Proceedings of 2004 IEEE/RSJ International Conference on
Intelligent Robots and Systems
September 28 - October 2, 2004, Sendai, Japan

Multi-modal User Interface for Teleoperation of ROBHAZ-DT2 Field Robot System

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Abstract— **This paper describes a multi-modal interface design and its implementation to a teleoperated field robot system. The ROBHAZ-DT2 is developed as a teleoperated mobile manipulator for hazard environment applications (e.g. rescue, explosive ordnance disposal, security). To complete these missions in outdoor environment, the robot system must have appropriate functions, accuracy and reliability. However, the more functions it has, the more difficulties for the operator to control the functions. To cope up with this problem, an effective user interface should be developed. The main challenge of this research is to make a simple and intuitive user interface and teleoperate the slave robot easily. This paper provides multi-modalities such as visual, auditory and haptic sense. It enables an operator to control every functions of a field robot, ROBHAZ-DT2 more easily. In this paper, an EOD (explosive ordnance disposal) demonstration is conducted to verify the validity of the proposed multi-modal interface.**

Keywords- multi-modal interface, field robot, teleoperation, mobile manipulator, haptics

I. INTRODUCTION

Recent rapid improvement of robot and control technology makes a robot take the place of human in dangerous work, such as a rescue tasks in disaster, patrol works in airport, even mission in war place. Several robots have been developed for these applications [1-3].

The final goal of these field robot systems is to accomplish all processes autonomously by their intelligence. Unfortunately, it is beyond the state of the art, and human intervention is still needed. Therefore, most of the developed field robot systems adopt *teleoperation control scheme*. In this scheme, the robot is a slave to face with the dangerous environment, while the operator manages the slave from a distance. Basically, a field robot system must have appropriate mission-oriented function, accuracy and reliability to complete its mission. Therefore, the functions of the robot, such as dexterity and various sensing ability, are mainly focused to develop the system. For this requirement, various sensors (e.g. vision, sonar sensor, inclinometer) are installed to gather environment information, and lots of joints are equipped for mobility and manipulation. Finally remarkable improvement has been achieved, and some field robots can be aware of the situation in detail and achieve dexterous motion enough to carry out a complicate mission.

However, the more functions the slave has, the more difficulties it means to operate the slave in teleoperation control scheme. The dexterous motion means that a complicated commands sets are required for operation, and the more information is gathered, the more confusion comes to the user. Not only to design the robot function but also to make a smart user interface becomes an essential technology. How to present information clearly to the operator is as important as how much information to be gathered. It becomes more serious problem to design the user interface of the teleoperation system.

The user interface carries out two functions: to command the robot, and to report the situation of the robot to the operator. For the command, most existing field robots use a joystick-type device, and the number of its degrees of freedom is too less to control all joints at a time [4, 5]. Furthermore, lots of field robot systems control the slave not in the Cartesian space but in the joint space, using their joystick-type input device. For the report, main view monitor and a few auxiliary indicators are used. Therefore, the dispersed indicators cause inattentiveness and the user cannot grasp the situation immediately. For this problem, not only vision sense but also various human senses should be used. Both command and report functions should be simple and intuitive in order to concentrate the operator's attention on a given mission.

The ROBHAZ-DT2 is a field robot system for hazard environment applications [6]. The prototype, ROBHAZ, was developed as a teleoperated mobile manipulator through our past research. It was designed mainly focused on the mission specific functions. In spite of various functions, difficulties in using properly the functions still exist. Multi-modal approach has been widely used as a solution for robot and HCI (human computer interface) application [7-9]. Using various human senses (i.e. visual, auditory and haptic sense), remarkable improvement of its user interface has been achieved in this research, and multi-modal interaction method for a field robot system is proposed. Finally, it enables an operator to control the field robot system simply and intuitively. This method is integrated in the ROBHAZ-DT2, and an experiment is performed to verify a validity of the proposed system.

