RECCOMMENDATIONS FOR CONDUCTING REAL-TIME HUMAN-IN-THE-LOOP SIMULATIONS OVER THE INTERNET

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Distributed simulations can improve the cognitive fidelity of simulated task environments because more operators can be added to the simulation without greatly increasing its cost. We report here on the development and execution of a distributed simulation/demonstration of ROVs flying in terminal airspace in order to investigate the feasibility of ROV flight in terminal airspace, and the feasibility of conducting simulations over the internet. The simulation involved pilots located at CSAAT, an aviation research lab at California State University Long Beach, and the Flight Deck Display Research Laboratory at NASA Ames Research Center, flying ROVs over the internet in a simulated airspace. We describe the procedures used to develop the simulation and offer recommendations for improving future simulations over the internet.

The development of flight simulator design throughout most of the last century was driven by the perceived need for greater physical fidelity (Lee, 2005). In fact, most uses of the term "fidelity" applied to the field of aviation simulation are referring to the realism of motion acceleration, handling, visual views, audio feedback, etc., of the simulator. The FAA classification schemes for simulators currently are based on fidelity of physical and sensory information.

The fidelity of modern flight simulation depends on more than physical and perceptual fidelity, however. Flight simulators must take into account the realism of the pilots' tasks, including, information acquisition and integration, decision making, problem solving and other cognitive activities. Lee (2005) refers to this characteristic of simulation as "cognitive" fidelity. Cognitive fidelity depends on the design of the simulator and the task environment. It is measured as the degree to which the task environment places cognitive demands on pilots that are comparable to those experienced in operational aircraft. For example, it has been shown that realistic radio communications are required for achieving cognitive fidelity by increasing pilot workload. Instead of a single role player (often the instructor in training simulations), realistic voice communications require air traffic controllers and pilots to create realistic "party line" effects (e.g., Lee, 2003).

Prevot (2002; Prevot et al., 2002) suggested that adding more air traffic management roles to a simulation will improve cognitive fidelity. According to Prevot, additional traffic management roles can be added either by automating roles that are not the focus of the research (e.g., automating ATC communications in a cockpit simulation), or by adding more role players to the simulation (e.g., adding more air traffic controllers to a simulation). Greater flexibility and fidelity is achieved with the latter solution, because automating tasks realistically can be costly. However, the greater flexibility achieved with the addition of role players can be expensive because these players require interfaces that may be different from the cockpit interface, and these interfaces must be networked with the simulation. Moreover, maintaining a pool of highly-trained, operationally-experienced simulation role players adds to the cost.

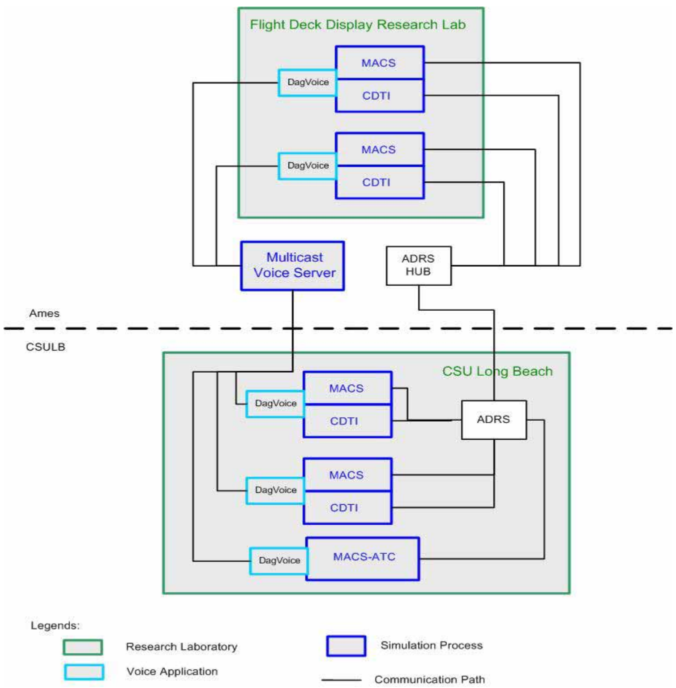
Distributed simulations are a promising method of improving cognitive fidelity while minimizing cost. Although the concept of distributed simulation is not new, previous distributed simulations normally involve facilities within the same organization, for example, the distributed simulations conducted by NASA Ames and NASA Langley (e.g., Johnson et al., 2005). In the distributed simulation being reported here, a federal research lab, NASA Ames Flight Deck Display Research Laboratory, and a research laboratory, Center for the Study of Advanced Aeronautic Technologies at California State University, Long Beach, located approximately 400 miles to the south participated in a joint simulation of ROVs in terminal airspace. Simulations of remotely operated vehicles (ROVs) in the national airspace system (NAS) seem optimally suited for distributed simulations with high levels of cognitive fidelity because little or no "out the window" information available in operational ROV workstation environments.

