry and Remote Sensing*, ISPRS, pp. 400–408.
- Livingston, M. A., Brown, D. and Gabbard, J. L., 2002. An augmented reality system for military operations in urban terrain. In: *Proceedings of Interservice / Industry Training, Simulation and Education Conference (I/ITSEC) 2002*, Orlando, Florida.
- Milgram, P., 1994. A taxonomy of mixed reality visual displays. *IEICE Transactions on Information Systems* E77-D(12), pp. 1321–1329.
- Piekarski, W. and Thomas, B. H., 2001. Tinmith-metro: New outdoor techniques for creating city models with an augmented reality wearable computer. In: *5th International Symposium on Wearable Computers*, IEEE, Zürich.
- Ribo, M., Lang, P., Ganster, H., Brandner, M., Stock, C. and Pinz, A., 2002. Hybrid tracking for outdoor augmented reality applications. *Computer Graphics* 22(6), pp. 54–63.
- Roberts, G. W., Evans, A., Dodson, A., Denby, B., Cooper, S. and Hollands, R., 2002. Look beneath the surface with augmented reality. *GPS World*.
- Rückversicherungs-Gesellschaft, M., 2002. Jahresrückblick Natur-katastrophen 2002. http://www.munichre.com/pdf/topics_2002_d.pdf, accessed in 2003.
- Scherzinger, B. M., 2001. History of inertial navigation systems in survey applications. In: M. M. R. Mostafa (ed.), *Photogrammetric Engineering & Remote Sensing*, Vol. 67number 11, American Society for Photogrammetry & Remote Sensing, pp. 1225 – 1227.
- Simon, G. and Berger, M.-O., 1999. Registration methods for harmonious integration of real worlds and computer generated objects. In: *Advanced Research Workshop on Confluence of Computer Vision and Computer Graphics*, Ljubljana, Slovenia.
- Talkenberg, H., 1999. Ein Beitrag zur Koppelortung für Fußgänger. PhD thesis, Technische Universität Braunschweig, Fakultät für Maschinenbau und Elektrotechnik.
- UNESCO Training Module on GIS-Module H-2, 1999. http://ioc.unesco.org/oceanteacher/resourcekit/Module2/GIS/Module/Modul%e_h/module_h2.html, accessed in August 2003.
- Welch, R. B., 1978. *Perceptual modification: adapting to altered sensory environments*. Academic Press.
- You, S., Azuma, R. and Neumann, U., 1999. Hybrid inertial and vision tracking for augmented reality registration. In: *IEEE VR 99*, Houston, USA, pp. 260–268.