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Fusing Multiple Sensors Information into Mixed Reality-based User Interface for Robot Teleoperation

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Abstract—**Mixed Reality commonly refers to the merging of real and virtual worlds to produce new visualization environments where physical and digital objects co-exist and interact in real time. Mixed Reality can also be used for fusing sensor data into the existing user interface to efficiently improve situation awareness, to facilitate the understanding of surrounding environment, and to predict the future status. The work presented in this paper fuses and then represents the real video and complementary information into one single Mixed Reality interface. A simulation platform to test the Mixed Reality interface for teleoperation is also discussed in this paper.**

***Keywords*—Mixed Reality, telerobitcs, situation awareness.**

I. INTRODUCTION

The Exploration of unknown environments is critical in mobile robot research due to its wide real-world application, such as search, rescue, hazardous material handling. However, telerobotics is not easy to implement in a remote manner and its performance is significantly limited by the operator's capability to maintain situation awareness [1]. Additionally, constructing mental models of remote environments is known to be difficult to human operators [1]. It can be difficult for distance estimation, obstacle detection and attitude judgment as well. Moreover, the problem can be further complicated by certain task-related and environmental factors. In order to efficiently operate a robot in remote sites, it is important for the operator to obtain and maintain sufficient awareness of the environment around the robot so that the operator can give informed and accurate instructions to the robot. Such awareness of the remote environment is usually referred to as *situation awareness*.

There are different methods that could improve the situation awareness in telerobotics. However, current mobile robot technology is not well developed for rescue robots and regardless, such robots are fully autonomous or telerobotic. Therefore human–robot interaction is a key component of a successful rescue system. The analysis of video data collected during the World Trade Center disaster response found that a variety of human–robot interaction issues impacted the performance of the human–robot teams on the pile [2]. The operator's lack of awareness regarding the state of the robot and regarding situatedness of the robot in the rubble is the most relevant factor to this study [3]. Operators also had difficulty in linking current information obtained from the robot to existing knowledge or experience [2]. The Florida task force and World Trade Center human–robot interaction studies reveal difficulties in operator teleproprioception and telekinesthesis, consistent with the previous problems [4].

Basically, these problems occur because the situation that the robot operator is distant from the actual robot based on such settings limitations. In order to efficiently operate a robot at remote spaces, it is important for the operator to be aware of the environment around the robot so that the operator can give informed, accurate instructions to the robot.

Despite the importance of situation awareness in remote-robot operations, experience has shown that typically interfaces between human and robots do not sufficiently support the operator's awareness of the robot's location and surroundings. The case of World Trade Center is a good example. According to the previous research [5], the robots were useful because they were able to get into small, dangerous areas that were inaccessible for rescuing workers; however, it was quite difficult for the operator to navigate the robot while searching the environment because the robots only provided video information to the operator. The results show that there is a limitation to the robot which comes from the limitation of the views of most cameras which creates a sense of trying to understand the environment through a 'soda straw' or a 'keyhole' [6]. It makes of difficult for an operator to be aware of the distance between robot and obstacles.

Conventional interfaces are one possible reason that operators demonstrated poor situation awareness in the previous studies. For instance, conventional 2D interfaces present related pieces of information in separate parts of the display. Such 2D interfaces require the operator to mentally correlate the sets of information, which can result in increased workload, decreased situation awareness and performance [7] [8] [9]. These negative consequences arise from a cognitive perspective because the operator has to perform mental rotations between different frames of reference frequently (e.g., side views, map views, perspective views) and fuse information [10]. To improve situation awareness in human–robot systems, some recommendations are proposed: (1) using a map; (2) fusing sensor information; (3) minimizing the use of multiple windows; and (4) providing more spatial information to the operator [8]. These recommendations are consistent with observations and recommendations from other researchers that involve human–robot interactions [2] [3] [5].

In this paper, a Mixed Reality-based (MR) human-robot visual interface is conceptualized and designed as an approach to improve the operators' awareness of a remote mobile robot based on the above recommendations. The MR interface is based on the affordances theory, which claims that information is inherent in the environment. Applying this theory to remote robots means that an operator's decisions should be made based on the operator's perception of the robot's affordances in the remote environment.

II. RELEVANT WORK

This section discuss the design theory and justification of Mixed Reality in Teleoperation

A. Gibson's theory of affordances

Before the new interface is designed, the concept of the new interface will be evaluated by perception theory which plays a critical role in the situation awareness. . In particular, it needs to identify what information is needed by a human, how it should be communicated, and how it will be interpreted.