Therefore we developed a distributed simulation consisting of pilots flying ROVs in a simulated airspace over the internet to meet the demands of cognitive fidelity.
We discovered distinct advantages to this arrangement and also faced unique challenges that were not related to the hardware, software and ROV operational environment. In this paper we will discuss this method of distributed simulation, and provide recommendations for increasing the efficiency within which such simulations can be realized. We will describe the simulation components and offer recommendations for future distributed simulations.
This will be followed by a discussion of advantages and disadvantages of distributed simulations.

Method

Simulation Architecture

The ROV simulations were conducted over the internet, utilizing flight simulation software developed at NASA Ames Research Center, and distributed to CSAAT at Cal State Long Beach. The networked simulation system consisted of four main components: the Aeronautical Datalink and Radar Simulator (ADRS), the Multi-aircraft Control System (MACS), the 4D-Cockpit Situational Display (4D-CSD), and the Flight Simulation Voice Over Internet Protocol (DagVoice), as illustrated in Figure 1.



Each pilot workstation consisted of two Desktop PCs. One workstation hosted the MACS software and one hosted 4D-CSD and DAGVoice. Kavoom! KM mouse/keyboard software switches were installed on each workstation pair to provide single keyboard and mouse control of both workstations. A PCI sound card or external sound card was used for the Voice-Over-IP operation. These pilot workstations were put on open network, with the firewall suppressed, which was essential for the transmission of TCP/IP data and the UCP voice packets without interruption during the simulation. The function of each software component is as follows.

- **ADRS:** A software process that routes information amongst client processes during a simulation (Prevot, 2002). Each flight simulation process (MACS, CDTI, etc.) is connected to an ADRS in order to communicate with other flight simulators and ATC. In the present simulation, two client ADRS processes served as proxy routers for pilot and ATC workstations at CSAAT. These communicated with the ADRS Hub at FDDRL, where the traffic scenario was run. The ADRS provided data about precise aircraft positions and states, flight plans, four-dimensional trajectories, controller inputs, air traffic management information, simulated radar targets, aircraft guidance inputs and health status information.

- **MACS:** A research tool, developed by the Airspace Operations Laboratory at NASA Ames Research Center, that is used for distributed real-time air traffic simulations, rapid prototyping, and concept evaluation (Prevot, 2002). MACS can be configured for several cockpit interfaces and operating modes. In the present simulation, MACS emulated the Boeing 777 cockpit for ROV pilots and a TRACON ATC workstation for the confederate ATC at CSAAT in Long Beach.

- **4D-CSD:** The 4D CSD is an advanced cockpit situation display that provides a volumetric representation of the surrounding three-dimensional traffic environment (Canton et al., 2005; Dao et al, 2006). Information that is inherently three-dimensional, such as traffic information, may be displayed in either a planar format (2-D, top down) or a perspective format (3-D depiction on a 2-D surface, where perceptual depth cues are utilized to provide information about depth). The CSD was augmented with a simulated terrain data base showing artificial ground objects. The location, size and shape of the lakes in the simulation were realistic and accurate, to provide accurate information for accomplishing the ROV mission.

