The Use of Augmented Reality, GPS and INS for Subsurface Data Visualisation

Dr. Gethin W. ROBERTS, Andrew EVANS, Prof. Alan H. DODSON, Prof. Bryan DENBY, Simon COOPER and Dr. Robin HOLLANDS, United Kingdom

Key words: Augmented Reality, GPS/INS Integration, Map Visualisation.

ABSTRACT

Augmented Reality (AR) is a technology that allows information stored digitally to be overlaid graphically on views of the real world. A vast amount of such information currently resides in office-based computer systems but is not readily accessible to engineers and managers in the field.

This paper addresses research being undertaken for AR systems that will allow people to *look* into the ground and *see* underground features. These features could be major geological structures, gas or water pipe-work or zones of contaminated land. This ability to view underground features will revolutionise many elements of fieldwork for a wide range of industries involved with the natural and built environment.

Fundamental to the success of such a system is the ability to position the user with respect to the coordinate frame of the geographical database. Without position and orientation, overlaying the data for visualisation is impossible, if the solution is not accurate enough then registration errors will occur which will affect the usefulness of the system. The integration of kinematic GPS and INS allows centimetre level positioning and orientation to be achieved, opening up many applications using this tracker technology based in the field of personal navigation (Ladetto, 2000), (Judd, 1997). One such application researched at the University of Nottingham is the integration of this positioning technology with AR.

The University of Nottingham is directly involved in developing what is known in the field of Augmented Reality as the Tracker Technology. The aim is to develop a modular approach to the solution enabling different grades of achievable accuracy and creating a technology demonstrator effective in a real environment. In terms of the required accuracy, it is envisaged that the highest quality of position and orientation will be achieved through using RTK GPS combined with an IMU utilising gyroscopes, accelerometers and magnetometers.

The paper describes the research underway at the University of Nottingham concerning the integration of RTK GPS and an IMU to allow robust and precise real time positioning and orientation. This data is then used in the AR system to superimpose the virtual image onto the real-world view of the user.

The basic concepts of AR are explained with emphasis on the *tracking technology* required for an effective system. Additionally some applications are discussed considering the different requirements of the positioning and visualisation system.

This work brings together two state of the art technologies, RTK GPS and INS integration combined with Virtual Reality technology, through the collaboration of two research groups at the University of Nottingham.

CONTACT

Dr. Gethin W. Roberts
Institute of Engineering Surveying and Space Geodesy (IESSG)
University of Nottingham
University Park
Nottingham NG7 2RD
UNITED KINGDOM
Tel. + 44 115 951 3933
Fax + 44 115 951 3881
E-mail: Gethin.Roberts@nottingham.ac.uk
Website: http://www.nottingham.ac.uk/iessg

The Use of Augmented Reality, GPS and INS for Subsurface Data Visualisation

Dr. Gethin W. ROBERTS, Andrew EVANS, Prof. Alan H. DODSON, Prof. Bryan DENBY, Simon COOPER and Dr. Robin HOLLANDS, United Kingdom

1 INTRODUCTION

Many utility companies maintain mapping for their subsurface assets. Much of it is paper based or stored digitally. For field use the data is often unreliable and occasionally completely wrong. It sometimes proves difficult to interpret the map data as a field operative and relate it successfully to the real-world view. This can increase the costs in engineering applications where excavation is an important feature. Often test excavations are required to examine existing subsurface assets and ensure the location is indeed known; the digging of trial holes is necessary before full excavation can take place. This adds to the inconvenience and traffic congestion caused by such an exercise and the trial hole is often left open for days or weeks until the main excavation takes place. Even after successful trial excavation it is possible for mistakes to be made, resulting in significant disruption for utility services and in some cases loss of life. A study by the Automobile Association of Great Britain in 1997 put the estimate of street openings for utility companies in the UK, at 4 million per year (Thomson, 2001). This is now believed to be a conservative estimate. An estimate of traffic delay costs conducted in 1994 was put at £1.23-1.65 billion per year, indicating a not unreasonable estimate of £2bn for total social and economic disruption (Thomson, 2001).

