Generating virtual environments to allow increased access to the built environment

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ABSTRACT

This paper describes the generation of virtual models of the built environment based on control network infrastructures currently utilised in intelligent building applications for such things as lighting, heating and access control. The use of control network architectures facilitates the creation of distributed models that closely mirror both the physical and control properties of the environment. The model of the environment is kept local to the installation which allows the virtual representation of a large building to be decomposed into an interconnecting series of smaller models. This paper describes two methods of interacting with the virtual model, firstly a two dimensional representation that can be used as the basis of a portable navigational device. Secondly an augmented reality called DAMOCLES is described that overlays additional information over a users normal field of view. The provision of virtual environments offers new possibilities in the man-machine interface allows intuitive access to network based services and control functions to a user.

1. INTRODUCTION

The problems of ergonomic access and control are particularly relevant to people with special needs when faced with poor building design and information support. This is highlighted in studies of disabled or elderly people in the community for instance in the 1991 RNIB survey by Bruce et al, 1991 a comparison is made between the level of independent mobility of young registered blind people in 1991 and the level found by Gray and Todd in 1965. It was found that the percentage level of independent mobility had not increased over time in spite of the increase in available mobility training. The difficulties in accessing the built environment are a major factor for this lack of mobility and are common across a broad range of people with special needs:

These issues are being addressed in the EU TIDE (Telematics Initiative for Disabled and Elderly) project ARIADNE "Access, Information and Navigation support in the *Labyrinth* of Large Buildings". ARIADNE is exploiting a new generation of networked intelligent buildings to provide an infrastructure that will enhance accessibility to the built environment. This is achieved through the use of new microwave smart card sensor technology that will allow the building to sense a user is in a particular place in a building and respond in an appropriate way to that users requirements. The smart card readers are networked around the building and can trigger local environment changes in the building or transmit information directly to the user through hand held devices and sophisticated talking signs. The ARIADNE network offers a powerful information and control resource that can be used by user interfaces with different levels of sophistication. More details of the ARIADNE project can be seen in Foster 1998a.

Exploiting networked control technologies as promoted by products such as ARIADNE, it is possible to create a virtual environment that is a mirror of the real environment, a concept promoted by Gelernter 1992. This is possible because the network infrastructure allows the real time passing of information and control commands between the virtual model and the actual environment. This control and information infrastructure ensures that the Virtual Environment remains concurrent with the real world, producing a mirror of the actual environment as can be seen in Figure 1.

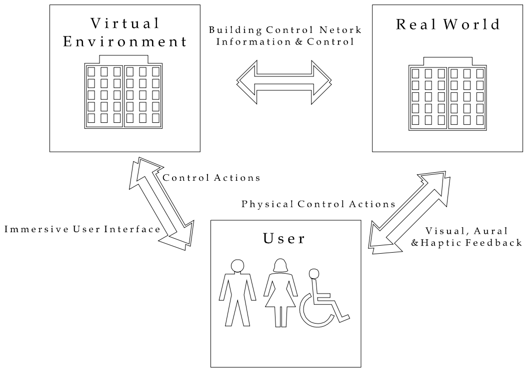

Figure 1. *Interaction either with the Real World or a Virtual Environment.*

The use of a Virtual Environment offers the user an alternative method of interacting with the building. When interacting with the Real World the user has to physically deal with the environment and receives physical feedback from the building itself. Having a virtual model of the environment offers an alternative control route as information contained in the model can be presented in a variety of ways which are tailored to the requirements of the particular user. Through the network infrastructure, control and information can flow seamlessly into the real environment and vice versa. This approach benefits the human user but can also be used to structure the environment of mobile robots within the built environment as presented by O'Hart 1998.

