Preprints of the 13th IFAC Symposium on Information Control Problems in Manufacturing, Moscow, Russia, June 3 - 5, 2009

Fr-B.6

A Comparative Study of Indirect and Direct Workspace Representation in Human-Robot Interaction

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Abstract: This paper presents a comparative study of indirect and direct workspace representation in human-robot interaction. Most of previous researches were using indirect workspace representation or were restricted to mobile robot applications. We extended human-robot interface with direct workspace representation for control of manipulator. Touch screen with representation of manipulators' task space was used as an input/output device with direct workspace representation. Experimental study showed that usage of direct workspace representation significantly improves accuracy and productivity of control in human-robot interaction. Proposed human-robot interface was tested with manipulator. Possible application areas were described.

1. INTRODUCTION

Human-robot interaction is a challenging issue in modern robotics. There have been many researches on human-robot interfaces which allow human to define control input for the robot and receive information about its state. Proper design of these interfaces improves the quality of human-robot interaction.

Baczynski et al. [2003] proposed to use touch screen for teleoperation systems. PDA with touch screen was used for mobile robot navigation (See Hwang et al. [2003]). Interaction interface of stylus with tactile display with touch screen was proposed by Kyung et al. [2007]. Keskinpala et al. [2003] proposed to use touch screen and vision system for remote control of mobile robot. Similar, Nilas et al. [2004] used PDA with interactive navigation software for teleoperation of mobile robot. Improvement of PDA-based human-robot interface for teleoperation systems was described by Park et al. [2006]. Human-computer interface based on touch screen was used in supervising industrial machines and systems (See Tansel et al. [2004], Valladares et al. [2000], Wu et al. [2007]). Several researchers performed human study for evaluating performance of interaction devices with touch screen (See Rodriguez et al. [2000], Schedlbauer et al. [2006], Takahashi et al. [2005]).

Most of mentioned researches used indirect workspace representation or usage of direct workspace representation was restricted to mobile robot applications. In this paper, we propose new human-robot interface based on touch screen and direct workspace representation. We present comparative study of indirect and direct workspace representation. Control accuracy and productivity of indirect and direct workspace representation in human-robot interaction are compared. Possible application areas are described.

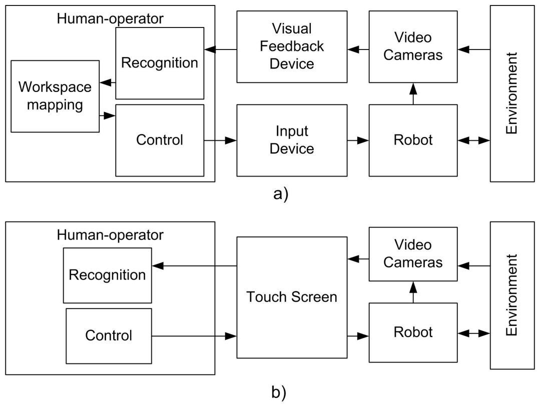

Fig. 1. Structural diagram of system with indirect workspace representation (a) and with direct workspace representation (b)

2. INDIRECT AND DIRECT WORKSPACE REPRESENTATION

2.1 Indirect Workspace Representation

In Fig. 1(a) shows the structure of a system with indirect workspace representation. We define system with indirect workspace representation as a human supervised control system in which mapping between the robot's task space and the input device workspace is done by human-operator. Human-operator gives a control input through an input device (joystick, computer mouse) by his/her hand. Displacement of input device is sent to the robot as

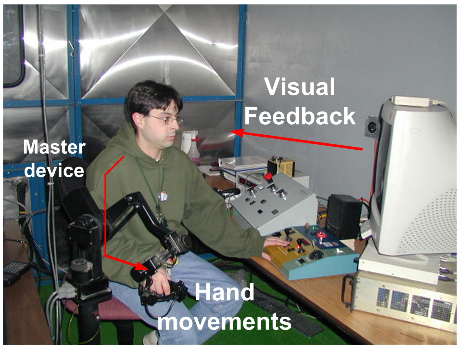

Fig. 2. Illustration for human-robot interface with indirect workspace representation. Human-operator controls slave manipulator with the help of master device and vision feedback at Pennsylvania Bureau of Radiation Protection

a control command. Robot is interacting with environment and vision information about this interaction is sent back to human-operator via visual feedback. Based on this vision information human decides how it is necessary to manipulate the input device in order to achieve desired motion of the robot. Illustration for such kind of robotic systems is shown in Fig 2. Human-operator receives vision information through visual feedback device and separately gives control input via arm movements. Human-operator should match information from vision system and realize respective master device movements. It is required for operator's brain to perform space mapping from task space of the robot into input device workspace.

