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Crowd simulation for emergency response using BDI agents based on immersive virtual reality

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ABSTRACT

This paper presents a novel methodology involving a Virtual Reality (VR)-based Belief, Desire, and Intention (BDI) software agent to construct crowd simulation and demonstrates the use of the same for crowd evacuation management under terrorist bomb attacks in public areas. The proposed BDI agent framework allows modeling of human behavior with a high degree of fidelity. The realistic attributes that govern the BDI characteristics of the agent are reverse-engineered by conducting human-in-the-loop experiments in the VR-based Cave Automatic Virtual Environment (CAVE). To enhance generality and interoperability of the proposed crowd simulation modeling scheme, input data models have been developed to define environment attributes (e.g., maps, demographics, evacuation management parameters). The validity of the proposed data models are tested with two different evacuation scenarios. Finally, experiments are conducted to demonstrate the effect of various crowd evacuation management parameters on the key performance indicators in the evacuation scenario such as crowd evacuation rate and densities. The results reveal that constructed simulation can be used as an effective emergency management tool.

1. Introduction

Emergency response management for man-made and natural incidents has become a key research field in today's world following frequent terror attacks and natural disasters on various crowded areas across the world. The paper focuses on modeling crowd behavior under terrorist bomb attacks in public areas and the required evacuation management. Effective crowd evacuation strategies require accurate prediction of the impact of environment on the behavior of the crowd. Naturally, the involvement of human lives demands high accuracy of such predictions. For these purposes, simulation is an ideal technique as it can accommodate randomness and detail needed in such models, and it enables a form of experimentation not possible with the real incidents. An accurate simulation model can enable the responsible governmental and law-enforcement agencies to evaluate different evacuation and damage control policies beforehand, which can in turn facilitate the execution of the most effective crowd evacuation scheme during the actual situation involving terror. Furthermore, it can allow the training of responders and emergency managers at a fraction of the cost of live training exercises [6].

Simulations involving dense crowds in large cities require a model of an environment and the people in the crowd that are present in that environment. Obtaining realistic data to model such crowds is a challenge in itself. The data so obtained can be so diverse that analyzing it effectively is extremely difficult. Therefore, most of the currently available crowd

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simulations model the crowd as groups of people with common characteristics or objectives. In this paper, we seek to construct a model of an individual with unique characteristics and instantiate it with different attribute values to create a crowd. Since the model of an individual is analogous to an agent, we propose to use an agent-based simulation modeling paradigm to construct a crowd simulation. In this paper, we employ extended BDI (belief, desire, intention) agent framework, which facilitates modeling of a human's mental functions. However, it must also be noted that there is an obvious trade-off between the improved accuracy obtained by introducing the rich BDI framework and computational speed. We plan to tackle this issue as part of our future research work.

The paper is divided as follows: Section 2 summarizes the literature survey and provides brief background information on the various techniques employed in this work. Section 3 discusses an overview of the proposed crowd simulation modeling scheme. Section 4 explains data extraction from safe human-in-the-loop experiments using VR for human behavior to model the agent. Various modeling techniques that facilitate the development of this crowd simulation are discussed in Section 5. In addition, this section also explains the algorithms, data structures and software tools used for the simulation development. Section 6 contains the results from the two phase experimental setup. Phase 1 involves experiments conducted in VR for the purpose of human behavior extraction. Phase 2 involves experiments of crowd simulations to estimate crowd trends and statistics as a consequence of a bomb explosion in the Washington DC mall area, and finally Section 7 concludes the paper and proposes future extensions.

2. Background information and literature survey

This section gives the background information and literature survey of three major areas involved in this paper, namely virtual reality, BDI agents, and crowd simulation.

2.1. Virtual reality

Virtual reality employs detailed computer graphics to create quasi-real 3D objects that respond to user interactions. Three essential characteristics of a VR system are (1) response to human interaction, (2) real time 3D graphics [12] and (3) immersiveness. The first two characteristics are self-explanatory. Immersion means the sense that either the user's point of view or some part of the user's body is contained within the computer-generated space [3]. Immersive virtual reality is defined as the use of various computer graphic systems in combination with various display and interface devices to provide the effect of immersion in an interactive 3D computer generated environment in which the 3D objects have spatial presence. Immersiveness in desktop VR is associated only with the immersiveness of the eye and interactivity is through the mouse or keyboard.

Virtual reality can be of various types, such as Cab Simulators, Projected Reality, Augmented Reality, Tele-presence and Desktop VR. Different kinds of VR have different levels of interactivity and immersions. Most virtual reality used in the engineering applications involves Desktop VR. However, Desktop VR does not completely immerse/involve humans and would result in comparatively insincere participation from the human's part. Hence, in this work, we use the CAVE Automatic Virtual Environment (CAVE) to create the computer generated space or environment. The immersive effect is created using the stereoscopic glasses to create the illusion of 3D in the brain and the 3 wall–1 floor space (to project the environment) to allow the user to stand within the environment itself. The interaction is through a 5-button VR WAND (similar to a joystick) controller and through a tracking system which tracks the position of the wand and the stereoscopic glasses. A high level of realism and response to the interaction is obtained by using a multi-processor high performance Linux computer cluster to run the VR graphics in CAVE. The z buffer and multiple processors ensure high graphic quality and smooth graphic transition. Design process for virtual reality applications has two driving requirements: First, the virtual environment and its interface should be tailored to the task. Second, stringent performance constraints must be met for the benefit of Virtual Reality to be realized [3]. In this work human characteristics for modeling an agent were extracted from VR-based human-in-the-loop experiments, which were designed (using powerful hardware) to meet the afore-mentioned design requirements.

2.2. BDI agents

Modeling human behavior for a given situation is extremely difficult. One of the commonly used ways is to design an intelligent agent, which mimics the overall (abstract) characteristics of a human. The intelligent agent [10] is a promising technique to model a human acting as a decision maker in an automated system. An intelligent agent is situated in an environment and acts autonomously within it, and people are the archetype for autonomous action [4]. An intelligent agent has its own characteristics such as autonomy, social ability, reactivity, and it is pro-active, cooperative, inclined to learn and adaptive [8]. Naturally, the accuracy of such intelligent agents is highly dependent on the modeling accuracy of the behavior of an agent. An agent modeled with the help of a richer architecture will better simulate the behavior of a human.

Various architectures/techniques such as Hierarchical Agent Control (HAC), Cognitive Agent Architecture (Cougaar) and Distributed Environment Centered Agent Framework (DECAF) have been proposed to model such intelligent agents [2].