

APPLICATION OF AN AUGMENTED REALITY SYSTEM FOR DISASTER RELIEF

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ABSTRACT:

The goal of an augmented reality system (ARS) is to superimpose in real time a real world scenery with a virtual extended version of itself. Such an ARS is, also developed as part of a disaster management tool of the collaborative research centre 461 (CRC461): "Strong Earthquakes". Rescue units are supposed to use the ARS as a tool to plan their actions on site using the possibilities offered by virtual reality. Regarding the reconnaissance strategy of the CRC461 there will be airborne laser scanning data collected of the whole affected area after an earthquake. This in turn means that the geometrical shape of the buildings is known. This three-dimensional data can be fused with other information available, e.g., digital elevation model, building structure and so on. This information can now be used as planning information for rescue units. The construction, of such a system, is a challenge in many ways. Firstly, the proposed work shows how digital surface models can be used in different ways for the on site calibration of an See-Through Head-Mounted Display (STHMD) and the connected head tracking devices. Next to this the paper will introduce special possibilities offered by such a technology to analyse possible rescue plans for collapsed buildings in the context of disaster relief. On the other hand there is a set of primitive analysis techniques like measuring distances without touching the object directly.

1. INTRODUCTION

The goal of an ARS is to superimpose in real time a real world scenery with a virtual extended version of itself. Such an ARS is also developed as part of a disaster management tool of the collaborative research centre 461 (CRC461): "Strong Earthquakes" [2]. Rescue units are supposed to use the ARS as a tool to plan their actions on site using the possibilities offered by virtual reality. Regarding to the reconnaissance strategy of the CRC461 there will be airborne laser scanning data collected of the whole affected area after an earthquake. That means that the geometrical shape of the buildings is known. These three-dimensional data can be fused with other information available, e.g. digital elevation model, building structure and so on. This information can now be used as planning information for rescue units. The construction of such a system is a challenge in many ways. One of the problems is the calibration of the used components. This calibration problem is analysed in detail in this paper.

An optical see-through augmented reality systems (ARS) consists in principle of a See-Through Head-Mounted Display (STHMD) and a head tracking device. The first approaches of optical see-through AR calibration tried to transfer the camera calibration procedures known from photogrammetry to the optical see-through systems. These techniques use simplifications of the real nature of the measured data. They do not regard that the measurements of the head tracking device are affected by sensor errors. As a result of this simplification a large number of observed image points is necessary to compensate the error in the model. In the case of disaster relief applications it is not possible to measure a large number of control points. This paper introduces an alternative method to calibrate a STHMD using no or only a smaller number of control points.

1.1 Equipment

The results presented in this paper are produced using the Ascensions Flock of Bird (FOB) Tracking System [1] and the i-glasses-Protoc STHMD (see figure 1). The basic source co-ordinate system is realised by a transmitter that is building a magnetic field. The two sensors of the system, further also referred to as "birds", are used as mobile sensors that can compute their orientation and position from measurements of the magnetic field of the transmitter.

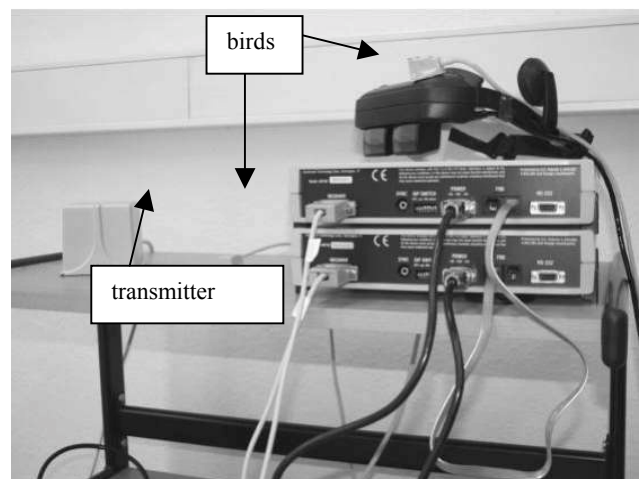


Figure 1. The components of the studied augmented reality

In figure 1 the first bird is attached at the glasses. The second bird is lying on the table between the glasses and the transmitter. The measurements of the sensors are the position in the source (transmitter) co-ordinate system and the orientation of its co-ordinate system in the source co-ordinate system.