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Section II is devoted to the design architecture of the ROBHAZ-DT2. The next two sections focus on the multi-modal user interface and control scheme for the ROBHAZ-DT2. Section III provides information of each interface module on the haptic, visual, speech and auditory interface, and Section IV deals with the proposed system integration. Section V shows experiment, and Section VI concludes the research results.

II. THE ROBHAZ-DT2 : TELEOPERATED FIELD ROBOT SYSTEM

The ROBHAZ-DT2 system is a teleoperated mobile manipulator, as shown in fig. 1. A mobile base is designed to get high adaptability to uneven terrain using passive double tracks, and a manipulator is equipped on the mobile base. The robot has totally nine degrees of freedom including the mobile base and the seven-degree of freedom manipulator with gripper. It can move in a hazard environment, and dexterous manipulation can be performed. Stereoscopic camera, ultrasonic sensors, inclinometers and force-torque sensor gather the environmental information to locally control the robot and to report to the teleoperator.

Figure 1. ROBHAZ-DT2 field robot system.

Fig. 2 shows the system architecture of the ROBHAZ-DT2. The user interface is composed of three components : visual interface, speech and auditory interface, and haptic interface. Commands are input by speech or operation of the haptic device. While the robot moves by a set of commands, it interacts with environment and gathers data with installed sensors (e.g. ultrasonic sensor, inclinometer). When the robot reports the sensed data via a wireless LAN, the environmental situation is understood by the teleoperator. All information is displayed on single scene of HMD and some information is represented as a force feeling or audio. In this manner, the operator can interact with the user interface intuitively.

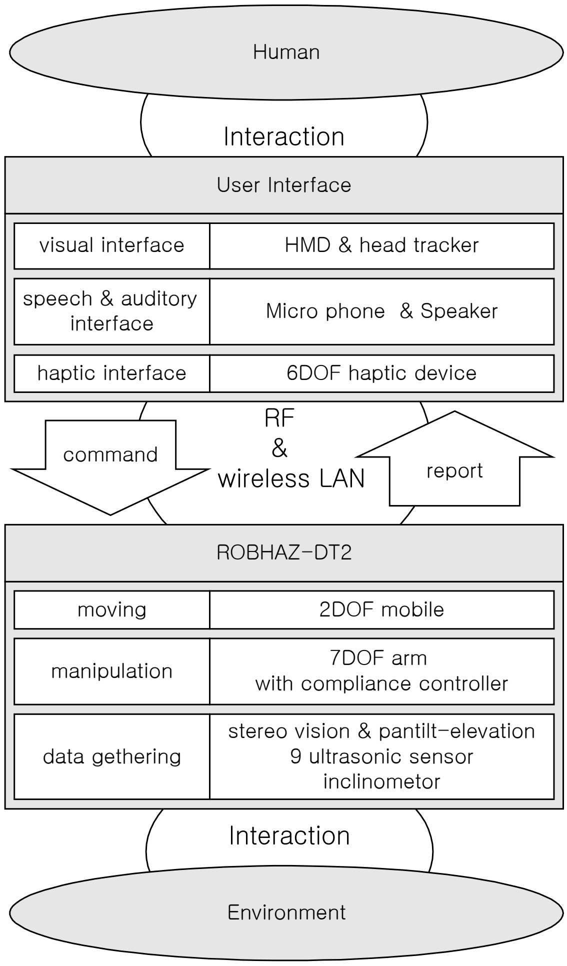


Figure 2. System architecture of the ROBHAZ-DT2.

III. . MULTI-MODAL USER INTERFACE OF THE ROBHAZ-DT2

The features of the user interface of the ROBHAZ-DT2 are classified as follows.

- Command to the robot
- Report the situation of the robot to the user.

Developing the user interface to have the mentioned functions, main design issues shows below.

- Simplicity :
    - All indicators are unified as one scene.
    - All input button and joystick are merged into one haptic device.
- Intuitiveness :
    - High level command by speech.
    - Human kindly report such as graphs indicator, human voice.
    - Motion command matching in Cartesian space.

