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ABSTRACT

Modern day crime scene investigation methods are continually being enhanced by the application of new technologies used to better analyze crime scene data and improve the presentation of such data in the courtroom, helping to solve and prosecute crimes. This paper describes a new system called IC-CRIME that integrates several new technologies to meet both of these needs. IC-CRIME employs laser scanning to produce realistic 3D models of a crime scene which it then incorporates into a 3D game environment. IC-CRIME creates an integrated platform that encourages investigators and forensic experts to view, explore, and annotate these models at any time from any web browser. A key goal of the system is to expand opportunities for collaboration between professionals whose geographic locations and time commitments would otherwise limit their ability to contribute to the analysis of the actual crime scene.

Categories and Subject Descriptors

H.5.1 [**Multimedia Information Systems**]: Animations; H.5.1 [**Multimedia Information Systems**]: Artificial, Augmented and Virtual Realities; I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Searchplan execution, formation, and generation; K.3.1 [**Computer Uses in Education**]: Computer Assisted Instruction; K.4.2 [**Social Issues**]: Abuse and Crime Involving Computers

General Terms

Design, Documentation, Experimentation, Human Factors

Keywords

Forensic, Evidence, Virtual Reality, Mixed Reality

1. INTRODUCTION

Crime Scene Investigation has benefitted from technological advances that facilitate the analysis and presentation of crime scene data [4, 9, 16]. This is particularly the case in the area of information presentation to technicians, investigators, forensic experts, jurors, and other participants of the judicial process [4]. This paper introduces a system, named *IC-CRIME*, that allows investigators to create a detailed and interactive re-creation of the physical space of a particular crime scene. This is accomplished through a combination of laser telemetry scans, digital photographs, and user-generated annotations. The current implementation incorporates scans produced using the commercially available DeltaSphere hardware and SceneVision software produced by 3rdTech [1]. IC-CRIME imports the data created by these tools into a 3D virtual environment that extends a browser-based commercial game engine. Using IC-CRIME, an investigator is able to revisit a crime scene long after a crime scene unit has completed data collection and the scene has been released by law enforcement. The system facilitates virtual walk-throughs, annotation of the scene with external data sources and comments, all in support of synchronous and asynchronous collaborative investigation.

The IC-CRIME system not only helps to preserve a record of the crime scene's spatial layout, but also facilitates collaboration among geographically distributed investigators and forensic experts. The system incorporates a commercial quality **game engine**, called Unity3D, to control navigation and communication between users of the 3D model. The Unity3D software provides real-time rendering of 3D graphics, detection of collisions between 3D objects, physics, networking, scripting, sound and animations. Using IC-CRIME, investigators can create a virtual meeting space, which appears in the form of a virtual investigative laboratory. Once created, a virtual lab can be accessed via the web by other investigators or forensic experts who no longer need to be physically co-located in order to collaborate on tasks related to the physical space of a crime scene.

2. RELATED WORK

The most significant applications of multimedia technologies to the area of criminal justice have fallen into two broad categories: the development of systems for the presentation of information in the courtroom and the implementation of software tools to assist in the investigative procedures related to the processing and analysis of the crime scene. The focus of our current work is on the later, but the IC-CRIME system shows potential for application in both contexts. Consequently, we describe work in both areas here.

One of the key applications of 3D technology that several researchers have focused on is the presentation of evidence to jurors, investigators, forensic scientists and other parties that are involved in the legal process [16, 10, 4]. Gibson and Howard [10] explored the use of virtual environments (VEs) created from photographs and videos of crime scenes. Their work was motivated by formative studies indicating that VEs could provide a useful aid for crime scene investigators. In particular, they described potential applications in the areas of analysis, training, and presentation of crime scene information. Their work suggests the need for effective *automated* creation of crime scene VEs due primarily to the immense effort involved in their manual creation when using traditional means based on architectural drawings and photographs.

While not focused on the investigative process, research by Dew et al. [6] provides favorable experimental results in support of the use of Augmented Collaborative Environments (ACEs) in the mediation of legal disputes between parties in different geographical locations. Artifacts in the form of videos rendered via computer graphics and virtual reality systems have been successfully introduced as evidence in a courtroom, as reported by Burton et al. [4]. Their work focuses on systems that use augmented video footage, augmented video animations, and augmented reality to provide additional information about a crime scene. These types of systems have been used successfully in court cases in the United Kingdom to assist in the prosecution and conviction of criminals. Further work [4, 16] also catalogues issues that may arise specific from the use of virtual reality and computer graphics systems to present information in courtrooms.