- **The Route Assessment Tool (RAT)** affords the ROV operators the ability to probe the airspace for potential conflicts and then make flight plan modifications. The RAT is used in conjunction with the 3D CSD which displays proposed flight plans and probed potential conflicts as operators make modifications to their filed routes. The detection of potential conflicts is invoked by another tool called the Conflict Detection and Resolution tool, or CD & R. The conflict alerting algorithms used to enable conflict detection were adapted from Kuchar logic (Canton et al., 2005).

- **DagVoice** is a flight simulation voice over internet protocol (FS-VoIP) capability developed in the FDDRL to support air traffic simulations and concept testing. This multicast, multichannel communication system emulates ATC radio communication in a laboratory environment.

Procedure

The simulation was developed to evaluate ROV flight issues with minimal modifications to the existing software. The ROV mission was to patrol lakes near the DFW airport, while avoiding approach traffic. ROVs were simulated as Cessna 172s having flight parameters similar to operational low altitude ROVS such as the U.S. Army Shadow. Flight procedures and rules of the road were developed jointly by weekly practice simulation runs over a six-month period, directly preceeding the simulation (Battiste et al, this volume). Pilot training was relatively brief because all pilots had participated in previous simulations at NASA Ames. However, as discovered during the simulation, the pilots could have benefited from additional training (Vu et al., this volume). After the one day of training at NASA Ames, two pilots flew to Long Beach and two remained at NASA Ames. The simulation commenced the following morning. A schedule of simulation runs was developed that provided complete crossing of all conditions, and minimized the time pilots spent at the respective simulation facilities.

Performance was measured with a combination of software and paper-pencil instruments. Pilot interactions with MACS and CSD were captured with Camtasia Screen Recording Software running in the background. Airspace system data was obtained with a separate MACS station running in Data Collection mode. Information regarding conflicts (e.g., level, time, intruder) were logged in 4D-CSD file formats and extracted off line after the simulation.

Results and Discussion

Data on the feasibility of ROVs in terminal airspace, usefullness of advanced CSDs and multiple ROV control issues were reported in previous papers in the symposium. As this was one of the first simulations of its kind conducted over the internet, we identified many issues that can affect the effeciency of distributed simulations and suggest methods of improvement. These can be categorized as hardware/ software, procedural and design issues. Surprisingly, communication between various software and simulation processes was relatively fast and smooth. Communications between the human experimentors and pilot participants at each facility was much less efficient, however.

Hardware, Software and Infrastructure Recommendations

Use identical hardware configurations. Although NASA FDDRL had been using this software in DAG TM simulations for several years, this was the first opportunity for CSAAT to install and use the software. Installing ADRS, linking CSAAT ADRS clients to the NASA hub, linking and flying CSAAT workstations in NASA's simulated airspace, and linking VoiceIP was greratly facilitated by the superior design of NASA simulation tools. Moreover, CSAAT purchased near-identical hardware for its simulation facility. In fact, our hardware was purchased from a NASA vendor and only after the hardware specifications were approved by NASA. The advantage of having identical hardware became immediately apparent when any operational problems arose; harware failures were quickly eliminated as their cause. Troubleshooting was also improved by installing remote access software (e.g. Real VNC) because engineers at one site could see the configuration of a remote site via the internet.

Initial tests of digital communication speeds using test scenarios were positive, as delays were withing acceptable limits. Lags in VoiceIP communications were noticeable only when we were also connected by telephone. Of course, these digital communication speeds were obtained without encrypting data packets. Obtaining acceptable digital communications speeds over secure networks may involve additional time and resources.

Procedural Recommendations

Whereas digital communications were acceptable, human communications were at times difficult and inefficient. The geographic distance between the organizations prevented regular meetings: at best, face-to-face meetings occurred every 2-3 months over the 12 month simulation development period, and only with a small subset of team members. In addition, documents and software were distributed primarily via email, which made it difficult to ensure that each facility always had the latest versions. The following recommendations are directed at improving communications and coordination between distributed organizations.

