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AN AUGMENTED REALITY UAV-GUIDED GROUND NAVIGATION INTERFACE IMPROVE HUMAN PERFORMANCE IN MULTI-ROBOT TELE-OPERATION

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ABSTRACT

This research proposes a human-multirobot system with semi-autonomous ground robots and UAV view for contaminant localization tasks. A novel Augmented Reality based operator interface has been developed. The interface uses an over-watch camera view of the robotic environment and allows the operator to direct each robot individually or in groups. It uses an A path planning algorithm to ensure obstacles are avoided and frees the operator for higher-level tasks. It also displays sensor information from each individual robot directly on the robot in the video view. In addition, a combined sensor view can also be displayed which helps the user pin point source information. The sensors on each robot monitor the contaminant levels and a virtual display of the levels is given to the user and allows him to direct the multiple ground robots towards the hidden target. This paper reviews the user interface and describes several initial usability tests that were performed. This research demonstrates the development of a human-multirobot interface that has the potential to improve cooperative robots for practical applications.*

INTRODUCTION

Multi-robot systems can often deal with tasks that are difficult for single robot. For example, teams of robots may be able to complete tasks such as multipoint surveillance, cooperative transport, and explorations in hazardous environments more efficiently. Additionally, time-critical missions may require the use of multiple robots working simultaneously to efficiently accomplish the tasks.

Controlling multiple robots is a challenging human-operator task. In multi-robot scenarios, one of the main challenges for a human operator in search and detection missions is to remotely control the semi-autonomous robots [1]. Thus, there is a need to research and develop technologies that can enable an operator to control groups of semi-autonomous robots.

Most human-robot interfaces for robot control have focused on providing users data collected by the robot and giving status messages about what the robot is doing. The conventional interface consists of several separate display windows to show information from the robot. [2] is an example of a conventional display from the Idaho National Laboratory (INL). The display may require the operator to integrate information, and this may increase the operator's workload. Another example of a conventional interface for multiple robots control was designed by Humphrey et al. [3]. Operators may have high workload from needing to simultaneously integrate each multiple status bar.

An alternative to conventional interface is a 3D virtual environment display based on a robot simulation. In contrast to direct interfaces, a virtual environment provides an external perspective which allows the operator to see the environment and drive the robot from viewpoints generated by the interface. Nguyen et al. [4] describe several Virtual Reality (VR) based interfaces for exploration, one of which is Viz. Viz has shown that VR interfaces can help the user understand and analyze the robot surroundings and improve the operator situational awareness. However, in virtual environments, the operator's attention is drawn away from the actual environment which can reduce situational awareness and dynamic situations not modeled in the VR world could pose significant problems.

In contrast to the virtual environment display, Augmented Reality (AR) is an advanced visualization technology which allows computer generated virtual images to merge with physical objects in real time. Unlike VR, the user enters and interacts with computer-generated 3D environments. AR allows the user to interact with the virtual images using real objects [5]. Researchers in robotics are beginning to use AR techniques in robotics because it provides direct views of the scene combined with the advantages of virtual displays for human-robot collaboration [6-8].

Communicating to robots and human, on the other hand, touch-based input may allow users to perform complex tasks in an intuitive manner [9]. Micire et al. [10] studied the control of a single agent with a multi-touch table. Moreover, a multi-touch (DREAM) controller [11, 12] using a multi-touch table is developed for multi-robot command and control [13, 14].

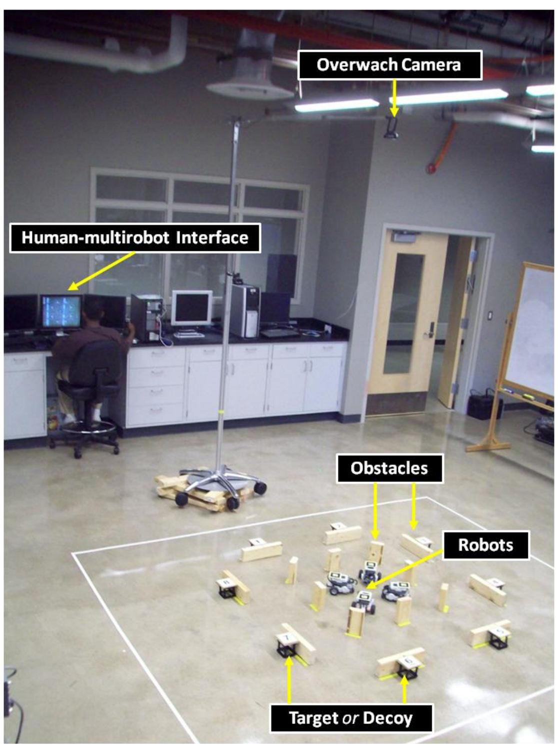

Figure 1: A group of semi-autonomous robots is controlled using the human-multirobot interface.