Western Power Distribution (UK) claims there are more than 2,000 incidents of damage to their power cables alone, each year. They also state that over the last 10 years in the UK, 86 contractor staff have been killed and more than 3,000 injured by striking live power cables (Thomson, 2001).

In the London borough of Camden, an area of approximately 17 km^2, there were 16,000 street closures for sub-surface work in the year 2000. The majority of excavations are *done blind*, whereby trial holes are used to locate the buried utilities. Recently as part of the Street Works Act (Section 74) it has been agreed that any work involving the opening of streets will cost the utility company involved £500 per day per opening. There is a need to increase the efficiency of Street Works in the UK to which accurate and reliable location of subsurface features would make a significant contribution (DLTR, 2001) (Knowles, 2001).

Surface data presented on maps and associated sub-surface information can be very difficult to visualise. Given strategic points of a buried pipe for example does not necessarily mean that the engineer can easily locate the installation. Assuming that reliable data exists, there is still the issue of map interpretation. Interpretation assumes that the map user is aware of the significance of scale, generalisation, map structure and the symbolic nature of cartographic representation (Keates, 1989). Reference surface features may no longer exist, spatial awareness and visualisation of map features in the real world can be a complex task.

Interaction and interpretation of map data in the real world can be simplified through the use of AR.

2 AUGMENTED REALITY

Augmented Reality is a technology based on virtual reality where virtual data is superimposed onto real life images, resulting in a mixture of the two environments. AR fills the area between the real world and the virtual world. It takes the information features of the virtual world and makes them easily accessible and relevant to the user. AR is not only a visually based system, another medium that is commonly augmented onto reality is the dimension of sound (Roberts, 2000). For example, a visitor at a museum may use headphones that inform him of the displays as he stands in front of each one. An intelligent system would also ask the user how long they intend to spend at the museum in order to calculate how much information to give about each exhibit.

Often AR augments data stored in many media and relays the information to the user dependent on their position in relation to the information source. The research underway at the University of Nottingham concentrates on using map information stored digitally for graphical overlay on views of the real world. A database is used that contains known positional information of the subsurface features. The AR system, knowing the position and orientation of the user can calculate which part of ground he is looking at and relate the database information accordingly. Added information can also be displayed as text or graphically, removing the requirement of continuous referral to a legend, allowing feature attributes to be much more accessible. The system will also allow user interaction to dictate what information should be displayed. This selection is likely to be voice activated and highlights the importance of effective user interaction with the database.

For AR to work in an unprepared environment it is important to have accurate tracking information. The requirement is for the highest quality position and orientation information related to the user with respect to the geographical database that the user intends to visualise. In the UK much of the collected data is referenced to the Ordnance Survey National Grid (OSNG), usually added to existing plans and maps. Thus it is vital that the user position and orientation must be directly related to the mapping frame.

One of the major issues with AR is the accurate registration of the real world objects with the virtual world. AR is capable of achieving pixel accurate registration in real time (Azuma et. al, 1999), although this achievement is limited to indoor, prepared environments. These environments are completely controlled such that the designer decides what exists and where. Traditional AR implementations such as medical visualisation or displaying instructions during manufacturing processes utilise these constraints to their advantage (AIMS, 2001).

The challenge for AR is to achieve accurate tracking and so allow clear registration in unprepared environments. Potential users could benefit from the improved situational awareness, navigation targeting and information selection and retrieval (Azuma et. al, 1999). The latter is addressed by the AR project underway at the University of Nottingham of which the first two benefits are also fundamental to its operation.