Situation awareness is defined as "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [7]. When applied to human-robot interactions, these definitions imply that successful interactions are related to an operator's awareness of the activities and consequences of the robot in a remote environment. Endsley's work has been used throughout many fields of research that involve humans interacting with technology and has been fundamental for exploring the information needs of a human operating a remote robot.

There is a view on the psychology of perception that people do not construct their percepts; but their visual input is rich and they perceive objects and events directly [11]. The information an agent needs to act appropriately is inherent in the environment. The term affordance is used to describe the relationship between the environment and the agent.

Fundamentally Norman disagreed with Gibson's approach of how the mind actually processes perceptual information, but he did come to agree with Gibson's theory of affordances [12]. Norman discusses perceived affordances, which are what the user perceives they can do with some thing whether or not that perception is correct [12]. He claims that the goal of design should be making affordances and perceived affordances the same. This idea is directly applicable to mobile robots because it is necessary that information be provided that supports the operator's correct perception of available actions for the robot. Norman also advocates that the culpability of "human error" can often be attributed to "equipment failure coupled with serious design error." Therefore, in cases where an operator does not perform well, it may be the consequence of a poorly designed system.

Endsley's definition of situation awareness fits with the affordances of Gibson in Human-Robot interactions [12]. Because when information is directly perceived, it should send a signal to the participant that how it can be used and how its effects will affect the environment. The challenge is to present the information from the remote environment to the operator such that the perceived affordances of the environment match the actual affordances and the operator can easily perceive, comprehend, and anticipate information from the remote environment. There are different ways to improve the quality of services provided to an operator for perceiving affordances of the environment.

B. Justification of Mixed Reality in Teleoperation

Basically, the traditional ways which are designed to improve the situation awareness are restricted by the narrow field of view of the sensors and unpredicted conventional map.

One of the disadvantages when navigating a robot with a conventional interface is that typical cameras have a narrow field of view. For example, a human's lateral field of view is normally 210 degrees; in contrast, the camera on a robot usually has a field of view of only 37 degrees [2]. The field of view that the operator has in an environment is very important to navigation. A poor condition of field of view has been attributed to negatively affect locomotion, spatial awareness, and perceptions of self-location. Further, Woods described using video to navigate a robot as attempting to drive while looking through a 'soda straw'. The one of the main challenges of the teleoperation is that an operator typically does not have a good sense of what is to the 'sides' or 'shoulders' of the robot. Moreover, the obstacles that should be considered are normally outside of the field of view [10].

One method for overcoming a narrow field of view is to use multiple cameras. For example, two cameras were used and it was proven that this improved an operator's ability to perform a search task [13]. Another method for improving field of view is to use a panospheric camera, which gives a view of the entire region around the robot [14]. While these approaches may help operators better understand what is all around the robot, they require fast communications to send large or multiple image with minimal delay and, also, clearly increase the cognitive work burden of the human operators. Therefore the proposed system restricts attention to robots with a single camera.

There is another method to improve robot teleoperation: using virtual environments to create a virtual scene that represents the real environment. According to previous research, one of the major issues involved is the situation awareness that the human operator has to keep during the teleoperation task. The operator can be assisted by Mixed Reality (MR) to maintain high situation awareness [14]. Several prototype-phase research projects have been implemented to apply Augmented Reality (a sub-mode of Mixed Reality) technique into various teleoperation systems [16] [17] [18]. All their work focused on applying Augmented Reality in teleoperation and ignored other sub-modes of Mixed Reality and Augmented Virtuality. The proposed main goal of this paper is to apply Mixed Reality technique in setting up a natural interface where surrounding scene visualization and structure are more available as a spatial reference aid.

III. SYTEM PROTOTYPING

This section discusses the Mixed Reality interface, the hardware of the system configuration, the simulation toolkit for the system design, and the advantages of a Mixed Reality interface used in the collaboration of multi-robots field.

