Virtual Environments for Scene of Crime Reconstruction and Analysis

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ABSTRACT

This paper describes research conducted in collaboration with Greater Manchester Police (United Kingdom), to evaluate the utility of Virtual Environments for scene of crime analysis, forensic investigation, and law enforcement briefing and training. We present an illustrated case study of the construction of a high-fidelity virtual environment, intended to match a particular real-life crime scene as closely as possible. We describe and evaluate the combination of several approaches including: the use of the the Manchester Scene Description Language for constructing complex geometrical models; the application of a radiosity rendering algorithm with several novel features based on human perceptual considerations; texture extraction from forensic photography; and experiments with interactive walkthroughs and large-screen stereoscopic display of the virtual environment implemented using the MAVERIK system. We also discuss the potential applications of Virtual Environment techniques in the Law Enforcement and Forensic communities.

Keywords: Virtual environments, computer graphics, radiosity, scene of crime reconstruction, MAVERIK

1. INTRODUCTION

Because they are ephemeral, scenes of crime present difficult data visualization problems. In all but the most exceptional circumstances, a scene must be examined quickly, and then returned to its original state. This poses enormous problems for investigating officers and forensic examiners, who wish to record as much information as possible at a scene, for subsequent analysis. This typically involves making detailed on-site measurements, and the use of conventional and video photography. Subsequently, investigators create scale drawings of the scene, and sometimes physical models.

In recent years improvements in technology have led to an interest in creating computer graphics simulations of scenes of crime. This approach offers several advantages over traditional methods. These include creating accurate views of the scene from any position (including those which could not be achieved by a photographer), interactive editing, and combining forensic photography with the computer model.

To date, most crime scene simulation/reconstruction systems provide adjustable 3D views of CAD models, rendered using standard local illumination techniques. While such systems can be of substantial benefit to investigators, they are not primarily concerned with creating reconstructions that attempt to be realistic.

The Advanced Interfaces Group has been collaborating with officers from Greater Manchester Police (GMP) since 1995, and more recently also with forensic scientists, in the study of potential uses of Virtual Environments (VEs) for analysis, briefing and explanation of data collected at the scene of a crime. One particular interest is the exploration of the use of VEs which are highly realistic, in terms of their geometry, and the visual quality of the rendered images.

In this paper we describe the construction and rendering of a large and detailed VE model of a garage complex using information derived from architectural floor plans, in conjunction with photographs of the actual scene. The garage was the scene of a crime, and the VE contains a wealth of detail, such as the physical layout of the whole garage, of the offices where the crime took place, and features such as blood stains on surfaces, captured with forensic photography.

The VE was constructed with a number of tools developed locally, together with the 3D scene modelling language MSDL. [1] Geometry was estimated and surface details were extracted from scanned images, captured from photographs provided by GMP, and the VE was then illuminated using the VRAD radiosity system developed within our research group. [2–5] It is possible to interactively explore the environment, using walk-through software built with the MAVERIK system. [6] The views are dynamically displayed to multiple participants using a large-screen stereoscopic projection facility. The model also includes a photographic gallery: several scanned forensic photographs of the scene have been placed within the VE at the approximately

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correct camera locations, making it possible to compare directly the pictures of the real scene with the corresponding synthetic views in the VE. The facility to generate arbitrary views from the VE leads to an understanding of the scene which is unobtainable from the photographs alone.

2. MODELLING THE SCENE OF CRIME

The case study undertaken in collaboration with GMP involved the graphical reconstruction of a crime scene. The crime under study took place in a garage, a complex environment containing large amounts of geometric and textural detail.

GMP provided an accurate floor plan of the garage premises, which had been drawn up by the scene of crime investigators. The creation of such floor plans is standard procedure in serious crime investigations of this kind. Also supplied was a set of forensic photographs. Some photographs presented overviews of the different rooms which comprised the garage: typically each room would be photographed from the corners inwards, thereby providing a reasonably complete coverage of the scene contents. Other photographs focussed upon the immediate environment of the crime itself, giving a detailed record of body arrangements, blood distribution and the locations of nearby objects. Uncalibrated cameras were used for the photographic work: no information was provided regarding precise camera locations, optical properties or exposure settings. However, some photographs contained police rulers, which had been placed in the scene in order to impart a sense of scale.