Work conducted by Schofield [16] for the reconstruction of criminal incidents provides evidence of the applicability of virtual crime scene reconstructions in real crime scenarios. Although his work does not provide evidence demonstrating the specific relations between the use of 3D models and the efficacy of this systems, it is important nonetheless to note that 3D models were part of the visual aids used in the successful presentation of the case he describes in the courtroom (and were also used during the investigative process). Schofield presents both advantages and disadvantages of the use of 3D technology in the courtroom. Among the benefits he cites is the potential to enhance the level of comprehension of an argument about the events of a crime, in particular when complex spatial and temporal data are involved. Increased efficiency in the delivery of complicated information, along with increased persuasiveness and presentations that more directly engage their audience are also cited as potential benefits.

Schofield notes the potential disadvantage that prejudice may be introduced when not all the parties have access to the same technology. Additionally, virtual crime scene reconstructions can potentially be biased. Schofield suggests that a detailed and accurate audit trail becomes essential to ensure that such bias is minimized. Finally, he points out that studies have shown that jurors are prone to perceive detailed reconstructions as the actual event [15].

Work in the area of augmented crime scenes by Gee, et al. [9] has focused on the implementation of systems to help in the collection and processing of evidence at the crime scene. Their system is based on the utilization of Global Positioning System and Ultra Wide-band data combined with digital photography and 3D annotation of scene data to create a virtual map of the crime scene. Investigators use the system to create a scene map in a collaborative manner with the assistance of a centralized control component. The main focus of the research is to explore the use of Augmented Reality (AR) to provide an efficient method to collect and display information about the crime scene in the context of the actual scene.

3. SYSTEM OVERVIEW

IC-CRIME is built using the Unity3D game engine and utilizes 3D models of crime scenes that are created using the DeltaSphere scanning hardware developed by 3rdTech [1]. The DeltaSphere system uses a laser and a high definition camera to create a **point cloud** representing the physical surfaces present in a real environment. Each point in the cloud is marked with coordinates relative to the global X, Y, and Z axes defined for a particular scene. The scanner provides a cloud of points sufficiently dense to model all the vertices of all the surfaces and objects present in the physical environment. However, a point cloud is inadequate to accurately depict the physical space of the crime scene. To address this need, the data from the point cloud is combined with the high resolution imagery collected by the camera to create a textured 3D **mesh** model of the scanned environment. A **mesh** is a grouping of points into two dimensional polygons (often triangles) that define edges, surfaces, and vertices of objects in the environment.

To construct these meshes, SceneVision combines overlays of different scans of the same location to support mesh alignment, coloring, and the removal or cleanup of unnecessary or noisy data. When the scans are first compiled into a 3D model they contain noise as well as overlapping polygons from multiple scans such as walls or floors. Multiple scans are often required because there is often no single vantage point from which all the relevant 3D data can be perceived without encountering an occlusion (e.g., furniture) that blocks the laser's view of a portion of the scene. The software helps to address these shortcomings in order to ensure that the scan more closely resembles the real-life location.

Once the model has been created and cleaned it can then be saved in the Wavefront OBJ 3D graphics format [14] and imported into the IC-CRIME software system. However, the IC-CRIME system is not restricted to the OBJ format,

