AN AUGMENTED REALITY SYSTEM FOR EARTHQUAKE DISASTER RESPONSE

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ABSTRACT

The paper describes the augmented reality system (ARS) developed as part of a disaster management tool of the Collaborative Research Centre 461 (CRC461) at the Universität Karlsruhe (TH). An ARS superposes an image of reality with a virtual image that extends the visible scenery of reality. Its use in the context of disaster management is to represent different invisible disaster-relevant information (humans hidden by debris, simulations of damages and measures) and overlay it with the image of reality. The design of such a system is a challenge in many ways, since the system integrates different methods like mapping, photogrammetry, inertial navigation and differential GPS. The paper introduces into the problems of earthquake disaster response and motivates the use of an ARS. It describes the used hardware components and discusses the data available and necessary for the system to be operational under real conditions. The main methods required to construct and use the system are explained. The achieved results are given and examined. Finally, some conclusions are drawn and suggestions for future work are given.

1. INTRODUCTION

The aim of an augmented reality system (**ARS**) is to superimpose a real-world scenery with a virtual extended version of itself in real time. While first works in the field of AR reach back to Sutherland (1968) first outdoor applications appeared quite late in literature (Feiner, 1997). The driving forces for the new possibilities have been on the one hand the development of the method of real time kinematic GPS and on the other hand the improvement and miniaturisation of orientation sensors. Several applications for outdoor augmented reality systems have been presented in recent years. In these studies, outdoor ARS is used for guiding visitors of a university campus (Feiner, 1997), explaining city planning (Piekarski et al., 2003) or guiding tourist through archeological sites (Dahne et al., 2003).

The following work wants to encourage the use of an ARS in the field of disaster management. The target group of this ARS are experts for Search and Rescue (**SAR**). The ARS is developed as a specialised equipment for supporting the rescuers that try to find people trapped in the rubble of collapsed buildings. The ARS is a part of a disaster management tool (**DMT**) of the Collaborate Research Centre 461 (CRC461) at the Universität Karlsruhe (TH). The disaster management tool is an experimental environment in which new methods for disaster prevention and reaction planning can be tested. In this context, the ARS component provides a most detailed view of the planning information. It represents different invisible disaster relevant information and overlays it with the reality in the same scale.

The ARS is particularly suited to communicate knowledge of experts of different fields that have to work together. Such a situation is described by Hirschberger et al. (2001) for SAR. The example illustrates the problems that occur during SAR activities: The authors describe the efforts of the fire brigades to rescue those trapped in a collapsed building. They report that even while there were SAR experts present they could not remove the debris themselves but needed hydraulic excavators. But, to conduct these excavators special personnel was necessary. The conductors of the excavators in contrary did not have the knowledge of how to remove the fragments best. Care has to be taken that fragments of the ceiling do not break and the remaining cavities are not destroyed. This technical knowledge has to be made comprehensible. Further more one has to communicate how to avoid fine-grained material trickling down to cavities underneath.

The situation shows that means are needed to easily communicate knowledge between experts and other personnel. In the mentioned case, the superposition of instructions and reality could help to guide the operations. The presented scenario is an application of an ARS directly after an earthquake, for the so-called disaster reaction phase. It should be mentioned, that an ARS might be applied in other phases of the disaster cycle as explained by the UNO (2004): disaster impact, relief, rehabilitation, reconstruction, mitigation and preparedness. In the preparing phase before an event the helpers could be trained with simulated damage situations displayed by an ARS. Another important measure to get prepared for a possible event is to establish consciousness in the population for the risks they are living with. Simulated damages superposed with reality could be a tool to show these risks. By doing this, it could improve the readiness to spend money for preparedness measures e.g. to strengthen the buildings and in that way to reduce the number of victims.

2. HARDWARE COMPONENTS

In principle, a mobile ARS consists of devices for measuring position and orientation, computing the virtual scene, displaying the combined result and, eventually, a digital video camera to capture the images of the reality.