2.2 Direct Workspace Representation

In Fig. 1(b) shows simplified structure of system with direct workspace representation. We define system with direct workspace representation as a system in which human-operator directly gives control input in task space of the slave robot without any mapping procedures. The main difference is the integration of input and visual feedback devices into one. In this research, we consider touch screen as an integrated interface device. On display of touch screen two dimensional projection of the slave robot's task space can be represented as a video stream from one or several cameras. Human-operator can directly give desired position for the slave robot in task space via touching the screen. It is not required to perform any mapping between robot's and input device's workspaces due to integration of visual output and control input in one device with touch screen.

We assume that human-robot interface based on direct workspace representation is more intuitive and can improve the quality of human-robot interaction.

3. COMPARATIVE STUDY OF INDIRECT AND DIRECT WORKSPACE REPRESENTATION

3.1 Task for Comparative Study

In this section, we compare the control performance of indirect and direct workspace representation. Accuracy and required time for task completion are experimentally compared.

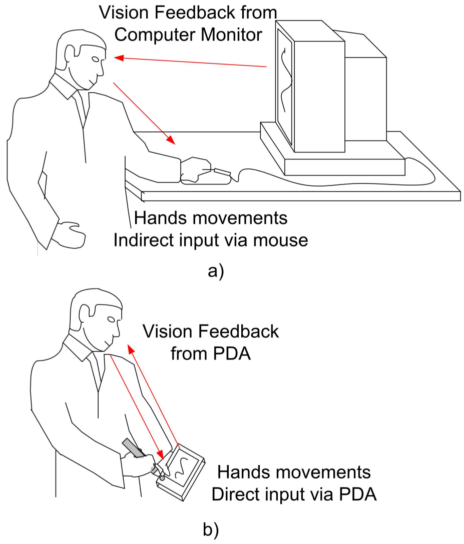

Fig. 3. Scheme for testing indirect control method (a) (with computer mouse) and direct control input (b) (with PDA)

Fig. 3 shows schemes of tasks for performance evaluation of indirect and direct workspace representations. For indirect workspace representation, computer mouse was used as an input device. Human-operator can move mouse in two dimensional horizontal space in order to control the pointer on the screen. PDA with touch screen was used as an input device for direct workspace representation. Human-operator can move stylus over the surface of the touch screen and directly see respective motion of the pointer.

For comparative study, trajectory following error was measured and analyzed. Three kinds of trajectories were used in experiments (Fig. 4). 12 subjects (6 male, 6 female, age 23-26, all right handed) participated in study. They were asked to trace polyline, sine and spiral curves using indirect input device (computer mouse) and direct input device (PDA with touch screen).

In experiment with indirect workspace representation, subjects were asked to trace the trajectory which was displayed on the screen via performing movements of computer mouse. In experiment with direct workspace representation, subjects were asked to trace the trajectory which was displayed on touch screen with the stylus. Curves displayed on computer and PDA screens were exactly same. Size of input area was 240x240 pixels. PDA with 3.8 inches screen with resolution 240x320 pixels and 17 inches LCD monitor with resolution 1280x1024 pixels.

First task was to follow the curve as accurate as possible without any time limitation. Second task was to follow the curve as fast as possible.

For tracing of polyline it was necessary to move input device (mouse or stylus) with constant speed in each of two dimensions. For tracing of the sine curve it was necessary to move input device with constant speed only in horizontal direction and move with variable speed in vertical direction. For tracing of spiral curve it was necessary to perform variable speed movements in all dimensions.