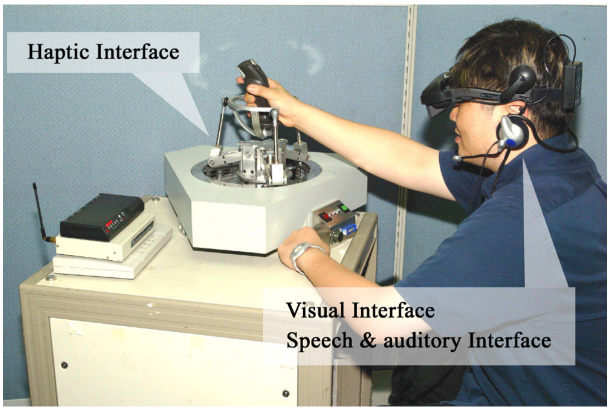


Figure 3. Multi-modal user Inerface for the ROBHAZ-DT2.

With this design constraint, multi-modal user interface for field robot system is integrated as shown in Fig. 3. The operator wears the HMD, head tracker and headset to interact with the slave. He grips the handle of the 6-dof haptic master. A keyboard, button, switch or any other display devices are not needed during the operation. Following subsections describe how it works.

A. *Haptic Interface*

In most 6-dof haptic devices, all six actuators are activated to create force feedback even when only simple motion is desired, since Cartesian space and the joint space are closely coupled in the device. It is desirable, therefore, that a haptic device is designed so that only necessary dofs are activated while other dofs remain unactivated depending on the situations. This strategy has several advantages. First, mass and moment of inertia of the moving parts are reduced, which leads to the improved backdrivability and transparency. Second, computational burden needed to solve kinematic and static equations involving all dofs for determination of the end-effector posture and the required force reflection are greatly reduced. Third, it is energy efficient because only necessary actuators are activated.

In this manner, a new 6-dof haptc device is designed for the ROBHAZ-DT2 [10]. The haptic master is composed of upper and lower mechanisms in the consideration of the manipulator and the mobile, as shown Fig. 4. The lower mechanism is designed to be a planar 3-dof parallel manipulator and the planar 3-dof (x, y translation, z rotation) exactly matches the motion of mobile. While the mobile is moving, only the lower mechanism is activated for force reflection. The upper mechanism is designed as a spatial 3-dof (x, y rotation, z translation) parallel manipulator and it is attached on the lower mechanism, as shown Fig. 4. Finally, the proposed haptic device has totally 6-dof. Once the robot reaches the goal, it performs a given task using the manipulator, using its full 6-dof motion.

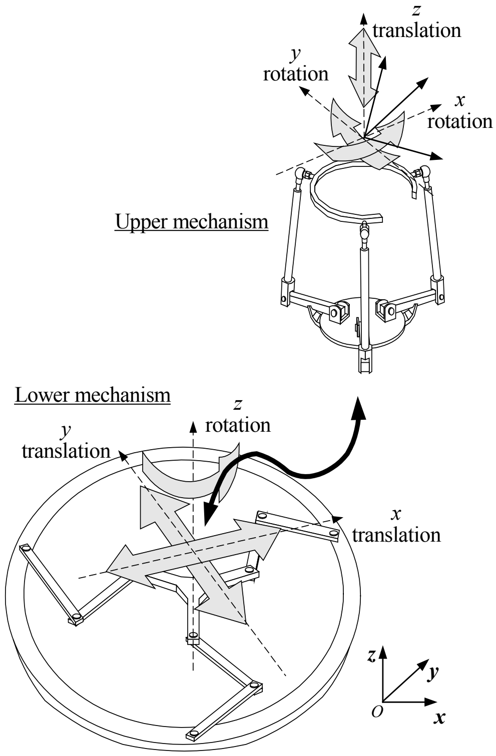


Figure 4. Structure of the proposed haptic master.