A police video of the crime scene was also made available, which included panning shots and some limited scene walkthroughs. Although this was not used as a source during the production of the graphics model, it afforded a useful means of evaluating the finished scene reconstruction.

The locally developed Manchester Scene Description Language (MSDL) was used to represent the graphics model. [1] This is a textual scene description language similar to VRML and other widely available model formats. Several factors influenced our decision to use this representation:

- We have already developed a number of applications which use the MSDL parser for scene input, and have built up an MSDL library of common scene components such as chairs and tables.
- A number of converter programs are available which allow the translation of externally-sourced files (such as DXF models) to MSDL. We can also convert from MSDL to formats such as Silicon Graphics' Inventor, thereby allowing the use of standard interactive tools for scene previewing.
- We have the ability to extend the MSDL language to suit our own modelling and rendering requirements. For example, we have added extensions to support texture mapping and radiosity information for high-quality rendering. These features were particularly useful in this case study.
- MSDL supports the development of *structured* models. The ability to describe a scene as a set of discrete, editable components is important in this specific application. For example, model editing will allow lights to be turned on or off, or the movement of objects within the scene for the purposes of hypothesis testing during the crime investigation.

2.1. Geometric model building

Generating a complex model from scratch is a challenging task. We therefore made a number of design decisions in order to make the process more manageable. The most important of these was to choose a level of modelling detail which was appropriate to the envisaged usage of the model. Some parts of the garage scene were sited well away from the actual crime location, and it was considered sensible to only attempt to reproduce a coarse depiction of these areas. More accurate representations were limited to the immediate vicinity of the crime.

In a typical scene, the number of distinct objects with size S greater than some chosen value K will often conform to the following rule:

$$Num(S > K) \propto \frac{1}{K} . \tag{1}$$

In other words, there are many more small objects than large ones. Providing a sensible cut-off in the level of detail used can therefore result in a considerable saving in modelling effort.

Another way in which the model building process was simplified was through the use of existing component libraries. Some model items, such as chairs and filing cabinets, were already available locally in MSDL format, while other items (such

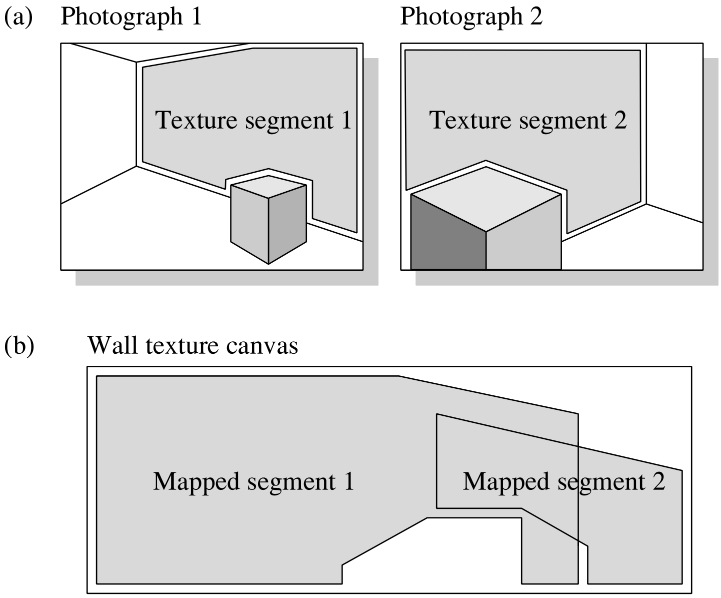

Figure 1. Extracting a wall texture from several photographs.

as cars) were downloaded via the Internet from public domain model sites. Often these components did not provide an exact match for those found in the real garage, but their use in non-critical areas was considered acceptable in providing an adequate environmental context.

The overall garage building structure was constructed by first digitising the floor plans, then vertically extruding the line segments to generate wall descriptions in MSDL. No attempt was made to use photogrammetric methods to determine actual wall heights from the forensic photographs. Instead heights were estimated and later refined by visually comparing the rendered model with the photographic images. The floor plan was also used to guide the placement of discrete objects within the scene, such as cars and items of furniture.