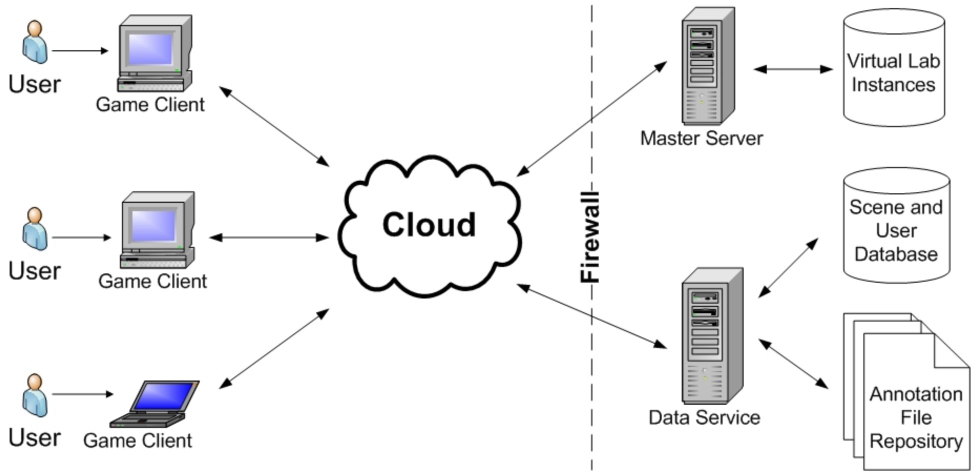

Figure 1: System Architecture

but can use any 3D model that can be supported by the Unity3D software [19]. This allows IC-CRIME to include models created directly in professional 3D modeling packages such as Maya [3], 3DStudioMax [2], or captured using alternative laser scanning hardware such as those produced by the Faro [7], and Z+F [23] systems. Unity3D is a video game development environment, or **game engine**, that can be used to create multi-platform video games [19]. A key advantage of using the Unity3D game engine is that it allows IC-CRIME to be run from inside any web browser, eliminating software installation issues while facilitating collaboration between experts that would otherwise be impractical due to time, cost or travel limitations.

The software uses a number of elements commonly found in commercial video games. For example, users interact with the IC-CRIME system through both first-person and third-person modes of interaction. In first person mode, the virtual camera is effectively paired with the position of the user's avatar in the 3D space. The user does not see the avatar but controls the viewpoint of the camera via the mouse, effectively looking through his or her avatar's eyes. In third-person mode, the camera orbits the user's avatar and its viewpoint is determined by the system in response to the user's movement within the 3D space.

Each user begins each session in third person mode inside the virtual laboratory, seen in Figure 2. Third person mode is a logical setting for the laboratory, as it is intended to be a virtual meeting place where users can initiate collaborative investigations. Users direct their avatars to walk around the virtual lab to access different portions of the system. The third person camera provides each user with a view of the virtual lab as well as each of the avatars of the other investigators actively using the lab.

A single user is able to load and control a scene within the virtual lab. The scene is the actual data reconstruction of the crime scene which is produced by the DeltaSphere hardware and SceneVision software. Scene data is stored on a centralized server and is password-protected for security purposes. The controlling user is free to translate, rotate, and scale the scene to better view it from the virtual lab space or to emphasize important elements to other users in the laboratory, as seen in Figure 3.

Once a scene has been loaded, it is projected in a large viewing area visible to all the users in the lab. Users are able to walk up to the scene and view it from the angle of the user controlling it. Each user can see other users' avatars, their users' names and can communicate with other users via text chat in this mode. The IC-CRIME system also supports a robust logging utility to ensure that an audit trail of user actions and conversations can be kept if necessary.

Each user can choose when to transition between the third person mode of the lab and a first person mode that puts him or her within the scene. First person mode allows the user to view the crime scene as if he or she were physically present there. Users are able to freely move around within the first person view and interact with the virtual representation of the crime scene as shown in Figure 4. The first person view provides each user with the fine level of control needed to inspect in-scene details (e.g, close up views of the environment, for instance from behind chairs or under tables).

The user interface controls for this mode are consistent with those of many commercial first person shooter (FPS) games, where the mouse controls the viewing angle and the keyboard controls movement. The first person mode also contains a robust annotation system that allows users to place markers with customizable notes in the physical space of the scene. These annotations can be used to indicate the location of important evidence or events within the scene, provide a focal point for text comments about that evidence, and link the spatial location of the evidence to external data such as lab reports, photographs or video. The user's interface to the annotation system can be seen in Figure 5.

Files and other data added to annotations are stored on a centralized database server where they are available for access by all participants with the correct set of credentials. After a user has added and updated the annotations for a particular scene, the user can select to save the current set of annotations for retrieval at a later date. This allows multiple sets of annotations to be created for a single crime scene. Also available in the first person mode is a set of collaboration and analysis tools. These tools include such things as a virtual measuring tape and a line-of-sight tester. More tools are planned in future versions of the system.