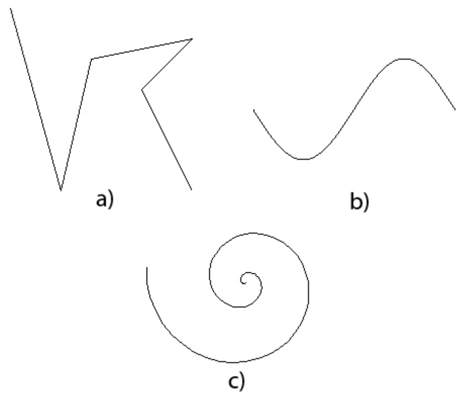

Fig. 4. Three curves which were used in experimental study: polyline (a), sine (b) and spiral curve (c)

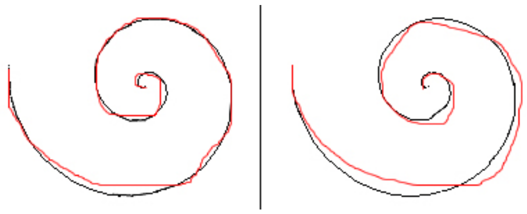

Fig. 5. Accurate (left) and fast (right) tracking of spiral curve using indirect input method for one subject

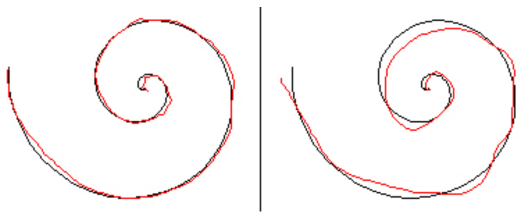

Fig. 6. Accurate (left) and fast (right) tracking of spiral curve using direct input method

3.2 Results and Analysis

In Fig. 5, experimental results for spiral curve tracking with indirect input device are presented. Accuracy was significantly reduced for the case of fast tracing.

In Fig. 6, experimental results for spiral curve tracing with direct input device are presented. In accurate tracing experiment, accuracy was higher compare to indirect control input. However in fast tracing, accuracy was reduced compare to accurate tracing. But still, accuracy was high enough for fast tracing with direct input device.

In Fig. 7, experimental results for accurate tracking for 12 subjects are presented. In indirect control input, it took from 8 to 40 s to complete the task. The longest time was required for tracking polyline and spiral curve. In direct control input, it took from 3 to 18 s to complete accurate tracking.

In Fig. 8, experimental results for fast tracking for 12 subjects are presented. In indirect control input, it took from 1 to 11 s to complete the task. Similar to accurate tracking, the longest time was required for tracking polyline and spiral curve.

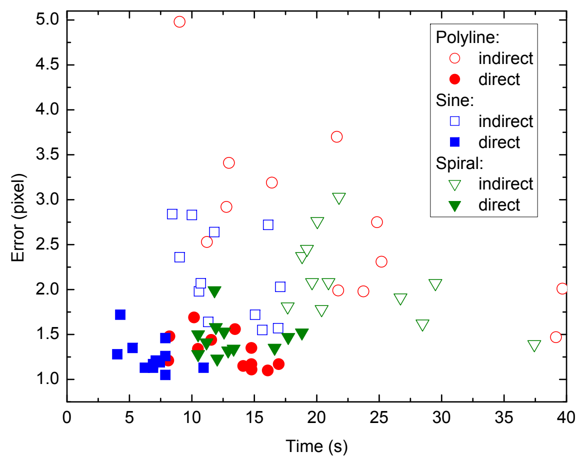

Fig. 7. Tracking error vs required time in accurate tracking for indirect and direct input devices for 12 subjects

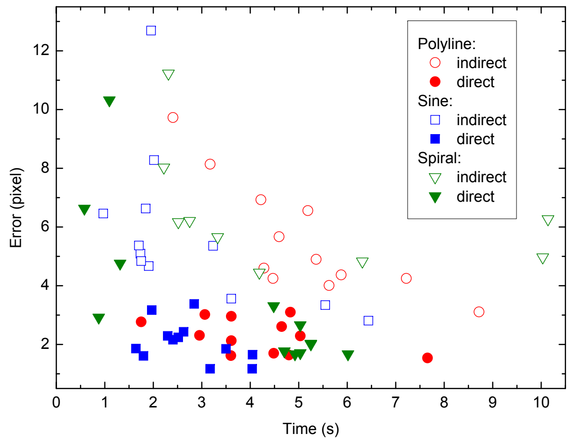

Fig. 8. Tracking error vs required time in fast tracking for indirect and direct input devices for 12 subjects

For all subjects accuracy was significantly improved and required time was reduced with direct input device.

In Fig. 9 and Fig. 10, average results for required time and error for fast and accurate tracking with indirect and direct input are presented. Experimental study showed that time required for tracking is smaller for sine curve. Tracking of polyline and spiral curve required larger time both for direct and indirect control input schemes.