For position tracking differential GPS is used. Real time kinematic differential GPS involves the co-operation of two GPS receivers. One receiver is stationary, another moving. The stationary receiver is positioned at a known location. The moving receiver (rover) collects the measurements needed to calculate the current position. The accuracy of the calculated position is improved by correction data computed by the stationary receiver. In the case of real time kinematic GPS the correction data has to be sent to the rover continuously to compute the position in a frequency of about 5 *Hz*. Depending on the geometry between the user and the set of satellites observed, an accuracy better than 5 cm can be achieved. For this study two *Trimble 4800* GPS receivers have been used. The roving receiver outputs co-ordinates in a local co-ordinate system. In this case, they are transformed to Gauss-Krüger co-ordinates.

The orientation is measured by the inertial measurement unit (IMU) *Xsens MT9* (www.xsens.com). The *Xsens*-IMU measures angular orientation of the sensor referring to an co-ordinate system defined by the local plum-line and magnetic north. Note that the IMU orientation does neither refer to the orientation of the GPS co-ordinate system nor the co-ordinate system of the camera or observer.

The user of the ARS can choose from two ways of displaying the superposition of virtual and real images. One can use a portable computer or a retinal display (see figure 2.). The retinal display used here is the *Microvision Nomad* (www.microvision.com). The *Nomad* is a wearable mobile see-through display that operates even in difficult lighting conditions e.g. looking against bright skies.

The framework for holding all the components is a backpack rack (see figure 1). A pole for the GPS-antenna, a tripod and an aluminium suitcase are mounted on the backpack. The suitcase contains all connectors, rechargeable batteries and a portable computer. The portable computer is only put away to the suitcase if the retinal display is used for displaying. A tripod that is mounted on the backpack carries the camera and an IMU measuring the orientation of the camera. A second IMU is attached to the retinal display.

3. DATA BASIS

The availability of data is a key constraint for the tasks of disaster management like e.g. communication, planning or simulation. This section of the article outlines which data are usually available, meaningful and necessary in the case of SAR. Generally, three-dimensional data are needed to create the virtual scene for the ARS. A first rough classification of the data can be established between: (1) data collected before the event, (2) data collected after the event and (3) simulated data.

3.1 Data Collected Before the Event

To hold relevant data ready for a catastrophic event is a part of disaster preparedness. As part of an emergency preparedness program, the plan developed before the construction of a building, could be stored in a central database. This could be mandatory e.g. for larger buildings accessible for the public. These plans could contain the main construction elements, the age of the building and the used materials. Already a simple overlay of the original construction and the destroyed building helps to interpret the situation. To collect detailed 3D construction information of all buildings of a city is obviously an enormous effort. A digital surface model of the city, e.g. measured by an airborne laser-scanner, could substitute the missing three-dimensional information.

3.2 Data Collected After the Event

As proposed by Schweier et al. (2003), airborne laser-scanner reconnaissance after the event seems to be suited best to get a quick survey of the number of the damaged buildings. The visual interpretation of the surface model is also useful. By selecting two points of the surface model the user can measure distances between objects that cannot be reached by a person. This is even more important in the case of collapsed buildings, because climbing the debris may be enough to unsettle the rubble and cause further loss of cavities. The superposition of laser-scanner data and reality using an ARS helps to interpret the surface model and to select the correct points.

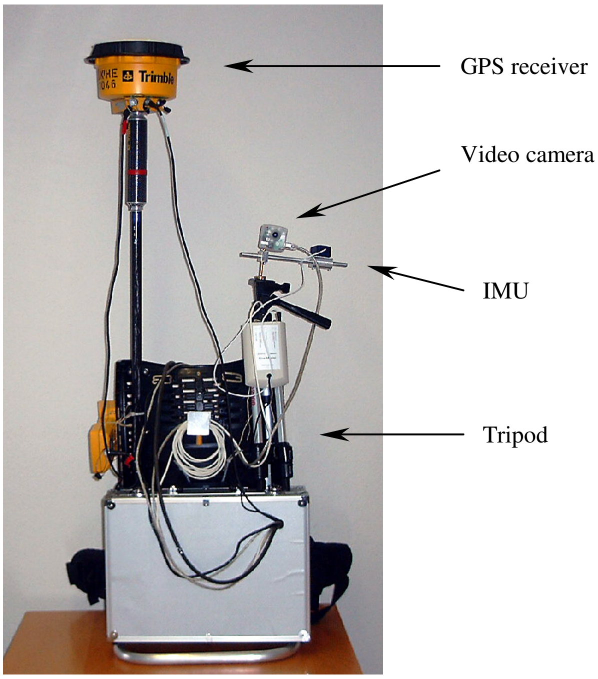

Figure 1. Detailed view of the back of the ARS

Figure 2. Left: hand-held option. Right: see-through option.

