A STUDY ON THE ENHANCEMENT OF MANIPULATION PERFORMANCE OF WHEELCHAIR-MOUNTED REHABILITATION SERVICE ROBOT

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Abstract –A wheelchair-mounted rehabilitation service robot called KARES (KAist Rehabilitation Engineering Service system) has been realized to assist the disabled / the elderly. One of the most important factors to be considered in the design of this system is to enhance reliability so that the disabled / the elderly can use with feelings of safety and confidence. For enhancing the reliability, it is suggested that autonomous manipulation and manual manipulation be integrated in a proper manner. The basic autonomous tasks for KARES are grasping an object on the table, grasping an object on the floor, and manipulating a switch on the wall. For manual manipulation of the disabled / the elderly, a 3D input device called SPACEBALL 2003 is used and an auxiliary device is designed for the disabled to facilitate rotational input function. Using this auxiliary device and SPACEBALL 2003, the disabled / the elderly are able to make a manual adjustment during the autonomous task. Integration of autonomous and manual operation proves to be robust and reliable. The performance of the system is verified by experiment.

I. INTRODUCTION

In the coming era, the activity of designing automation systems should not be confined to manufacturing area but be directed toward "service sector" as well. A service robot is re-programmable, sensor-based mechatronic system that can perform useful works to human activities [1]. Functions of service robots are generally related to the ordinary human life like repair, transfer, cleaning, and health care, etc. Service robots may include rehabilitation robots, surgery robots, housekeeping robots, repair robots, and cleaning robots, etc. In this paper, rehabilitation service robots are mainly considered.

The objective of rehabilitation service robots is to assist physically handicapped or weak persons such as the disabled / the elderly to lead independent livelihood. In the case of Korea, the number of people who are 65 years old or more is 5.7% of the total population at present but it is reported to be steadily growing. Also posteriori physically disabled people tend to increase due to industrial or traffic accidents, etc. In a sense, everyone has a possibility to be handicapped because of unfortunate accidents or inevitable outcomes of the nature. Thus, development of a system that can assist humans for their incomplete activities and lost senses is strongly desirable.

The history of the rehabilitation service robots is relatively short [2]. Rehabilitation service robots can be divided into three classes with respect to mobility; workstation-based systems, mobile systems, and wheelchair-based systems [3].
KARES (KAist Rehabilitation Engineering Service system) has been realized in KAIST to assist the disabled / the elderly for the independent livelihood without any assistance as shown in Fig. 1.

Fig.1. KARES

Specifically, KARES is a wheelchair-mounted rehabilitation service robot and consists of powered wheelchair, 6 DOF robotic arm, a gripper, the controller of the robotic arm, color vision system, force / torque sensor, driver, and user interface, etc (Fig. 2). VORTEX (Everest & Jennings, USA) is used as the powered wheelchair of KARES. Mu gripper RH707 with on/off control and 0.5 ~ 7 kg•f gripping force is used as the gripper. To control 6 joints and a gripper on the robotic arm, a multi-motion controller is used.

To recognize the environment, two sensors, i. e., vision and force / torque sensors are equipped. JAI-1050 color CCD camera is used as the vision sensor. This camera can be easily mounted on the robot end-effector for small size (12mm in diameter) with a remote head type. To process vision information, Genesis board (MATROX) is used. JR3 (50M31, 140g, 50mm in diameter, and 31mm in thickness) is used as the 6 DOF force / torque sensor. For the manual control of the robotic arm, 6 DOF input device with 10 keys (SPACEBALL 2003) is mounted upon the side of a wheelchair. In addition, simple voice commands can be used to operate the robotic arm.

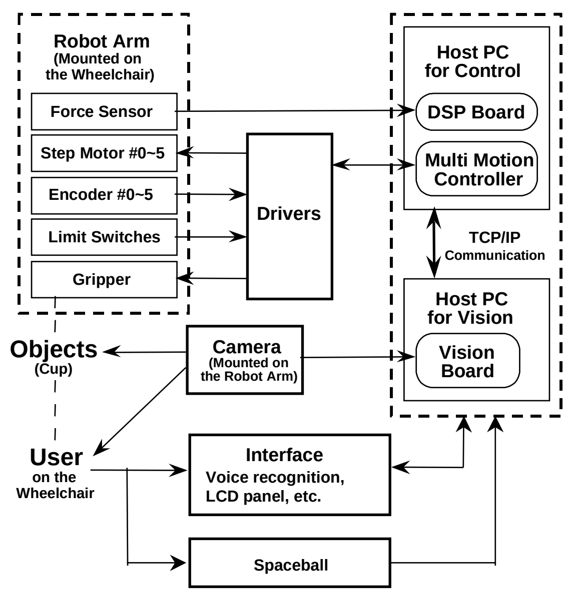

Fig. 2. Overall block diagram of KARES.