Accuracy of tracking was significantly improved in experiments with direct control input device compare to experiments with indirect control input device (Fig. 10). Both in experiments with indirect and direct control input devices with fast tracking lowest accuracy was achieved in tracking of spiral curve. In experiments with accurate tracking with indirect input device largest error was achieved for tracking of polyline. In same experiment with direct input device, average errors were approximately same for all three kinds of curves.

In general, usage of direct input device improves accuracy for more than two times while required time is reduced approximately two times, as well. Operation with touch screen is more accurate and takes less time, while operation

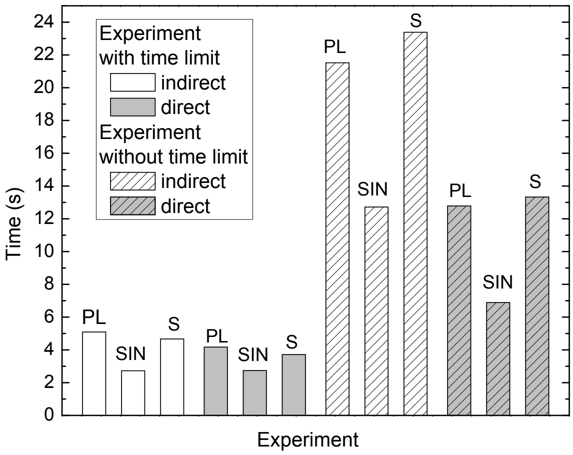

Fig. 9. Average required time for fast and accurate tracking with indirect and direct control devices. "PL" - polyline, "SIN" - sine curve, "S" - spiral curve

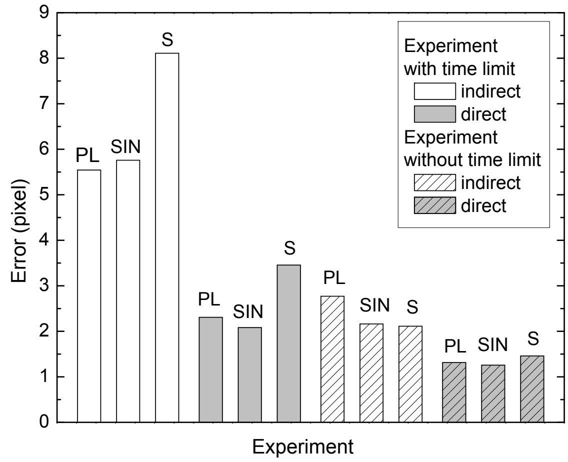

Fig. 10. Average tracking error for fast and accurate tracking with indirect and direct control devices. "PL" - polyline, "SIN" - sine curve, "S" - spiral curve

with mouse is either not accurate or very slow. Usage of touch screen based devices makes input more natural for human-operator.

4. VISIBILITY STUDY OF DIRECT WORKSPACE REPRESENTATION WITH 3-DOF MANIPULATOR

A simple 3-DOF manipulator was designed for testing direct workspace representation based on touch screen. A prototype of KUKA KR-150 industrial manipulator was used (Fig. 11). Height of manipulator in gaunt state was 333 *mm*. Dynamixel AX-12 servomotors from Robotis were used in manipulator. ATmega128 from Atmel Corporation was used as a microcontroller.

In Fig. 12, scheme of experimental setup which was used for testing direct workspace representation for control of manipulator is shown. Human-operator give desired position input for manipulator's end-effecter by pointing touch screen of PDA. Human-robot interface control program and PDA are shown in Fig. 13. Kinematic model of manipulator was represented and updated in real time on the screen of PDA. Human-operator could directly give

Fig. 11. 3-DOF manipulator used in experiments

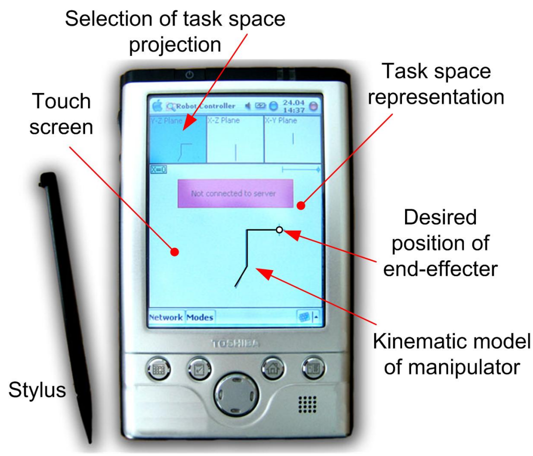

Fig. 13. Direct input interface for manipulator control based on PDA

desired position in task space of the manipulator. There was a function to select one of the three projections of the manipulator's task space, as well. As a result, operator could control robot in 3D space 2D input device. Information about desired position was sent to desktop computer via TCP/IP protocol and wireless network. Computer was communicating with AVR microcontroller with the help of USB port. AVR microcontroller was sending respective control command to servomotors of manipulator. Actual position of manipulator was sent back to PDA interface in order to represent actual configuration of the robot. All software and firmware was developed by using C/C++ and NI Labview tools.