It should be pointed out that even the ARS itself could be used to create three-dimensional information. The creation of geometry by the ARS is possible even if no prepared data are available. Like in close range photogrammetry one could imagine that points can be reconstructed if the image co-ordinates of the points are measured from different positions. Of course, choosing points by an ARS when the image is moving continuously is difficult. It is e.g. not possible to visualise both views at the same time. In section 4 a method is developed that simplifies the creation of three-dimensional objects for ARS applications.

3.3 Simulated Data

To test the ARS, data were simulated, containing the geometry of damaged buildings according to the methodology described by Schweier et al. (2003). Simulation at the scale of building parts should not be misunderstood in this context as the prediction of damages at buildings after an earthquake. Such an simulation seems to be impossible as there exist various aspects that cannot be modelled easily. For instance the failure of building parts can be caused by bad workmanship, poor material as well as deficiencies in the statics. Furthermore, furniture inside the buildings could alter the building's behaviour in the case of an earthquake. The location of cavities - a place where trapped persons survive more probably - can be influenced by furniture. That means a realistic simulation of a real collapse is not possible since too many things are unsure. However, simulated damages make sense being used for SAR training purposes.

4. METHODS

Next to hardware and data, a software is needed to run an ARS. The tasks of the software are to perform the superposition and to enable the user to interact with the virtual world. To handle these tasks the following photogrammetric methods have been developed: a method of computing the needed calibration-parameters to calculate the superposition and a method of simplifying the creation of shapes for new virtual objects.

4.1 Superposition

The superposition is achieved by mixing a picture of the reality with a synthetically generated image rendered by 3D computer graphics software. The picture of the reality is taken by a camera or directly observed by the retina of the user of the retinal display. If the retinal display option is used, the process of mixing is solved by hardware since the user sees both pictures through the transparent display at the same time. If the camera option is used, the video stream of the camera is simply used as the background of the scene displayed by the 3D graphics software. The remaining problem is to render the 3D image geometrical correctly. For this one has to know the correct mapping, defined by a combination of transformations and referring transformation parameters. The process of determining these parameters can be interpreted as a calibration process.

While indoor AR calibration is widely studied in literature (a survey is given by Leebmann (2003)), no detailed description for outdoor AR calibration can be found in literature. Outdoor AR calibration has analogies to airborne photogrammetry using INS and GPS for measuring the exterior orientation of the camera (Cramer et al., 2002). The functional model for ARS can be described by a concatenation of several transformations. The transformation of the point:

$$x = \begin{pmatrix} x \\ y \\ z \\ w \end{pmatrix}_{reference-system}$$

in homogenous co-ordinates is expressed by the product of several four-by-four matrices of the form:

$$\mathrm{T}_{from}^{to} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}_{from}^{to}$$

with r_{ik} being components of a rotation matrix and t_i being the components of a translation. A three-by-four projection matrix

$$\mathrm{P}_{eye}^{display} = \begin{bmatrix} c_1 & 0 & x_0 & 0 \\ d & c_2 & y_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

is used to transform the point from the camera or eye-system into the display-system: where c_1 and c_2 represent the scale in the row and the column direction respectively (these scales are often expressed as focal length and aspect ratio), x_0 and y_0 are the principal point co-ordinates and d is the skew of the image. The projection of the point $\vec{x}$ is the point $u = \begin{pmatrix} n & m & h \end{pmatrix}'$:

$$u = \mathrm{T}_{GaussKr\ddot{u}ger}^{display} x_{GaussKr\ddot{u}ger} \tag{1}$$

The perspective projection is the non-linear function pD which transforms the display co-ordinates to image co-ordinates:

$$v = \begin{pmatrix} x/w \\ y/w \\ z/w \end{pmatrix} = pD \begin{pmatrix} x \\ y \\ z \\ w \end{pmatrix} \tag{2}$$

