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Civil Engineering Application for Virtual Collaborative Environment

Mauricio Capra, Marcio Aquino, Alan Dodson,
†Steve Benford, †Boriana Koleva-Hopkin

University of Nottingham
Institute of Engineering Surveying and Space Geodesy and Mixed Reality Laboratory
{iszmc, iszma, iszahd}@nottingham.ac.uk
†{sdb, bnk}@cs.nottingham.ac.uk

Abstract

The motivation for this project was to find a way to give engineers, and the community affected by Civil Engineering work, information that is often difficult to visualise via computer screens, 2D plans or even scale models. We developed a Digital Scale Model using the existing expertise at the University of Nottingham on Space Geodesy and Mixed Reality. The user works in a collaborative Virtual Environment (VE) where it is possible to share with other users, new ideas, points of view and solutions that appear in the timeline of a construction, pursuing reduction of costs and improving agility. This paper is an introduction of the project developed at the University of Nottingham and describes the concept of Digital Scale Models. Hardware, software and results will be presented and discussed.

Key words: Augmented Reality, Civil Engineering, Collaborative Environment

1. Introduction

Civil Engineering scenarios have been the subject of study of Augmented Reality researchers for a long time. Piekarski[8] and Feiner[3] are just a few examples of what has been developed involving the visualisation of VE in outdoor areas using AR. But due to the low-cost technology and easy access to mobile computers, most engineers are still using the scale models or 2D layouts to demonstrate the modifications that will be implemented in the area of a new construction. The investors, builders and the public affected have to use a lot of imagination to realise how the environment will look in the future. The problem with this representation is that it does not give us the sensation of being side by side with the changes. In our approach, the engineers will not only have the facility to make decisions on, for instance, the best position for the Civil Engineering project, but they will also be able to observe, analyse, share information and discuss with their team the best way to carry out the work.

The users of our system are divided into two main groups: field and office users. The first refers to the person that will wear the developed system in the target area, where the project is to be (or is being) carried out. The field user will see, with the help of a see-through Head Mounted Display (HMD), the digital and real environments seamlessly. The outdoor user shares the VE with the office users thanks to a wireless network. The latter, with the help of a computer screen and a mouse, can operate the VE from their desks. The public affected by the construction is a sub-set of the field user. With only part of the equipment used by the field users, they will be able to liaise with the engineers, solving possible doubts about what will be modified and giving suggestions about the new investment.

2. Motivation

There are a good number of ongoing outdoor AR projects around the world [9, 10, 8, 11, 2]. This project finds its motivation as the high precision GPS culture inherent to the Institute of Engineering Surveying and Space Geodesy (IESSG) encounters its correspondence on the Mixed Reality (MR) know-how existing at the Mixed Reality Laboratory (MRL). The idea is to take advantage of a combined use of these two technologies to create a collaborative AR environment where the users can share their expertise to the benefit of the development of Civil Engineering projects. Our approach is to meet the requirements of Civil Engineering with available – computers, sensors, GPS receivers and the software developed inside the University.
This paper also introduces an AR research group created at the University of Nottingham that has a focus on the Civil Engineering necessities.

3. Field and Office Users

People that live in an area affected by a new construction always want to know how much their lives will be changed after the end of the project. On the other hand, engineers need to discuss with their colleagues if what they had imagined for the project can be achieved or not.

Two main groups were identified as users of the project: the office and field users. Figure 1 presents a macro-view of what each user will need, between hardware and software, to work with the system.

The office users can see and explore the VE on the screen of the computer with the aid of a standard mouse. The environment in the first instance can only be configured with the VE, without the interaction of the field users. The movements inside the VE are totally free and the users explore it with the ability to move through the objects that are displayed. The objects can have their positions changed by the drag and drop mouse features. If more than one office user is sharing the VE, all changes will be noticed by the users. An avatar represents field and office users on the VE.

