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MiRTE: Mixed Reality Triage and Evacuation Game for Mass Casualty Information Systems Design, Testing and Training

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Abstract—In this paper we introduce a Mixed Reality Triage and Evacuation game, MiRTE, that is used in the development, testing and training of Mass Casualty Incident (MCI) information systems for first responders. Using the Source game engine from Valve software, MiRTE creates immersive virtual environments to simulate various incident scenarios, and enables interactions between multiple players/first responders. What distinguishes it from a pure computer simulation game is that it can interface with external mass casualty incident management systems, such as DIORAMA. The game will enable system developers to specify technical requirements of underlying technology, and test different alternatives of design. After the information system hardware and software are completed, the game can simulate various algorithms such as localization technologies, and interface with an actual user interface on PCs and Smartphones. We implemented and tested the game with the DIORAMA system.

I. Introduction

In this paper we introduce a Mixed Reality Triage and Evacuation game, MiRTE, that is used in the development, testing and training of Mass Casualty Incident (MCI) information systems for first responders. The game combines immersive virtual environments and actual MCI response information systems such as DIORAMA[1], WISSARD[2], CodeBlue[3], and AID-N[4].

Our simulation game is based on the source game engine from Valve software [7]. We created immersive virtual environments to simulate various incident scenarios, and enable interactions between multiple players. It can simulate the behavior of patients and paramedics, while players can take control of part or all or paramedics when playing the game. Virtual reality and games has been used to study human behavior in emergency situations and aid incident planning [5, 6]. What distinguishes MiRTE from a pure computer simulation game is that it can interface with external mass casualty incident management systems, such as DIORAMA. So when playing the game, the player can use the actual DIORAMA devices and user interface to gain situation awareness, locate patients, and coordinate the operation, similar to regular trials performed with human subjects.

In the early stage of the development cycle, the game can simulate the behavior of all patients, first responders, and incident commanders and run simulation for different scenarios. Such simulations will enable system developers to specify technical requirements of the underlying technology, and test different design alternatives, e.g. different localization technologies, incident area zoning, patient assignment algorithms. After the user interface design is complete, the game can simulate localization technologies to be used, and interface with an actual user interface on PCs and Smartphones (e.g. Android based phones). Domain experts can play the role of first responders and incident commanders in the game in a large scale incident, to help refine the user interface, first responders communication protocols, and cooperation strategy.

MiRTE provides the following advantages:

1. Enables seamless integration of the user community feedback during the design and early development phases. During the development of the actual system, it is important to keep the field experts and first responders in the loop from the design phase, and incorporate their feedback into the system incrementally during the development process. Comments from the first responders are most accurate and valuable when they can try a prototype system on field trials. However, it is typically late in the system development process when all the hardware and software components of a system are ready for a field trial. For example, for triage and evacuation application, we can evaluate which graphical user interface is more intuitive for first responders, voice instruction from commanders, a top-down map, or an augmented reality locator? What coordination strategy among first responders can reduce redundant visits to patients and evacuation time while minimizing the communication overhead between them? The answers to these questions may have major impact on the design of the system, and should be answered in an early stage before all hardware and software specifications are determined.
2. Enables us to test the actual system in diverse and complex MCI scenarios. It is very expensive, time

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consuming and logistically difficult to scale MCI trials to scenarios that include hundreds of human subjects. Obviously, such trials are very significant to testing and debugging MCI information systems. Such trials can test location awareness and cooperation among first responders. Moreover, we can use the game for studying different design alternatives of the system, and improve its design. For example, we can study how patient localization accuracy will affect the evacuation time.

3. Enables the training of the first responders in a virtual environment. The performance of first responders gradually improves as they get familiar to the system. So before we start costly actual field trials, it is important to train the responders with the system operation.

The paper is organized as follows. In the next section we introduce the mixed reality game design. Section III describes the human factors and Section IV introduces the experiments we conducted. Section V concludes the paper.

II. MIXED REALITY GAME DESIGN

Our game is built with the Source game engine released by Valve software[7]. It is a complete game engine with default implementation of networking, physics, AI non-player characters (NPCs), and graphics. Using the game engine requires much less effort than development based on a pure graphics engine. The platform provides a number of tools used to customize the engine and a low level C++ API with good community support. The source game C++ API enables modification of almost every aspect of the game engine, and provides greater freedom and performance over the scripting language API provided by other game engines, e.g. unreal engine used in [6].