Since the three rotations between rover and eye-system are not commutative they have to be kept separate and cannot be combined.

$$\mathrm{T}_{world}^{display} = \mathrm{P}_{eye-system}^{display} \mathrm{T}_{IMU}^{eye-system} \mathrm{T}_{source}^{IMU} \mathrm{T}_{rover}^{source} \mathrm{T}_{GaussKr\ddot{u}ger}^{rover} \tag{3}$$

The combination of the equations (1), (2) and (3) leads to an equation that can be used for the bundle adjustment. If the transformation parameters for $\mathrm{T}_{rover}^{source}$, $\mathrm{T}_{IMU}^{eye-system}$ and $\mathrm{P}_{eye-system}^{display}$ are introduced as unknowns in the bundle adjustment, they can be determined and used as calibration parameters. The parameters of the transformations $\mathrm{T}_{source}^{IMU}$ and

$T^{rover}_{GaussKrüger}$ are introduced as observations into the bundle adjustment and the weighted square sum of their errors is minimised.

4.2 Creation of New Virtual Objects

The following method described to construct the shape of new virtual objects aims to simplify the registration of the geometry in contrast to classical photogrammetric methods. The goal of the method is to measure 3D points using perspective images without assigning image point correspondencies. Correspondencies of polygons are used instead of correspondencies of points. The idea to use polygon features for photogrammetric reconstruction can be found in the literature for stereo reconstruction from camera images. Forkert (1993) uses polygonal curves registered by a camera to reconstruct a three-dimensional spline description of the polygon in the object space. He extends the well-known observation equations for image points by the restriction that the distance between the point in object space and the three dimensional curve is observed to be zero.

The spline-constraints of Forkert's (1993) approach can be avoided if not the distance in the image space of the projected points is minimised but a distance in object space of a three-dimensional polygon. That means every measured image point of the polygon establishes together with the projection centre a ray. The polygon point in object space is defined as a point on the ray with a given distance to the projection centre. If the distance to the projection centre was known, the points on the rays build a three-dimensional polygon. But, the distances of the points on the rays to the projection centre are unknown parameters in the beginning. To reconstruct the three-dimensional shape of the observed polygon, one searches for the set of unknown parameters that minimise a certain distance between two observations of this polygons from different perspectives. The used polygon distance is developed in the following.

The distance of a *discrete* set of points can be defined based on a bijective mapping of the one set of points Q to another set of points P. Such a distance is e.g. used by the so-called Helmert-transformation to compute the transformation parameters from the one point set to the other.

$$d(P,Q)=\sum_{i=0}^{n}(Q_i-P_i)^2$$

If one wants to extend the definition for a discrete set of points to a *compact* set of points one has to define a bijective mapping from the one compact set to the other. Such a compact set of points is a polygon. If two polygons were identical then the mapping of the points from one polygon to the other can be done using the arc length of the polygons as a bijective mapping. But if the polygons differ, e.g. because of the random noise of the observations, then the simple arc length cannot be used. In that case, the normalised arc length of the polygons is more appropriate. The normalised arc length means that every point on a polygon is represented by a value between 0 and 1. The distance of the two polygons is now the integral of the distance of the points of the same normalised arc length. In formulas:

$$d(p,q)=\sum_{i=0}^{n}\int_{b_i}^{b_{i+1}}(q_i(b)-p_i(b))^2\,db \qquad (5)$$

with:

$$b_i=\frac{\sum_{k=0}^{i}\sqrt{(P_k-P_{k+1})^2}}{\sum_{k=0}^{n}\sqrt{(P_k-P_{k+1})^2}}$$

where n is the number of different arc length values for the points of both polygons. p and q are the symbols for the two polygons.

Since the Euclidean distance for point sets is transformation sensitive, the created polygon distance is also transformation sensitive. The parts of the sums are differentiable. Therefore, the complete expression (5) is differentiable. This property simplifies the search for a minimum of the defined distance.