A wireless network links field and office users. The field users, at the bottom of the diagram (Figure 1), have in a backpack a notebook and an RTK (Real Time Kinematic) -GPS receiver. A crash helmet was adapted to hold the TCM2-50 (tilt sensor and magnetic compass) and the PCGlasstron (see-through HMD) on the field user's head.

The digital objects combined with the real environment will compose what is visualised by the field user. The RTK-GPS receiver gives their position on the ground and the head's movements are logged by the electronic compass and tilt sensor, thus allowing the update of the image projected in the see-through HMD. The user is free to explore the projected VE through the objects that compose the scene. The system can be configured to work with only one user in the field (stand alone user) or it can be shared with other field and office users.

Another type of field user are the people affected by the construction. The general public can explore the Mixed Reality (MR) environment, creating and clarifying doubts generated during the lifetime of a civil engineering project.

Both groups of users in Figure 1 have the MASSIVE-3 and Equip platforms running their computers. They have stored onto the hardisk a data space that represents the VE. Out of the computers that are integrating the external equipments, the server manages the data space and shares the information via wave-LAN in a multicasting service. Information such as, users and objects positions, user's head movements, GPS coordinates, video and audio, are examples of what can be logged and distributed to the other computers. The clients receive the new data, thus updating their own VE. The user is now placed in what is called a collaborative environment.

The visual perception of MR for the office user is enabled when the field user carries a video camera. The images of the real world are added in a background of the VE giving a combined view of the real environment with the new construction. The users communicate to each other through the voice channel, sharing different points of view in an easy way to discuss and solve divergences.

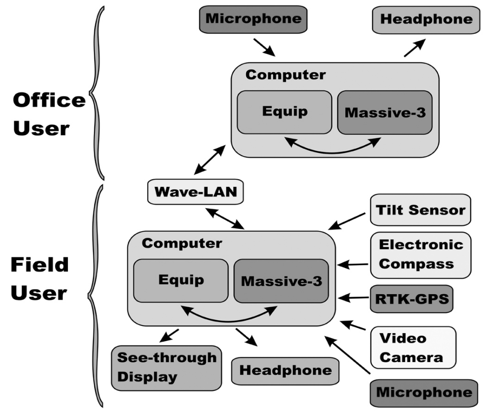

Fig. 1 Field and Office User

The idea is that the people who live in or use the area be given the opportunity to see the VE added to the environment, without making use of some additional features available for the technical users, like voice communication or the possibility to interact with other users. For non-technical users these facilities can bring more difficulties than advantages. But, regardless of this fact, the public is able to clarify doubts and forward suggestions when in disagreement.

4. Hardware and Software

Further to the devices shown on Figure 1, the field user has in their backpack, a Toshiba Satellite Pro – 6100, with 1.6 GHz Mobile Intel Pentium 4 processor and 256 MB of Random Access Memory (RAM), that integrates the platforms and the external devices.

The VE is displayed in a SONY PCGlasstron Head Mounted Display – PLM-S700. The device was set up with the maximum screen resolution for PC video card: Super Video Graphics Array (SVGA) with 800 **x** 600 (dot **x** line); 53.7 horizontal frequency (kHz) and 85 vertical frequency (Hz).

For constant changes of parameters and modifications in the code during the "out of the office test phase", a twiddler2 handheld keyboard-mouse by Handykey Corporation is being used.

Like most AR projects, we are logging the user's head movements with a TCM2-50 circuit board by Precision Navigation. It is a very light circuit board equipped with an embedded RS232 interface. The circuit board offers a tilt sensor with range between +50 to -50 degrees (roll and pitch) and a magnetic compass.

