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VIRTUAL INTERFACE WITH GUARDED TELEOPERATION CONTROL OF MULTIPLE HETEROGENEOUS ROBOTS

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ABSTRACT

The objective is to develop a human-multiple robot system that is optimized for teams of heterogeneous robots control. A new human-robot system permits to ease the execution of remote tasks. An operator can efficiently control the physical multi-robots using the high level command, Drag-to-Move method, on the virtual interface. The innovative virtual interface has been integrated with Augmented Reality that is able to track the location and sensory information from the video feed of ground and aerial robots in the virtual and real environment. The advanced feature of the virtual interface is guarded teleoperation that can be used to prevent operators from accidently driving multiple robots into walls and other objects.

I. INTRODUCTION

Teams of heterogeneous robots could perform a variety of tasks such as multipoint surveillance, cooperative transportation and explorations in hazardous environments. For example, in hazardous environments hazards need to be found as soon as possible; a group of robots can detect multiple hazards simultaneously to perform time-critical tasks efficiently. However, until robots permit effective fully autonomous, the human operator cannot be removed from the loop. Situation awareness [1] and workload [2] play key roles in multi-robot scenarios. It is necessary to develop human-robot interfaces that permit the effective management of multi-robot systems. In this project, we developed a human-multiple robot system, see Figure 1, that enables an operator to control groups of heterogeneous robots to perform cooperative algorithms for search and detection missions. Human operator in the control loop using the proposed virtual interface will be able effectively to control multiple robots behaving semi-autonomously.

Figure 1: Human-Multiple Robot System: a human operator can control groups of heterogeneous robots.

II. TEST-BED

A. System Overview

To allow an operator remote controlling groups of heterogeneous robots collaborating with each other, we present a test-bed to implement semi-autonomous multi-robot behaviors controlled by a single operator for indoor contaminant localization tasks. The test-bed, see Figure 2, combines a real and a virtual environment which linked every real robot to its virtual counterpart.

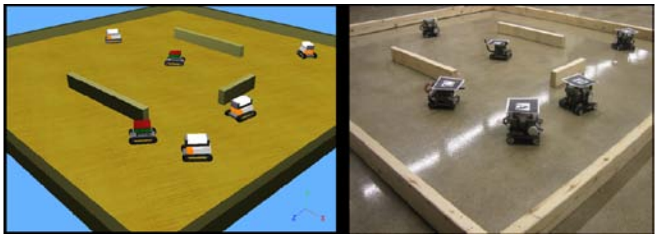

Figure 2: Test-bed: Virtual and real world which linked every real robot to its virtual counterpart.

The virtual world is developed in the simulation environment, Webots™ [3], a simulation and prototyping software package from Cyberbotics, Ltd. In the real environment, we use the open source "ARToolKit" library [4-5] to obtain the positions of physical multi-robots, and to display their sensing data.

B. Team of Heterogeneous Robots

A team of heterogeneous robots with different dynamics or capabilities could perform a wide variety of tasks. In this study, we work with heterogeneous robots of ground and aerial robots. The aerial robot is a pan-tilt camera attaching to a tripod. The ground robots consist of a team of four NXT-Tankbot agents and three SRV-1 agents [6]. Each NXT-Tankbot is equipped with a MINDSTORMS NXT [7] that interfaces with sensors and actuators on the robot. This MINDSTORMS NXT supports Bluetooth communication so that the robots can be controlled wirelessly. The SRV-1 robot supports wireless network access so that the robots can be control wirelessly. A video camera is on the SRV-1 robot, live video from any SRV-1 robot can be viewed to support reconnaissance missions. Both NXT-Tankbot and SRV-1 robot are small enough to operate in a laboratory environment. All robots are modeling in the virtual environment.

C. Coordinate Systems

ARToolKit is used in the test-bed to register the real robots to the virtual robots for the indoor laboratory environment. ARToolKit includes registration algorithms based on predefined markers, and it gives the position of the marker in the camera coordinate system. In the real environment, we fixed a fiducial marker "X" on the floor of the test-bed. The marker coordinate system is used for global coordinate system in the real environment, and it is linked to the coordinate system in the virtual environment.

The relative transformation between a marker of a robot and the static marker can be computed. For example, Transformation "Tx" is the transformation of the static marker "X" in the camera coordinate system, and Transformation "Ta" is the transformation of the robot with marker "A" in the camera coordinate system. The inversion of the transformation "Tx" multiplied by the transformation "Ta" gives us the transformation of marker "A" in the static marker "X" coordinate system. In the transformation, we can obtain the position and orientation of robot with marker "A" in the global coordinate system of real world. Figure 3 shows the position and orientation of physical multi-robots is obtained from the Augmented Reality system.