The Source engine uses a client/server architecture. The server maintains the state of the game entities and enables interactions among clients. To ensure consistency of simulation on all clients and prevent cheating, the server runs all game physics and NPC AI. Clients primarily handle user input, communicate with the server, and output game graphics and sound.

Without loss of generality, to validate and illustrate the game we have implemented it for the DIORAMA system [1]. We modified several parts of the default server and client implementation of the source game engine to implement the triage and evacuation procedures. The modifications can be categorized into the following groups: Game initialization and rules (Section II.A), interface to the DIORAMA system (Section II.B), and AI controlled patient and paramedic NPCs (Section II.C).

A. Game initialization and rules

The scenario configuration module reads the patient layout parameters from a configuration file, and generates patient NPCs. Different simulation parameters, e.g. localization accuracy, visibility of the triaging tags are also configured. The evacuation statistics module records the route of paramedics and events of patients being triaged and evacuated. We also use the command line console provided by the game engine to enable developers to change scenarios and simulation parameters.

B. DIORAMA interface

DIORAMA interface includes modules that enable our simulation game to interact with the DIORAMA system such as: a) enable players to use actual DIORAMA devices for situation awareness, b) enable NPC paramedics in the game and c) interpret DIROAMA GUI instructions for paramedics.

The localization interface module provides patient and paramedic locations to an external program simulating the physical localization process of different technologies. For example, in the DIORAMA system, we use active RFID readers deployed in the incident area to track paramedics wearing RFID tags. The program will simulate RFID beacons sent by RFID tags carried by the paramedics, and generate signal strength readings of RFID beacons received by RFID readers at various locations based on wireless channel models. These signal strength readings are sent to the localization engine of the DIORAMA system to estimate the location of paramedics.

C. AI controlled NPCs

We created patient and paramedic AI controlled NPCs:

1. Patient NPCs simulate the behavior of the patients. There may be a large number of patient NPCs in a scene, so their implementation needs to be efficient. The primary properties of patient NPCs are their location and triage levels of red, yellow, black and green. Following procedures of trials with human subjects, in the current implementation, NPCs stay at their initial location and follow paramedics when they are being evacuated. The patient NPCs are flexible to adopt new behavior in future implementations.
2. Paramedic NPCs triage and evacuate patients. There are two variant implementations, one group using DIORAMA technology and one comparison group not using it. The detailed design of the patient and paramedic NPCs based on the Source engine SDK reference NPC are discussed in detail in the next section. Note that we do not have an incident commander role in the game. We enable paramedics to read their assigned patients' location directly on their DIORAMA device. The DIORAMA system automates the dynamic region and patient assignment to paramedics. The incident commander only operates through the DIORAMA GUI, and helps the DIORAMA system make decisions. Thus, the incident commander only communicates to the paramedics with the DIORAMA interface, and does not have a corresponding physical entity in the game.

D. Creating scenarios

The Source game engine provides the Hammer Editor tool for level designers to create level architecture, place NPCs with scripted events, and add AI navigation nodes for NPCs. Large scale geometry blocks are first added to the level to create outlines of buildings, walls and roads. Then, small static entities, e.g. trees, furniture, decorations are added to increase the visual detail of the level. The level is populated with NPCs, and scripts that trigger NPC behavior or other events. Using the Hammer Editor tool, we create realistic mass casualty incident scenarios in the virtual environment. In addition to creating visual elements of the virtual environment, we also need to specify the distribution of patients in the scene, their severity of injury, the number of paramedics available on the scene, and places of interest such as the staging area where the patients are evacuated. Scripts defining the above elements are read by the scenario configuration module of our game to complete the setup.

III. HUMAN FACTORS IN PARAMEDIC NPC DESIGN

One particular goal of an information system such as DIORAMA is to identify human weaknesses, and help paramedics keep track of important information and plan their evacuation. Our mixed reality game provides an excellent platform for observing human decision models, abstracting and verifying decision models in terms of NPC implementation, and explores system design opportunities that can improve paramedics' performance.

We implemented AI models of patients and paramedics based on the source game engine's NPC reference design. NPCs in the game share the following functions: sensing the environment, changing their state, select a schedule and perform basic tasks of a schedule. These functions are called at scheduled intervals to enable NPCs to interact with the environment.

