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The role of virtual reality in planning and designing underground stations

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Abstract

With the evolution of Virtual Reality Technology at an ever increasing rate it is now possible to model complex systems with an increased level of detail and accuracy which has not been easily achieved before . Although virtual reality is still a research and development tool its applications in the commercial world are far reaching , these have been clearly demonstrated by the enormous media attention and commercial interest in recent virtual reality exhibitions . The CrossRail project team and London Underground Limited have embarked on a programme to develop virtual reality models to enhance existing models to assist with future station planning , design and evacuation. The purpose of the paper is to describe the research and development of virtual reality model to visualise and simulate station architecture and passenger flows within a rail transport environment . There is a vested interest in the Mass Transit Industry such as London Underground's to understand the complex passenger flow and behavioural issues to enable good station design Current models used to model passenger movements in a rail station , model passenger flows at an aggregate level and does not incorporate behavioural characteristics in detail . Virtual reality offers a new approach to passenger flow modelling to be pioneered . Passengers can now be modelled individually and exhibit behavioural characteristics . In addition the model can be visualised in three dimensions in a 'life-like' environment to improve the users level of perception of passenger flows in confined spaces . A conventional model is only as good as the mathematics being applied to it , the results it generates are therefore controlled by the mathematics the modeller knows how to apply . Unlike conventional passenger flow modelling , treating human beings as 'ball-bearings' or as a fluid , Virtual Reality breaks the whole world down into individual elements - humans , walls , trains , escalators , fire , smoke etc. - each with its own characteristics , displaying its own consistent influences on and reactions to one another . The familiar Laws of Dynamics and other mathematical equations should then be easily recognised . One of the huge challenges is the simulation of the human thinking process which dictates human decision making , sensitivity to environments and changes .

1. Introduction

Many believe Virtual Reality to be the most sophisticated simulation and visualisation software that exist today . Recent marketing has mainly concentrated on the promotional aspects perhaps not communicating the more serious applications . Most have automatically linked virtual reality with the computer games and leisure markets (Traherne[1]) . However serious research and development is underway in most industrial sectors ; defence , medical , education and transport (Roberts[2],Ernshaw[3],Gannon[4]). Forward thinking companies have realised that there are potential benefits of applying virtual reality to their particular industry and have invested at an early stage . Despite the media hype and excitement there is one fact to bear in mind at the present time . Virtual reality is still considered to be a research and development tool . It is not yet possible to buy 'off-the-shelf' applications , requiring software to be developed in-house or externally .

The application of virtual reality in rail transport is still in its infancy with few published articles . To date rail transport applications developed include ; Computer Based Training (CBT) (Lewell[5]) , Egress Analysis and Visualisation (Duke[6]) . Further uses identified include ; Station Planning , New station design , Rolling Stock design , Accessing Station Standards & Evacuation (Gannon[4]) . In a rail transport environment virtual reality can be considered to be a logical extensions to current simulation/visualisation methods currently employed (Gannon[4]) and not an expensive alternative . The immediate advantage that it has over Computer Aided Design (CAD) being that the user can interact and immerse themselves within the virtual environment/world (i.e. design of new underground stations). In addition to its visualisation capabilities objects can be given intelligence and behavioural characteristics within the environment (i.e. passengers moving) , allowing for more realistic modelling of 'real-life' situations in 3 dimensions , hence virtual reality .

The aim of the paper is to demonstrate the role of virtual reality within a rail transport environment focusing on its visualisation , immersion and interaction capabilities . Highlighting the advantage of virtual reality when compared to current modelling techniques (i.e. 2/3D CAD and physical models). Such uses illustrate virtual reality as a Visualisation tool and as a Passenger Flow/Egress Analysis tool . Current research and development is being carried out by both London Underground Limited (LUL) and the CrossRail Project Team (Crossrail) to develop models to help plan and design current and future underground stations .

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2. Overview of Virtual Reality Systems

There are a limited number of virtual reality systems currently available ranging from PC DOS based systems to UNIX workstations . LUL and CrossRail have both invested in a PC DOS based desktop virtual reality system , with an incremental cost of around £7,000 (i.e. additional hardware and software) . Although it is widely understood that software development is restricted on a 486/66Mhz PC platform it is intended to port models to a higher order UNIX based workstation , taking advantage of the parallel processing architecture for more intensive applications . An overview of the basic software , hardware and sensors required for a desktop virtual reality system and details of full immersion hardware are given below.

Hardware & software

The PC DOS based 486/66Mhz system requires a SPEA 860 graphics card and typically 16Mb RAM to achieve a suitable performance . Two types of virtual reality software are available for application development ; a library of 'C' routines or an interactively based system .