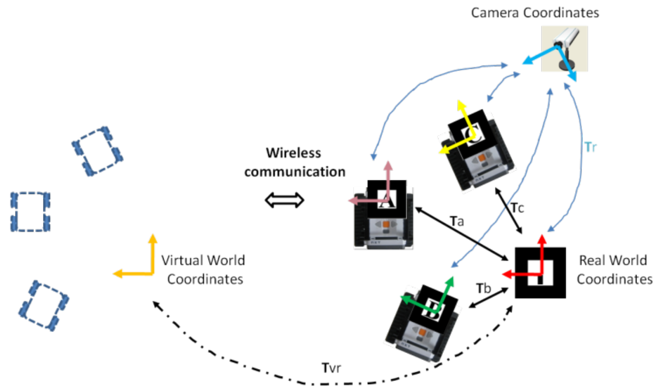

Figure 3: Coordinate systems: virtual world and real world coordinates are links.

III. METHODS

A. Drag-to-Move

To move the real robot an operator can select the corresponding virtual robot, and then drag it to the target location. The corresponding real robot will be moved to the target position in the real environment that is the same as in the virtual environment. In the virtual interface, once the position of the virtual robot is changed, the system will calculate the relative orientation between the new position and the previous position. The real robot first rotates to the direction which it is going toward to, and then the real robot translates to the new position. At new position, if the orientation of real and virtual robot is different, the real robot rotates until the orientation of the real robot is the same as the orientation of the virtual robot. Figure 5 shows a real robot is controlled by an operator via the virtual interface. This method provides with capabilities that reduce the number of required commands to control multi-robots.

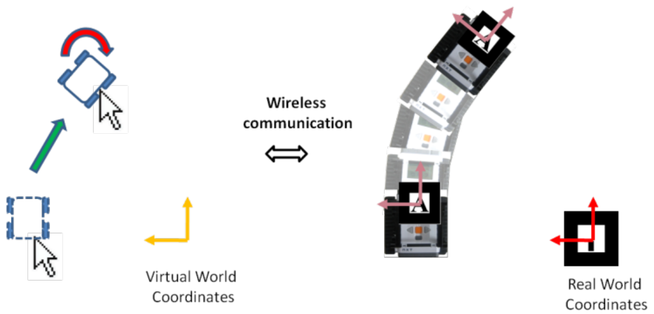

Figure 4: Moving the real multi-robots using Drag-to-Move method on the virtual multi-robots.

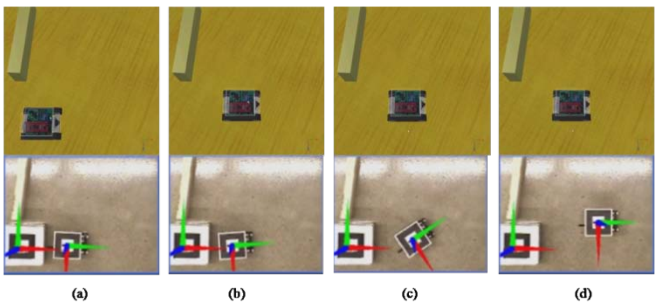

Figure 5: Results of moving the real multi-robots using Drag-to-Move method on the virtual multi-robots.

B. Image Guidance and Tracking

The purpose of the image guidance and tracking in the test-bed is to reduce operators' workload. Our implementation is based on tracking markers using the camera to determine the robot's position and orientation with respect to the marker. The marker is attached on the top of the ground robot. The marker tracking is implemented with ARToolKit.

The transformation between the marker and the camera can be determined by ARToolKit. In Figure 6, the corresponding angles of pan and tilt for the camera can then be calculated in real time by the equations below. Figure 7 shows the ground robot with a marker moving around the test-bed, and the pan-tilt camera automatically tracks the ground robot. The ground robot is always on the center position of the video view from the camera.

$$Pan = \tan^{-1}\left(\frac{X_m}{Z_m}\right) \quad (1)$$

$$Tilt = \tan^{-1}\left(\frac{Y_m}{\sqrt{{X_m}^2+{Z_m}^2}}\right) \quad (2)$$

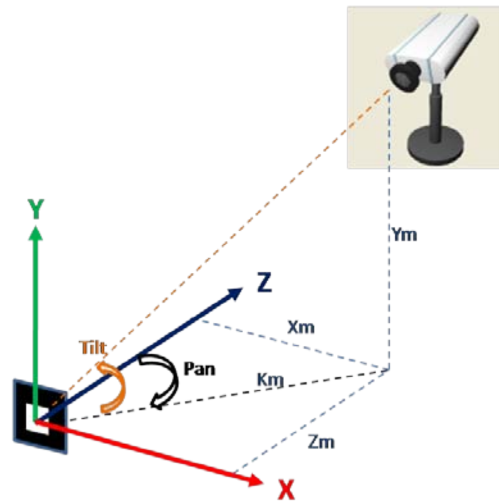

Figure 6: The angles of pan and tilt are depends on the relation of marker and camera coordinate systems.