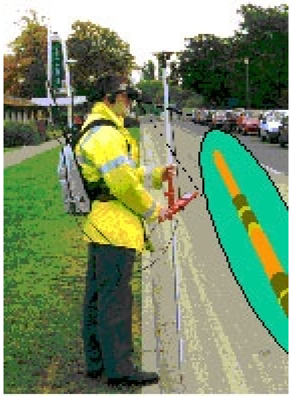

Figure 1 The Outdoor AR Concept

One of the concerns is the method for presenting the data to the user. A number of methods have been examined, the first approach is to use a head-mounted display unit. This allows the user to view the digital information in its exact location on the real-world view (Figure 1). This method is susceptible to latency issues with respect to the system updating the images to cope with user head movement. This can sometimes lead to the user suffering from motion sickness. Another problem for this method is caused by the positioning system requiring placement on the user's head and will cause considerable stress unless the equipment can be miniaturised substantially.

A second approach is to superimpose the virtual image onto an image of the real world and display it on a laptop. Once again this is achieved by using a digital video camera to capture images of the real world. However, in this situation the tracking technology has no requirement to be head mounted, but must of course be directly related to the camera mount to position and orientate the camera view. Establishing the system in this way means that although latency can not be eliminated its effects are greatly reduced, the camera motion will be much less dynamic and more manageable for the system. However, the screen image is difficult to see when operating outdoors, especially in bright sunlight.

The current stage of development employs the concept of *Virtual Binoculars* combining the features of both the HMD solution and the laptop. User comfort is maximised by ensuring that the binoculars are only used for visualisation when the user desires, the display is linked to a laptop so that it is also possible to move away from the head-mounted display and view the images on a laptop, ideal for group situations.

3 GPS/INS INTEGRATION

The standard AR system will produce results based on an uncoupled position and orientation solution taking the output direct from the GPS and INS devices. The modular nature of the design intends to use GPS solutions provided by standalone, DGPS, or RTK GPS dependent on the application, accuracy requirements and available budget. Considering the same factors the choice of INS will use either a digital compass module or a gyro stabilised unit. In all cases it is necessary to provide heading information from a variety of sources due to the nature of the application. It is not possible to rely solely on GPS because the user will be fairly static at the time of system interrogation. An INS unit of gyroscopes and accelerometers also needs some means of initialising heading, augmentation with a 3axis magnetometer compass module provides a good solution.

The position and orientation solution being researched by the IESSG is focussed on achieving the highest possible accuracy whilst still being *affordable*. Different applications require different levels of performance, some examples are shown in Table 1, the project has focussed on the the most demanding application assuming that success in that area will ensure a good solution in the other application areas.

Table 1 Accuracy requirements for potential users of augmented reality for sub surface visualisation.

Application	Required Accuracy (m)	Anticpated Working Range(m)
Ore-body exploration	2	20
Contaminated site investigation	1	20
Visualising Geology	10	100
Mine data visualisation	0.5 / 2	5 / 20
Flood emergency	0.5	100
Subsurface Rescue scenarios	1	50
Location of buried utility services	0.10	5
Visualising cut and fill operations in civil engineering	0.10	10
Planning	1	20
Archaeology	10	10

This project focusses on the higher precision applications and therefore uses RTK GPS for positioning [Roberts et al. 2001]. The GPS receivers used for this project are Leica SR530 RTK capable receivers. The orientation solution is currently taken from a TCM2-50 digital compass. During the research period other devices have been tested such as the Crossbow DMU-AHRS [Roberts et al. 2001].

As the project develops it is intended to integrate the two systems so that solutions are still available to the user in more testing situations for GPS such as urban canyons which will be a problem for the engineering applications concerning cable and pipe location in urban areas.

The prototype system currently works as an uncoupled solution taking the outputs from the GPS receiver and the INS without any filtering. The applications that will first use the AR system will be GPS friendly open environments. Thus the need for any filtering and coupling of the devices should not be necessary to obtain a satisfactory solution. Future plans include a coupled system that will allow effective positioning and orientation in GPS hostile environments, such as urban canyons, and a generally more robust position solution.

