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Technical Section

Automatic camera control meets emergency simulations: An application to aviation safety

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ABSTRACT

Computer-based simulations of emergencies increasingly adopt 3D graphics to visualize results and thus generate complex dynamic 3D scenes with many potentially parallel events that affect large groups of virtual characters. To understand the portrayed scenario, a viewer could interactively control a flying camera or switch among a set of virtual cameras that have been previously placed at modeling time. The first solution imposes a cognitive load on the viewer that can distract him/her from the analysis task, and (s)he might miss events while moving the camera. The second solution requires additional work in the modeling phase, and even a very large number of cameras could fail to correctly frame events because of dynamic occlusions. More sophisticated automatic camera control methods could help, but the methods in the literature are designed for sequential dialogue-like events that involve at most two or three characters and therefore would not work. In this paper, we present a fully automated, real-time system that is able to monitor events in emergency simulations, select relevant events based on user-provided filtering rules, and control a virtual camera such that the events of interest are properly presented to the viewer. To illustrate how the system works in practice, we also describe the first application of automatic camera control to the domain of aviation safety.

1. Introduction

Computer-based simulations of emergencies are increasingly used for a variety of purposes, including planning, prediction of outcomes, accident investigation, and training. Systems have begun to adopt realistic 3D graphics to visualize simulation results (e.g., [1–3]), thereby generating complex, dynamic 3D scenes with many potentially parallel events affecting large groups of virtual characters. Presenting the resulting animations to a viewer in an effective manner is thus challenging.

The traditional approach to the visualization of 3D simulations is to place multiple virtual cameras in the scene at modeling time and switch among them at run time to observe the different events that occur. However, as the spatial complexity of the scenario and the number of events increase, even a very large number of cameras could fail to correctly frame many events, e.g., because of dynamic occluders that prevent any of the pre-defined cameras from adequately capturing some of the action. Moreover, manually placing the virtual cameras can require a considerable modeling effort that in general must be repeated for each simulation. Even for the same simulation, multiple camera setups may be necessary based on what features a viewer finds the most interesting. For example, a safety expert could be interested in how the entire emergency egress of a crowd from a building evolves, while a firefighter who uses the same simulation for training would need to focus on details that are relevant to first response duties in the field such as the location and evolution of fires.

An alternative solution is to let the viewer interactively control a flying camera during the simulation. However, this approach imposes a cognitive load on the viewer that can distract him/her from the analysis task and that has the additional disadvantage that (s)he might miss events while moving the camera.

Automatic camera control methods could provide solutions to such problems, thus relieving the user from the burden of manual camera placement, selection, and control. However, most methods that have been proposed in the literature are designed for sequential dialogue-like events involving at most two or three characters and are thus not suited to situations that include several parallel events involving many characters. Indeed, none of these solutions have been adopted for emergency simulations.

In this paper, we present a novel and fully automated, real-time camera control system for emergency simulations that is able to monitor interesting events and present them to a viewer. We

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propose to organize such a system into two conceptual modules: a *Camera Operator* and a *Director*. The *Camera Operator* is based on extending a recent virtual camera computation approach [4] to calculate, whenever needed, a virtual camera that aims at visualizing the maximum number of currently occurring events of interest. The *Director* then analyzes the virtual cameras that are computed by the *Camera Operator* and chooses which camera to use and when to use it to visualize simulation events to the viewer. To illustrate how the system operates in practice, this paper applies it to a complex case in the domain of aviation safety. However, the system is not limited to aviation and could be utilized in other emergency domains.

The paper is organized as follows. In Section 2, we briefly review past work on computer-based emergency simulations and automatic camera control and motivate the need for the proposed approach. In Section 3, we describe the proposed camera control system, and in Section 4, we apply the system to a full aircraft evacuation scenario that reproduces the main aspects of a well-known recent accident. Finally, in Section 5, we conclude the paper and outline future research directions.

2. Related work and motivations

2.1. Computer-based emergency simulations

Computer-based emergency simulations are increasingly used for a variety of purposes, including planning, prediction of outcomes, accident investigations, and training. In particular, emergency evacuations have received considerable attention in the literature. Gwynne et al. [5] reviewed 22 evacuation models and classified them into three main categories: optimization, simulation and risk assessment. EXODUS is a well-known evacuation model that was successfully applied to analyze both building [6] and mass-transport [7] evacuations. The system includes specialized modules to model very specific aspects such as (i) the characteristics of occupants (e.g., age, gender, and physical disabilities), (ii) their movements and behaviors, and (iii) the physiological impact of toxicity due to smoke. A variant of EXODUS, called airEXODUS [8], is specifically tailored to aircraft evacuation.