Several experiments for testing the usability of direct workspace representation were performed. In Fig. 14, experiment when human-operator controls manipulator with the help of PDA is shown. Several subjects were asked to perform three tasks: trajectory following (Fig. 15(a)), points reaching (Fig. 15(b)) and interaction with an object (Fig. 15(c)).

Experimental study showed that direct workspace representation with touch screen is very natural and intuitive for human-operator. Direct workspace representation is intuitive because operator can see response for his/her action immediately on the screen. This is important because it decreases time of training for new subjects. In addition,

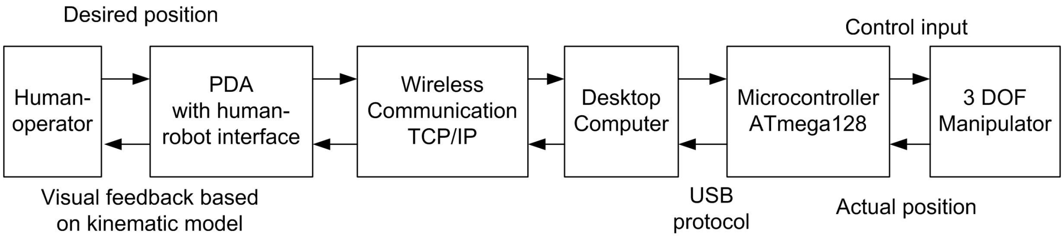

Fig. 12. Scheme of experimental setup for testing direct control input for manipulator control

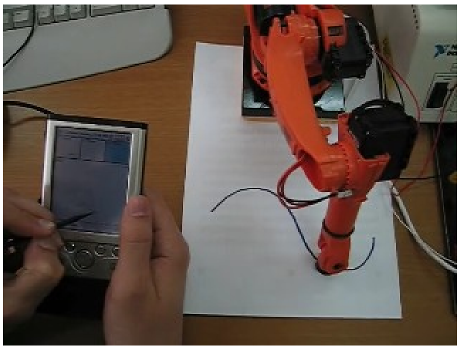

Fig. 14. Human-operator controls manipulator via giving end-effecter's desired position through PDA

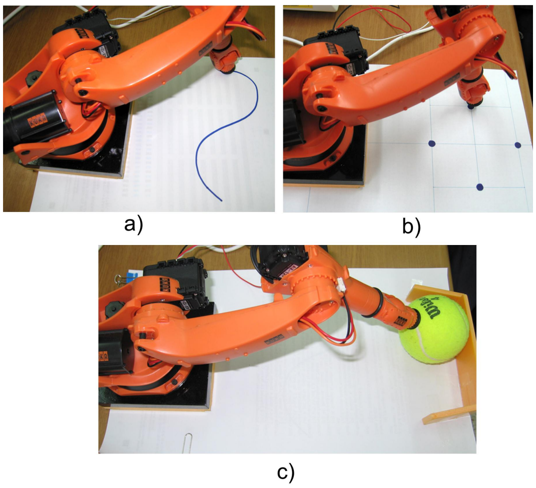

Fig. 15. Testing direct control method for manipulator control

stylus which is used for PDA is very common to human, usage of stylus is similar for usage of pen or pencil in daily life.

With the help of touch screen human-operator can control not only the position of manipulator but set also the speed. By using stylus with touch screen operator can tap-and-hold on actual position of end-effecter of manipulator on the screen and then can move stylus over the surface of the screen to new position thereby can control the speed of manipulator.