The target users of KARES are those who have limited manipulability and limited mobility, including the physically disabled and the elderly that have difficulties in using arms and legs. Also some potential users are persons with spinal cord injuries (C5, C6 and C7) who have difficulties living independently [4] and need engineering solutions.

II. SYSTEM PROBLEM DESCRIPTION

For intelligent service robots, friendly human-machine interface, reliable human-machine interaction, and compatible human-machine integration are three major functions to be captured during the design [5]. Specially, the human-machine interaction is an important issue in the rehabilitation robotics. The operation of a robotic arm for grasping, moving, and contacting with the target is essential. In some sense, manual or direct control of the robotic arm is similar to the operation of a tele-manipulator. However, compared with tele-manipulator, the manual control of the robotic arm by physically disabled persons would take a high cognitive load on the user part since they may have difficulties in operating joysticks or pushing buttons for delicate movements. The limited movement of manual operation can be enhanced by incorporating autonomy for the robotic arm [6][7].

Specifically, KARES is designed to be capable of conducting 4 basic autonomous tasks. The first task is to pick up a cup on the table for drinking. The second task is to pick up a pen that is laid on the floor. It is noted that the users that sit in the wheelchair have difficulty in picking up objects on the table or on the floor. The third task is to move an object to the user's face for drinking, eating, or for touching. Finally, the fourth task is to operate a switch on the wall.

For these tasks, it is found that a key issue is recognition of a target in the environment. With information of the environment, motions of the robotic arm can be divided into free-space motions and constrained-space motions [5]. In the free-space motions, vision-based control is useful for the accurate motions. In the constrained-space motions, it is possible for the moving robotic arm to come in contact with external objects, and thus force-based control is useful for appropriate motions. These are complementary with each other. Therefore, various information of the environment needs to be obtained from vision and force sensors, etc. and they are used to carry out autonomous tasks (Fig. 3).

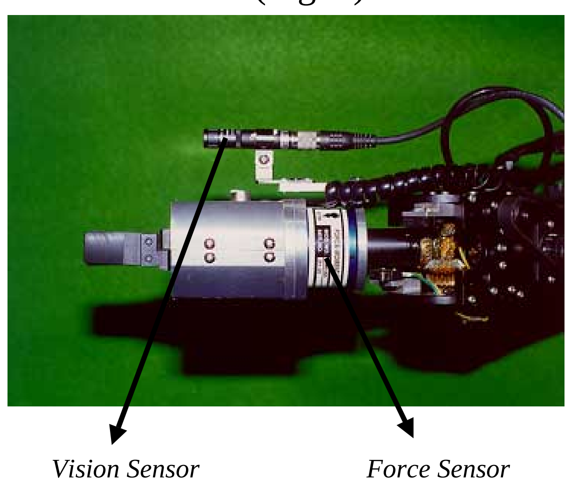

Fig. 3. Vision and force sensors on the end-effector.

It is remarked that, in general, autonomous manipulation of a wheelchair-mounted rehabilitation service robot is vulnerable to some basic technical problems. First, vibration of the robotic arm exists due to the user's motions and due to the action of contact with objects in the environment. Also, the rubber wheels of the wheelchair can be a source of vibration. The vibration of the robotic arm can be a serious problem for the autonomous tasks. Second, the vision sensor is not robust to the change of illumination in the complex environment. Finally, an autonomous task is executed based on a finite number of pre-programmed manipulations. For a real world problem, such a sequence of discrete manipulations may render an unsatisfactory form that is quite different from human's way of executing a task.

If someone controls the service robot by manual manipulations, he (or she) may perform various tasks or continually to attain robustness to the complex environment and to reduce vibration of the robotic arm. Note that the disabled or the elderly has difficulties in manual manipulation. Hence a specified device is designed for the disabled / the elderly to easily manipulate the robot and it is proposed that autonomous manipulation and manual one be integrated to enhance the manipulation performance.

III. MANUAL MANIPULATION FOR THE DISABLED /THE ELDERLY

The robot arm of KARES has 6 DOF. To manipulate such a robot, 3D input device is needed but, the disabled / the elderly, in general, cannot operate such a 3D input device very well because of their limited manipulability and mobiity.

For the disabled / the elderly to manually manipulate the robot easily, it is proposed that a 3D input device called SPACEBALL 2003 is adopted with an auxiliary device which is designed for the disabled to facilitate the rotational input functions (Fig. 4).

