Proceedings of IMECE2002
ASME International Mechanical Engineering Congress and Exhibition
November 17-22. New Orleans, Louisiana

IMECE2002-32668

DEVELOPMENT OF A TELEROBOTIC SYSTEM TO ASSIST PERSONS WITH DISABILITIES

N. Pernalete
npernale@wmich.edu

W. Yu
wyu@eng.usf.edu

B. Fritz
bfritz@eng.usf.edu

R. Dubey
dubey@eng.usf.edu

ECE, Western Michigan University

Rehabilitation Robotics Laboratory
University of South Florida

ABSTRACT

This paper describes the development of intelligent mapping from a haptic user interface to a remote manipulator to assist individuals with disabilities performing manipulation tasks. This mapping, referred to an assistance function, is determined on the basis of environmental model or sensory data to guide the motion of a telerobotic manipulator while performing a given task. Human input is enhanced rather than superseded by the computer. [8]

Three manual dexterity assessment tests commonly used in occupational therapy field were chosen to implement several forms of assistance functions designed to augment the human performance. The test bed used for these tasks consisted of a six-degree-of-freedom force-reflecting haptic interface device, PHANToM with the GHOST SDK Software. One of the tests was chosen to be implemented in a real telerobotic system consisting of the haptic device as a Master and the Robotics Research Corporation manipulator (RRC K-2107) with a vision system and laser range data as a Slave.

The results demonstrated that the forms of assistance provided reduced the execution times and increased the performance of the chosen tasks. In addition, these results suggest that the introduction of the haptic rendering capabilities, including the force feedback, offers special benefit to motion-impaired users by augmenting their performance on job-related tasks.

INTRODUCTION

Several disabilities such as Muscular Dystrophy, Cerebral Palsy, Multiple Sclerosis and Cerebrovascular Accidents present symptoms including limited movements or maneuverability, reduction in strength, spasticity, tremor, and a wide range of dexterity problems. These symptoms do not necessarily involve any reduction in the touch and/or feel senses. Therefore, if haptic feedback can be incorporated into the telerobotics system, these users can benefit from the enhanced interface from using touch and feel interactions.

Since there are no adequate models to predict human manipulation forces, Hollerbach [2] concluded that a haptic interface to a simulation is the best way to predict that a human will be able to perform a task comfortably. In addition, the unique attributes of the touch sense and force reflection in combination with their adaptability properties, make haptic devices suitable for applications in human augmentation, filtering and supporting manual activities by the variously disabled [3]. Moreover, Rosenberg [10] has shown that force feedback can enhance manual performance in virtual environments and telemanipulation systems. A method for utilizing sensory or model data to modify the operator input in teleoperation for improved task execution and without overriding the operator's command to has been used in nuclear clean up tasks. [8-9]. We are preferably to apply this approach to develop a telerobotics manipulator system to assist persons with disabilities.

This paper is organized in the following way. The following section provides the background of previous applications of robotics for vocational rehabilitation. The next section covers the description of the assistance function concept and development; and the three different manual dexterity assessment tasks that were implemented. Experiments and their results for various forms of assistance are explained in the following section. Conclusions are presented in the last section.

BACKGROUND

The traditional use of robotic systems for people with disabilities has been to augment or replace the loss of functional abilities. A growing number of applications utilize the technology of these systems as a tool for vocational rehabilitation and educational training processes.

A study done by J. Schuyler et al. [5] shows the use of common standardized assessment tasks from the occupational therapy field to evaluate human performance augmented by a rehabilitation robot. Although their time results were modest in comparison to the performance of the non-disabled population, they indicated that the individuals with disabilities would not have been able to execute the given tasks without the help of the robotic system.

NOMENCLATURE

Symbol	Description
V_{slave}	Velocity of the Slave Manipulator
V_{master}	Velocity of the Master Manipulator
ScaleFactor	The scaling matrix
$\vec{V}_{projection}$	The projected velocity in the desired trajectory
$\vec{V}$	Actual Velocity of the master
$\vec{B}$	Desired trajectory vector
$\left\Vert\vec{B}\right\Vert$	Magnitude of the desired trajectory vector
$\vec{F}$	Force vector
$\vec{F}_M^C$	Master constraint force
K_F	Constant magnitude of the constraint force
K	Scale factor greater than one
k	Scale factor less than one

ASSISTANCE FUNCTION DEVELOPMENT

Assistance Concept Description

The underlying idea behind the assistance function concept is the generalization of position and velocity mappings between master and slave manipulators of a telerobotic system. Environmental model and on-line sensory data used to determine this mapping helps in guiding the remote manipulation to perform a given task. This concept was conceived as a general method for introducing computer assistance in task execution without overriding an operator's command to the manipulator. [8-9]. Rosenberg [10] developed a general concept known as Virtual Fixturing in which force feedback information is used to assist user performance in reducing the completion times of manual assembly tasks.