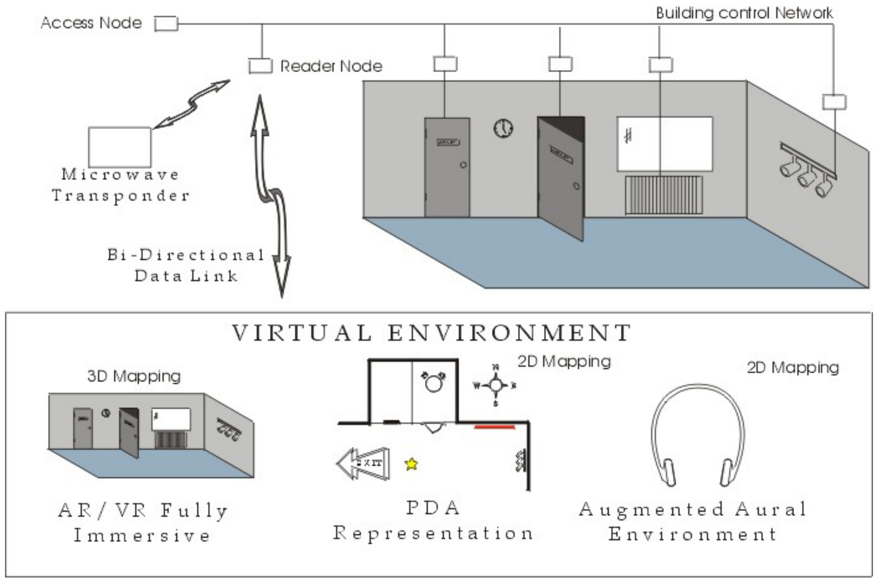

Figure 2. *Obtaining a virtual model of the local environment.*

The underlying concept of this paper is that the model of the environment can be provided by the building itself. The entire building is split down into manageable sections, often rooms and corridors, and the model of the local environment is held locally on the network nodes that are physically installed in the building as can be seen in Figure 2. Moving around the site allows a User with a suitable transponder to extract the local information via a microwave link managed by a Reader Node. Associated with the Reader Node is an Access Node which is a device that holds the virtual representation in a Local Object Model. Once a virtual model is available it can be presented accordingly, two main methods being presented in this paper:

1. **Three Dimensional Mapping using AR/VR Immersive Environments.** A 3D augmented Reality suite called DAMOCLES is presented, the Head Mounted Display (HMD) of which is based on the 'I-Glasses' headset from Virtual I/O Ltd. These have onboard tracking, and are cheap and lightweight but allow the generation of both fully immersive Virtual Environments and semi immersive Augmented Environments that superimpose additional information upon a users normal field of view. This device and associated computer could be made portable by mounting on an electric wheelchair. Original background to this research being presented by the author and Hammond (1996) of an augmented reality designed to interoperate with the control system of a smart house.

2. **Two Dimensional Augmented Aural Environments.** A prototype of a novel navigational tool is described based on an audio based device translates the environments into useful speech facets. The

device contains a compass and pre-recorded sampled speech generation. This device could be the basis of a navigation device for visually impaired people.

2. GENERATING LOCAL MODELS

One of the major problems with the generation of virtual environments is that models quickly become large and unwieldy, this is a particular problem if the VR device is incorporated into a mobile unit. To combat this and to fit the models within the memory constraints of the network infrastructure the entire building model is decomposed into a series of smaller models called Local Object Models (LOM). A more detailed account of Local Modelling techniques can be seen in Foster 1998b. In a typical installation, Reader and Access nodes are placed strategically at 'decision points' within the building. These decision points are the places where routes diverge forcing a user to make a navigational decision.

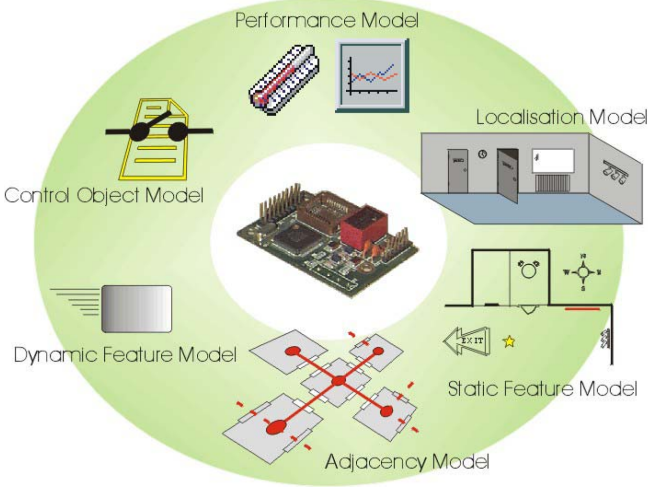

Figure 3. *Model classes within the Local Object Model stored on a network node.*

The Local Object Model can be seen in Figure 3, and is implemented on each Access Node in the ARIADNE network. Contained within the Local Object Model there are several model classes which form a distributed data resource across the network. These can be discussed in more detail:

- **Localisation Model.** The localisation model contains a physical description of the environment local to the node. Generally this is represented using VRML or a Cartesian / Polar 2D mapping.
- **Static Feature Model.** The Static Feature Model contains a list of objects that are not accessible directly through the network but are of interest to a user, for instance telephones, seating areas, toilets etc.