Establish an audio and visual communication link for developers, experimentors and test pilots that is fast and reliable. Our major communication method throughout the development and execution of the simulation was a conferencing telephone located in each lab. We also utilized Microsoft Netmeeting for visual communications, but the research workstations within each facility were spread out and not everyone was always in camera range. Consequently, communications were often difficult. Moreover, pilot debriefing sessions were less informative because of the difficulty in exchanging information. Our future simulations will be facilitated by establishing a reliable audiovisual communications channel within each simulation laboratory. The communication system should link all rooms (testing, debriefing, etc.) at each facility, so that communication is simple and natural.

Create and maintain a digital repository of simulation software, paper forms and data files used in the simulation. As both the method and purpose of the simulation were new, software was updated frequently, simulation procedures were continually being refined and paper instruements were often changed. Our primary means of exchange software and documents was email. Email limited the size of files that could be sent and made it difficult to keep track of the latest versions of frequently updated documents. We recommend, therefore, that a digital repository such as an FTP or Web site be established, with the responsibility for its maintaince clearly defined. This site would ensure that all workstations were configured with the latest software versions and configurations. Possibly, a central hard drive image could be stored here. Therefore, the complete workstaion configuration (i.e., graphics settings, file structure) would be identical across organizations.

This repository should also contain the latest versions of paper and pencil instruments to ensure that all experimenters are using the same versions throughout the simulation. The data base could serve as a central storage location for the performance logs and pilot videos collected after the simulation so that all distributed organizations have equal access to the data.

Establish a formal readiness procedure that will determine when the simulation is ready for test participants. Although minimal modifications to existing software were required in this project, inserting ROVs into the existing software did require some changes. For example, terrain was added to the 4D-CSD to provide a view of the lake. Other changes involved adjusting flight parameters for terminal airspace rules of the road. In future simulations we expect greater software and procedural modifications, and recommend that a formalized procedure for determining what critical problems or roadblocks need to be overcome for a successful simulation along with possible solutions to the problems. Critical problems during the development of the simulation would be identified, acceptable solutions to each problem determined and specific criteria for determining when a problem is considered solved would be established. Moreover, it would determine when to freeze the simulation so that pilot and experimenter training could commence.

Simulation Design Recommendations

Distributed simulations will be effective only if it can be shown that the effects of independent variables are not confounded with the test site. That is, one must be sure that superior performance is caused only by the specific experimental condtions, and not by the location or organization where some conditions were run.

Control and assess differences in performance between test sites. Counterbalancing and randomization techniques can prevent confounding simulation location with the effects of independent variables, but effective distributed simulations require that participant performance is equivalent across organizations. Assuming compatible hardware and infrastructure, performance differences may be due to training or procedureal differences between organizations. To eliminate these effects, it is important to establish formalized training procedures so that test particpants, confederates and experimenters at each organization are equally prepared. For example, in our simulation, all pilots were trained at NASA Ames before some travelling to Long Beach. A more practical solution, however, would be to train pilots together over the digital network.

Other strategies that can be used to minimize or at least measure organizational differences inlcude running a sufficent number of participants at each organization, and establishing performance baselines prior to test runs. In the present simulation one pilot performed consistently poorer than the remaining three pilots. As only two pilots were tested at each location, it is impossible to determine if this pilot's poorer performance was due to differences in ability or the idiosyncracies of one test site. With a baseline assessment of each pilot at the test site, individual performance differences might have been determined.

Summary and Conclusions

We found that distributed simulations between diverse organizations can be an efficient method of providing higher cognitive fidelity because the cost of adding more role players can be spread across the organizations involved. For example, if some roles require highly trained individuals, organizations can be chosen for the distributed network based on the availability of trained operators. Possibly, one organization with a pool of air traffic controllers could be networked with another organization having trained pilots or ROV operators. Or, an air traffic control simulation could be developed by networking ATC organizations located within each sector being simulated. This would provide access to air traffic controllers with knowledge of the airspace in the geographic area.

In future simulations we plan to add more roles over the internet, for example, ROV payload operators, air traffic controllers and airline pilots, in order to improve the cogntive fidelity of our simulations. We expect that these future simulations over the internet will be facilitated by implementing the recommendations discussed here.

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