4 INTEREFENCE ISSUES

In the interests of portability for the AR system and potentially wear-ability it is necessary to use the smallest antenna available. It is hoped to use an L1/L2 patch antenna, with diameter of 90 mm, designed for aerial applications, Figure 2.

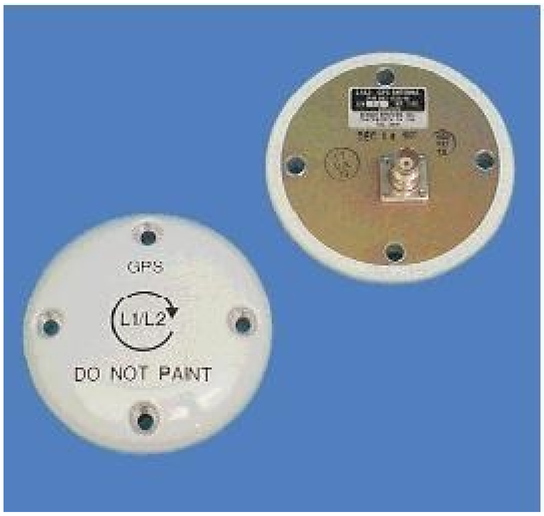

Figure 2 Sensor Systems Patch Antenna

The performance of the patch antenna is excellent [[2]Roberts et al, 2001], degradation of the signals due to multipath is not easy to measure and not of significant worry when compared to the effects of magnetic disturbances and the electromagnetic interference caused by the the proximity of components in the virtual binoculars. The biggest limitation to the highest possible accuracy is the effect of complete loss of lock. Using the patch antenna it was noted that jamming of satellites was occuring resulting in ambiguity resolution becoming almost impossible. The cause of the problem has been highlighted as a shielding problem of the power supply for the video camera. The short term solution of mounting the bulkier Leica AT502 antenna a few centimetres from the source of intereference achieved robust RTK position solutions (Figure 4 (right)).

5 INTEGRATING THE VIRTUAL AND REAL WORLDS

Virtual data quality is a very important factor in a reliable working system. Much of the existing digital data available in the UK is referenced to the existing Ordnance Survey (OS) map data. Thus the position information and the survey data must agree else the system can never work effectively. If there is an offset that is constant then it will be possible to account for it in the field.

The system to date is still in the developmental stage. However the modular design of the project means that it should be possible to interchange positioning devices and visual devices as the application dictates. For example the user may only want a low accuracy system utilising standalone GPS positioning combined with a Head Mounted Display (HMD) that would incorporate a simple 3-axis magnetometer. A higher accuracy application may use dual frequency RTK GPS and an INS that has gyroscopes, accelerometers and magnetometers.

Figure 3 shows the test area that was surveyed by RTK GPS using the Leica SR530 and conventional surveying. Figure 4 shows the development of the equipment. The first trials used a mini camera mounted together with a digital compass unit on a tripod and required manual coordinate input into the AR system. At the working prototype stage the position is provided by RTK GPS coordinates converted to the local coordinate system. The resulting overlaid graphical data on the real-world view is shown in Figure 5.