2.2. Incorporating textures

The use of scene texture information plays an important part in the construction of realistic 3D scenes. A specific objective of this work was to extract texture information from the forensic photographs in order to represent authentic surface detail within the graphics model. It was particularly important to incorporate textures from photographs of the crime scene itself, as these contained large amounts of information related to the events of the crime, such the distribution of blood traces. (We regret that we are not at liberty to present here images relating to the blood distribution.)

The process of texture extraction was largely performed ‘by hand’ using a photo retouching package. The texturing of a particular model component – a wall, for example – would typically consist of the following stages:

1. Forensic photographs containing assorted views of the wall in question were digitised. A blank texture canvas was then created with a resolution and aspect ratio suited to the size and shape of the wall. Texture segments of the wall were then marked out on the photographic images as shown in Figure 1(a). Each individual texture segment was then mapped onto the canvas using suitable perspective corrections in a patchwork manner (Figure 1(b)).

2. Attempts were then made to unify the characteristics of the mapped texture samples. One problem was a lack of tonal consistency from patch to patch. Exposure settings varied widely between photographs, and varying illumination angles and intensities resulted in a diverse range of Lambertian reflection effects. Brightness and contrast adjustments were applied to individual patches in an effort to minimise differences between patches.

3. Further tonal adjustments were then made in an attempt to remove any trace specular reflections from the texture samples. Although this was done manually, there is scope to remove unwanted specular components in an automated manner. Global illumination artifacts, such as cast shadow regions, were also compensated for using local adjustments (shadows

Figure 2. Comparison of hardware (left) and radiosity shading (right).

would later be re-applied to the scene during the radiosity rendering phase). We are currently developing 'inverse radiosity' methods, which will allow global illumination artifacts to be identified and filtered out as an automatic process.

4. Finally, wall texture regions not visible in any of the source photographs (the white areas of Figure 1(b)) were filled in using a texture cloning technique. An alternative method would be to synthesise new texture patches based upon a spectral and tonal analysis of the extracted segments.[7]

The specific task we were presented with – building a model of a garage – highlighted a much overlooked aspect of computer graphics modelling, namely the representation of dirt and disfigurement within a scene. A common failing of computer graphics images is that they often appear too pristine. Real world environments (garages in particular) contain considerable accumulations of dirt, and feature many imperfections and other defects resulting from their active history. It is possible to apply blemishes by hand to scene textures in order to fabricate a worn appearance.[8] Within the garage model we experimented with the use of dirt textures extracted from the forensic photographs. Some parts of the model were deliberately left clean (untextured) to allow a comparison of presentation methods to be made. We have recently experimented with physical simulation methods which allow the transport and deposition of dirt within an environment to be modelled.[9,10] We hope that such techniques may be applied to synthetic scenes in order to create more lifelike models with inherent imperfections.

3. RENDERING THE MODEL

When reconstructing models which represent scenes of crime, it is essential to present views of the scene which match the corresponding views of the real environment as closely as possible. In terms of illumination, video and photographic evidence rarely represents the real scene (as perceived by a human observer) accurately, due to the effect of the extra lighting normally introduced to enable bright enough images to be captured.

Rather than map textures extracted from the images to provide illumination details, we have chosen to simulate the lighting using a radiosity algorithm. This means the illumination in the rendered environment is not limited to that present in the photographs from which the material and texture information was retrieved. The facility to experiment with different lighting conditions provides a powerful investigative tool which normal photography and video recordings cannot offer.

The standard illumination models that are present on graphics workstations and PC graphics accelerator hardware give simplistic results that are not perceptually realistic. Hardware illumination models are not physically based, and only account for local illumination from point or directional light-sources. Global illumination algorithms are capable of providing far richer illumination details such as shadows and inter-reflections, and also allow models of the human visual system to be employed to reproduce a perceptually accurate image on the screen.[5] Figure 2 contrasts the different results obtained by simple hardware shading, and radiosity shading.

