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## USAR: A GAME BASED SIMULATION FOR TELEOPERATION

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We are developing simulations of the National Institute of Standards and Technology (NIST) Reference Test Facility for Autonomous Mobile Robots (Urban Search and Rescue) in order to develop and test our strategies for Robots-Agents-People (RAP) team coordination and control. We have shortened the simulation development cycle to a mere two months by using a commercial game engine to provide high quality graphics and dynamics and taking advantage of the sophisticated development environments available for modern games. In this paper we present our architecture and approach for using engineering models, digital photographs, and physical measurements to rapidly produce game-engine based high fidelity teleoperation simulations.

### INTRODUCTION

High fidelity computer-based simulations have been expensive, time consuming, complex, and required expertise to develop and operate. These restrictions have stifled the true potential of such simulations by restricting their use to entities with ample funds, equipment, and personnel in place. By using commercial video game technology we have simultaneously eliminated many of these limitations and increased simulation quality. Using Epic Games Unreal Tournament technology we have produced a virtual environment complete with realistic dynamics and high quality graphics in a remarkably short amount of time and with no specialized equipment.

In this paper we describe a simulation of the National Institute of Standards and Technology's urban search and rescue (USAR) Orange Arena created using the Unreal Tournament computer game. In addition, we discuss our experiences and findings gathered during experiments using our simulated USAR facility to develop and test strategies for simple robotic teleoperation.

### ROBOTICS FOR URBAN SEARCH AND RESCUE

In the wake of the Kobe Earthquake that decimated the Japanese city with the same name, urban search and rescue applications have generated increasing interest. The natural disaster turned the densely populated city into a tangled mass of rubble severely hindering the efforts of rescuers searching for survivors. In response to this disaster the USAR domain has emerged as a canonical task for teleoperation and robotics. The first robot-based rescue simulation (Kitano et al, 1999) emphasized strategic aspects of the problem, but many robotics researchers remained concerned with creating robots to perform the immediate tasks of navigating over rubble, identifying victims, or relaying accurate information back to base. Researchers at NIST responded to these concerns by creating the NIST Reference Test Facility for Autonomous Mobile Robots (Jacoff, Messina, & Evans, 2001) to serve as a testbed to recreate common USAR tasks. Unveiled at the 2000 AAAI Mobile Robot Competition, the USAR facility (Figure 1) consists of three arenas of progressive difficulty:

- The yellow arena: built to resemble an office environment, the yellow arena presents the simplest challenge for USAR robots. The obstacles present are mainly perceptual in nature including mirrors, venetian blinds, heavily shadowed areas, and other confusing textures.
- The orange arena: this scenario contains all the challenges found in the yellow arena. In addition, the orange arena presents more physical obstacles such as debris, stairs, holes, and rubble littered ramps.
- The red arena: designed to resemble an actual disaster zone, the red arena is the most difficult arena to navigate. The terrain is so irregular and haphazard that even rugged robots have trouble traversing it without becoming entangled in debris, stuck in crevices, or rolling over.

These arenas were designed to be portable, modular, and replicable in an attempt to make them simple to reconstruct by researchers and organizers of robotic competitions around the globe.



Figure 1 The NIST UASR Testing Facility. Orange Arena (near) and Yellow Arena (far)

## GAME-ENGINE BASED SIMULATIONS

Though the NIST arenas provide an effective reference task for USAR, they still pose many challenges to researchers including the need for space to put an arena, time to construct an arena, and money for materials to build an arena. In addition, designing, building, and experimenting with a robot in this environment can be time consuming and costly if a design aspect is flawed or ineffective. We believe many of these pitfalls can be avoided by using a computer-based simulation to evaluate the effectiveness of a control strategy or physical component before committing to a design. However, real time “out the window” or “through the camera” computer-based simulations have classically been difficult to create requiring high fidelity graphics and realistic dynamics in order to be believable. Using commercial video game engines, the underlying technology on which computer games are built, high quality simulations can be created at a much lower cost and in considerably less time (Lewis & Jacobson, 2002). In two months, using only standard desktop computers, the Unreal Tournament video game, and with limited prior knowledge of computer graphics we have created a preliminary fully functional simulation of NIST’s Orange Arena (Figure 3) and a collection of robots to traverse it. The simulation described in this paper was originally developed to serve as a testbed to study strategies for teleoperation methods and the coordination of robot teams, software agents, and people for USAR tasks. In the future we hope USAR researchers from other institutions and organizations will use the simulation to pursue their own research related to USAR tasks and robotics.