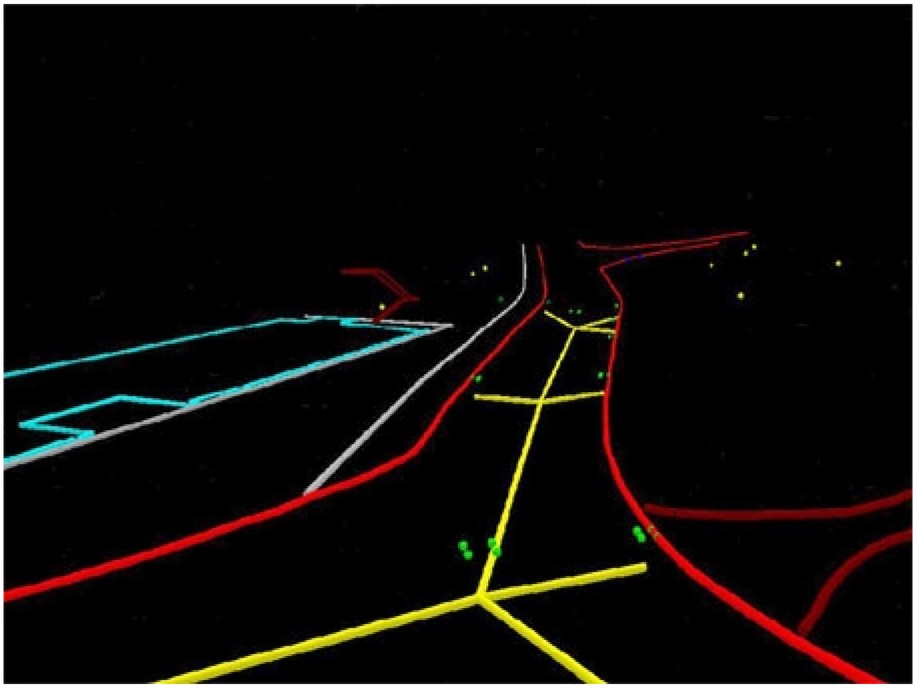

Figure 3 The map data in the virtual world

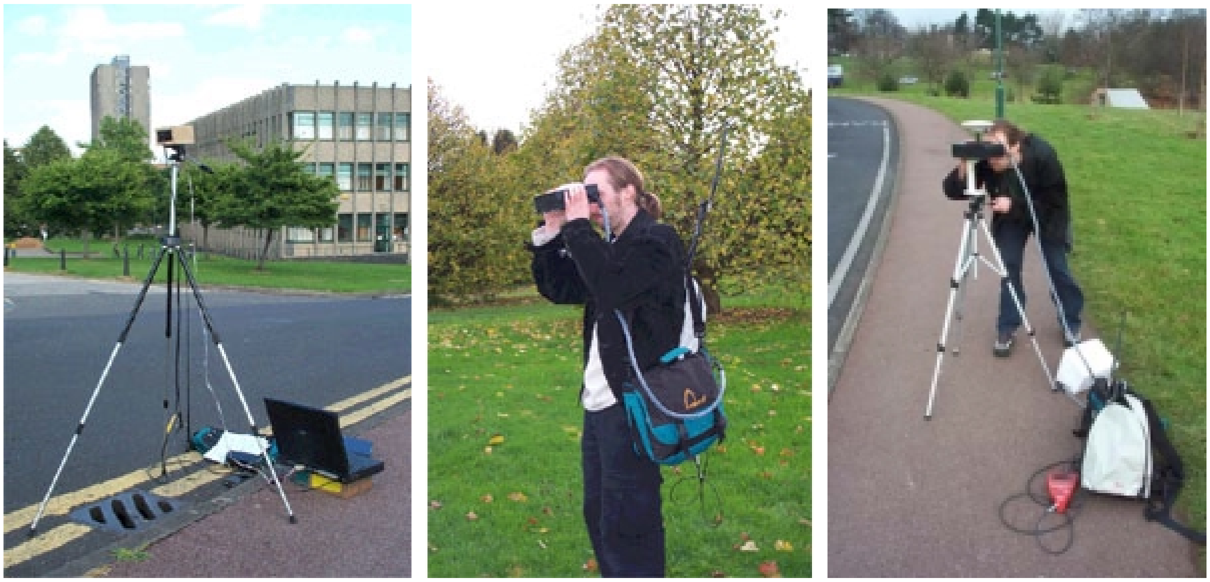

Figure 4 Camera and digital compass unit development. First trials (left), Working prototype (middle), Overcoming EMI problems (right).