Considering that we wish to provide unconstrained navigation around the virtual environment, the radiosity method has an additional advantage: it provides a completely view-independent map of the variations in illumination over each surface, which can subsequently be rendered from any viewpoint using graphics hardware.

Figure 3. Radiosity mesh (left), and resulting image (right).

Figure 4. Different radiosity solutions using artificial lighting (left), and a daylight model (right).

As well as requiring an accurate geometric model, surface characteristics such as reflectance coefficients are needed in order to correctly simulate the illumination in the scene. These are currently estimated from the forensic photographs, with all light sources having a simple diffuse intensity distribution, although more sophisticated automated techniques are currently under investigation. The radiosity simulation was then performed, using the VRAD software developed locally, resulting in a hierarchical representation of the variations in illumination over each surface.

One important consideration for any radiosity algorithm is how to transform radiosity values (measured in physical units) into colours suitable for display on a monitor screen or other display device. This problem, known as 'tone-reproduction', occurs because the dynamic range of displayable luminance values for a monitor screen is far less than that of a real scene. Several tone-reproduction models have been proposed for post-processing single images.[11–13] All of these techniques are modelled on the process of 'adaptation', whereby the sensitivity of the human eye adapts itself to account for different levels of illumination. In this way, a dark scene will appear dark, with the correct levels of visibility as would be present when viewing the real scene.

Computing a radiosity solution for large environments is a very slow process. One novel feature of the algorithm used in the work described in this paper is that only those aspects of the solution that are deemed perceptually important are computed to any great accuracy. This reduces the time required to illuminate the environment enormously, since a large proportion of the computations performed for each solution have little perceived effect on its quality when considered individually.[14] Figure 4 shows images from two different radiosity solutions of the garage model, one illuminated using artificial lighting, and the other generated with a daylight model.

3.1. Interactive Rendering

The rendering software for this model was built using the MAVERIK system, and allows a user to navigate around the environment using a variety of input devices, ranging from a conventional desktop mouse to a 3D mouse with six degrees of freedom. Various output devices are also supported, including a multi-participant large-screen stereoscopic projector system and stereoscopic head-mounted display. MAVERIK run on Silicon Graphics equipment, and also on PCs using the Mesa OpenGL-like library.[15] On PCs, interactive frames rates are easily achievable with a low-cost graphics accelerator card such as a Voodoo 2.

Radiosity algorithms can produce very complex representations of illumination – for the garage model, $26,500$ original polygons generated more than $200,000$ triangles after subdivision to capture details such as shadows and high illumination gradients. Culling and level-of-detail algorithms must therefore be employed if an adequate frame-rate is to be achieved when viewing the model. View frustum culling (in conjunction with a hierarchy of bounding volumes) selects those parts of the model in view for each frame. The hierarchical representation of radiosity over each polygon is then traversed, and a level-of-detail selected for rendering. In this way, fewer triangles need to be rendered in areas that have received a high level of subdivision, provided those areas are distant from the viewpoint.

4. APPLICATIONS OF THE SIMULATION

The pilot project described in this paper has established that VEs have serious potential for aiding Police work. The VE has been evaluated by a number of Police officers, forensic scientists and forensic educators working with computerised investigation techniques, and their response has been very favourable.

There are several specific uses of the VE which have already been proposed, which future work will investigate in detail. This section outlines a number of the proposals.

Data analysis. The fact that the VE is a true three-dimensional reconstruction of the real scene affords the opportunity to superimpose onto the scene visualisations of data captured during forensic analysis. One important application would be the visualisation of bullet trajectories.

Witness statement evaluation. Most scenes of crime are short-lived. In many cases it impractical to leave the scene undisturbed indefinitely, and after investigators and forensic personnel have visited the scene to collect evidence, the scene must soon be cleaned, tidied, and returned to its normal function. In effect, the actual scene of crime has disappeared. Capturing the original scene as a VE, however, "freezes" it, and allows a degree of subsequent investigation to take place. One application would be to evaluate the accuracy of witness statements. For example, it is simple to determine what parts of the scene are visible from different vantage points. If a witness claimed to be able to see an object or some action from their viewpoint, this could be checked interactively using the VE – an evaluation which can prove awkward using only paper data and photographs.