A. Interface

The robot is equipped with sensors that face different angles. These sensors help to reconstruct the virtual image of the surrounding environment. The original resources include two types of data: one is digital image which is captured by the front camera, and the other is sensor data which is scanned by the laser scanner and sonar system. However, not only conventional sensor fusion issues in teleoperation need to be considered, but also the interface needs to be designed based on the human operators' needs and limitations. The operator is required to browse a multi-windows display, interpret the information, and reconstruct it in their brain to obtain situation awareness. According to the previous research, the cognitive workload of the operator in the complex environment or a multi-windows display can be significantly high and leads directly to fatigue, stress and inability to perform other tasks [4].

The problem can be solved by fusing the data from the sensors into the single display that enables the operator to quickly perceive and acquire situation awareness. The scanned information can be considered as complementary information to video streams, which can reduce the uncertainty of measurements and increase the reliability of the system. The interface employs Mixed Reality technology to interpret the scanned information to virtual environment, which can further improve the coverage and effectiveness of sensors. The hypothetical view of the Mixed Reality interface is shown in Figure 1. It shows three scene layers: inner virtual layer, real layer, and outer virtual layer. The inner virtual layer defines the augmented information of the real layer. The arrow which is presented in the Figure 1 is an example. Real layer refers to the real-time video, and the virtual entities in the inner virtual layer are registered in that video. The outer virtual layer is rendered based on raw data from the scan sensors. For example, the purple wall in the Figure 1 is reconstructed based on the spatial parameters which are captured by the scan sensors.

Figure 1. The hypothetical view of Mixed Realty interface

The Mixed Reality interface fuses information from sensors and displays the fused data to operator in a real-time manner. The perspective view in the interface is changed from robot view to a third person view as shown in Figure. 2. The robot itself is also visualized in the interface so that the spatial correlation between robot and objects can be apparent in the interface.

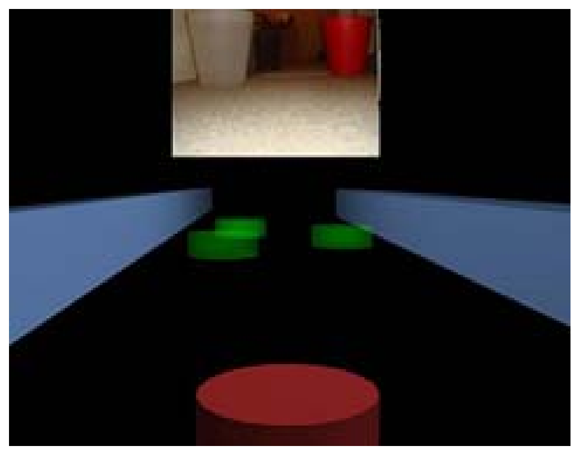

Figure 2. The spatial correlation between robot and objects

B. Configuration

In order to fusing sensors into the Mixed Reality interface, an E-puck robot is employed as the implementation platform.

The robot is redesigned based on the model of E-puck (Figure 3), which has a simple mechanical structure and electronics design. It offers many functions with its sensors, processing power and extensions which satisfy the requirements of this research project. Moreover, E-puck can be integrated into the Webots simulation software for programming, simulation and remote control of the remote robot. The redesigned E-puck robot is equipped with sensors facing different angles, which help to reconstruct the visual image of the surrounding working environment. The goal of the robot is to obtain a perception of the environment from the observed scenery and to provide the enhanced visual interface which can increase the operator's situation awareness.

Figure 3. The E-puck robot [19]

The E-puck robot is an open tool and is easily modified with the requirements of the Mixed Reality interface. Table 1 below shows the technical details of E-puck.

TABLE I. TECHNICAL INFORMATION OF E-PUCK [19]

Feature	Technical Information
Size	***about 7 cm diameter***
Battery	***about 3 hours with the provided 5Wh LiION rechargeable battery***
Processor	***Microchip dsPIC 30F6014A @ 60MHz (about 15 MIPS)***
Motors	***2 stepper motors with a 20 steps per revolution and a 50:1 reduction gear***
IR sensors	***8 infra-red sensors measuring ambient light and proximity of obstacles in a range of 4 cm***
Camera	***color camera with a maximal resolution of 640x480 (typical use: 52x39 or 640x1)***
Microphones	***3 omni-directional microphones for sound localization***
Accelerometer	***3D accelerometer along the X, Y and Z axis***
LEDs	***8 red LEDs on the ring and one green LED in the body***
Speaker	***on-board speaker capable of playing WAV or tone sounds.***
Switch	***16 position rotating switch***
Bluetooth	***Bluetooth for robot-computer and robot-robot wireless communication***
Remote Control	***infra-red LED for receiving standard remote control commands***
Expansion bus	***Expansion bus to add new possibilities to your robot.***
Programming	***C programming with the GNU GCC compiler system***
Simulation	***Webots facilitates the programming of e-puck with a powerful simulation, remote control and cross-compilation system.***