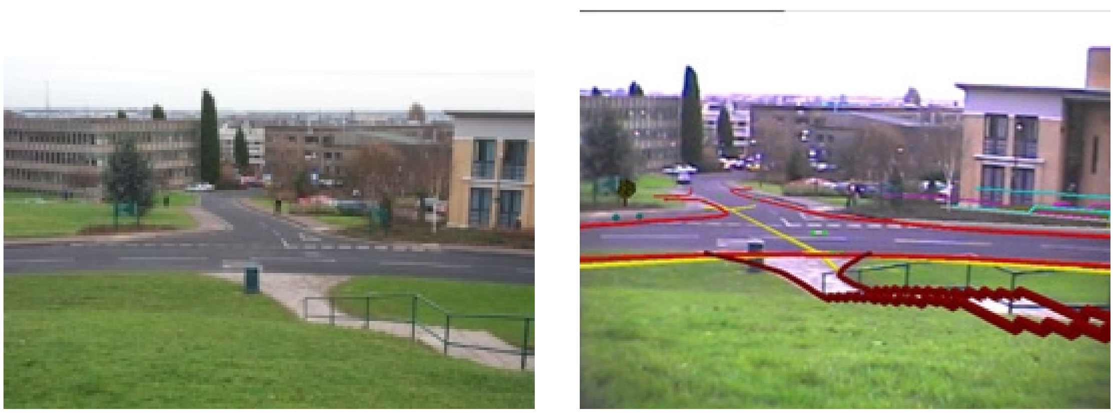

Figure 5 Real world view (left), system view with data overlayed (right).

6 SUB-SURFACE DATA VISUALISATION

Using AR for subsurface visualisation is a very specific application. There are many more applications for such an AR system. The following is a list of some of the possibilities using such technologies:

- Leisure and historical activities; such as the possibility of using the technology for role playing, or Visualising historical buildings as they looked centuries ago;
- Visualising archaeological artefacts;
- Visualising how a proposed structure would look like from a specific location, and assessing the environmental impact of building such a structure;

- Using AR technology in "war games" to simulate the enemy;
- Using AR technology for engineering applications, to visualise data relating to structures that are not visible, usually buried.

As shown the list of possibilities is endless, however, it is obvious that all these applications have a variety of positioning and orientation accuracy requirements. The system developed at the University of Nottingham is modular in nature, and it is proposed that when using the prototype it will be able to interchange various modules, such as incorporating a less precise GPS or orientation device. In addition, visualisation technology is advancing at a quick rate, thus the possibilities of using AR animation in the future is not by any means impossible. The applications then could include AR visualisation of moving objects such as *enemy soldiers*, flow rates in pipes, the animation of flood predictions in situ.

7 CONCLUSIONS

This paper has highlighted some of the issues to consider when bringing together the two technologies of AR and high accuracy positioning for engineering applications. At the end of the defined research period a working prototype will be presented demonstrating the capabilities of these combined state-of-the-art systems.

This is an exciting project in terms of data visualisation with a vast number of applications that could benefit from a refined system. Most importantly the modular design of the system lends itself to meeting the requirements of many different applications and expenditure budgets.

Although the current components used in the prototype make it bulky, miniaturisation will come as the technologies develop. An important aspect to this work is the accuracy of the data to be visualised. The application researched for this paper is concerned with visualising buried pipes and cables. The user can only augment the virtual image where the system shows them to be. Therefore, it is vital that accurate survey data of such features are conducted during installation or through a non-intrusive seismic or ground penetrating radar survey. Else, the user will visualise an image in completely the wrong position; the system is not a pair of x-ray glasses.

ACKNOWLEDGEMENTS

This 24-month R & D project has received a grant under the UK Government's DTI Foresight Link Award Scheme. The Foresight link funds projects with the understanding that the contribution will be matched by sponsorship from industrial partners. Support has been received from Leica Geosystems, Pipeline Integrity International, Rio-Tinto, Nirex, Land Quality Management Ltd, The Minerals Research Organisation and Geotec Surveys Ltd.