In case that there was a absolutely identical curve with the same number of base points at the same arc-length, then it was sufficient to search simply the null of the distance.

$$d(p,q)=0 \qquad (7)$$

Due to errors differences between the curves should be allowed, one searches only the minimum of (7). To search the minimum one has to derive equations of equation (7) and solves the system using the Newton method. The condition for the minimum for n unknown parameters x is:

$$\begin{aligned}\frac{\partial d(p,q)}{\partial x_1}&=0\\ &\vdots\\ \frac{\partial d(p,q)}{\partial x_n}&=0\end{aligned}$$

5. RESULTS

As an example for an application a simulated collapse based on a detailed 3D-model of a building was used. A digital surface model of the campus of the university measured by a laser-scanner was also available. In figure 3 and figure 4 parts of these data sets can be seen. Then, the overlay was generated using the video camera based ARS. In figure 5 a picture taken by the video camera is shown. The camera looks to that corner for which the damage was simulated. The superposition of the camera image of the corner and the laser-scanner data is pictured in figure 6. The laser-scanner data have been used to measure the points to compute the calibration parameters. The superposition proved to be of good quality as long as the camera remained in the volume spanned by the observed image points used for calibration.

In figure 7 parts of the simulated damage and some virtual humans are added to the scene. This would be the view used for the training of SAR experts. In the view only selected fragments are displayed. Figure 7 shows that the laser-scanner model helps to interpret the simulated scene. Since the laser-scanner model is transparent and the damages not, one can distinguish which fragments are sticking out and which do not. Otherwise the user had the impression that all fragments were flying in front of the building.

In figure 8. an example for the polygon method is displayed. Two polygons have been digitised that should describe the corner of the building. The red dots are the points on the blue rays established by measured image points and the projection centres. The red points are connected by red lines and define like that the polygons. For each measured bundle of rays one obtains a polygon. The image shows the two polygons. Due to a height error of the GPS receiver the left polygon is measured too low. This creates an accordion effect for both reconstructed polygons. This effect could be avoided, if more than two polygons would be digitised to measure the polygon and an unknown free mean polygon is determined by minimising the sum of distances from the mean polygon to all measured polygons.

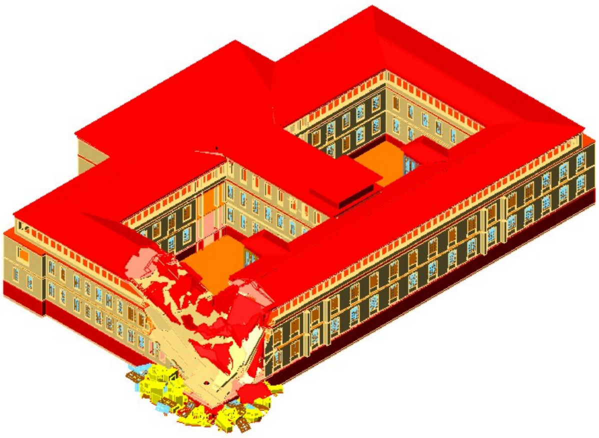

Figure 3. Simulation of a damage (Schweier et al., 2003).

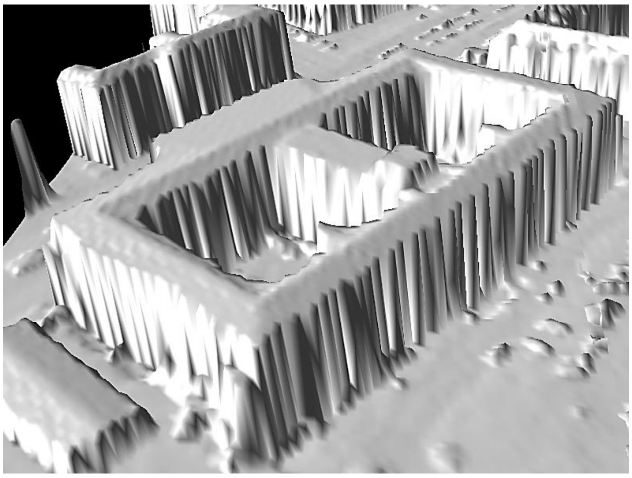

Figure 4. Laser data of the studied building.