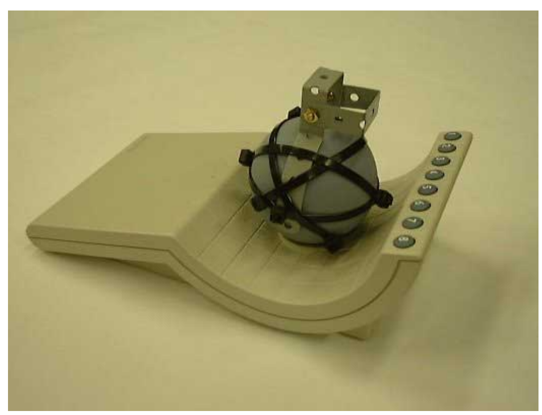

Fig. 4. SPACEBALL 2003 and auxiliary device

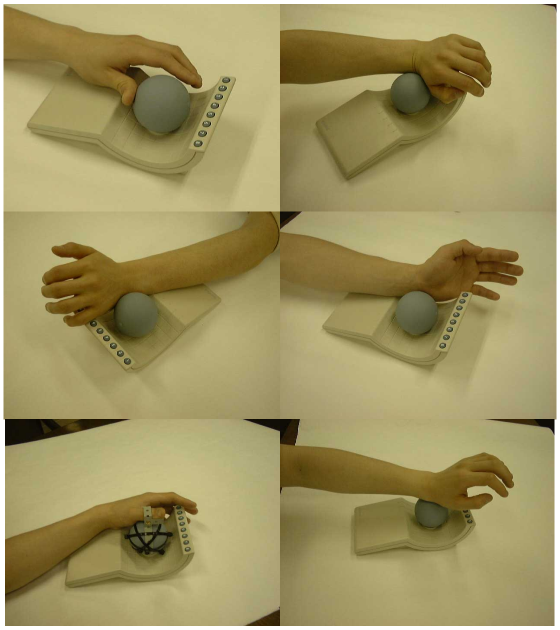

Fig. 5. Hand shapes for translational inputs

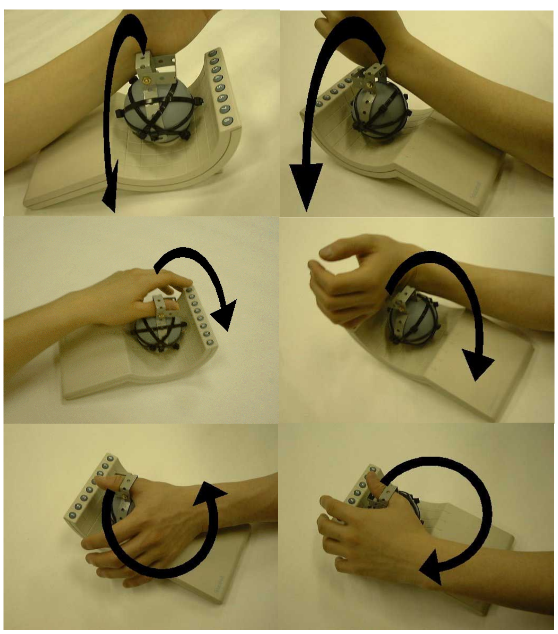

Fig. 6. Hand shapes for rotational inputs

The auxiliary part is designed because those with C6 and C7 (C: Cervical nerves) quadriplegia can use the thumb but cannot use other fingers and so, in general, they cannot generate rotational inputs.

Using this auxiliary device and SPACEBALL 2003, the disabled / the elderly can now make a maual adjustment (Fig. 5,6).

IV. INTEGRATION OF MANUAL AND AUTONOMOUS MANIPULATION

There are two types of manipulation in integrating manual and autonomous manipulations. One is manipulation for known objects and the other is manipulation for unknown objects.

For known objects, autonomous manipulation can be possible, but to be robust against vibration of the robotic arm and for complex environment, we integrate manual and autonomous manipulation. For unknown objects, autonomous manipulation is impossible so manual manipulation is carried out.

For manipulating a robot manually, sensitivity setting of the robot movement is an essential factor for efficient task. If we don't use sensitivity setting, the robot runs with only one speed and thus the time for completing a task can be long. In this paper, the sensitivity is a scalar number from zero to three representing the maximum limit velocity level for a specific unit direction. If the sensitivity is zero for some unit direction, then the robot cannot approach toward the direction.

In order to release the load of the disabled / the elderly, we propose an automatic sensitivity setting. The automatic sensitivity setting is a method of setting automatically the sensitivity of each unit direction of the gripper in the Cartesian coordinate. For automatic sensitivity setting, we assume that the distance from the gripper to the object plane (a plane which the target object is placed) is known. This assumption is valid for the table and floor task in the home environment. Then we proceed as follows: First, we set the basic sensitivity (the sensitivity of the direction which is normal to the object plane) using the distance from gripper to the object plane. Second, we set the sensitivity of the other direction larger than the basic sensitivity. If the distance from the gripper to the object plane is less than 5cm, then we set the basic sensitivity zero to protect the collision between robotic arm and the object plane.