A. NPC sensory

NPCs sense the environment to discover new entities that could be seen or heard. Different types of NPCs find entities of interest to their role and their current state, and generate conditions relevant to their roles, e.g. a new patient is in sight, a new region is discovered, etc. In our evacuation game, the NPCs can also generate conditions based on inputs from the DIORAMA interface module, reflecting changes in patient information and evacuation plan.

B. NPC memory

NPC states are their long term memories that affect the behavior of NPCs in terms of schedule selection. In the current implementation, a NPC patient has only one state of waiting in place for evacuation. In future implementations NPC patient scan adopt more complex behavior, e.g. green patients can flee the scene on their own, and red patients can die if not rescued in time. NPC paramedics have three states: idle, triage and evacuate. State transitions are induced by DIORAMA instructions through conditions.

Source game engine does not have a very sophisticated short term memory model. Different variables are used for task specific working memories, and only a few bit masks defined for more responsive NPC task execution. We implement a generic paramedic memory model based on observations from previous DIORAMA trials with human subjects that enable paramedic NPCs to remember patients they have visited and places of interest. More importantly, the model also defines the probability of losing pieces of memory over time, to simulate paramedic behavior more realistically. Due to memory loss, a paramedic may visit a patient multiple times to check his/her triage status, and traverse incident regions he had visited before to make sure that every corner is covered. The search trajectory in a specific area is guided by information nodes placed densely around the map. Paramedics must establish line of sight to all information nodes to complete the search in an area in order to find patients obstructed by debris or vegetation. These information nodes encode paramedics' knowledge of the incident area layout and their memory of places they have visited. The regions assigned to paramedics are also represented by information nodes, so that paramedics can keep track of their progress in a region. Information nodes are organized in hierarchies, including detailed information nodes of the area the paramedic is currently performing tasks kept in his working memory, and the areas he has explored in his long term memory. Navigation nodes also encode the information of various places of interest, e.g. the staging area where the patient is evacuated to in the simulation.

C. NPC schedules and tasks

Schedules are NPCs high level goal, e.g. *searching for patients, triaging a patient*, etc. NPCs then choose a schedule according to newly set conditions, their state and memory. For example, a paramedic in *triage* state, with no found patients in memory, will choose the *searching for patients* schedule. When he sees patients, he will keep locations of patients in memory, and trigger the condition of *finding a patient*. The condition can interrupt the paramedic's *searching for patients* schedule, and select *triaging a patient* schedule. The paramedic will continuously select and perform *triaging a patient* as long as there are patients not yet triaged in memory. Then he would resume to *searching for patients* schedule. When he finishes the area currently assigned, he may interact with the DIORAMA system which triggers new conditions. He would either be assigned to new regions, or in case the triage phase has finished, transition from *triage* state to *evacuate* state.

Once a schedule is picked, the NPC will perform individual low level tasks making up the schedule. For example, *triaging a patient* schedule includes the following tasks, *choose patient to triage, get path to target, move to target, stop moving, facing patient, and perform triage*. Some of these tasks are implemented by the source game engine, e.g. path finding, NPC movement. We customized some tasks particular to the triage and evacuation game. Heuristics observed from the DIORAMA trials with human subjects are used to optimize NPC task execution. For example, when there are multiple patients in sight, the paramedic will choose a triage sequence that minimizes the distance they need to travel.

IV. EXPERIMENT

In this section, we use our triage and evacuation game with fully simulated paramedics and patients to compare the evacuation times obtained by DIORAMA and PAPER trials. We briefly explain the DIORAMA and PAPER trials. For more details on the triage and evacuation protocols see [1].

PAPER trials: during the triage period the paramedics tag each patient with a SMART tag which represents the patient severity of injury (red, yellow, green and black). In the evacuation phase the paramedics search for the red patients which need to be evacuated and then the yellow patients.

DIORAMA trials: each paramedic tags each patient with a D-tag along with a SMART tag. We assume that the DIORAMA system is already in place [1]. The location of each patient is computed by the DIORAMA system and displayed on the DIORAMA GUI along with the severity of injury. In the evacuation phase, the Incident Commander assigns a specific geographical area to each paramedic. Using the DIORAMA GUI (on their Smartphone) which displays the patients' locations along with the severity of their injuries, each paramedic evacuates first the red patients and then the yellow patients.

We would like to find out what is the DIORAMA reduction of the evacuation time when compared with the PAPER system.