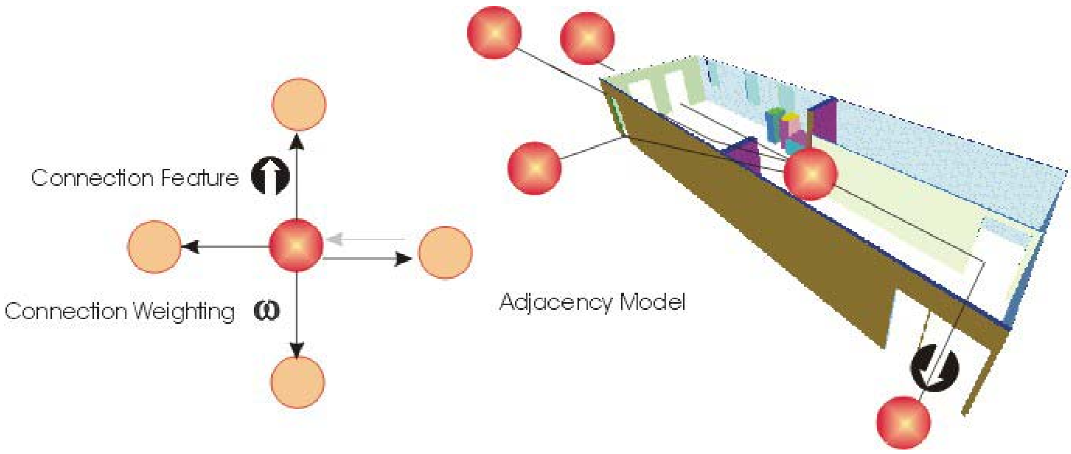

Figure 4. *The Adjacency Model.*

- **Adjacency Model.** The adjacency model represents the navigation links between neighbouring Localisation Models as can be seen in Figure 4. Connections between areas are given a weighting depending on distance and difficulty and the route must be achieved by passing through a connection feature which is typically a door or archway. A holistic view of the entire network produces an interconnecting lattice of adjacency models that provide a navigational map of the building an example being shown in Figure 5. This lattice can be used as a framework for network wide services such as the parallel searching agents as presented by the author in Foster 1997.

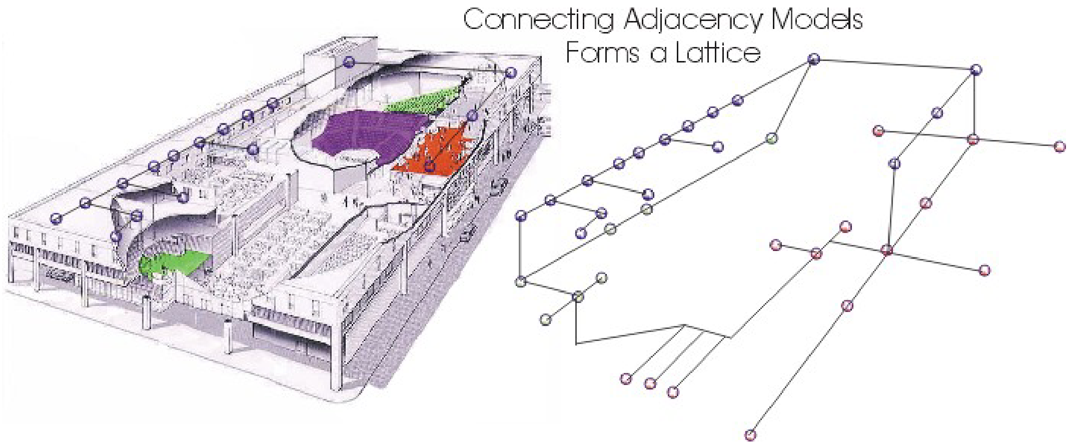

Figure 5. *A navigational topology lattice generated from connected adjacency models.*

- **Control Object Model.** The Control Object Model contains a list of devices that are able to be controlled through the network such as window openers, lights and heating.
- **Performance Model.** The performance model is related to network maintenance and keeps a model of the performance of the control objects in case of sensor or actuator failure.
- **Dynamic Feature Model.** The Dynamic Feature Model keeps a record of the tagged devices that are currently in the local area. This model can be used to perform a network search to locate a particular person or tagged object.