REFERENCES

AIMS (2001) VR and Multimedia Training Applications. AIMS Solutions Home page. http://www.aims-solutions.co.uk.

Azuma, R., Lee, J.W., Jiang, B., Park, J., You, S., Neumann, U. (1999). Tracking in unprepared environments for augmented reality systems. Computers & Graphics 23, page 787-793, Elsevier Science Ltd.

DLTR (2001) (Department for Transport, Local Government and the Regions). Street Works: Charges for Occupation of the Highway. Consultation Paper. http://www.roads.dtlr.gov.uk/consult/newroads2/index.htm.

Judd, T. (1997) A personal dead reckoning module. Proc. IONGPS 97.

Keates, J. S. (1989) Cartographic Design and Production. 2nd Edition, Longman Scientific & Technical, ISBN 0-5820-30133-5.

Knowles, N. (2001) Personal communication. Geotec Survey Ltd, Godalming, UK.

Ladetto, Q. (2000) On foot navigation: continuous step calibration using both complementary recursive prediction and adaptive kalman filtering. Proc. IONGPS 2000.

Roberts, C. (2000) Sonic Landscapes. http://www.gmat.unsw.edu.au/snap/new/sonic_demo.htm.

Roberts, G., Evans, A., Dodson, A., Denby, B., Cooper, S & Hollands, R. (2001) Integrating GPS, INS and Augmented Reality for sub-surface visualisation. Proc ION-GPS-01, The 13th International Technical Meeting of the Satellite Division of the Institute of Navigation, Salt Lake City, USA, September.

[2]Roberts G W, Meng X, Dodson A H. (2001) Data Processing and and Multipath Mitigation Approaches for GPS/Accelerometer Based Hybrid Structural Deflection Monitoring System, Proc ION-GPS-01, The 13th International Technical Meeting of the Satellite Division of the Institute of Navigation, Salt Lake City, USA, September.

Thomson, J. (2001) Factors affecting utility installations and the mitigation of disruption in streets. In Proc. Int. Symp. Underground Construction 2001, London, UK.

BIOGRAPHICAL NOTES

Dr. Gethin Wyn Roberts is a lecturer at the IESSG, the University of Nottingham. His research interests include the applications of kinematic GPS and its integration with other sensors.

Andrew Evans is a research associate at the IESSG. He has a BSc in Surveying and Mapping Science (1996) from the University of Newcastle, UK and a PhD in “Long baseline kinematic GPS” (2001) from Nottingham. His current research focuses on using GPS and INS for Augmented Reality.

Prof. Alan Dodson is Director of the IESSG, Dean of the Faculty of Engineering and Deputy Head of the School of Civil Engineering. He has a BSc in Civil Engineering and a PhD in Engineering Geodesy, both from Nottingham. He has extensive research experience in a range of subject areas including physical and space geodesy, and engineering surveying. His main current research interests are the application of the Global Positioning System (GPS) to a range of environmental, engineering and navigation applications. He is also collaborating with IESSG and European colleagues in the development phase of the proposed European satellite navigation system, Galileo. He is president of Section 1 of the International Association of Geodesy and a Fellow of the Royal Institute of Navigation.

Bryan Denby is Professor of Minerals Computing within the School of Chemical, Environmental and Mining Engineering. His research interests lie in the field of Virtual Reality and research activities primarily linked to the application of advanced computer techniques to the minerals sector.

Simon Cooper is a Research Assistant at the University of Nottingham. He has as a BSc in Computer Science with Printing and Photographic Technology and is currently researching hardware and software user interfaces for augmented reality.

Dr Hollands is a Research Fellow in the AIMS Research Unit, University of Nottingham and the Technical Director of AIMS Solutions Ltd. He is primarily responsible for a range of projects developing tools and applications utilising virtual reality for training and visualisation. He is the chairman and founder of the UK Virtual Reality Special Interest Group and author of The Virtual Reality Homebrewer's Handbook.