Figure 5. Video image

Figure 6. Superposition of video and laser-scanning model

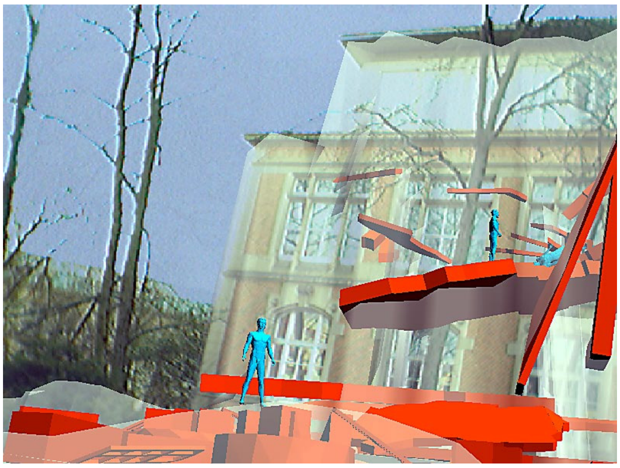

Figure 7. Mixture of the laser-scanner data, the video and the simulated damages

Figure 8. Digitised polygons.

6. CONCLUSIONS

The previous sections presented an outdoor ARS used as part of a tool for earthquake disaster management. Possible hardware configurations have been shown and possible data available in case of an disaster has been discussed. A method to establish the match between real-world scenery and virtual extension and a new method to reconstruct polygonal shapes is given. The results of first experiments of the method to reconstruct the shape of polygonal objects have been shown. From the results in section 5 it can be concluded that, despite minor difficulties, the methods are working and might be of use in the case of an disaster. To prove the usability in that case a larger set of virtual planning possibilities has to be offered by the system and the ARS has to be tested using real damages.

REFERENCES

Cramer, M., Stallmann, D., 2002. System Calibration for Direct Georeferencing. International Archives on Photogrammetry and Remote Sensing IAPRS, Volume XXXIV, Com. III, Part A, ISPRS Commission III Symposium, Graz, pp. 79-84.

Dahne, P.; Karigiannis, J.N., 2002. Archeoguide: system architecture of a mobile outdoor augmented reality system. Proceedings of the International Symposium on Mixed and Augmented Reality, ISMAR 2002, pp. 263- 264.

Forkert, G., 1993. Photogrammetric Object Reconstruction using Free-Formed Spatial Curves. In: Gruen, A. and Kahmen, H. (editors): Optical 3-D Measurement Techniques II. Herbert Wichmann Verlag, Karlsruhe.

Feiner, S., MacIntyre, B., Höllerer, T., Webster, T., 1997. A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. Proceedings of the First Int. Symp. on Wearable Computers, ISWC '97, October 13-14, 1997, Cambridge, pp. 208-217.

Hirschberger, S., Markus, M., Gehbauer, F., 2001. Grundlagen neuer Technologien und Verfahrenstechniken für Rettungs-, Bergungs- und Wiederaufbaumaßnahmen; Berichtsband des Sonderforschungsbereiches 461 (Starkbeben: von geowissenschaftlichen Grundlagen zu Ingenieurmaßnahmen) für die Jahre 1999-2001, Karlsruhe, pp. 639-686 .

Leebmann, J., 2003: A stochastic analysis of the calibration problem for augmented reality systems with see-through head-mounted displays. ISPRS Journal of Photogrammetry and Remote Sensing, Special Issues on Challenges in Geospatial Analysis and Visualization, pp. 400-408.

Piekarski, W.; Thomas, B.H., 2003. Tinmith - mobile outdoor augmented reality modelling demonstration. Proceedings of the Second IEEE and ACM International Symposium Mixed and Augmented Reality, pp. 317- 318.

Schweier, C., Markus, M., Steinle, E.: Simulation of earthquake caused building damages for the development of fast reconnaissance techniques, Natural Hazards and Earth System Sciences, accepted September 2003.

Sutherland, I.E., 1968. A Head-Mounted Three-Dimensional Display. Proceedings of the AFIPS Conference, Vol. 33, Part I, pp. 757-764.

UNO, 2004. The United Nations Disaster Management Training Programme (DMTP), http://undmtp.org/sitemap.htm (accessed 1.2.2004).

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