3. INTERPRETING THE VIRTUAL MODEL

3.1 A Navigation Aid Using A 2 Dimensional Environment.

To interpret the virtual model from the building a prototype of a hand held navigational device has been developed. It consists of a small microprocessor, currently a Neuron 3150 device which provides audible output through a ISD 33180 speech chip. This contains up to 180 seconds of analogue sampled audio which can be split up into an arbitrary number of sample segments. The device also has a basic compass facility through the use of a Vector 2X magnetometer from Precision Navigation, which provides bearings with a resolution of 1°.

The virtual model is downloaded to the device via the microwave link. In this case a two dimensional environment can be compactly represented as a set of *n* features **F** local to the decision point in the building. (1).

$$F = \{ f_0, f_1, f_2, ... f_n \} \tag{1}$$

$$f_n = \{ i, \omega, \delta, \phi \} \tag{2}$$

Where a feature f_n contains the following information i an id number that is directly associated to a audible message on the hand held device, ω is the target size of the feature, δ is the distance and ϕ the bearing direction to the feature. (2).

A typical usage scenario can be considered, the user moves around the building until a decision point is reached, at this juncture, being in range of a Reader Node, the hand held device receives the two dimensional local model from the building and alerts the user via a simple buzzer. The user can then place the device into a 'locate' mode via a simple button press. In this mode points the user scans the device around the room, when the bearing from the compass device matches the feature bearing given in the model, that particular feature is announced to the user who then is able to orient themselves at the feature they are pointing towards.

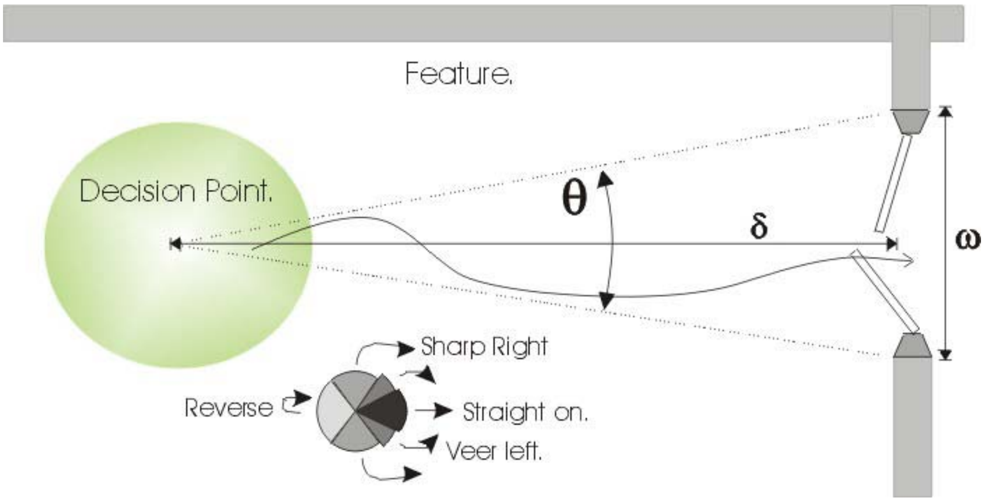

Figure 6. *Taking a bearing from a decision point to a target feature.*

Having located the feature the user can then track towards the object by placing the device into a 'follow' mode. With reference to Figure 6, the bearing to the object is taken via the compass device and the user can set off towards the object. To stay on course the user must stay within an error angle θ in order to reach the goal successfully.

$$\theta = \tan^{-1}(\frac{\omega}{\delta}) \quad (3)$$

The desired error angle is a straightforward calculation (3). If the user continues within that given error angle the destination should be found, however if the user deviates from the bearing simple audible messages are given to nudge the user back on track. A nominal template for this facility can also be seen in Figure 6, where the user is prompted to veer, make a sharp turn or reverse to get back on course. The effects of any errors in following the desired bearing are summative so successive errors can place the user in an unknown position until another decision point is reached. However assuming the user is able to keep more or less on track, it is possible to navigate through the building by travelling from decision point to decision point.