Desktop and Full Immersion sensors

Interaction between the user and the system being by means of two hardware sensors ; a spaceball and mouse . The spaceball (as shown in figure (1)) allows the user to navigate virtual worlds in 3 dimensions (i.e. yaw , pitch and roll) . The mouse cursors function is to allow the user to select objects within the virtual environment allowing user interaction . The degree of immersion is a function of the interface between the user and the computer . It is widely accepted that for full immersion , a Head Mounted Display (HMD) is worn by the user giving the illusion of being within the virtual environment/world .

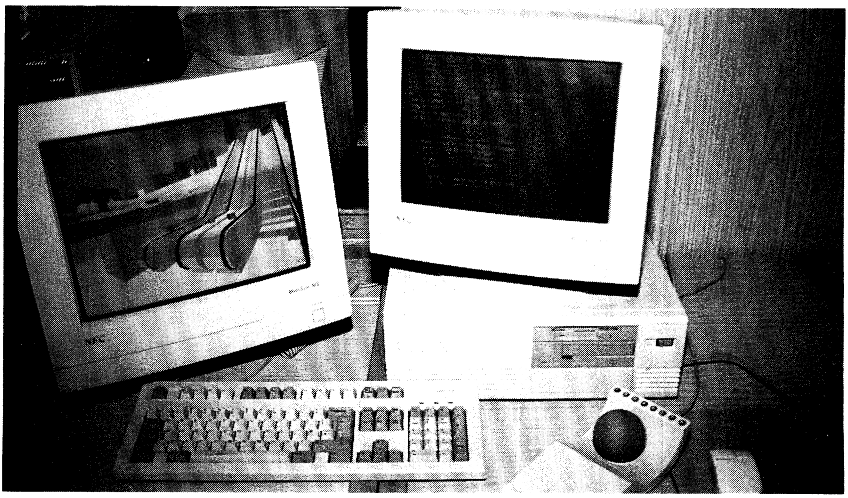

Figure 1 : Virtual reality hardware .

3. Virtual reality used to visualise underground stations

A project the size of CrossRail has the potential turnover of many thousands of drawings during the planning and design phase , most of them in two dimensions . Engineers and architects are faced with the daunting task of piecing drawings together like pieces of jigsaw to make some sense of the final design. During that process it is always possible that details are overlooked or even misinterpreted (i.e. 2D designs clashes are difficult to identify) . Not everyone is blessed with the ability to create 3D images accurately in his/her mind from an abundance of 2D information. It is not a natural transformation to represent 3 dimensional images in 2 dimensions . Someway to aiding 2D interpretation has been the use of axonometric drawings to accompany 2D designs . However , the construction industry still creates drawings in the traditional way (i.e. in 2D CAD or even on the drawing board) . Industry has been reluctant to transfer from 2 to 3 dimensions due a combination of reasons ; lack of experienced 3D CAD modellers available , the time that it would take and the cost involved . It is a 'Catch-22' situation .

One of the many capabilities of virtual reality being a visualisation tool , allows 3D images to be displayed and instantly rendered . Both LUL and Crossrail have developed 'Architectural' virtual reality models of current and future underground stations . Figure (2) illustrates an 'architectural' model of an LUL station . The user can navigate through the virtual 'station' by means of a spaceball and interact with objects (i.e. lifts , escalators) within the world by means of the mouse cursor . The models contain most architectural features of a stations (i.e. Ticket halls , booking offices) as well as Mechanical and Electrical (M&E) elements like Automatic Fare Collection (AFC) gates, lifts and escalators . A completed model can be used for a variety of purposes ; as a Public Relations tool , training tool for operators or fire fighters or simply just for trying out new designs . If more realism is required within the model , objects within the virtual world can have photographic images placed on them , allowing for more realism .

Comparing 2/3D CAD, physical models and virtual reality models .

A quantitative comparison between 3D CAD and Virtual Reality cannot be easily made due to the rarity of 3D CAD information , as mentioned . However , the advantages of using virtual reality in design becomes more prominent after the object building stage. For both 3D CAD and a basic virtual reality model (i.e. stationary model) a 3D image is required . A virtual reality stationary model is built from an exported 3D CAD file (i.e. data exchange file) . Whilst CAD images , physical and virtual reality models all assist in the visualisation process and aid perception , virtual models offer all the benefits of 2/3D CAD and physical models . Table (1) illustrates by category the qualitative benefits that are achievable when using a virtual reality modelling approach .

Table 1. Comparing 2/3D CAD , physical and virtual reality models.