The complex motions of the ROBHAZ-DT2 are easily commanded by the haptic interface. The continuous command mentioned above, such as the velocity of mobile and the position of arm, is ordered with the haptic master. The operator grips the handle of the haptic device and moves his hand, and the robot exactly moves along the direction. The mobile moves intuitively with the moving mode. In this case, only the 3-dof of the haptic device is used. The manipulator is operated in manipulation mode with full 6-dof of the haptic device.

Another feature of the haptic interface is that it exerts the forces on the operator. Thus the operator can notice the situation of the robot with feeling the forces that indicate the distance from obstacles or the inclination of robot.

B. *Speech and Auditory Interface*

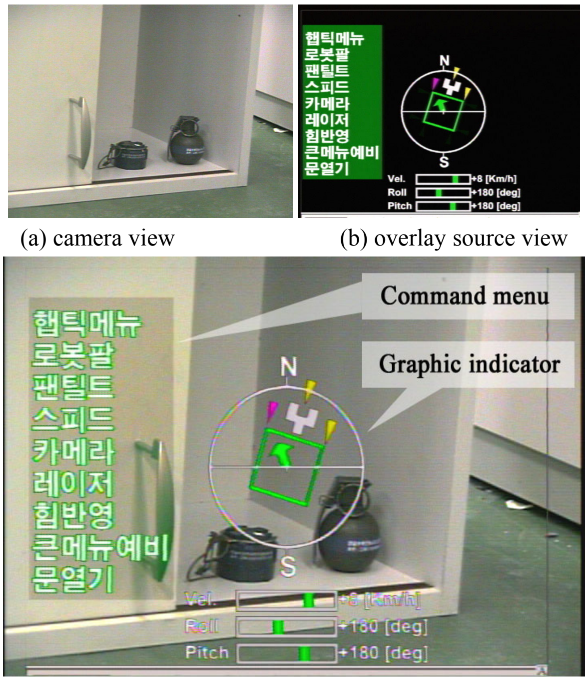
In this research, the operator sends two types of commands to the robot. The one is a selection command and the other is a continuous command. For example, the selection between moving and manipulation mode, the reset of the robot arm and mobile base, the on/off and reset of pan-tilt motors, the speed selection of the mobile, the selection among installed cameras are defined in the selection commands. These commands are executed through the speech recognition.

When the operator says a word which has been defined as a selection command, the speech interface can be aware of the word. If the speech recognition system successfully recognizes what he says, the recognized command pops up on the HMD for confirming. Finally, the operator would decide to execute or cancel the command with the button on the haptic master.

A speech synthesis engine can synthesize the human voice. The auditory interface can warn of the approach of obstacle by sound.

C. Visual Interface

The visual interface shows the robot's view, the status of sensed data, and the status of speech commands. A stereoscopic camera with a pan/tilt mechanism are installed on the ROBHAZ-DT2. The operator wears the head tracker and it generates a pan/tilt command from the 2-dof head motion. Thus the stereoscopic camera moves along the direction of his head. As a result, the operator looks at the view he wants to see as shown in Fig. 4(a).



(a) camera view (b) overlay source view

(c) user view

Figure 5. The visual interface for ROBHAZ-DT2.

The vision information is sent via a RF channel while the sensed data is reported via an independent wireless LAN channel to reduce the traffic in data communication. A source for video overlay is prepared with the reported data, as shown Fig. 4(b). The recognized speech command is highlighted on left side to confirm. When obstacle is detected by ultrasonic sensor, it shows around robot icon in the middle of the scene. Other useful and important information (i.e. velocity, heading direction, view direction, arm posture and etc.) are shown by bar graphs. It is overlaid on the remote video sorce pictures and unified to single scene. Finally the operator sees the stereoscopic picture and the status of the robot at a glance immersivly on the HMD. The overlaid view is shown in Fig. 4(c)

IV. Integrated System and Control

While the user carry out a mission, it usually classified two tasks, the one is to move the mobile base, and the other is to operate the manipulator. The operation modes are mainly divided a navigation mode and a manipulation mode. The user selects the operation modes by speech. As the navigation mode selected, the user operate the mobile base to move he wants by haptic device, and he feels repulsive force when an obstacle detected by ultrasonic sensor. When the mobile base reaches in the vicinity of the target he wants to handle, the user changes the operation mode from navigation mode to manipulation mode. The control schematic diagram for ROBHAZ-DT2 is shown in Fig. 6.