We have developed a system to combine virtual and augmented reality interfaces capabilities with human supervisor's ability to control the robots [15]. The role of this human-multirobot interface is to allow an operator to control group of heterogeneous robots in real time and in collaborative way. This paper presents results from a user evaluation of the real multiple robot system in which three interface conditions were evaluated (i.e. Joystick, Point-and-Go, and Path Planning). Results show that the novel multi-robot control (Point-and-Go and Path Planning) reduced their mission completion times compared to the traditional joystick control for target detection performance.

SYSTEM DESCRIPTION

The system hardware configuration is shown in Figure 1. The human-multirobot interface (see Figure 2) is a top-down view from the stationary camera. We assumed that the top-down view could be taken from a manned or unmanned aerial vehicle.

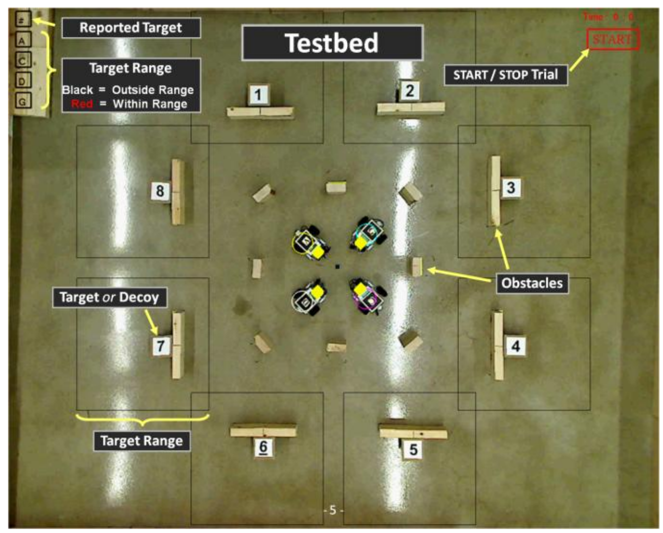

Figure 2: The human-multirobot interface is a top-down view from the stationary camera. We assumed that the top-down view could be taken from a manned or unmanned aerial vehicle.

Hardware

Four Mindstorms NXT robots were used as the remote robots. The NXT robot includes two NXT motors with encoders used for differential drive and a third passive caster wheel to maintain balance. An infrared sensor with a 240 degree view is attached on the NXT robot (see Figure 3) to search and detect infrared beacons. A marker on top of a NXT robot is used for position reading of the multi-robot system and for viewing robot status using AR software. The NXT robots are controlled through a Bluetooth connection.

A HiTechnic infrared electronic ball was used as a contaminant source. The infrared ball was hidden by one of the decoys.

The testbed was equipped with a Logitech Webcam Pro 9000 with autofocus to obtain video frames at a resolution of 1280x1024 and at a refresh rate of 10 frames/ sec. The video was displayed on a 17" liquid crystal display (LCD) computer monitors.

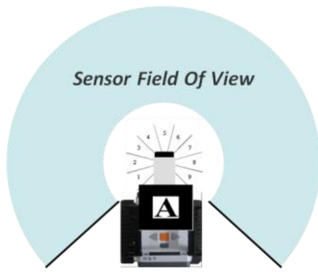

Figure 3: A marker is attached on the top of a NXT robot. The marker is detected by AR software to measure a robot position and to generate virtual images to merge with a robot in real time. An infrared sensor with a 240 degree view is attached on the NXT robot to search and detect infrared beacons.