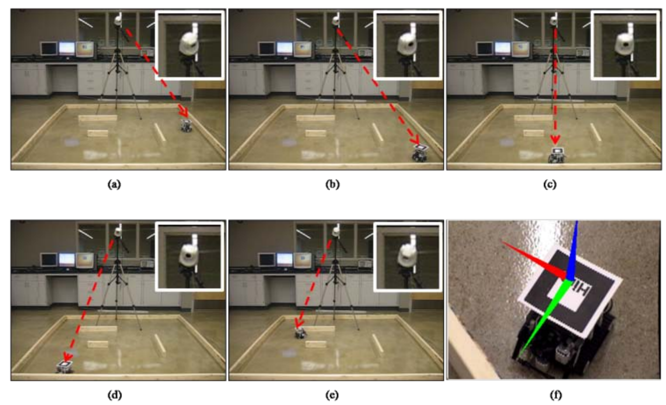

Figure 7: Results of the image guidance and tracking, (a)-(e) are the images in the video sequence show the pan-tilt camera tracking a ground robot. (f): the video feed from the pan-tilt camera shows the ground robot is always on the center position of the video view.

C. Guarded Teleoperation

Guarded teleoperation can be used to prevent operators from inadvertently colliding into obstacles when operators drive a mobile robot. In Figure 8, the system enables an operator controls the physical and virtual robots simultaneously, the real robots use the virtual sensors on virtual robots to avoid collisions by removing the portion of any movement that would cause a collision. In this way, changeable virtual walls and objects along with virtual sensors can be used to control and constrain the behavior of the actual robots for simulation and training applications.

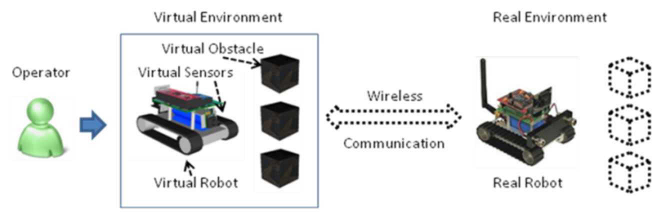

Figure 8: Guarded teleoperation: The real robot uses the virtual sensors on the virtual robot to avoid collisions by removing the portion of any movement that would cause a collision when an operator drives a mobile robot.

D. Visualization of Sensing Information

The sensors on each robot monitor the sensing data. We used Augmented Reality to generate virtual images of their sensing data levels to merge with physical robots in real time. The virtual display of the levels is given to the user, and allows him to direct the multiple ground robots towards the target.

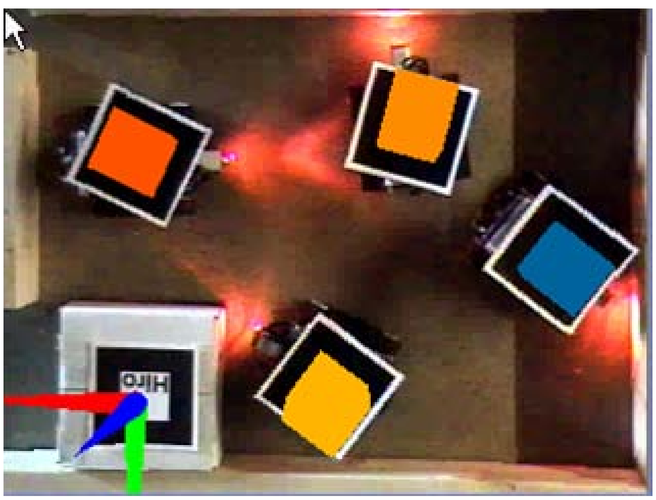

Figure 9: Visualization of sensing information overlay on multi-robots.

IV. CONCLUSION AND FUTURE WORK

This work focused on the development of a human-multiple robot system that enables an operator to control groups of heterogeneous robots in a collaborative approach. The intention was to manage the operator's workload and promote situation awareness by combining the virtual and augmented reality techniques. The virtual interface presented in this work provides with capabilities that reduce the number of required commands to control teams of heterogeneous robots, and significantly reduces an operator's workload. The visualization of sensing information allows the operator to view sensing information overlaid onto the view of the operating scene in real time.

Future work will develop cooperative behaviors for the semi-autonomous multi-robots and will evaluate the human-multiple robot system with participants who are operating the teams of heterogeneous robots using the virtual interface for the searching of sound sources.

V. REFERENCES

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