This system is not yet applicable outside of a laboratory because of two reasons: (1) The transmitter has to be placed on a fixed place and can not be moved. (2) The transmission of the i-glasses-Protoc STHMD is too low. The system has been chosen to develop the algorithms with a cheaper and more accurate equipment. The smaller sensor errors of the FOB in contrast to mobile navigation sensors simplify the development process.

Next to the technical equipment there was a laser-scanning dataset available of the city of Karlsruhe. This dataset covers also the campus of the university. Therefore it was possible to use the view through the window of the laboratory (see figure 2 and 3). This view has been used to test the correctness of the method.

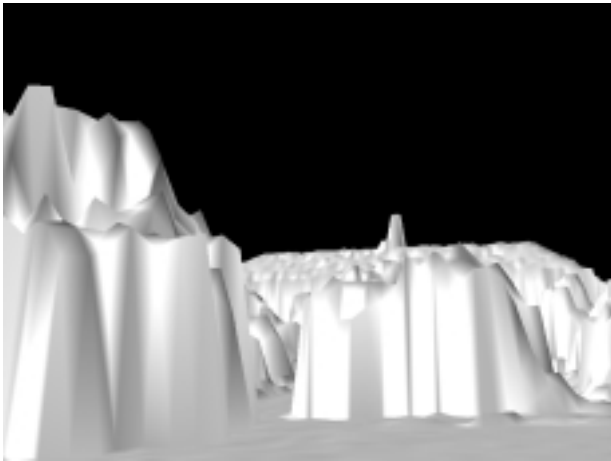


Figure 2. Virtual view of the laser scanning DEM.



Figure 3. Photograph of the virtual view in figure 2.

1.2 Mathematical model

In this section the standard formulas for STHMD calibration are given (for detailed information about different methods of STHMD calibration see [1]). These formulas are later adopted to the special conditions in disaster relief situations. STHMD calibration has to take more coordinate systems into account than camera calibration. The transformations between these systems can be expressed in four-by-four transformation matrices. The transformation from the world co-ordinate system to the display-system can be written as:

$$\mathbf{T}_{World}^{Display} = \mathbf{P}_{Eyesystem}^{Display} \mathbf{T}_{Sensor}^{Eyesystem} \mathbf{T}_{Source}^{Sensor} \mathbf{T}_{World}^{Source} \quad (3)$$

In figure 4 the different co-ordinate systems are sketched. The world co-ordinate system and the source co-ordinate system coincide in this picture (1). The origin of the eye co-ordinate (2) system is at the position of the observers eye. The sensor co-ordinate (3) system is attached to the glasses and has for this reason a fixed relation to the display-co-ordinate system (5). Besides to the intrinsic parameters of the optical system the transformation from sensor to eye co-ordinates (4) defines one set of calibration parameters.

Using formula (1) the projection of the point x can be written as:

$$u = \begin{pmatrix} x & y & z & w \end{pmatrix}' = \mathbf{T}_{World}^{Display} x \quad (4)$$

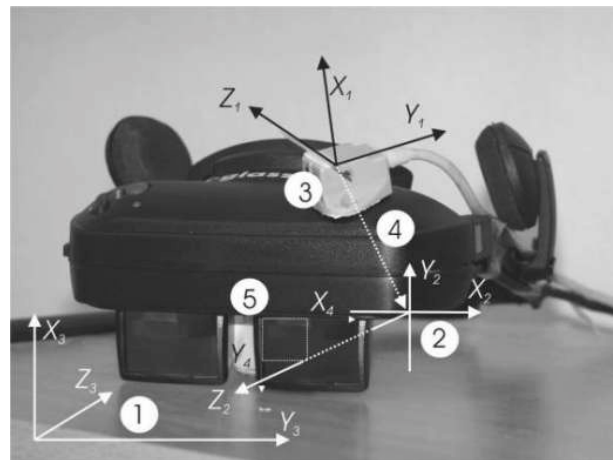


Figure 4. Sketch illustrating the involved co-ordinate systems.