The Leica SR530 is a 24-channel GPS receiver capable of tracking both the L1 and the L2 carrier phases with high accuracy and with an on-board RTK capability. This device can provide positions with approximately

2cm of accuracy when it is working together with a reference station.
In order to manage and support all external devices connected with the computer logging and sharing information in a data space, the MRL has developed a platform known as EQUIP. This system links the real world (represented by the data received from the equipments) and the VE allowing the data to be accessed and updated in different modes even on machines positioned over extended distances and for long periods of time. EQUIP provides the distribution of data in real time for different types of applications running on different machines using its own serialisation protocol. Any number of data spaces can be created with no limit for data items. The processes are connected in the system, which can write, update, read and delete from the data space. Once the data is shared, each modification of the values means an update on all interested applications using the system. This means that any communication between external hardware and the VE must pass through the data space. There are several advantages of using the EQUIP: support for multiple languages, multiple and independent data spaces and asynchronous communication between data spaces [6].
Generally when it is necessary to include another device in the system, a new Java component of EQUIP needs to be programmed in order to supply the different formats of communication. Then, the programmer just needs to publish the data to the data space.
Once the data is logged, the VE needs to be generated. To create and manage the VE it is necessary to use another system, namely MASSIVE-3, which was also developed at MRL. As mentioned by Greenhalgh[5, 4] MASSIVE-3 is a multi-user collaborative VE system. It allows multiple users to view and become embodied in a 3D audio-graphical virtual world. It supports real-time audio communication between users, and dynamic modification of virtual world. All data made available on the data space is read and directed to the correct variables inside MASSIVE-3. In our case, the avatar that represents the field user has the movements related to the data that originally came from the tilt sensor, RTK-GPS and the magnetic compass.

5. Prototypes

The first experiments with MASSIVE-3 and EQUIP, were performed around the IESSG building area. Such experiments were necessary to provide an initial assessment on how to handle the problems and to configure the system, as well as ascertaining what is necessary to program using these platforms. A collection of GPS coordinates was taken around the IESSG building to feed a database that was interpolated generating a square mesh that represents a Digital Terrain Model (DTM) of the area. The interpolation was produced using the Surf software. With the building coordinates and some pictures taken around it in hand, it was possible to model the VE shown on Figure 2.

In the office environment, the VE can be shared with other users via the intranet or wave-LAN (Local Area Networks) cards. Figure 2 shows the office user's viewpoint of the VE and a second office user represented by an avatar. At this point, the basis of the office user concept was validated and we then focused on integrating the external devices for the field user as shown in Figure 1.
New Java classes were programmed in order to supply the communication between EQUIP and the external devices. The messages are divided in small tokens where the useful data are logged on the data space to be read later by MASSIVE-3.

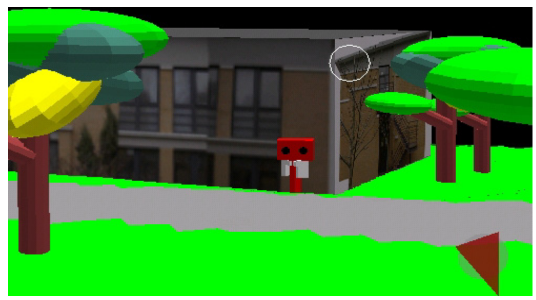

Fig. 2 IESSG Building

The second prototype started with the design of a tram station. We modelled the platform and the furniture that will be fitted, following 2D plans provided by the company in charge of building a new tram system in the city of Nottingham. Scales and colours of the furniture were respected giving some realism on the 3D model. The field user was first tested working without interaction with the office user. It is what we called a standalone user. With the outputs of the RTK-GPS receiver, the magnetic compass and the tilt sensor, the user's movements are translated to the avatar. As a result, the VE is displayed on the see-through HMD from the viewpoint that the user is positioned. Figure 3 shows the field user's view of the tram station.

Fig. 3 Tram station

The first tests were done in an open area inside the University campus where it is possible to stay far away from the VE to take panoramic views. The user is free to walk around the area where the VE is projected to take a look from different angles, exploring and analysing it.

Among the virtual objects the users can stay next to what is supposed to be the new construction, becoming conscious of how the real environment will be affected in the future.