Category	2D CAD	3D CAD	Physical Model	Virtual Reality
Labour Cost	Low	Medium	High	Medium
Interactiveness	No	No	No	Yes
Detail Inspection	No	Yes	No	Yes
View Flexibility	No	No	Yes	Yes
Full Immersion	No	No	No	Yes
Instant Rendering	No	No	N/A	Yes
Object Intelligence	No	No	No	Yes
Object Motion	No	No	No	Yes
Design Clashes	High	Medium	Medium	Low
Understandibility	Low	Medium	Medium	High

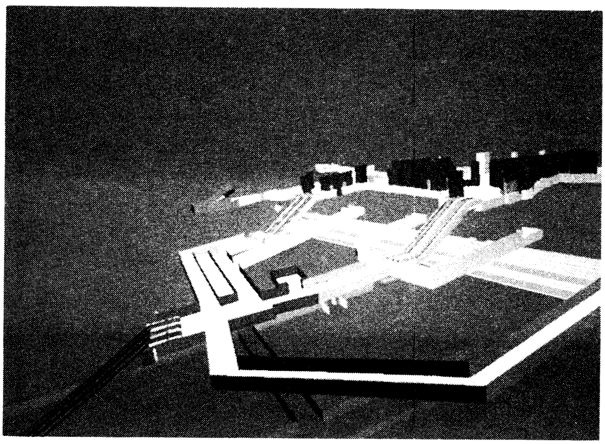

Figure 2 : A virtual reality architectural model of an LUL station .

4. Virtual reality used for passenger flow / egress modelling

To date most software written to simulate passenger flows has been at an aggregate level . The technique engaged by most of the commercial software packages is more than likely to be purely mathematical (i.e. differential equations) or queue based with little or no hints of human behaviour being considered at all , especially the interaction and communication between objects

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. To date passengers have been modelled as if they were "Ball bearings" or batches in an "Assembly line " . Human behaviour cannot be ignored when dealing with passenger flow or egress analysis simply because people do not always behave in an orderly manner , they do interact and communicate with each other. Bearing these facts in mind it is inevitable that new approaches passenger flow and egress modelling using virtual reality have been pioneered . The analysis has become more object based and the approach is from "first principles" rather than mathematical equations. For example, the speed of a person walking is determined by how "urgent" it is for him/her to get to their destination and whether there are obstructions in their way or any other physical restrictions. In a Virtual World, the "passengers" are able to interact with other elements such as fire, smoke, alarm, P.A. System, personnel, fire fighters or even between one another. These aspects of flow modelling have not been able to be considered or incorporated in passenger flow models until now. CrossRail and LUL have both started to research and develop virtual reality passenger flow and egress models to be used as a tool in support of new Underground designs , exploiting the object based capabilities of virtual reality .

Features of the models

An overview of both models is given below focusing on the features of the model . Both models contain similar elements with the exception that the egress model contains elements naturally relating to catastrophic circumstances (i.e. fire) . Though humans have been known to be unpredictable under certain circumstances an order within the chaos that humans display can be identified . It is from this predictable outcome that the basic rules that govern the human action are derived . Armed with such knowledge , a model that produces acceptable spectra of results can be built that better approximates the true situation . Virtual Reality has enabled the simulation of fire and smoke to a degree that allows different scenarios to be tested. Although no one is claiming that virtual reality can be used to predict a potential disaster accurately, it on the other hand can provide vital insight to a fire danger so that correct measures of fire engineering can be incorporated in designs.

The station .

The station through which the passengers move is represented in 3 dimensions to scale (i.e. one to one) . This is either taken from a 2D file extruded to 3 dimensions on a CAD system and exported in '.dxf' format or built from scratch , refer to section (3) .

Passenger objects and mixed ability

Passengers on an underground system consist of people with mixed ability and physical attributes. In both models passengers are represented by 3 dimensional dynamic objects (i.e. one to one scale). The dimensions of which are derived from anthropomorphic data of different groups (i.e. British male , female etc.) ,

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which is used to generate the spectrum of typical passengers on the underground system. Mixed physical abilities of passengers are simulated by specifying varying maximum speed attainable and also different lung capacity for each individual (i.e. for egress) .

Routing , way finding and decision making

Each passenger has an objective and moves on a route , that varies , within the station to achieve this . The basic general chain of thoughts of a human with an objective and the associated action are largely controlled by three main parameters known as Objective, Motivation and Constraint (Still[7]). Also to be taken into consideration is the factor which changes the objective and/or motivation called triggers/stimulants (i.e. smoke, fire, alarm, signs, PA announcement and other passengers).