Figure 2: Walking in the Virtual Lab

Figure 3: A Scene Loaded in the Virtual Lab

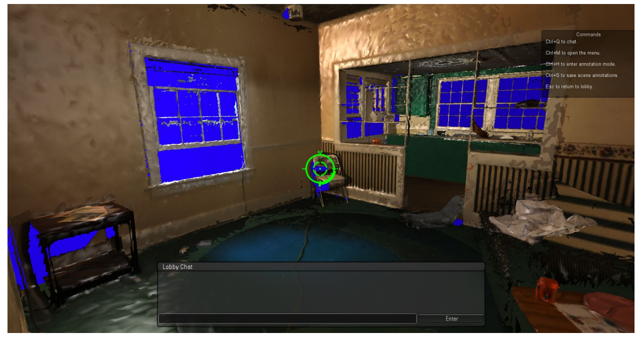

Figure 4: Moving in First Person Mode

Figure 5: Viewing an Annotation in First Person

4. CORE COMPONENTS

One central problem often faced by investigators is the effective communication of hypotheses regarding actions that led up to the evidence observed at a crime scene. Effective communication of what-if scenarios could aid in the collaboration between the investigative team. The discussion of scenarios could aid witnesses in explaining their observations to detectives. Demonstration of hypotheses to juries could more readily convey key points about the crime scene and the crime itself. Currently, the specification and communication of such what-if scenarios are performed either verbally or with pencil and paper sketches; there is little or no computer support for the expression of hypothetical reenactments.

In the work we are currently pursuing within the IC-CRIME project, we are building user-friendly tools that will assist users in the authoring of what-if scenarios. Based on these scenarios, the system will automatically create *cinematics* – video sequences that play out within the virtual crime scene – that capture the scenario's action and clearly convey its dynamics.

These cinematic sequences may be used to provide directed fly-throughs of the scenes or to provide visualizations of hypothetical scenarios explaining the possible action behind the scene's evidence. A *story editor* will be added to the system to allow users to author the stories underlying the hypothetical scenarios. Generating a cinematic sequence requires the effective selection of shots (including camera placement, movement, field of view) and shot sequencing. Manual specification of all the details required to create a coherent cinematic would be extremely time-consuming and require an understanding of cinematic principles beyond what could be expected of our targeted users. Instead, we are constructing a *cinematic generator* that will convert the high-level authorial preferences of the user into meaningful cinematic sequences.

In the authoring tool we're building, the use of story as an interface metaphor provides a mechanism to help users add structure to hypothetical scenarios. However, writing a complete and coherent story by hand can be a time-consuming and error-prone process. The story editor aids the user in fully specifying a coherent narrative by leveraging previous work on the automatic creation of stories using *planning algorithms* [20, 21], systems that reason about complex temporal and causal relationships between actions in order to create action sequences in a given task domain that achieve a set of input goals. In our application, this reasoning is used behind the scenes to take unstructured user specifications of events in a crime scene and piece together a causally and temporally consistent action sequence that can explain the state of the scene as captured in the static scan data.

4.1 Story Editor

In the context of this research we use the concept of *story* to refer to the sequence of events and actions related to a specific crime scene. The purpose of the story editor is to enable investigators and forensic experts to author reenactments of the events of the crime for which the 3D scene model has been created. The motivation for this component is twofold: first because it has been shown that 3D models of crime scenes are an important and effective visual aid to the legal process both in and out of the courtroom [4, 16], and second, because previous research in narrative theory and psychology tells us that humans use stories to describe events to each other and also to attain a better understanding of the world in which they live [13]. Thus, we ground our research on the potential usefulness that the construction of narrative can bring to the processes of crime scene reconstruction and evidence presentation.

While story telling is a familiar task for many people, the task of creating a story that meets specific constraints regarding timing, physical layout, motive, physics, causation and other elements drawn from the evidence of a crime scene requires reasoning about a large space of potential action sequences and the complex inter-relation between the actions that appear in them. In our design, we are leveraging the capabilities of a previously developed planning algorithm [22] to assist in the authoring tasks. In our model, the human author works in a mixed-initiative mode [8], where control and initiative in the story authoring process is passed back and forth between the user and the system. Mixed-initiative story generation systems have typically focused on the implementation of a graphical user interface front-end for a plan-based story generation system (e.g. Wide-Ruled [17]). Such systems allow the user to specify story elements in an intuitive interface, then extract more formal story constraints from this interface and pass them to a planning system responsible for constructing the space of potential stories that the constraints specify.