There are some drawbacks to this approach, the major problem is shared with many VR applications and that is tracking the user. The broad area covered by the microwave readers cannot locate the user very accurately, roughly in a 10 metre radius which adds error to the initial starting point for the following mode. This problem can be addressed by using other communication media such as a directed IR link from the ceiling which will locate the user to within roughly a 2 metre radius before initiating the following mode.

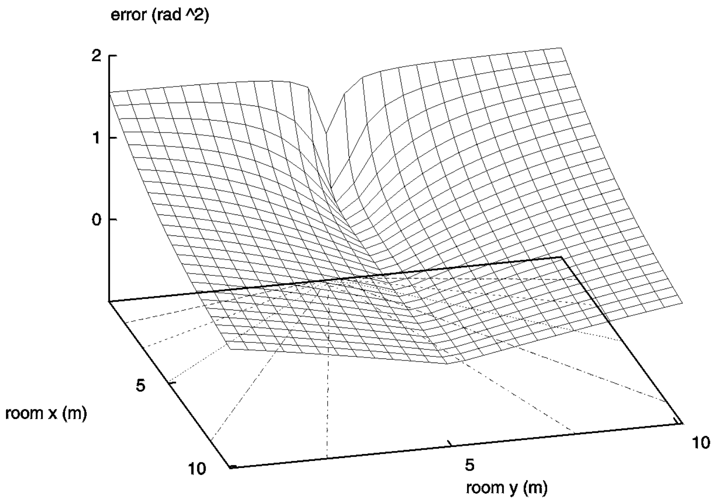

Figure 7. *A surface depicting the bearing error across a 10m×10m room space.*

Using bearings to navigate means that the system is sensitive to positional errors, considering a 10m×10m space with an origin at (10,5) and a target at (0,5) the surface in Figure 7 shows the extent of bearing errors related to position. There is a zero error directly along the bearing between the origin and the location of the target feature. Imagining that the target bearing is to go directly north, when the user is far away from the destination feature the bearing error is tolerable. However this error quickly increases the closer the user is to the destination.

The other drawback with the device as it stands is that the compass is affected by magnetic fields and soft iron within the building, this can mean that magnetometer readings are distorted by metalwork within the building structure, furniture and also magnetic fields from VDUs. The Vector 2X has a built-in hard-iron calibration algorithm. This compensates for magnetic fields generated by a host system such as the housing and electronics. When mounting the compass in the host system, care should be taken to minimize the possible sources of magnetic interference. For instance, mounting screws should be non-ferrous. Unfortunately it is extremely difficult to compensate for dynamic changes in the magnetic field strength. However in practice the device is intended to be used in relatively open areas away from such interference which quickly drops off with distance due to the inverse square law. Another problem with the magnetometer is that it must be kept perfectly level for good results. In order to accurately measure the X and Y components of the magnetic field, the compass needs to be aligned parallel to the surface of the Earth. Typically this is achieved by using a gimbal mount or placing the compass in a bubble of oil allowing gravity to level the compass. Tilting the device gives increasing bearing error per degree of tilt and, due to the Earth's magnetic field, this is an effect that is more pronounced the nearer the magnetic pole the device is used.

3.2 An Immersive 3D Augmented Reality Environment - DAMOCLES.

Another method of representing the virtual models contained on the network is through an immersive 3D environment where the user wears a Head Mounted Display (HMD) and stereoscopic information is produced. An augmented reality overlays image information on the normal field of view of the user much like a head up display. The augmented reality suite presented in this paper is DAMOCLES, so called because the original image used to test the HMD was a large sword which appeared to float above the head of the user.