Software

The ARToolKit augmented reality system is used to determine the position and orientation of each robot. A marker is attached to the top of each robot. Client-server system for data communication has developed in the testbed. The robot server is programmed to communication with NXT robots using Bluetooth. AR client delivers localization data obtained from an overhead camera to ground robots, and it displays the synthesized views. Visual C++ in Visual Studio 2008 is the programming language used for AR and robot communication API software development. Not eXactly C (NXC) in Bricx Command Center is the programming language used for NXT robot to configure the infrared sensor and robot communication.

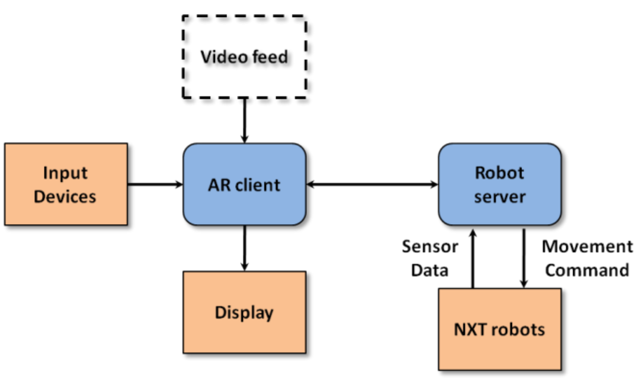

Figure 4: AR client programs share robot state information and display the synthesized view. Robot server programs read robot sensor data and send movement commands.

AR INTERFACE FOR MULTI-ROBOT CONTROL

This section describes three features of the interface used for user evaluation. First, we describe the Point-and-Go algorithm developed for multi-robot control and the Path Planning implemented for obstacle avoidance. Then, we describe the joystick control of the multiple robots. Finally, we explain the sensor data and robot messages visualization.

Point-and-Go Mode

A point-and-go algorithm is developed for single human operator controlling multiple robots. The operator is able to select any ground robot using a mouse left click, and then designates a goal location in the video feed from an overhead camera (see Figure 5). A navigation algorithm is developed that allows the robot turns toward the desired goal location, drive straightly toward the goal, and then stops at the target.

If a robot is stuck with an obstacle, the user is able to reverse the robot using mouse right click (see Figure 5).

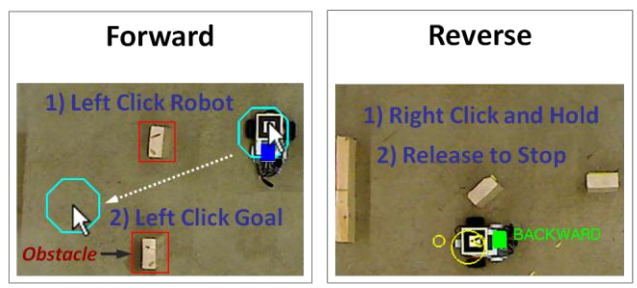

Figure 5: Point-and-Go is a high level instruction that allows an operator to control multiple semi-autonomous robots simultaneously.

Path Planning Mode

An A* algorithm path planning algorithm [16] is implemented to the system. The A* algorithm allows the multiple robots to traverse to the target location with obstacle avoidance and shortest path.

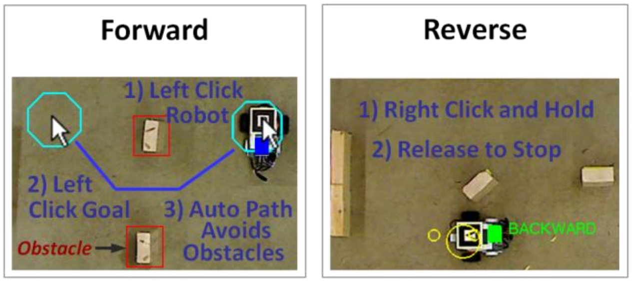

Figure 6: The path planning algorithm allows the multiple robots to traverse to the target location with obstacle avoidance and shortest path.

Joystick Mode

A joystick (ExtremeTM 3D Pro; Logitech, California) was used to manipulate the direction in which the robot moved when in joystick mode. The joystick push-pull axe was used to control the forward and back movements for translation of the robot, and the joystick rotation (twist left, twist right) axe was used to control the turn left and turn right movement for rotation of the robot. Four corresponding joystick buttons were used to select the robots.