One of the main challenges in using a plan-based approach to story generation is the syntactical complexity that is typically involved in the use of a planner. Typically, users of planning systems interact directly with the systems via commands written in a Lisp-like formal language or using a custom-built XML markup schema. Although some systems have been developed to assist in this process (e.g Bowyer [5] and Bowman [18]), typically these have focused on a general use of planning technology and there has been no specific emphasis on story authoring or creation of cinematic sequences. Additionally, these systems have not provided an interface that makes it possible for non-experts to use a planning system.

Our work on the story editor will thus focus on the creation of a model of interaction that facilitates and simplifies the authoring process. The interface will enable non-expert users and the AI-planner to collaborate with each other in the elicitation and refinement of the story elements. Additionally, the interface will make it easy to adjust or modify story parameters in order to evaluate different scenarios.

To implement the story editor we will design a graphical user interface (GUI) that provides a layer of abstraction between the user and the plan-based narrative generator. The narrative generator will be based on the Longbow planning system [22]. The interaction between the GUI and the planner will be managed by a component dedicated to facilitating the use of planning technology through interaction made possible by a formal language that encodes the necessary and sufficient knowledge to generate the initial world state and set of goals that define a planning problem.

The story editor will be a core component of the IC-CRIME software. As users create re-enactments they will be able to interact with the 3D model of the crime scene and whenever feasible use direct manipulation of scene elements to define story events or elements. Additionally, although there may be multiple methods to represent the generated story, such as text narrative, storyboards, and plan visualization, it is our goal to take full advantage of the 3D virtual environment and use it in the creation of a cinematic rendering of the story. The cinematic component is described in a following section.

4.2 Cinematic Generator

The second central component currently being developed for IC-CRIME is a tool which will take the data structures representing the story actions specified by users in the Story Editor and create cinematics depicting the action sequence's events. The animation of character actions based on script-like story plans is relatively straightforward. In contrast, the automatic selection of camera shots and shot sequences used to visualize the action sequences, along with the timing constraints between the character actions and the filming activities, the shot composition decisions and the determination of the transitions between shots are tasks that are significantly more complicated.

To create effective cinematics, we build on our prior work [11] using an approach to automatic cinematography in which camera directives are created based on a view of cinematics as intentional communicative action. This approach views the composition of shots and shot sequences as a problem similar in nature to the composition of natural language discourse, with the coherence of a sequence of shots being determined by the rules that constrain the relations between adjacent shots and shot sequences similar to the rules that constrain adjacent segments of a paragraph of text [12].

5. CONCLUSION

The IC-CRIME system provides a collaborative environment for crime scene investigators and forensic experts to interact with a detailed and realistic 3D model of a real-world crime scene. The design provides an investigative team with access to important details about the scene without requiring them to visit the actual physical location in the short window of time where the crime scene is secure. A key advantage of the system is that it preserves crime scene physical space data by storing 3D models of the actual scenes. These models make it possible to visit the scene after it has been released by the investigators or in the event that it has been destroyed.

Investigators using the IC-CRIME system can annotate each scene in multiple ways to aid in their investigation. The environment is based on a game metaphor that takes advantage of the advanced graphics, physics modeling technology, and interaction paradigms that are an integral part of modern video games. The system will be extended in future versions to include an expanded set of tools for use within the 3D models of the scenes as well as introducing story generation capabilities to assist in the creation of crime reenactments.

The IC-CRIME system demands sophisticated human-computer interfaces to provide novice users with a collaborative 3D workspace, and direct the generation of complex cinematic sequences. Our research focuses on balancing the expressive power of the system with the need to simplify the work of novice users unfamiliar with 3D simulation technologies. We plan to continue to extend the system to support enhanced manipulation of the visual and audio elements to leverage fully the evolution of their underlying technologies. Our goal is for IC-CRIME to serve as a common platform that integrates a range of media into a powerful collaborative workspace.

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