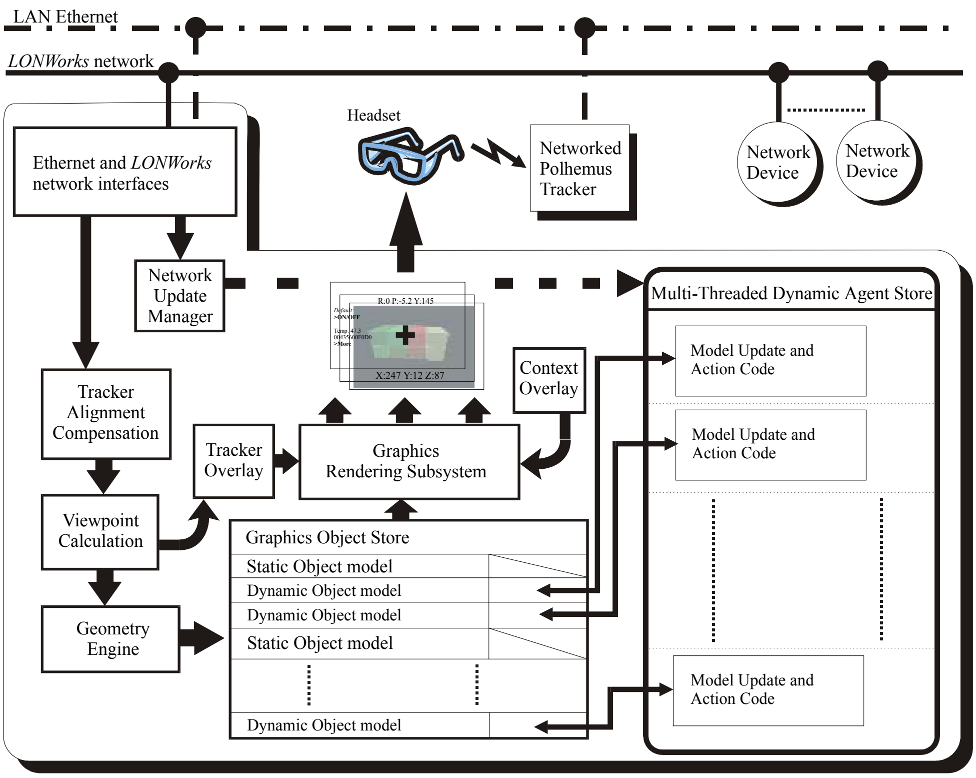

Figure 8. *A block diagram of the DAMOCLES system.*

Augmented reality falls between the two extremes of complete VR and full reality and depending on the system in question there exists a continuum of possible degrees of augmentation that can be offered to the user as discussed by Milgram 1994. This ranges from simple wireframe overlays to full colour enhanced images to present the abstracted display of measured values. A human user is certainly more comfortable with data that only slightly modifies his view of the environment, this approach eliminates the nausea effects often associated with fully immersive environments.

The aim of the DAMOCLES system is to permit a user to be physically present within a real world environment and to obtain enhanced interfaces to a variety of different objects within that world. This is achieved by the use of a stereo-graphic HMD with half silvered optics allowing the user to view overlaid computer generated imagery on the real surroundings. The ultimate goal is to allow a user to freely wander around a built environment in a similar way to the *Touring Machine* proposed by Feiner 1997. However unlike the unidirectional touring machine system DAMOCLES has the requirement for detailed information about devices in the network and the ability to interact with them.

A block diagram of the system is shown in Figure 8. At any point in the network a client computer may be connected, and at the same location a magnetic tracking system is sited, the Polhemus tracker in this case. Given a knowledge of the location of the base point for the tracker the location and orientation of the HMD can be determined. With the current tracking device this is restricted to a radius of 1-2m from the transmitter. There are considerable problems associated with using a magnetic tracker in most locations, not least of which is its spatial calibration to ensure good static accuracy as discussed by Azuma 1995.

Once connected to the network the remote client obtains information from the network about the devices in its location. Unlike the 2D mapping system DAMOCLES uses a more centralised client server architecture rather than a truly distributed approach so the initial transactions are with the central database server. It would be more efficient if all the of the location information could be obtained without referring to the database server. However this would require that the users computer know where it was within the network, and since one of the features of the network is the location transparency of a device, it is simpler to refer to a main database for the initial datum at present. Once the virtual environment is generated it is then displayed upon the HMD with due regard to position and orientation.

Given localisation information from a server DAMOCLES then proceeds to build a graphical model description. The system first takes graphical data from a device constructing an object within the virtual part of the AR. Attached to each device is a description of the dynamic behaviour of that object. This takes the form of code modules or agents that act upon the model description within the AR. If the construction of the object within the virtual world is complicated because of regular changes to the device, then instead the code module contains all the information required to construct a simulacrum of the device, these two scenarios are shown in Figure 9.