This concept was also used by Bettini et. al. [11] to provide assistance algorithms for direct manipulation by applying constraints on the motion of a tool shared by the user and the robot. These algorithms improved the human's ability to perform precise motions, while allowing them to maintain application control (steady hand concept).

The assistance functions can be classified as regulation of position, velocity and contact forces. All of these assistance strategies are accomplished by modification of system parameters. A simple form of position assistance is scaling, in which the slave workspace is enlarged or reduced as compared to master workspace.

The velocity assistance is commonly used in approach and in avoidance of objects in the workspace. In both cases, the velocity scaling varies according to whether motion in that particular direction is serving to further the desired effect of the motion.

Finally, the force assistance function consists of imposing some constraints based on attractive or repulsive potential fields.

Three Manual Dexterity Assessment Tests

These assessment tests are used to evaluate the physical manipulation abilities of individuals. The performance is measured by the time it takes to execute a specific task. Also, qualitative observations of reliability, stability and endurance are taken into account by occupational therapists.

The idea of choosing a set of manual dexterity tests is to assess the human-robot haptic system performance by applying it to tests that are regularly employed in the occupational therapy field.

Minnesota Rate of Manipulation Test

This is one of the various psychomotor tests that have been developed to assess various functions of the arm and hand, which include grip, finger dexterity, manual dexterity, and wrist speed [4].

This test requires the use of cylindrical blocks of 3.5 cm. in diameter and 2.2 cm. long. These blocks are to be manipulated among a set of holes located on a table or board. These holes are 3.8 cm in diameter and 1.3 cm deep. When the test starts, the blocks are located in the holes.

Among the five different subtests that the Minnesota Rate of Manipulation test has, two were chosen for this application.

They are: The Placing test, which consists of moving the cylindrical piece from one hole to another, and the Turning test, which consists of turning the cylindrical piece over in the same hole. The main purpose of these subtests is to assess fine finger and manual dexterity.

Jebsen Hand Test

The objective of this test is to assess the hand function as an important part of the evaluation of a person's functional capabilities. "The ability of a patient to use his hands effectively in everyday activity is dependent upon anatomic integrity, mobility, muscle strength, sensation, and coordination" (Jebsen et al. [6]).

This test is based on the manipulation of a range of various items such as cans, paper clips etc. Two subtests were picked among the seven subtests available for this task. The subtests consist of picking up cans (empty or full) from a specific point and placing them onto a shelf.

The main function of these subtests is to assess arm and hand strength.

Box and Blocks Test

This test measures gross manual dexterity and is frequently used in research and rehabilitation. This test consists of moving one-inch blocks from one side to another in a two-sided box. Figure 1 shows the representation of this task.

Assistance Functions For The Three Tests

Various forms of assistance functions were implemented with the purpose of comparing their effects in time execution for the tasks. Special focus will be given to the assistance functions that provided better time results as shown in the results section.

Each assistance function is for a specific type of movement of the manipulator and not for a certain task. So each task may require multiple assistance functions.

Regulation of Positions

Two functions were implemented in this case: Linear and Planar Assistance function. In these functions, the motion of the manipulator is constrained to lie along a given line or plane [8]. This is to help the persons with disabilities operate more stably.

Regulation of Velocities

In this type of assistance function, the mapping between the master and slave is done based on velocities. In these particular tasks, this strategy is used to provide assistance in approaching the goal. Thus, the velocity scaling used varies according to whether the motion in a particular direction is serving to further the desired effect of the motion. In the approach assistance, the velocity is scaled up if the motion reduces the distance between the current and goal positions of the manipulator. Otherwise, the velocity is scaled down.

Two different approaches were used to implement the scaling factor. In one case, the user is asked to enter a scaling factor between 0 and 1. The scale-factor introduced is used to scale the velocity up in the directions of motions in which the goal and end-effecter are located, and to reduce the velocity in the direction away from the goal. In the second case, the scaling factor is increased or decreased proportionally to the location of the end-effecter with respect to the goal and workspace limits.