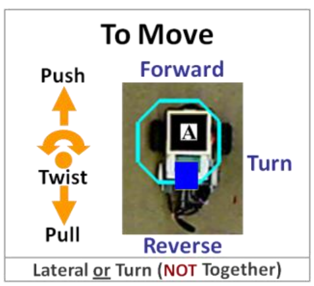

Figure 7: Push / pull the joystick to move the robot. Twist the joystick to turn the robot.

Sensor Data and Robot Status Visualization

The AR interface displays virtual sensor pebbles from each robot in real-time and drop the pebbles on the robot's path of its traverse to generate a sensor network. It allows operator using the visual sensor network information to direct the multiple ground robots towards the infrared source. The capabilities allow the robots to localize multiple sources simultaneously.

The AR interface also provides users data collected by the robot and giving status messages about what the robot is doing. If the robots are unable to maneuver around an obstacle, the AR interface will also display "Help" message when the robot calls for help from the operator to identify the obstacle.

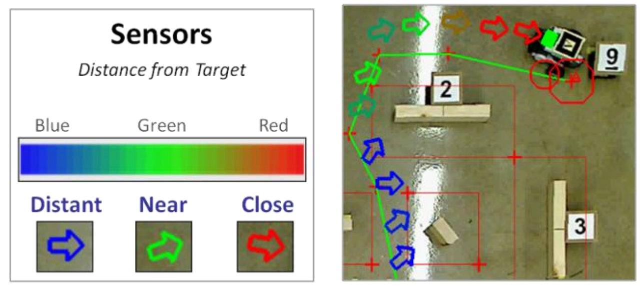

Figure 8: The robots detect infrared signals and drop "pebbles" when in motion. Arrows indicate direction and distance to a source.

EXPERIMENTATION

Experimental Design

Evaluations were performed for three interface conditions: Joystick, Point-and-Go, and Path Planning. Three trials were run at each condition, for a total of nine runs per subject.

A within-subjects design was selected to avoid participant variations such as spatial ability, with a number of protections against order effects:

1) The conditions were tested in counterbalanced order;
2) Participants received condition-specific training prior to each set of trials and met proficiency standards; and
3) Measured rest time was employed between conditions to counter operator fatigue.

Apparatus

All trial runs were conducted on a square testbed. Eight identical numbered boxes were placed at fixed positions, two per side of the testbed, equal distance from the center of the course. A total of sixteen obstacles were located between the boxes and the center of the testbed. Eight equal size barriers served as fixed points against which the boxes were positioned, impeding both the physical path and line-of-sight to each box.

Four otherwise identical mobile ground robots were marked with black upper case letters against a white background for the purpose of identification by the operator. The robots were initialized in a square formation at the center of the testbed prior to each trial, with each pointing to the nearest corner to ensure equal traveling distance to the nearest two numbered boxes. The testbed layout and initial robot poses were symmetrical about four axes, corner to corner and side to side.

For each trial, one numbered box was randomly assigned as the target and a concealed infrared source placed inside. The remaining seven boxes served as decoys during the trial. Sensors integrated on the robots detected signal strength and direction to the signal origin with respect to the robot frame of reference.

The sensor data was relayed to the system interface and control software, with noise introduced to simulate target dispersal and environmental effects on signal integrity. Detection vectors were displayed as overlay graphics on the video interface, pointing toward the apparent signal source with a color range indicating signal strength.

Measurements

Data acquisition during each trial captured time-stamped operator input and system status change events, along with the position of all four robots. These objective data were collected to enable analysis of task completion times, identify source times, and neglect times. Demographic information, subjective workload per trial, and subjective usability per condition were also collected for analysis.

Trial Tasks

For all trials, including one practice and three evaluation trials per condition, the participant was given two tasks:

- Locate and Report the Target
- Move Robots within Target Range

As the robots were navigated by the operator through the testbed environment, sensor information on the video interface provided indications of where a randomly assigned target was positioned. Potential targets not assigned served as decoys. Subjects were instructed to report the suspected target by pressing the number key on a computer keyboard corresponding to the box number of the suspected target.

Upon reporting the target, participants were tasked with moving all robots to within a target range defined by a rectangular perimeter around the target. Color changing display icons, one for each robot, indicated when the range task was completed.

Once the correct target had been identified and all robots successfully navigated into range, a status icon alerted the operator to report completion of all tasks.

Practice trials consisted of searching for one target among three decoys with two robots. Evaluation trials consisted of searching for one target among seven decoys with four robots.