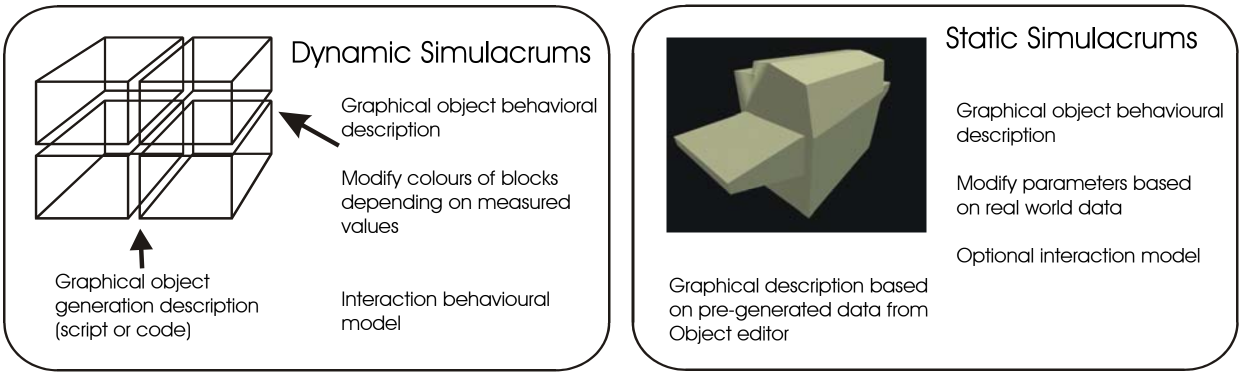

Figure 9. *Graphical object model derivation*

Both OpenGL and DirectX rendering libraries have been used, currently the latter has been selected due to performance considerations on the PCs and the option to easily implement high speed stereoscopic rendering. The choice of rendering system has an influence upon the type of graphical models that can be stored. If fast and efficient model transfer is to take place, size and complexity is dependant on the graphics library being used. Since the models are to be stored on the devices themselves then they must be as compact as possible whilst still conveying the required detail.

After the localised world has been generated from the Local Object Models in each of the nodes in the area interaction can then occur between the user and any devices that support external stimulation via the Local Object Model. Two forms of object update relevant for display purposes may occur. Firstly, changes in the physical world sensed and supplied by a device will entail changes in the graphical object within the virtual part of the augmented reality, for instance doors opening will require angular transformations of their simulacrums. Secondly, multimodal data sets require abstracted information to be generated and displayed. Depending on the type of the measured parameter this can be quite complex. For example displaying a colour representation of black body temperature requires translation into a suitable range and then mapping to some colour. In both cases the modification to the graphical object is handled by a software agent running in a separate thread within the virtual world. The source of this code is either a system database or from the device itself. By breaking the overall system down into compact discrete objects the size of model update agents is small, and the virtual environment does not have to deal with a flood of information trying to update thousands of objects.

When using a mirror world any device in the network that has an actuator attached to it can be controlled, this introduces a number of issues. Safety must be considered, particularly if the users interactions could harm other people or cause the controlled object to go out of limits. Concurrency problems occur when the users requests conflict with the control algorithms already operating within the device. Concurrency is also an issue when multiple users may be interacting with the model and the actual device leading to issues of prioritising control. At the present time restrictions have not been imposed upon what a user of DAMOCLES can do to the controlled environment but there is provision within the existing agent control framework to add priority management and process limiting features.

DAMOCLES was designed to operate with a diverse range of networked devices. Consequently an interaction method that is consistent for all objects has been implemented by using a context sensitive linguistic paradigm. A method whereby each dynamic code agent implements a default verb specific to that device. For instance an electric window opener has a default reflective action that is to open or to close. Highlighting a selected window object within the users field of view selects that device, a button press then invokes the default verb for the object, and in this case the window opens. More complex verb sets are accommodated in the software by permitting a selection to linger on the object, after a delay a list of available actions is presented to the user via the HMD. A consistent approach has been presented to the user that is easily understood whilst allowing flexibility for more complex functions to be implemented.