In a way finding exercise, a virtual passenger being "instructed" to look for their first objective/exit point. Approaching the first objective, the next set of instructions would be passed on to the virtual human ready for them to act upon. Therefore, the instructions are always one step ahead of the actions, all logically set out like a tree diagram. At all stages, the decision whether to respond, change or ignore the instruction is also affected by the interaction of the virtual passenger to other objects. With such in-built flexibility the precise outcome of such an analysis is often quite unpredictable and varies from one analysis to another .

Flocking

A phenomenon displayed by human, and animals, when they are in a group with all sharing the same objective and doing the same action. Each individual has some influence on the surrounding individuals. Therefore a certain action instigated by an individual can cascade down from one end of the group to the other with a domino effect or spread like concentric ripples in a pond. This effect is particularly apparent when there is a bottleneck in the system and the effect of an individual who decides to turn round and take alternative route can be observed.

Triggers

A trigger can affect/change the objectives and motivation of many passengers. It takes the form of an announcement, fire, smoke, alarm, other passengers etc. Each virtual human should be built to react to triggers such as those mentioned. However, there should be a degree of randomness amongst the virtual humans in the time taken to react to a certain trigger because in real life not everyone reacts to a trigger simultaneously.

Model outputs
The models can both be visualised in real-time - showing the movements of passengers through the station . In addition to the graphical visualisation , performance statistics are collected . Typical statistics from the passenger flow model include ; the throughput of passengers , queue sizes and delays . The egress model is mainly concerned with the time taken to evacuate a station and the number of fatalities .

Calibration
Eventually the fully developed model will be used to study passenger flows and egress analysis . The egress model involving elements of threats like smoke and fire. This exercise will then form part of a Quantitative Risk Analysis (QRA) in any building design. To reach the point where the technique is acceptable for such use, rigorous calibration exercises must be carried out . Video recordings of passenger flows are being analysed to understand the behavioural characteristics of passengers moving within a station . This information is useful for adjusting parameters involved in decision making and speed of travel.

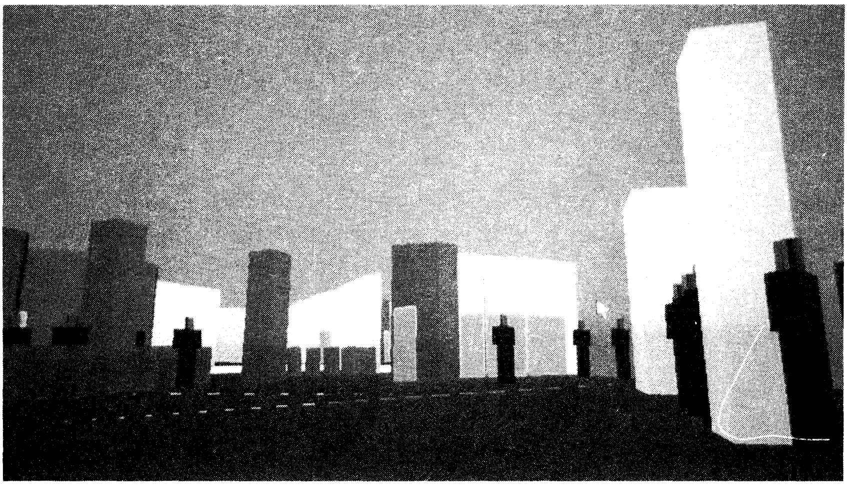

Figure 3 : The passenger flow virtual reality model

5. Conclusion

This paper has demonstrated research and developments being carried out by London Underground Limited and the CrossRail Project Team using virtual reality. The key advantages that this new technology has over existing modelling techniques being interaction and immersion . A virtual reality system can be introduced into a company at a relatively low cost incremental cost (around £7,000) . A company can then start to develop their own applications

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and explore the possibilities within their own organisation . This new and exciting technology has enabled new ways of modelling and data representation to be pioneered . Information can be displayed in ways never achieved before allowing user interaction and immersion.

This new technology has enabled existing CAD information to not only be used but enhanced , therefore making virtual reality a logical extension to existing project practices and not an expensive alternative . Companies that have made the move from 2D CAD to using virtual reality models are making a quantum leap in terms of visualising designs and aiding perception . In addition virtual reality has been successfully applied to passenger flow and egress modelling enforcing new modelling approaches to be pioneered .

Potential future developments in Rail Transport include : enhancing existing passenger flow/egress and visualisation models ; a public relations tool for the consultation of future railway extensions ; pioneering a virtual reality information system (VRIS) enabling the information of various disciplines to be centralised . Although , virtual reality in most companies are still at the research and development stage - the limits are boundless !.

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