C. Simulation Toolkit

The interface is designed with the simulation robot and then evaluated in the simulation environment. After this stage, the system is then translated to the real E-puck robot. The Webots robot simulator is employed in the simulation stage. Webots uses the ODE (Open Dynamics Engine) for detecting of collisions and for simulating the rigid body dynamics. The ODE library allows to accurately simulating the physical properties of objects, such as velocity, inertia, friction, etc.

Webots offers the possibility to flexibly build a robot model based on the requirements of the Mixed Reality interface. When designing a robot model, the different sensors can be selected from Webots which includes a database of sensors and actuators that are frequently used in robotic experiments, for instance, proximity sensors, light sensors, touch sensors, GPS, accelerometers, cameras, emitters and receivers, servo motors (rotational & linear), position and force sensor, LEDs, grippers, etc.

The model of the E-puck robot which is designed in the Webots includes a digital camera which is installed in the front of the robot and eight surrounding sensors which are equipped on both sides and rear of the robot. Figure 4 shows how the robot scans the obstacles.

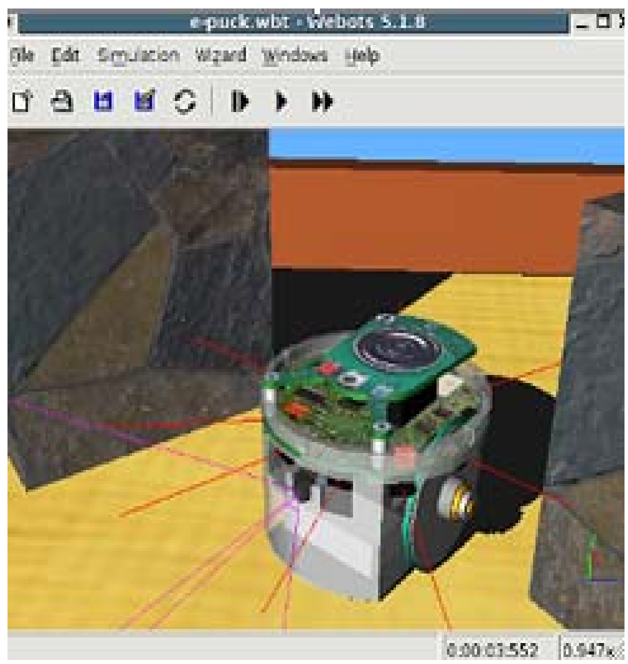

Figure 4. Robot Scanning in Simulation Environment

D. Collaboration

Although the research field of robotics is well established, there has been relatively little work on human-robot collaboration. Basically, this type of collaboration is going to become an increasingly important issue as telerobotic plays a critical role in human-robot collaboration. Navigation in an unknown environment is a good example. Recent research has pointed out that scant attention has been paid to joint human-robot teams, and making human-robot collaboration natural and efficient is crucial to future space exploration [20].

Previous research with humans has shown that grounding, situation awareness, a common frame of reference and spatial referencing are vital in effective communication [21]. Clearly, there is a growing need for research on human-robot collaboration and models of communication between humans and robotic systems.

Mixed Reality can be used for overlaying 3D virtual graphics onto the views of human operators of the real world. However, it can also be used to fuse and represent the 3D maps of multi-robots, which allows for real-time interaction with these 3D maps, enabling a human operator to know others' surrounding environment and manipulating it directly.

A new team collaboration model for multi-robots exploration is also presented in this paper. The approach is based on using Mixed Reality interface that provides the capability of human operators to observe each other's behavior, acting in concert to reduce redundant cognitive workload. The multi-robots can sense nearby environments and draw a 3D map. The maps are combined together and fused into a mega map which is represented into the Mixed Reality interface. The location of each other robot can also be displayed in the interface. Figure 5 shows the hypothetical view of the robot with the Mixed Reality system. This allows the robots to obtain a map with higher accuracy in a less time-consuming manner than would be possible with robots acting independently. Moreover, by exploiting the ability of the robots to see each other's map, it can predict the future status such as finding the shortest path, avoiding obstacles and searching survivals.