5. POSSIBLE APPLICATION

In this section, we describe some possible application areas of direct workspace representation. Direct control input devices can be used for control of manipulator which operates in undetermined environment. For instance, proposed

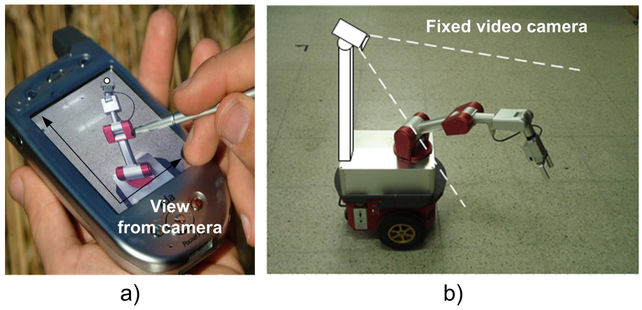

Fig. 16. PDA with touch screen and vision system can be used for direct control of mobile manipulator

human-robot interface can be applied for teleoperation of mobile manipulator.

In Fig. 16, we propose application of direct workspace representation which is based on integration with vision system. Video camera(s) should be attached to mobile platform in order to transmit general view of mobile manipulator. Video stream from the camera is displayed on the screen of PDA. Human-operator can see manipulator on the touch screen and directly control its end-effecter by pointing the screen with the stylus.

There are several important things which should be considered in this application. First, for control manipulator in 3D space it is required to use at least two cameras which can display two different projections of manipulator. Second, position and orientation of all cameras which are attached to the robot should be fixed and cannot be changed. This is important because view from the cameras is directly mapped to coordinate system of the touch screen which is used for input desired position. Disadvantage of this control scheme is that presented direct input method is two dimensional. However, it is required to control manipulator in 3D space. Therefore, operator should switch between different projections of mobile manipulator at least two times. Another disadvantage is absence of any haptic feedback in teleoperation. Devices with touch screen do not allow human-operator to feel interaction forces from the slave robot.

In order to overcome the disadvantages of direct workspace representation with touch screen device we propose another human-robot interface which is shown in Fig. 17. This human-robot interface is based on combination of haptic master device and augmented reality (See Vallino et al. [1999]). Human-operator manipulates master device in order to control remote slave robot and can feel interaction forces from manipulator via haptic feedback. Vision feedback is transmitted to human-operator not by independent computer monitor as it has been done in

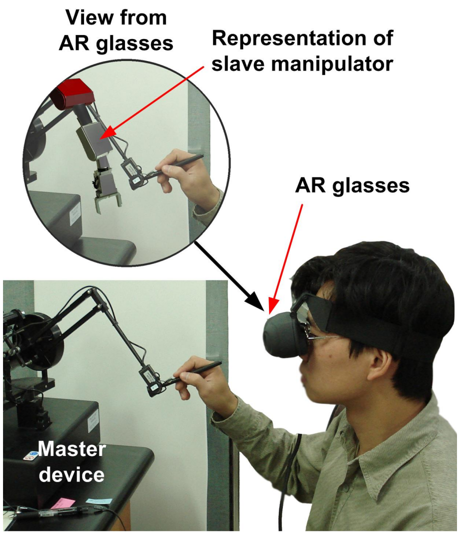

Fig. 17. Augmented reality (AR) can be used together with master devices for direct input control in 3D space

conventional systems. Augmented reality glasses is used to combine view of the master device and video stream which is received from cameras installed on the slave robot. Combination of two master and slave workspace views with the help of augmented reality allows human-operator to give direct input commands in 3D space. As a result, human-operator directly controls and supervises the slave robot. This human-robot interface is similar with exoskeleton devices when human and robot are integrated into a single system (See Perry et al. [2006]).

6. CONCLUSION AND FUTURE WORKS

In this research, direct workspace representation for control of robotic systems is proposed. Comparative study between conventional indirect and proposed direct workspace representation methods showed that direct workspace representation significantly improves the quality of control process. Both accuracy and productivity were improved.

Proposed human-robot interface with direct workspace representation was tested through the experiments of controlling 3-DOF manipulator with PDA. Experiments showed that direct workspace representation was natural and intuitive for human-operator.

In future, we plan to research more about application of direct control input. We plan to realize a system with combined vision and augmented reality and apply it to bilateral teleoperation of mobile manipulator.

Another interesting idea for future works is controlling manipulator with kinematic redundancy. If manipulator has seven or more DOF with relatively short links like a snake, it can reach nooks or curved pipes. In case of redundancy each joint of the slave robot which is displayed on the touch screen can be controlled independently.

ACKNOWLEDGEMENTS

This work was supported by the grant for industry-university cooperation laboratory program in 2009.

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