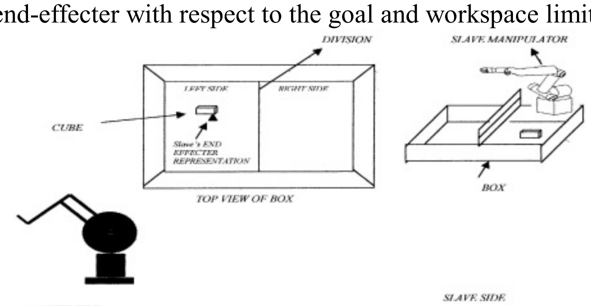

Figure 1: Representation of the Box and Blocks Test

For velocity regulation, the scaling factor's changing was depicted in Figure 2. The scaling factor's value depends on the subtask being executed and the direction of travel.

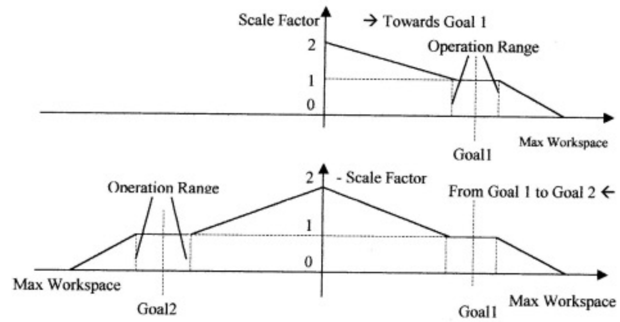

Figure 2: Scaling Factor Function

The relationship between the master and the slave velocities is described as:

$$V_{slave} = scaleFactor * V_{master} \tag{1}$$

The commanded positions to be sent to the slave's controller are calculated by discrete integration using the sampling time and the previous positions.

Force Assistance Function

The idea of this kind of assistance is to augment the user's dexterity by imposing some constraints based on attractive or repulsive potential fields. These attractive or repulsive potential fields are virtual constraints that are implemented in the master's control in order to help the operator carry out some complex tasks such as staying on a perfect line or moving away from the undesired zones as the approach suggested by Turro et al. [7]. Figure 3 shows the representation of concept.

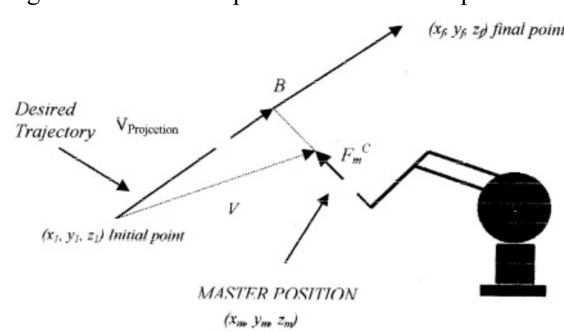

Figure 3: Representation of the Force Assistance Function

The projection of the operator's Cartesian position on the desired trajectory is obtained using the dot product as:

$$\overline{V}_{projection} = \frac{\vec{V} \cdot \vec{B}}{\left\|\vec{B}\right\|^2}\vec{B} \tag{2}$$

Where B is the trajectory vector, from beginning point to the end point. V is the vector between the beginning point and the current point of the end effector.

An attractive potential field whose amplitude increases with the distance between the end-effecter and the projected point then surrounds the curve or control surface.

The force vector is then calculated as:

$$\vec{F} = \vec{V} - \overrightarrow{V_{Projection}} \quad (3)$$

The corresponding attractive force on the haptic's device end-effector can be multiplied by a constant coefficient K_F in order to adjust the effects of this force (coefficient for viscosity). This factor was set to 0.015 after a trial and error process and some consulting with the manufacturer (Sensable Technologies).

$$\overrightarrow{F_m^C} = K_F * \vec{F} \quad (4)$$

In this case, the operator will easily move on the no-constraints directions, but will have to fight high torques on its master device to go away from it. The constraints were imposed on Y- and Z- axes to help the operator move on the X-axis.

Box and Blocks Test Using Assistance Functions

This test consists of moving cubes from one side to another in a two-sided box. A top view of the box is used and the blocks are randomly located on the left hand side, and dropped anywhere on the right hand side of the box (see Figure 1). Assistance was provided through an arrangement of different scaling in positions.