After receiving a signal from the other robot, the virtual robot can be displayed in the interface. The correlation between robots such as location, distance and situation can be clearly and easily presented to the operator. Figure 6 shows the other robots in the Mixed Reality interface.

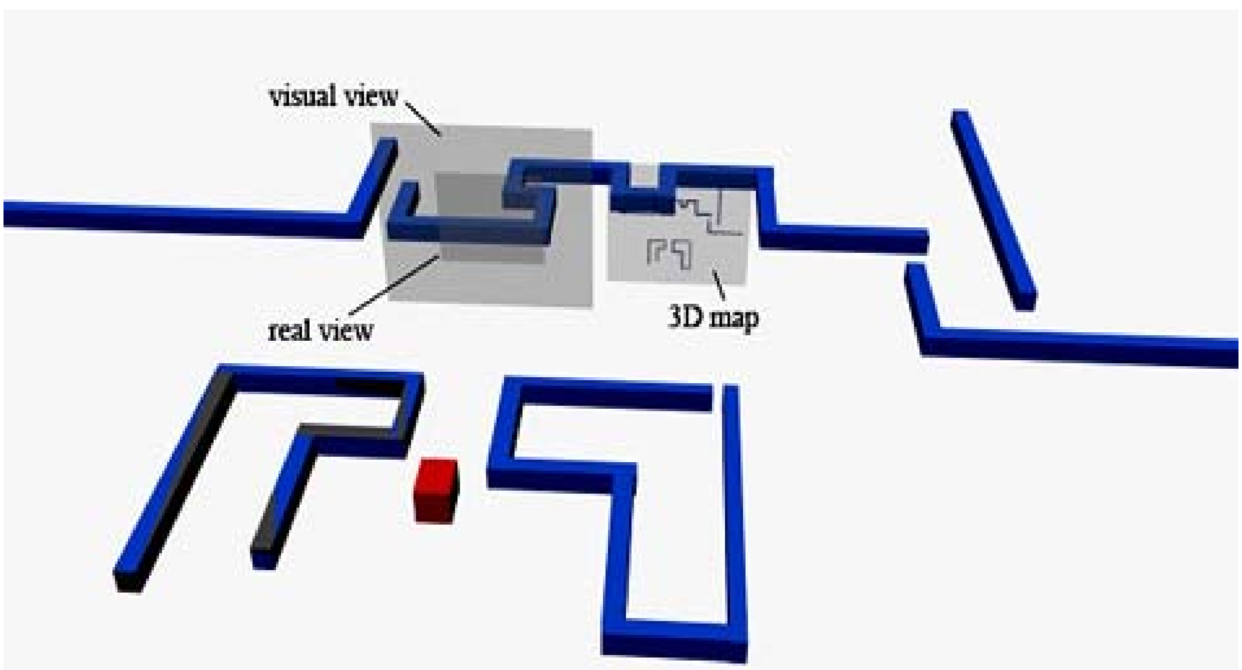

Figure 5. The hypothetical view of the robot with Mixed Reality system (red cube represents the robot)

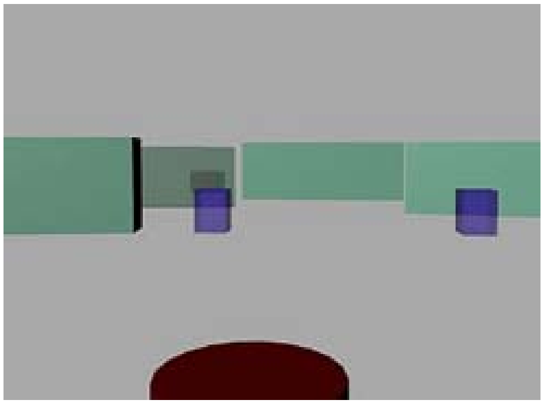

Figure 6. Collaboration in Mixed Reality interface

IV. SUMMNARY

This paper presents a Mixed Reality interface for remote robot teleoperation, which increases the situation awareness by fusing data from multiple sensors. The robot for testing is equipped with camera, sonar and laser sensors to create a 3D virtual environment overlay which could improve the estimation of relative distance and mapping of spotting of surrounding obstacles. Mixed Reality technology which is used to fuse data into the interface could significantly increase the operator's situation awareness and spatial cognitive skills that are critical to telerobotics.

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