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The Journal of Systems and Software 74 (2005) 255–268
The Journal of Systems and Software
www.elsevier.com/locate/jss

Simulating autonomous agents in augmented reality

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Received 23 September 2003; received in revised form 13 January 2004; accepted 17 January 2004
Available online 28 February 2004

Abstract

In many critical applications such as airport operations (for capacity planning), military simulations (for tactical training and planning), and medical simulations (for the planning of medical treatment and surgical operations), it is very useful to conduct simulations within physically accurate and visually realistic settings that are represented by real video imaging sequences. Furthermore, it is important that the simulated entities conduct autonomous actions which are realistic and which follow plans of action or intelligent behavior in reaction to current situations. We describe the research we have conducted to incorporate synthetic objects in a visually realistic manner in video sequences representing a real scene. We also discuss how the synthetic objects can be designed to conduct intelligent behavior within an augmented reality setting. The paper discusses both the computer vision aspects that we have addressed and solved, and the issues related to the insertion of intelligent autonomous objects within an augmented reality simulation.

Keywords: Simulation; Augmented reality

1. Introduction

Discrete event simulation is widely used to model, evaluate and explore operational contexts of real systems under varying synthetic conditions. Simulation runs can predict the capabilities and limitations of a system which is being designed, its ability to operate under different load conditions, or to predict the performance of a system which is either being modified, or to predict the performance of a system which is being evaluated for future operating conditions. Traditionally, discrete event simulation has concentrated on the algorithmic description and control of synthetic entities which are being modeled as they accomplish some meaningful function. Research in simulation has devoted much attention to appropriate workload representation and output data analysis.

Modern discrete event simulators often use a graphical interface both as an input and as an output medium to simplify and enrich the user's interaction with the simulation both before, during and after the simulation runs. Many simulation tools also provide an animated graphical interface which offers a real-time visual description of a simulation in real time.

A useful and very significant leap forward in simulation technology is to be able to evaluate synthetic simulated conditions in realistic settings. The idea here is to ask questions about "what would happen if ..." in the context of a real environment and actual events. This challenge is the focus of the work addressed in this paper where we mix simulation with reality in real time, in order to examine how novel simulated conditions can actually interact with a real system's operation. This interaction can go in both directions: the course of the real world can be modified by virtual entities, and the virtual objects are constrained to operate in the real world. Mixing reality with simulation in real time raises some very interesting conceptual and practical issues such as:

- How will reality change its behavior as a function of its interaction with synthetic objects, when the real

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0164-1212/$ - see front matter
doi:10.1016/j.jss.2004.01.016

active entities become aware of the behavior of the synthetic entities?

- How will the synthetic entities be programmed to interact with and react to the real (natural) environment?
- How can all these interactions be controlled, programmed and run concurrently in real time?

When one enters into a novel field of research and development to chart unknown terrain, it is both prudent and constructive to base ones work on a practically significant experimental setting, in addition to dealing with the conceptual issues. This is the approach we have taken here. We address some of the issues we have outlined above, and present design principles and solutions in a practical context.

1.1. Augmented reality for training systems

One of the increasingly important application areas of simulation is in education and training, where simulation can be used to illustrate concepts and provide exercises that allow the learner to train in a realistic environment. The use of real scenarios enhanced by "what if" situations offers a very stimulating learning setting for self-learning and self-evaluation.

The use of purely synthetic scenarios in training systems reduces the authenticity of a learning or training exercise, and this can leave the learner with the impression that he/she is interacting with a non-relevant game. The insertion of simulation driven virtual objects in real scenes will offer a higher degree of motivation to the learner, who will face a realistic stimulus approaching that of a real situation under real-time operating constraints. Compared to a real exercise, it will also have significantly reduced costs and hazards. This is particularly true in the field of military training systems where real exercises have costs and hazard levels which approach those of military operations. Important application areas where mixing synthetic and real training environments in a simulation will have major impact on the benefits of the training include:

- medical education,
- transportation system management (e.g., control of multiple aircrafts, control of trains, airport management),
- management of power generation and management systems,
- financial transactions such as trading in stocks and commodities,
- management of communication networks.

Our own work is motivated by the design of embedded training, where the term "embedded" means that the training system is built into the actual operational system, and that the operational system and the training system are designed to be used jointly. Many fields of application for augmented reality-based training systems have a need for real-time interaction between the learner and the augmented reality which is being observed. Augmented reality will include a significant human sensory environment with a visual component, as well as sound, touch, physical motion and pressure, and even smell. Thus, an augmented reality surgical training operation table, could allow the surgeon to sense the smell of blood and of the chemical products which are being used, as well as to feel the pressure of the organs as the synthetic surgical instruments are being applied to the synthetic patient, whose resulting vital signs and endoscopic images are also being shown on an appropriate set of screens.

In the work we present here, we concentrate on the visual component. However, many of the principles that we develop in this work are in fact generic, and they can also be used to deal with other media. For instance, we could consider:

- sound environments mixing real and synthetic sounds,
- a smell environment introducing real and synthetic smells,
- an environment including touch or pressure which are sensed when a human operator manipulates real and synthetic tools,
- or a multi-sensory augmented reality environment combining all five senses.

Another important component of this paper is the set of algorithms that we have designed and used to control the motion of the synthetic objects. This part is detailed in Section 3. These algorithms are based on two principles:

- The collection of objects pursue one or more goals, such as attaining a specific destination or a region in the scene. This element introduces our use of Reinforcement Learning as a means for objects to autonomously try to attain these goals (Sutton, 1988; Gelenbe et al., 2001), based on a Random Neural Network implementation (Gelenbe, 1993).
- Additionally, these objects have a collective behavior which is related to two different aspects: (a) in everything they do, they need to take into account patterns of collective behavior—we approach this through Social Potential Fields (Reif and Wang, 1995); (b) furthermore their collective behavior is also influenced by Imitation of the object which may be perceived as the most effective, or of the leader.

1.2. Organization of the paper

The rest of this paper is organized as follows. Section 2 describes the visual augmented reality system we