As here perspective projection is occurring the perspective division (pD) has to be applied:

$$v = \begin{pmatrix} x/w & y/w & z/w \end{pmatrix}' = pD(u) \quad (5)$$

If more than one sensor is available and attached to the glasses, the constant connection between different sensors can be written as:

$$\Xi(\mathbf{T}_{Source}^{SensorB}) = \Xi(\mathbf{T}_{SensorA}^{SensorB} \mathbf{T}_{Source}^{SensorA}) \quad (6)$$

Where Ξ is the function that decomposes a four-by-four transformation matrix into the rotation angles and the components of translation.

1.3 Calibration problem in unprepared environments

In this section a special mathematical model for augmented reality calibration in unprepared environments is motivated. This model was developed to have an simple intuitive method to calibrate the system outside of the laboratory. The known

calibration methods for STHMD are very complex for an user that might not have photogrammetric knowledge. The methods described in literature expect that the user assigns points in the world-coordinate system to image points. In an unprepared environment we do not have predefined control-points. Especially after an earthquake one can not expect certain given control points. Since calibration is a fundamental prerequisite for See-Through AR the question is how to get the necessary calibration information after an earthquake. The solution lies in the reconnaissance strategy of the CRC461: there it is assumed that there will be a current DEM available that was produced by a laser-scanning flight. The idea is to use the geometric information of a DEM to generate all the needed calibration parameters. If there was an DEM one could think of a calibration procedure as follows: In the first step one chooses a three-dimensional point by pointing to it in a perspective view with the mouse (picking). This point on the surface of the DEM has to be assignable to a point in the real world. In a second step the user could measure the appropriate image coordinates seen through the glasses. Such a method has been implemented and tested. The experiments showed that this method has one severe drawback: the low density of a common airborne laser-scanning model (0.5 m) is too rough to identify enough points that allow a reliable solution for the calibration parameters. The figures 2 and 3 illustrate this problem. The approach that is described in the following section uses not points that are assigned to each other but polygons. One easily specifiable feature of the DEM is the silhouette: the separation line of the earth and the atmosphere. This line can also be easily created with the glasses. Using the measured image points and navigation-sensor observations a three dimensional polygon can be created. The distance of this polygon to the computed three-dimensional polygon of the silhouette is then minimised.

1.4 Three-dimensional representation of the silhouette

Every point of the polygon that is measured by the user refers to a different orientation of the image plate since the user should be allowed to move his head freely while measuring the silhouette. Thus, it is not possible to represent the polygons in a single image coordinate system. Therefore the image points have to be represented in the three-dimensional rays. For every ray one has to introduce an additional unknown parameter that defines the point on the straight line. All these points on the rays build the so called observed polygon.

In contrast to the observed polygon the representation of the virtual silhouette of the DEM is not unique. The virtual silhouette differs also from image orientation to image orientation. All of the topologically connected partial silhouettes are combined and the minimum least squares of the errors is computed. is calculated for all possible combinations. In the end the minimum of all combinations is taken. The computation of the silhouette itself is not trivial and consists of four steps:

1. All meshes of the DEM that cannot be seen in the observer's perspective are cut away (clipping). This is necessary to increase the speed of the following steps.
2. The remaining meshes are then projected to the image plate. Here for every DEM point for meshes have been built and projected. The projected meshes build triangles in the image plate the silhouette is the result of the union of all these triangles to a closed polygon (see figure 5).

3. As defined above the polygon used in this paper is not a closed one. The polygon used here can be computed if one projects the plumb line of the DEM points into the image. This projected plumb line vector together with the image point build a straight line. By counting the cuts of the straight line (image point connected with an infinite far point in the direction of the plumb line) with the closed polygon one can separate the desired points from the rest.
4. For the reconstruction of the three-dimensional points one has to distinguish two groups of points. One group of the polygon have their origin in a projected DEM point. The other group of points is the result of the cut of an edge of one triangle with another. Thus, these cuts are represented by two points in the third dimension.