In general, EXODUS and the other evacuation models attempt to precisely compute the values of several variables to predict an evacuation outcome or analyze a real case, but they do not focus on real-time interaction (e.g., interactions that dynamically affect an evolving simulation) and have limited visualization features (e.g., 2D maps or simplified 3D models). In particular, the EXODUS system can be used with vrEXODUS, which is a 3D visualizer of the simulations that operates as a graphics post-processor of previously generated simulations. The Glasgow Evacuation Simulator [9] introduced the possibility of opening or closing routes in real time to test different evacuation paths. Moreover, the simulator supports the visualization of an evacuation using CAD-CAM 3D models of buildings, but occupants are represented only by colored cylinders.

In addition to advancing the simulation domain, improving the realism of graphics and real-time interaction with the simulator would extend the application of evacuation models to training, thus allowing trainees to learn by directly interacting with virtual objects and characters. Moreover, with the help of 3D animations, trainees could virtually experience emergency scenarios that are difficult, expensive and dangerous to reproduce in the real world, thereby getting a better understanding of complex scenarios and cause–effect relationships [10,11]. Systems that employ realistic 3D graphics consider various emergency scenarios such as car accidents with fire and toxic gas propagation in road tunnels [1], smoke hazards in subway stations and schools [12], fire drills in buildings [13], and evacuations of airports [3] and nuclear facilities [2].

2.2. Automatic camera control

Current approaches to the visualization of the 3D simulations discussed in the previous section are based on either placing virtual cameras in the scene at modeling time, and switching between them at run time, or manually controlling a moving camera at run time. However, depending on the spatial complexity of the scenario, even a very large number of cameras or a very skilled manual control will fail to correctly frame certain events, e.g., because of dynamic occluders. Moreover, manually placing the cameras can involve a considerable modeling effort, which in general has to be repeated for each simulation, and manual camera control in real time imposes a cognitive load on the viewer that can distract him/her from the analysis task. Many emergency simulations involve hundreds (or even thousands, as in simulations of the 9/11 attack [14]) of independent characters and many different types of events that are occurring in parallel over an area that could be very large. As a result, it is very hard to select and visualize all of the relevant details of such emergencies with the camera control approaches of current simulators.

Automatic camera control methods could offer a method of addressing these issues. In the following, we analyze the main aspects that an automatic camera control system must consider to present a simulation. For each aspect, we briefly discuss the state of the art and illustrate why current approaches are not adequate for emergency simulations.

The first fundamental aspect is how to find virtual cameras that ensure the visibility of events of interest. Current automatic control approaches can be organized into two main categories: approaches that search for virtual cameras anywhere in the scene and that can consider an arbitrary number of targets [4,15,16], hereinafter called *global solvers*, and approaches that focus on ensuring the continuous visibility of one [17,18] or a few [19,20] dynamic targets and that search only in a region around a current camera. In both approaches, visibility is typically defined in terms of a combination of various visual properties such as target screen size, occlusion, and angle from which the target is observed. In emergency simulations, events might occur anywhere in the scene; therefore, the ability to find virtual cameras anywhere in the scene is substantially more important than ensuring continuity in visualizing the simulation. Unfortunately, most global solvers typically suffer from performance issues because they rely on stochastic optimization strategies (e.g., population-based algorithms) to sample the search space. An exception is a recent proposal by Ranon and Urli [4], who introduced more effective candidate camera initialization and evaluation strategies whereby a single virtual camera can be computed in tenths of milliseconds (instead of hundreds) in quite complex scenes.

The ability to find cameras that can frame various current events of interest is only the first step toward the broader goal of conveying meaning (or at least making it inferable) to a viewer. This topic has been the subject of several research papers, e.g., [21–24], that focus on narrative events and mimic the language of films by encoding cinematographic rules such as typical shots and continuity editing. However, such approaches are limited to film dialogue-based interactions among two or three characters and to consider one event at each time. For example, the *Virtual Cinematographer* [23] and the FILM system [24] are able to film events in real time by selecting among a set of *idioms*. An idiom contains information about the number of targets, shot types and, in the *Virtual Cinematographer*, the timing of transitions between shots to best communicate events, such as three virtual actors conversing, as they unfold. Camera placement is selected among a few