The operator moves the handle carefully to the direction to the object, watching it through the HMD. The installed encoder reads the motion of a joint angle $\mathbf{q}_h$ and the haptic controller translates it to a pose $\mathbf{x}_h$ in Cartesian space with forward kinematic analysis. A local controller for manipulator in the ROBHAZ-DT2 receives a scaled command $\mathbf{x}_s$ by the TCP/IP communication. After computing inverse kinematics of manipulator, the desired position of joints $\mathbf{q}_d$ is determined.

Compliance control is applied to manipulation tasks. Not only it can protect the manipulator from the contact with environment by improper command or unexpected trouble, but also it is adequate for some dexterous tasks (e.g. opening door, writing on the board, wall scratch). Compliance control is performed by employing commercial 6-dof force-torque sensor mounted between the wrist of the manipulator and the gripper. The exerted force $\mathbf{f}_s$ in Fig. 5 is measured by the sensor. Therefore, desired position of joints $\mathbf{q}_d$ is modified to an adjusted position of joints $\mathbf{q}_a$. The measured force is used not only for compliance control but also force feedback to the haptic device. The sensed force $\mathbf{f}_s$ translated to scaled force command $\mathbf{f}_h$, and joint torque τh is computed by Jacobian analysis of the haptic interface, then each motor installed haptic device is controlled to put force as much as the desired joint torque τ_h. As a result, the operator feels the feedback force $\mathbf{f}_f$. In controlling a mobile manipulator, the interaction between the manipulator and the mobile base or uncertain environment is a very important issue. When a manipulator interacts with an uncertain environment, the control system should be able to estimate the unknown stiffness of the environment and control both the position and force of the manipulator simultaneously. There has been a growing interest in the research on the compliance control of a mobile manipulator. A compliance control strategy to protect serious damages in an unknown environment is proposed for the ROBHAZ-DT2. The details of control are a control schematic diagram in Fig. 6.

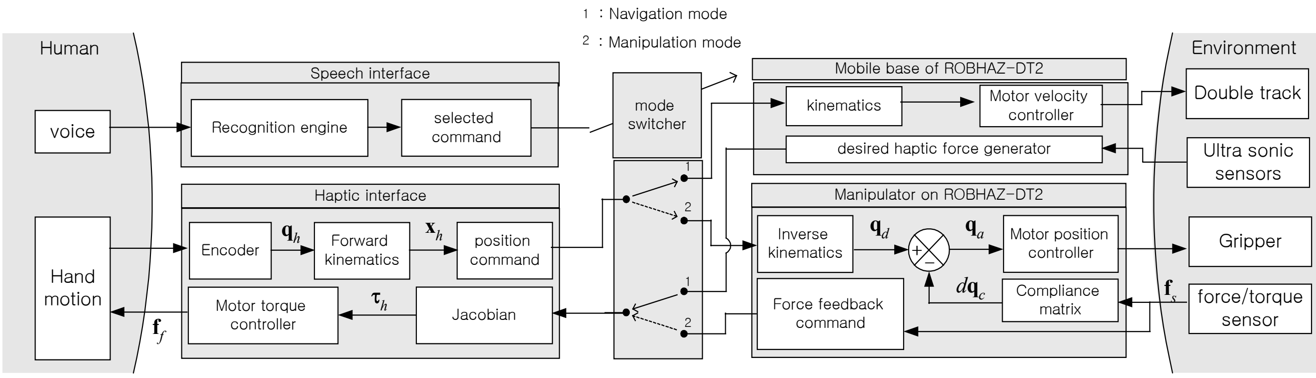


Figure 6. Control schematic diagram for the ROBHAZ-DT2.