6. Collaborative Environment

To allow field and office users to share the VE in real time a wave-LAN communication link was set up. A video server was also set up in order to offer a better perception of the real environment for the office user. The images come from a web-camera connected to the field user's crash helmet. The real environment is displayed on the background of the office user's view of the VE. However, if the office user does not follow the field user, the VE will be explored from the office user's angle and the background will be shown from the field user's view. The office user will only see the background and the VE that the field user is seeing if both are positioned at the same place. The goal of the project is achieved when both users are sharing the same VE, looking at the same AR view and discussing the best plan for carrying out future works.

Generally, the number of field and office users is not limited by the system. It is possible to share the VE with several field users. With different arrangements on where the data space is created the VE can be spread over the Internet and more office users can be added.

7. Problems and Adjustments

Following Azuma [1] it is possible to list the main sources of static errors such as: distortions in the HMD, mechanical misalignments in the HMD, incorrect viewing parameters and errors in the tracker. Distortions generally happen when the HMD has wide Field-of-View (FoV) displays. The second source of problems can be characterised by poor function of hardware. This project focused on the last two sources of the problems. After calculating the HMD's Vertical FoV some targets were positioned on the ground. All targets were also identified with virtual objects that should be positioned where the real objects was placed. The final result of the calibration is not perfect but the virtual objects are now placed very close to the real targets.

It was also noticed that the field user's view presented a small shifting on the visualisation giving an uncomfortable sensation for the users. The errors in the tracker can be reduced with constant calibration but because of the backpack's frame the soft magnetic field always contributes distortions. The solution adopted was to add a Kalman filter to the system. The filter is well suited to navigation applications, which contain states that are time-variant, even in real-time. It is a recursive algorithm, which filters measurements using knowledge of the system dynamics and the statistical properties of the system measurement errors [7]. The filter works in two phases. The first is the prediction. It starts by estimating the first values that will come from the sensor (state vector) and how much error there is in the values (covariance matrix). The second phase is the measurement update resulting in new estimated values and an updated covariance matrix. Being recursive, the filter is based on the last estimate calculated and the current measurements without the necessity to log data to reprocess.

Figures 4 to 6 show 61 samples of the data related to the magnetic compass, pitch and roll. The dark line represents the raw data from the tilt sensor and the light line the same data after being processed with the Kalman filter. In all cases it is noticeable that the lines of the graphs are now smoothed. The result for the field user is a stabilised image with a small delay only noticeable when the field user makes fast movements with the head, otherwise the delay is almost imperceptible. If the user does not make any movement, the VE visualisation is completely stable.