Witness assistance. A related application is to bring witnesses of the original scene into contact with the VE, to help them recall what they saw. The witness could explore the scene, and it would be possible, for example, to animate aspects of the alleged crime incident.

Route visualisation. Tracking the possible movements of individuals within a building would assist in scenario evaluations. Alternate entrance or escape routes might be traced between rooms, and lengths and walk/run times could be automatically computed and compared.

Briefing officers. A reconstructed scene of crime VE has significant potential as a briefing tool. Using a large-screen stereoscopic display, multiple participants can share in interactive analysis of the layout of the scene, and the superimposition of forensic and other data as described above. It is our experience that the combination of a large-screen stereoscopic display, a detailed geometrical model of the scene, realistic lighting, and interactive walkthrough, results in most observers having a useful sense of "presence" in the scene. This has obvious psychological benefits when the observers are exploring the relationships between objects and conditions within the scene.

Hypothesis evaluation. Investigating officers often wish to suggest and test alternative hypotheses for how events may have occurred at a scene of crime. Traditionally this has involved the use of drawings and partial reconstructions using scale or life-sized models. A VE provides an alternative approach which is in many ways more flexible. For example, objects connected with the crime might be interactively moved around the scene in order to determine how they might have been used or moved; bullet trajectories and impact data might be used to estimate the positions of individuals using guns, for example.

Training. Within the police force training now accounts for a significant portion of the budget. Thus, the development of virtual environments for training is a fruitful area to explore. Current methods for training include the use of buildings which contain full-size purpose-built scenes of crime, in which crimes are simulated, and which contain ‘evidence’ for trainee officers to identify and evaluate. An interactive virtual environment, however, would provide the ability to move furniture, open and close doors, adjust lighting conditions, as well as moving around, checking sight lines, and so on. Creating traditional “real-life” scenes is a costly and labour-intensive activity, and while they are likely to remain a vital “hands-on” aspect of training, VEs have the potential for assisting with this kind of evidence-gathering training at a greatly reduced cost.

Lighting evaluation. Currently, scenes of crime are recorded using still photographs and video. Because artificial lighting will sometimes be used in order to capture images which are bright enough for subsequent study, the lighting in the images will often be incorrect. Further, the crime may actually have been committed in the dark, or under greatly different lighting conditions than captured in the forensic images. With a VE, we have the facility to experiment with different lighting conditions, by changing the parameters associated with the light sources (including light coming through windows), and recomputing the overall illumination of the scene. This provides a powerful investigative tool which normal photography and video recording cannot offer.

Security planning. A VE has potential for planning security operations involving the protection of individuals. Such models could also be used for briefing colleagues and other agencies.

Crime prevention. Here, the emphasis would be on designing new buildings, or housing schemes, or re-developing existing ones. Different views could be obtained and different lighting conditions simulated.

Courtroom uses. The VE and the virtual photographic gallery within it has the potential for explaining more traditional evidence during court cases, and although there are clearly serious difficulties associated with the use of “virtual evidence”, this is an area that merits further investigation.

5. CONCLUSIONS

The pilot project described in this paper has provided numerous insights into the possible applications of scene of crime modelling using virtual environments. The most important feature of the work is the combination of fast perceptually accurate lighting simulations, with large-screen stereoscopic projection, which together transform the images from being traditional “rendered 3D models” into highly-realistic virtual environments in which observers can feel a sense of presence.

However, the construction of VEs “by hand”, even with the support of CAD modelling tools, is an extremely time-consuming process. It is only through the use of automated construction techniques that the creation of VEs can become cost-effective. The next phase of the work described in this paper is to investigate methods for automatically extracting geometry, texture and lighting information from sequences of video images, from which the corresponding VE can be semi-automatically constructed. This is the goal of the REVEAL project, a three-year programme of work funded by the Engineering and Physical Sciences Research Council, which began in April 1998.[16]

It is the authors’ belief that the ability to quickly create richly structured, accurate and realistic VEs will not only prove of significant importance for the future development of computer-assisted scene of crime analysis, but for many other applications.

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