For every image point of the polygon this procedure has to be repeated. In figure 6 an example for such a partial silhouette of one image point perspective is shown.



Figure 5. The union of the triangles of the projected meshes give a closed polygon.

1.5 Extension of the standard model

In the following the used distance measure for polygons is defined.

There are several papers that give distance measures for polygons. [4] survey the most common distance measures. The distance measures found in literature have several deficits: Some of them are only applicable to two-dimensional polygons. Some are not transformation sensitive. Others are not differentiable with regard to the transformation parameters. Some of the distance measures do not satisfy the three conditions for metrics. A distance measure is called a metric if it fulfils for all polygons x , y and z the following conditions:

1. $d(x,x)=0$
2. $d(x,y)=0$ implies $x=y$
3. $d(x,y)+d(y,z) \geq d(x,z)$

The above properties and conditions are pre-requisites for a unique solution and a good convergence when solving the calibration parameters. The distance measure used here is a generalisation of the Euclidean distance measure of point sets. There was nothing similar found in literature. The Euclidean distance is a metric in the three dimensional space. The Euclidean distance of point sets that may be the result of a differentiable operation (e.g. an Euclidean transformation) is

differentiable. The Euclidean distance of a discrete set of points is based a bijective mapping of the one set of points Q to another set of points P .

In case we want to extend the definition for a discrete set of points to a compact set of points we also have to define a bijective mapping from the one compact set to the other. If the two polygons were identical then the parametrisation of the points on a polygon by the arc length is 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 normalized arc length of the polygons is more appropriate. The normalized arc length means that every point of the two polygons 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 normalized arc length. In formulas:

$$d(P, Q) = \sum_{i=0}^n \int_{b_i}^{b_{i+1}} (Q_i(b) - P_i(b))^2 db \quad (7)$$

with:

$$b_i = \frac{\sum_{k=0}^i \sqrt{(P_k - P_{k+1})^2}}{\sum_{k=0}^n \sqrt{(P_k - P_{k+1})^2}} \quad (8)$$

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. In the intervals between the arc length values one has

to integrate along straight lines. That integral for straight line segments is solvable.

Equation 7 is a metric measure for the distance of polygons. Since the Euclidean distance for point sets is transformation sensitive, the created polygon is also transformation sensitive.

1.6 The combination of the different models

To compute the optimal calibration parameters the least squares method is used for solving the system of equations 5 and 6. The goal is to combine the different types of observations in a natural way: point observations and polygonal observations. To reach this goal one has to derive equations from equation 7 that are conditions for the minimum of the distance of the polygons. The condition of the minimum of Eq. (7) for the unknown parameters p is:

$$\frac{\partial d(P, Q)}{\partial p} = 0 \quad (10)$$

This equation shows that all the introduced unknown parameters that define the point on the rays of the observed polygon can be solved. The minimum condition is also valid for all other unknowns. The equations for the conditions of the minimum of the distance of the polygons are also affected by the random errors of the observations. The minimum conditions are combined with the other equations (5 and 6) and used to determine the minimum least squares of the errors of the observations.