In the trials with human subjects we tested the two systems in a 100x100 feet area with 20 patients and one paramedic [1]. We obtained an average evacuation time reduction of 42% for DIORAMA trials when compared with the PAPER trials. The results we obtained in the simulation are consistent with the results obtained with human subjects.

It is obviously very costly and time consuming to run significantly larger experiments, i.e., large areas, large, number of patients and large number of paramedics) while we can test these results with MiRTE simulator. Therefore, we use simulation to test the performance of DIORAMA and PAPER trials in a 200x200 feet area with 80 patients and 3 paramedics. The patient distribution is not uniform: 10 red patients and 10 yellow patients are clustered on the lower left and upper right of the region, as shown in Figure 1. We assume that the localization error of DIORAMA system is uniformly distributed from 0 to 30 feet. We limit the visibility of the triage tag to 10 feet, so that the paramedics need to get close to a patient to examine his triage status.

Table I. Evacuation Statistics

	DIORAMA	PAPER
Red patients evacuation time (sec)	288	1307
Yellow patients evacuation time (sec)	567	1813
Redundant visits for 3 paramedics	14/9/24	42/32/74
Distance traveled for 3 paramedics (feet)	2001/2305/2092	4411/4016/4001

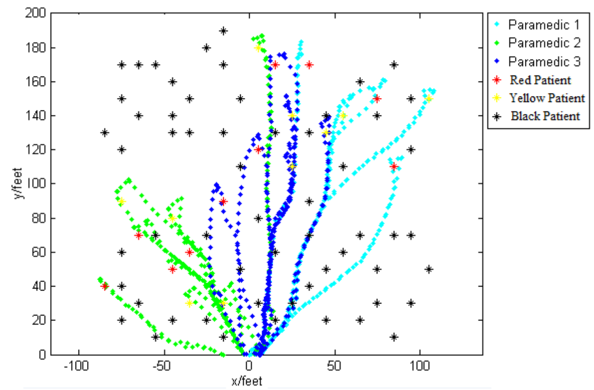

Figure 1. Paths of paramedics in DIORAMA trials

As shown in Table I which summarizes the evacuation statistics obtained by MiRTE, the evacuation time reduction of the DIORAMA trials over the PAPER trials is 68%. The evacuation time reduction results from avoiding redundant visits. We plot the path of the paramedics in the simulation for the DIORAMA trial in Figure 1. For DIORAMA trial, the paramedics are scheduled to evacuate different regions, and go straight to their assigned patients. On the other hand, the paramedics in the PAPER trials will also search area with black patients, i.e., increasing the evacuation time of red and yellow victims. Note that inaccurate patient localization in the DIORAMA trials will sometimes lead paramedics to the incorrect patients, causing redundant visits.

V. CONCLUSION

In this paper we introduce MiRTE, a mixed reality triage and evacuation game for the development, testing and training of Mass Casualty Incident (MCI) information systems for first responders. We use MiRTE with simulated paramedics to study the performance gain from using DIORAMA in large incidents with multiple paramedics. In the future, we will invite paramedics to play the game, to refine the NPC model, and improve DIORAMA design.

REFERENCE

[1] A. Ganz, et al. "DIORAMA: Dynamic information collection and resource tracking architecture," in Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE, 2010, pp. 386-389.

[2] Wireless Internet Information System for Medical Response in Disasters (WIISARD), http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1839464/

[3] K. Lorincz, et al. "Sensor networks for emergency response: challenges and opportunities," Pervasive Computing, IEEE, vol. 3, pp. 16-23, 2004.

[4] T. Gao, et al. "The Advanced Health and Disaster Aid Network: A Light-Weight Wireless Medical System for Triage," Biomedical Circuits and Systems, IEEE Transactions on, vol. 1, pp. 203-216, 2007.

[5] S. Jain and C. R. Mclean, "A concept prototype for integrated gaming and simulation for incident management," in Simulation Conference, 2006. WSC 06. Proceedings of the Winter, 2006, pp. 493-500.

[6] A. C. A. Mol, C. A. F. Jorge and P. M. Couto, "Using a Game Engine for VR Simulations in Evacuation Planning," Computer Graphics and Applications, IEEE, vol. 28, pp. 6-12, 2008.

[7] Source Game Engine SDK, http://developer.valvesoftware.com/wiki/SDK_Docs