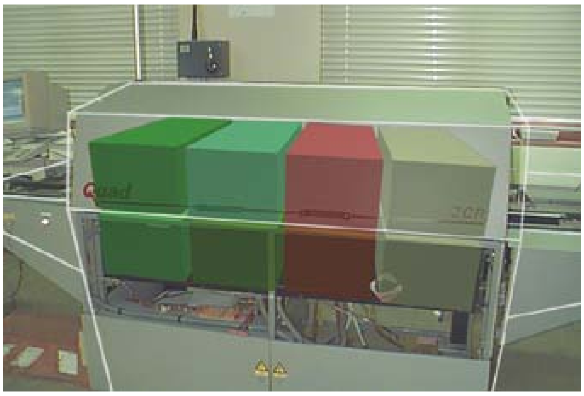

Figure 10. *An AR snapshot of heated zones in an oven.*

Figure 11. *Wearing the DAMOCLES HMD.*

A snapshot of the augmented reality system can be seen in Figure 10, here the system is installed in the Distributed Systems Research Lab. Looking at the network controlled machinery in the lab displays the state of that equipment. Figure 10 showing an oven which has various heated zones with temperatures displayed in a suitable colour. In this case the third zone from the left is actually coloured red, indicating a high temperature being detected by the networked node controlling the device. Note some static registration errors on the wireframe overlay, a result of tracker calibration.

Figure 11 shows a picture of the DAMOCLES HMD in action, the Polhemus tracker is visible mounted above the head of the user. This picture has actually been enhanced with DAMOCLES highlighting of control features, in this case the wooden framed glass door in the background is actually highlighted as a controllable network object.

4. CONCLUSIONS

This paper has presented the use of networked building control systems as an infrastructure to support distributed virtual environments. Two methods of interacting with these distributed models have been discussed, the first being a prototype of a hand held navigational device which could be used by a person with visual impairments as an orientation and navigation device. This device shows considerable potential although there are some basic problems associated with the use of a compass within a building.

The second system presented is the DAMOCLES augmented reality system that offers a novel method of controlling devices within the built environment. The system augments the normal field of view of a user by superimposing additional information derived from the network, and controllable objects can be selected and activated simply by the act of looking at them. Presently the system is a laboratory prototype and considerable development is required before it could be a truly portable device.

5. REFERENCES

R.T. Azuma (1995) "Predictive Tracking for Augmented Reality", PhD dissertation UNC Chapel Hill Dept. of Computer Science technical report TR95-007.

I Bruce, A McKennell and E Walker (1991) *Blind and partially sighted adults in Britain: the RNIB survey*, Volume 1, Published by HMSO

S. Feiner, B. MacIntyre & T. Hollerer, (1997) "A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment", *Proc. ISWC '97,* Cambridge, MA, pp. 74-81.

G.T.Foster & J.P.N. Glover. (1997). Supporting Navigation Services Within Intelligent Buildings. *Proceedings of the First Mobinet Symposium.* Athens.

G.T. Foster, D.E.N. Wenn & J.P.N. Glover. (1998a) ARIADNE - Exploiting a new generation of Intelligent Buildings. In *Improving the Quality of Life For The European Citizen. Technology For Inclusive Design and Equality.* pp 388-391. Porrero & Ballabio (eds.) pub. IOS Press 1998.

G.T. Foster. (1998b) "*The use of local modelling techniques to facilitate information and resource management schemes in distributed control systems*." PhD thesis. University of Reading.

D. Gelernter (1992) "*Mirror Worlds*" pub. Oxford University Press. ISBN 0-19-507906.

Gray & Todd.(1967) *Mobility and Reading Habits of the Blind*, Published by HMSO

J.C.Hammond, P.M. Sharkey & G.T. Foster (1996) "Integrating Augmented Reality With Home Systems" *Proc. 1st European Conference on Disability, Virtual Reality and Associated Technologies.* ECDVRAT, Maidenhead, UK, 1996.

P. Milgram & F. Kishino (1994) "A taxonomy of mixed reality visual displays", *IEICE (Institute of Electronics, Information and Communication Engineers) Transactions on Information and Systems*, Special issue on Networked Reality, December.

F.J. O'Hart & G.T. Foster.(1998) "Creating dynamic mobile robot environments from an intelligent building" Proc. *Third European Robotics and Intelligent Systems and Control Conference EURISCON.* Athens, June 1998.