V. EXPERIMENT

As a result of full integration of the system, a simple EOD demonstration task was successfully executed in real outdoor environment shown in Fig. 7.

(a) Start and climbing

(b) Running on irregular surface

(c) Approach

(d) Grip

(e) Moving for disposal

(f) Disposal

Figure 7. Demonstration of explosive ordnance disposal.

The demonstration setup for the EOD is artificially constructed for feasibility test. As shown in Fig. 7, an operator remotely controls the robot by means of the haptic device and a head mount display. First, he controls the mobile vehicle and manipulator to access the explosive ordnance. By means of the double-track mechanism, as shown in Fig. 7(a)-(c), the ROBHAZ-DT2 could easily travel over stairways and irregular surface. During the accessing motion, the operator could monitor the stereoscopic view transmitted from the pan-tilt stereo camera mounted in front of the robot, and also helping information, such as a velocity and an obstacle approach, is overlaid on the view. When the robot comes near the explosive ordnance, the operator could easily change the control mode by saying the command to start manipulating. The robot recognizes the command and activates its manipulator. In manipulating the object placed in a car shown in Fig. 7(d), the operator could approach, grip and pick up an imitated bomb by feeling the contact forces via the haptic interface and monitoring fine view transmitted from the camera equipped at the arm's gripper. Then it moved to a safe place for the disposal.

VI. CONCLUSION

In this research, a multi-modal interaction method for teleoperated field robot system using various human senses is presented. Proposed user interface composed of three components, such as visual, speech and auditory, haptic interface. The following special features are summarized.

- The operator makes the command by speech and a motion.
- All information is shown on a unified scene of HMD.
- The operator feels the contact forces by the haptic feedback.

In this work, actual system integration and control method are presented in detail.

As a result, an intuitive and simple user interface for in teleoperated field robot system has been developed. An EOD experiment is performed to verify the usefullness of the proposed system, and its practical effectiveness has been successfully tested.

REFERENCES

[1] K. Nonami and N. Shimoi, "Development of teleoperated six-legged walking robot for mine detection and mapping of mine field," Proc. of the 2000 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp, 775-779, 2000.

[2] http://www.remotec-andros.com/

[3] http://www.highcomsecurity.com/

[4] M. D. Penny, S. Cotter, N. Beagley, N. Smith, and K. Wong, "A comparison study of operator performance with three controllers for a remotely operated vehicle," IARP workshop on robots for humanitarian demining 87-92, 2002.

[5] Y. Takahashi and I. Masuda, "A visual interface for security robots," International Workshop on Robot and Human Communication, pp.123-128, 1992

[6] Sungchul Kang, Chanhyun Cho, Jonghwa Lee, Dongseok Ryu, Changwoo Park, Kyung-Chul Shin and Munsang Kim, "ROBHAZ-DT2 Design and integration of passive double tracked mobile manipulator system for explosive ordnance disposal," , Proceeding of the IEEE/RSJ Intl.Conference on Intelligent Robots and Systems, pp2624-2629, 2003.

[7] P. MacGuire, Fritsch, J. J, Steil, F. Rothling, G. A. Fink, S. Washsmuth, G. Sagerer and H. Ritter, "Multi-modal human-machine communication for instructing robot grasping tasks,"for instructing robot grasping tasks" Proc. of IEEE International Conference on Intelligence robotics and systems, 2002.

[8] Soshi Iba, Christian J.J. Paredis and Pradeep K. Khosla, "Interactive Multimodal Robot Programming," Proc. of IEEE International Conference on Robotics and Automation, 2002

[9] Saeed Shiry Ghidary, Yasushi Nakata, Hiroshi saito, Motofumi Hattori and Toshi Takamori, "Multi-modal human robot interaction for map generation," Proc. of IEEE International Conference on Intelligence robotics and systems, 2001.

[10] D. S. Ryu, C. H. Cho, M. S Kim, and J. B. Song, "Design of a 6 DOF Haptic Master for Tele-operating a Mobile Manipulator," Proc. of IEEE International Conference on Robotics and Automation, 2003.