We decompose the table task and the floor task in order to integrate manual and autonomous manipulation (Table 1).

Subtask 1 and subtask 3 is pre-programmable but subtask 2 is changed every time and isn't robust for the vibration of the robotic arm and complex environment.

For unknown object, subtask 1 and subtask 3 is operated full-autonomously and subtask 2 is operated full-manually. But for pre-known object, subtask 1 and subtask 3 are operated full-autonomously and subtask 2 is operated by the manual adjustment during the autonomous motion.

Table 1. The decomposition of each task

Table task	e.g. Catching the cup on the table and moving the cup to the lip	
	Subtask 1	Move the gripper near the table
	Subtask 2	Catch the object using the vision and force sensor
	Subtask 3	Move the object near the lip
Floor task	e.g. Catching the pen on the floor and moving the pen to the lip	
	Subtask 1	Move the gripper near the floor
	Subtask 2	Catch the object using the vision and force sensor
	Subtask 3	Move the object near the lip

The task begins by the voice command (e.g. "table", "floor", etc.) and subtask1 is performed. If the object is not known, the robot sends voice message to the user for manual manipulation.

If the object is known, the subtask 2 is performed automatically and the manual adjustment based on the automatic sensitivity setting is possible. And if no contact force exists during the subtask 2 or the user wants manual manipulation, manual manipulation is started.

The subtask 3 is started from the user's voice command or recognition of the weight of the object.

V. RESULTS

To confirm the robustness against vibration of the robotic arm, we have set up a scenario for known object that the position of the handle of a cup is changed from ‘a’ to ‘b’ in Fig. 7. Vibration of the robotic arm can be interpreted as the change of the position of the target object from the viewpoint of the robot. In this figure, the solid line represents the trajectory of the robot end-effector. When the robot arm closes in the handle of the cup, the user interrupts the autonomous manipulation by the fail detection of autonomous task. Then, the change of the cup is overcome by the human’s direct control.

Moreover, subtask 2 can be performed for an unknown object. Also manual manipulation during the subtask 2 can manage the errors of the sensors by the complex environment.

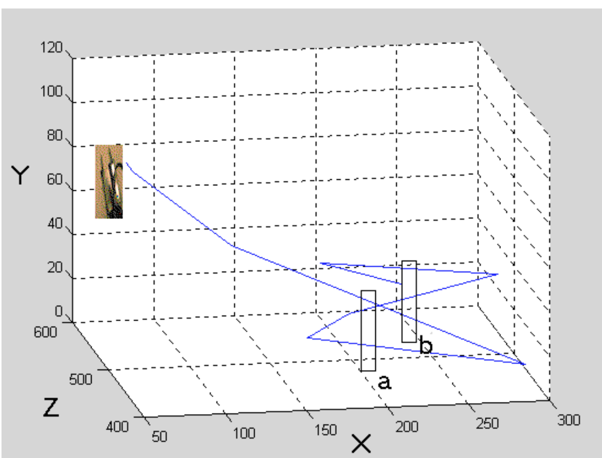

Fig. 7. Experiment for the robustness of the integration of manual and autonomous manipulation

VI. DISCUSSION

In manual manipulation, there usually exist both translational components and rotational components in a command by user’s operation because the operation by hand of the disabled / the elderly are very limited. Thus only one component between them is transferred to the controller by using a button as an additional input.

For the various kinds of the disabled / the elderly to use KARES, another input device may be needed. For C6 and C7 quadriplegia, SPACEBALL 2003 and the auxiliary device are enough. But, for C5 quadriplegia, head movement, eye gaze, EMG (electromyography), or EEG (electroencephalogram), etc. can help in inputting the user’s command.

VII. CONCLUSIONS

It is reported that a service robot called KARES is designed as a rehabilitation service robot with a wheelchair-mounted robotic arm to assist the disabled / the elderly for the independent livelihood. KARES can do four basic autonomous tasks using color vision and force / torque sensors.

But vibration of the robotic arm and the errors of the vision sensor in the complex environment are found critical factors in conducting tasks. For enhancing the reliability, we have proposed a strategy of the integration of manual and autonomous manipulation. And for the disabled / the elderly to use 3D input device easily, it is reported that the auxiliary device is needed.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the help provided by Taejon St. Mary's Hospital, Korea and National Rehabilitation Center, Korea.

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