Epic Game’s Unreal Tournament game engine serves as the backbone for our simulation (Wang, Lewis & Gennari, 2003). The Unreal game engine is implemented with a client/server architecture that allows many clients, known as bots, to be inserted into a common instance of the game and to be remotely controlled over a network. Access to Unreal Tournament over a network is possible due to the Gamebot modification that is the API (Gamebots 2003) that supplies the methods to allow remote operation of a bot to occur. Gamebots is essentially an extension to Unreal’s game engine that allows a client to interface with an instance of the game via a standard TCP/IP connection (Kaminka et al, 2002). A simple text-based protocol built on top of TCP/IP, the Gamebots API makes the full array of commands needed to control a bot available to operators over a network. Using Gamebots API multiple bots, controlled by disparate operators, can interact in a common environment as if they were all being operated locally. The control chain of operator-RETSINA agent (Rectenwald, 2002)-Gamebots-video feedback (Figure 2) replicates the control chain of operator-

RETSINA on Intel Staytem board-robot-video feedback of the experimental robots our team is developing.

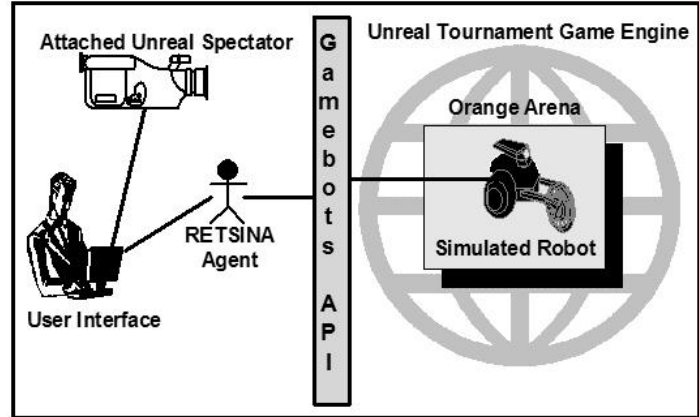


Figure 2 Architecture of Simulated Orange Arena

### Simulating the Orange arena

In November of 2002 a team of ten researchers visited the NIST USAR facility to collect data needed to construct the simulation and identify design requirements necessary for robots to operate in these environments. As the middle arena in the hierarchy of difficulty, the orange arena poses some very interesting challenges to both robotic locomotion and perception. To produce a useful simulation of this arena we had to accurately duplicate these challenges so the same affects they have on operators of actual robots will be experienced by operators of simulated ones. These obstacles include stairs, dim lighting, a limited field of view, low-bandwidth video (e.g. 1.5 frames/second), and confusing textures such as clear plastic and mirrors. In addition, an assortment of rubble and debris has been created and scattered throughout the simulation. Pipes, bricks, paper, and plastic netting have been simulated with the properties and attributes needed to govern how they interact with robots in the simulation. Robots may become tangled in the netting, stuck on a pipe, blocked from a victim by a brick, or lose traction on paper littered on the floor. The team returned from NIST’s facility with a collection of observations and data including CAD models, physical measurements, luminance measurements, and digital photographs of the arenas. The ProEngineer models were simplified and converted to a format suitable for high frame rate animation using Nugraf to 3D Studio Max. Once processed, the CAD models were re-exported in Unreal Tournament format and inserted into the game. The digital photos taken were inserted directly into the simulation as textures for the arena walls, floors, and lighting. Finally, a collection of victims including full and partial human bodies were constructed and placed in the arena.

Based on the victims found in the actual arena, the simulated victims boast realistic physical appearances and dynamics. In the future we hope to extend the malleability of objects in the arena to allow experimenters to quickly reconfigure walls, redistribute the victims, and generate new and more challenging obstacles.



Figure 3 Simulated Orange Arena

### Simulating Robots for the Orange Arena

Controlled by a combination of human operators, the Gamebots API, and RETSINA agents, simulated robots can easily be created and inserted into the virtual arena with incredible ease and at practically no cost. Vehicle dynamics are based on the physical dimensions of the vehicle itself including the type and size of wheels used, the robot's frame, the mass, and center of gravity. In parallel with the development of this simulation a team of researchers at Carnegie Mellon University (CMU) developed a physical replica of the orange arena complete with a collection of robots. The simulated robot developed for the simulation (Figure 4) models a two wheeled robot designed by the CMU team to navigate through rubble. The dynamics and physical dimensions of the simulated vehicle are based on the dynamics and dimensions of the actual one. This allows the proposed design to be evaluated in a believable facsimile of the robot's operating environment before actually being implemented.



Figure 4 Example Robot in the Simulated Orange Arena

A camera feed is obtained from the simulation by running an additional copy of Unreal Tournament in spectator mode and attaching this view (camera) to the robot. By harnessing this view we can create a "through the camera" user interface for teleoperation. The robot control interface (Figure 5) controls both our robot simulation and an experimental robot built at CMU complete with the same controls, FOV, and camera control. Features found in the simulated interface include headlight controls, low-bandwidth video (1.5 frame/second), an attitude indicator, a battery level indicator, and a communication link level indicator. Synchronization between the interface and the state of the simulation is assured because feedback from the game engine is transmitted in the order of one packet per tenth of a second. Although the current simulation provides an accurate model for teleoperation future versions will require sophisticated sensor models including ultrasonic, laser based, and heat sensors to simulate varying levels of robot autonomy and safeguarding.