Participants

Counterbalancing of three conditions necessitates a participant population size that is a multiple of nine. 18 naïve subjects from the student and faculty bodies of Wayne State University took part in the experiment, with varying exposure to human robot interaction. All participants were treated ethically, took part in the study voluntarily, and were assured that results will be kept anonymous and confidential.

Procedure

Each participant took part in one session, approximately two hours in duration. Subjects first read a Research Information sheet explained the general scope of the experiment and the voluntary nature of his or her participation.

A. Pre-Evaluation

A questionnaire was administered prior to introducing the specifics of the experiment to collected demographic data and self-assessments of exposure to automobile driving, video game play, remote control devices, and mobile robot operation. The subject next viewed a self-paced presentation introducing the format of the experiment and summary of tasks to be performed.

B. Condition Cycle

A common test cycle was followed for all three interface conditions. The interface familiarization, evaluation trials, and workload assessments were administered sequentially for each condition to counter order effects in memory.

1) *Familiarization*

   A self-paced presentation provided specific instruction on how to operate the interface condition under evaluation. The material also covered the display and interpretation of sensor and status indicator graphics.

   A practice trial was conducted with a limited search task to familiarize the subject with the interface and task performance. Two robots were placed at the center of the testbed and one target was randomly selected among four potential targets.

   Participants were required to meet a timed proficiency standard established by pilot testing. The practice scenario was repeated until proficiency was demonstrated.

   A summary of the interface remained visible for reference during all practice and evaluation trials.

2) *Evaluation Trials*

   Once proficient with the interface under test, subjects performed three evaluation trials. Four robots were place at the center of the testbed and one target was randomly selected among eight potential targets.

3) *Between Conditions*

   A two minute break was administered after the first and second conditions. Following the third condition, the session advanced to post-evaluation without a break.

C. Post-Evaluation

After completing all trials, participants appraised the usability of all three interface conditions. Operators answered questions on a seven point scale to assess five usability factors: learnability, efficiency, memorability, errors, and satisfaction. A comments field at the end of each usability assessment provided an opportunity for long form feedback. Lastly, participants were asked to select an interface condition preference and provide rationale for their selection.

EXPERIMENTAL RESULTS

The analysis showed that the task completion times were significantly reduced in the Point-and-Go condition (see Figure 9).

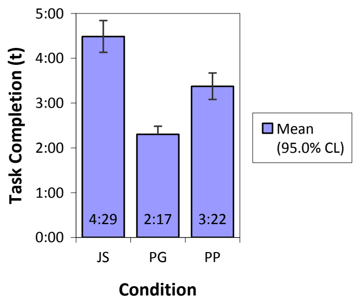

Figure 9: Task completion times

The analysis of the operators' source identify performance revealed that participants reported the target faster in the Point-and-Go condition than in the Path Planning condition and in the Joystick condition (see Figure 10).

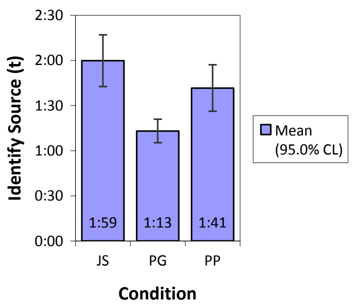

Figure 10: Identify source times

The joystick designed to allow an operator to control only one robot at a time. For the reason the neglect time was much longer in the Joystick condition than in the Path Planning condition and in the Point-and-Go condition (see Figure 11).

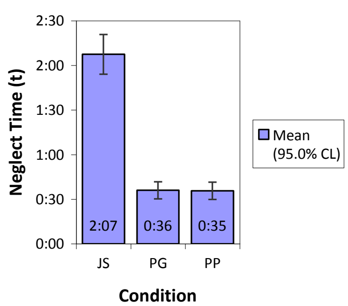

Figure 11: Neglect times

CONCLUSION AND FUTURE WORKS

In the current study, we investigated the different interface conditions on human operators' performance of control multiple robots to complete target detection task. Result show that the AR navigation interface has the potential to improve operators' performance to control groups of semi-autonomous robots in search and detection mission.

The next step in this research is to obtain video frames from an UAV. Since the camera is not in a fixed position, a fiducial marker on the ground plane will be used for a reference point. An AR Drone quadricopter will be used for this research.

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