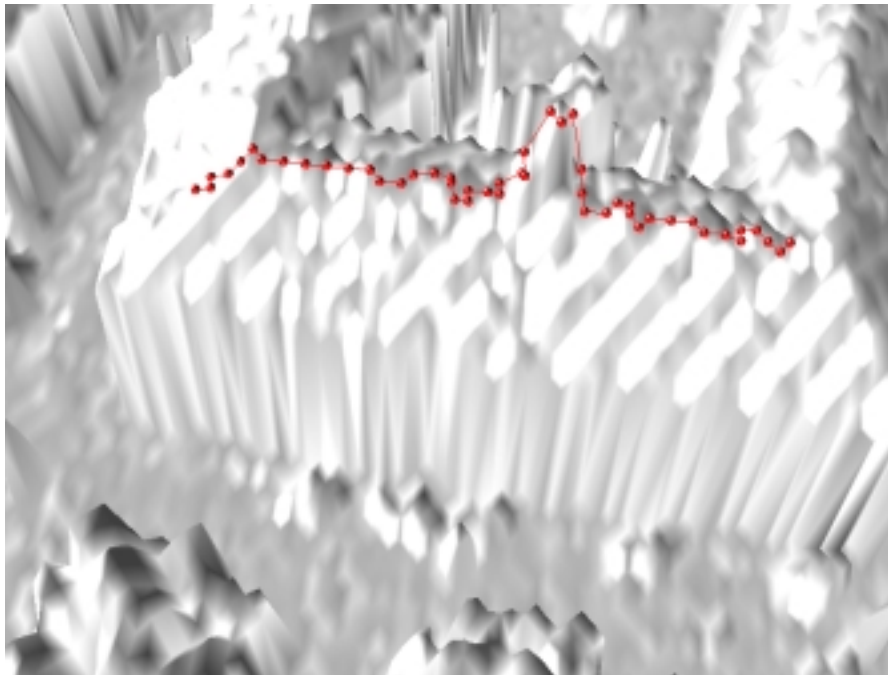


Figure 6. A part of the three-dimensional representation of the Silhouette of the vie in figure 2.

2. APPLICATIONS

The AR technology offers a variety of possibilities to support disaster relief operations. In this section some application ideas are presented.

After an earthquake there is only a few information available on which the rescue plans can be based on. One important source of information would be the three dimensional airborne laser scanning flight immediately after the event. This dataset can not only be used for the generation of a damage survey, but also as basis for three dimensional planning on site. The laser scanning DEM can be used as a framework to which all other geometrical information can be added.

In the sections above it was shown that the laser scanning dataset can be used to determine the transformation parameters that are necessary to overlay the image that is seen by the human eye with a virtual image containing the planning information. The combination of the plan and the reality enables the planner to check the plausibility of the plan.

An example is the analysis of possible rescue plans for collapsed buildings in the context of disaster relief. Walls can be made virtually transparent (figure 7) and relevant information about sloped persons or possible accesses to these persons can be sketched. Analysis techniques like measuring distances without touching the object directly can be performed: the user selects with a pointer displayed in the glasses two points in the reality for which he wants to know the distance. The distance can then be calculated by cutting the ray of the image points with the DEM.

Next to the geometrical information it is possible to annotate the reality with non geometrical information like text or symbols (see figure 8).



Figure 7. The idea is to use virtual reality for planning rescue activities. In the figure one can see a virtual cut through a damaged building.

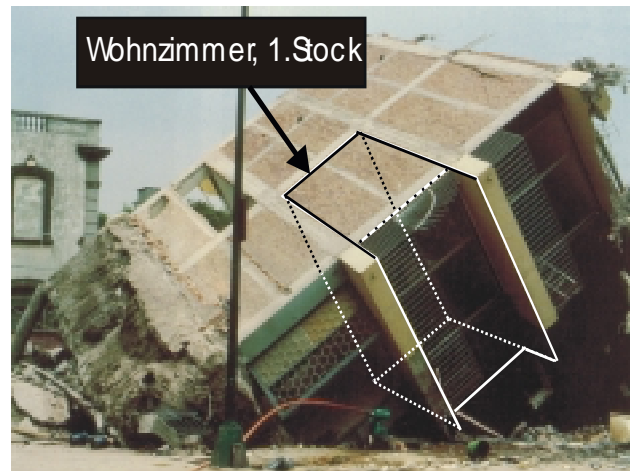


Figure 8. The real world can be extended by non geometrical information.

3. CONCLUSIONS

A calibration method for unprepared environments as they are needed for AR applications for disaster relief has been presented. The algorithm has been tested. A detailed study of the quality of the reachable accuracy has not yet been made. Next to this some possibilities to apply AR to disaster relief are discussed in the paper.

4. REFERENCES

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5. ACKNOWLEDGEMENTS

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