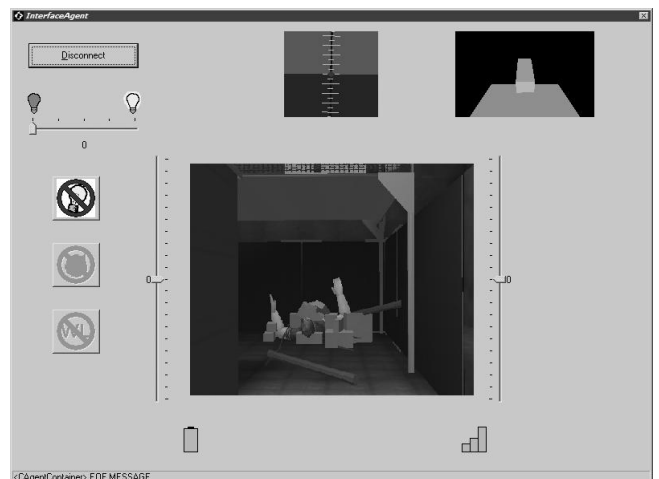


Figure 5 Simulated Interface for Teleoperation

## INITIAL FINDINGS AND DISCUSSION

Research involving the operation and control of remote vehicles ranges from exploration of harsh environments such as planetary exploration to searching disaster areas by traversing haphazard rubble filled environments to find victims.

In the initial stage of our research we are using our simulation to experiment with control and aiding strategies affecting teleoperation of mobile robots. In the USAR environment robots must be small with little capacity for heavy or large components. These limitations are complicated by the components available, the capacity of available communication channels, and financial restrictions that may be imposed on expendable robots. As a result USAR robots are frequently forced to operate with low-bandwidth video feeds and limited sensing capabilities. In addition, imagery from fixed cameras may limit an operator's field of view complicating the task of identifying objects and target recognition (Hughes & Lewis, 2002; Casper, 2002; Tittle, Roesler & Woods, 2002). In fact, Murphey's (2003) leading conclusion from experience operating robots at the World Trade Center site was that the greatest difficulty in USAR involved perception and identifying victims rather than locomotion or navigation.

Another common problem encountered in teleoperation is situational awareness or the lack thereof. In a review of experiences teleoperating robots at Sandia National Laboratory McGovern (1991) reported that all accidents for egocentrically (camera) guided mobile robots involved rollovers, usually by an operator unaware of the accident's imminence. In comparison to McGovern's testing grounds, the Orange Arena contains more rigorous and potentially hazardous obstacles such as stairs, gaps, shadows, confusing textures, and debris to confuse the operator's judgment of attitude.

Even when operators are given full control of five degrees of freedom (two position, three view) they may still become lost (McGovern, 1991), perceptually disoriented (Casper, 2002), and encounter trouble processing survey information (Hughes & Lewis, 2002). Our initial studies are concentrating on perception, control, and situational awareness for teleoperation. One of the most difficult tasks confronting a teleoperator is controlling the camera that must be used both to navigate the robot and search the environment. A fixed camera reduces confusion by always showing the operator what is in front but makes exploration difficult because the robot must be repositioned to acquire new views. A moveable camera by contrast makes visual exploration easy but may be disorienting when the camera is pointing somewhere other than the direction of movement. In an experiment to be

reported in Hughes et al. (2003) we compared coupled and decoupled camera views for a navigation and search tasks similar to USAR finding best performance in a condition in which separate cameras were dedicated to search and navigation. In a second ongoing study we are comparing gravity-referenced video window with a separated display for attitude control. In the gravity-referenced display the visible parts of the robot provide an indication of attitude that may be less confusing than the normal "out the window" camera view. The gravity reference acts to convert the egocentric camera view to an exocentric one. So far the USAR simulation has proved useful for both of the functions for which it was designed. It has provided a proving ground for testing ideas for incorporation in real robots and served as a tool for investigating more general issues in teleoperation. When sensor models are incorporated it will become capable of supporting a full range of robotic experiments involving automation, cooperation and control of multiple robots.

We have developed a simulation of the NIST's orange arena using commercial video game technology. Using Unreal Tournament's game engine and the Gamebots API in conjunction with the RETSINA agent framework we have created a simulation that provides researchers with a high quality affordable testbed to evaluate the design and performance of remotely operated robots in urban search and rescue environments. Though our work has initially been focused on developing control strategies for teleoperation, we hope to eventually extend our research to more complicated issues including cooperation robot teams for USAR and developing strategies for autonomous control.

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