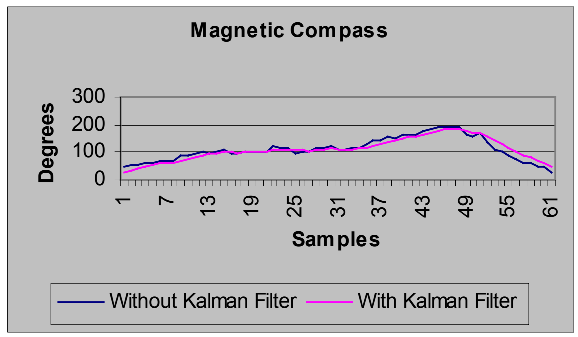

Fig. 4 Magnetic Compass data

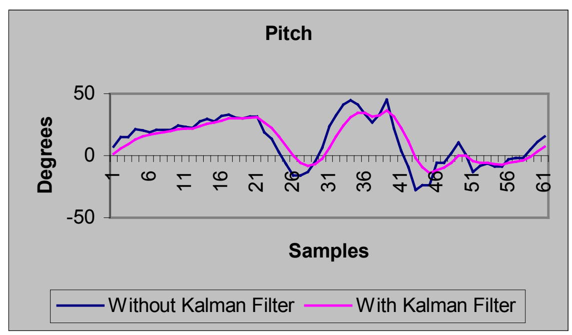

Fig. 5 Pitch data

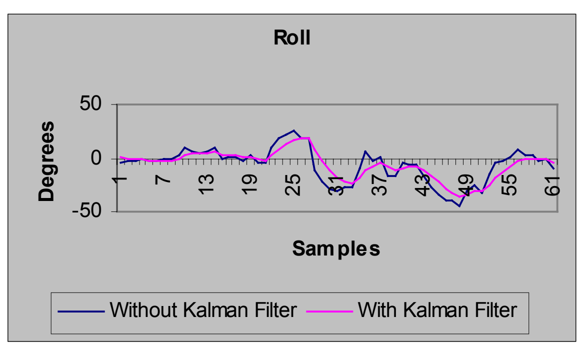

Fig. 6 Roll data

8. Final Experiments and Users Feedback

The final tests were achieved when audio and video started being shared between the users. Office and field users can collaborate with each other on the same VE. The tests were performed inside the University Campus and the users were divided into the following categories: workers in Civil Engineering, technicians and engineers, and people without the skills of the two previous groups. The people interviewed had different ages and knowledge about computers and positioning devices. A questionnaire was offered providing an opportunity for them to express their feeling about the whole project and on some specific points. The questions were directed firstly for the basic concepts of AR, shifting the point when the users finished the experiment with some knowledge about the subject. For the engineers, questions like: "How do you imagine an AR system to be?" sound trivial. Therefore, the answer is always associated with the video option and not with the 5 human senses. Both people, technical and non-technical, responded similarly: "I saw something like this in a movie." or "My son has a video-game that has VR embedded". However, all the people interviewed concluded that the system would be useful for the designated purpose. Workers were asked if the visualisation would help them to understand what the engineers are working towards. The answers were positive and concluded that if the visualisation of their work was shown in parts, many common mistakes related to miscommunication could be avoided. Engineers remarked on the qualities brought by the project, such as the collaboration between the team of engineers and how easily they would express the needs of the construction to the workers. The possibility of changing the VE in real time was also praised by them, bringing about new ideas on how to work in an exciting and dynamic way.
A previous explanation was given for the general public before they started to experiment with the AR visualisation. The results were also positive and they easily understood the basic concepts and how it worked. They enjoyed walking through the VE and looking at panoramic views of the whole environment. Once more they approved of the AR system. New constructions could be better accepted from the beginning if a visualisation of the environment in its final stage had previously been shown.
Most of the complaints were about the weight of the backpack and the crash helmet. The RTK-GPS receiver is heavy and there is also the added weight of the notebook, batteries, cables, antennas and the frame of the backpack. The second complaint is about the update of the position in the VE when the user starts to walk faster. The system is updated by the GPS signal, which has a frequency of one coordinate per second.

9. Conclusion

This paper described 2 years of a workgroup created between IESSG and MRL at the University of Nottingham. The focus was to attend to the needs of people from Civil Engineering using the resources of AR. Nowadays, field and office users can share their experiences and conclusions in order to pursue a reduction of costs and improve the agility of the development.
The project was based on the resources provided by the laboratories. The platforms Equip and Massive-3 were modified several times to attend to the objectives of the project. The result is a fast and well-structured data space able to receive and transmit messages from/to external devices and computers.
The most important point achieved by this work was the feedback from the possible users. The backpack weight will be the first problem to be solved. The RTK-GPS receiver is heavy and expensive. We had been working with hand held equipment, with new techniques to give us enough precision for this kind of system. The real time update for the GPS signal is another problem that is out of our scope. To predict movement does not mean that it is possible to guess a coordinate. The development of the Galileo satellite constellation will push AR projects towards a new phase of discoveries and challenges.
Figure 7 shows the field user wearing the see-through HMD and the tilt sensor on his head and the backpack with the GPS antenna. On his side, an RTK-GPS reference base is placed.

Fig. 7 Field User

Acknowledgments

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