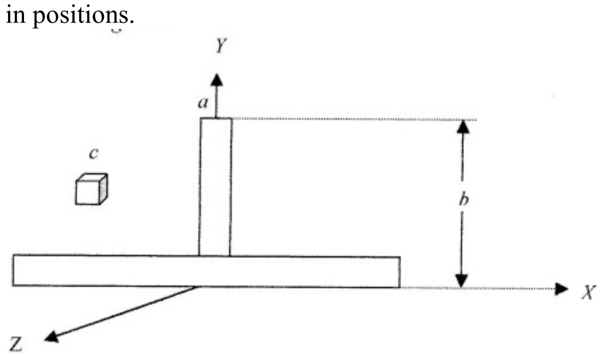

Figure 4: Representation of the Box Dimensions

Figure 4 shows the dimensions of the box. Based on the position of the slave (given by SlaveX, SlaveY and SlaveZ*)*, the velocity mapping is done using the following formulations:

If the cube is on the left side of the box and SlaveZ < b*,* then the assistance is provided by scaling up (*K* factor) the master's velocity in X and mapping it to the slave's velocity in Z. The velocities in the other directions are scaled down (using k factor) as follows:

$$V_{slave} = \begin{bmatrix} 0 & 0 & k \\ 0 & k & 0 \\ K & 0 & 0 \end{bmatrix} V_{master} \quad (5)$$

Where K>1 and 0<k<1. This mapping matrix can simplify the task operation. When the user moves the master on a horizontal line (X axis), the slave moves the cube outside of the box (positive Z direction).

This mapping is done to minimize the users' movement in executing the task, and translate their simple movements (especially coming from persons with disabilities) into more complex ones.

Once the cube is lifted to a certain height (higher than the wall '*b*'), the user's movement on the X-direction is scaled up and directly mapped onto the slave's movements to help in crossing to the other side of the box using equation (6).

$$V_{slave} = \begin{bmatrix} K & 0 & 0 \\ 0 & k & 0 \\ 0 & 0 & k \end{bmatrix} V_{master} \quad (6)$$

Where K>1 and 0<k<1.

Finally, after the slave manipulator crosses the wall, it is ready to drop the block. The motion of the operator on the X-axis is mapped onto a motion on the negative direction of the Z-axis as in equation (7). In this way, the velocity of the master in the X-direction is translated onto a velocity of the slave into the negative Z-direction.

$$V_{slave} = \begin{bmatrix} 0 & 0 & k \\ 0 & k & 0 \\ -K & 0 & 0 \end{bmatrix} V_{master} \quad (7)$$

Where K>1 and 0<k<1.

Box and Blocks Test Using Sensor Based Assistant Function

A combination of the linear, planar and velocity assistance, referred to as the sensor assist function (SAF), was developed in this case. The SAF essentially uses sensory data to perform variable velocity mapping from master to slave (Figure 5).

The testbed used consisted on the PHANToM and the seven degree-of-freedom slave robot, a RRC K-2107. The sensors include a DME 2000 Laser Range Finder (LRF), and a vision system using a Hitachi KP-D50. These sensors are mounted on the end-effector as shown in Figure 7.

The SAF involves a variable combination of the linear and velocity assistance to modify the master input velocity to achieve optimal operator performance. The vision system is used to scale the master velocity in the direction of the goal object, and avoid known obstacles such as the wall. The image processing software, Halcon, uses edge detection and obtains the center pixel value of the goal object in the camera's view. Once the end-effector grabs the object, the software obtains the edge of the wall, which is used to avoid the obstacle. The LRF is used in the velocity assistance in the Z-direction depending on the depth of the obstacles, and object.

There are seven stages of assistance shown in Figure 6. At the start of the task, the robot is in the home position and there is no scaling until the object is seen by the vision system.

The first stage involves minimizing the distance the end-effector is from the object in the X-Y plane. The second stage adds z-direction scaling as the manipulator moves down

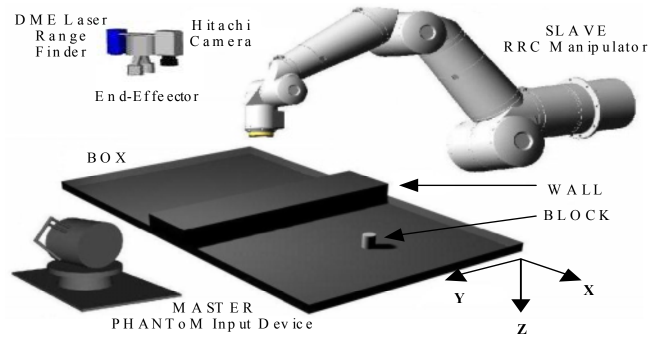

Figure 5: B&B Test Using Sensor Assisted Teleoperation

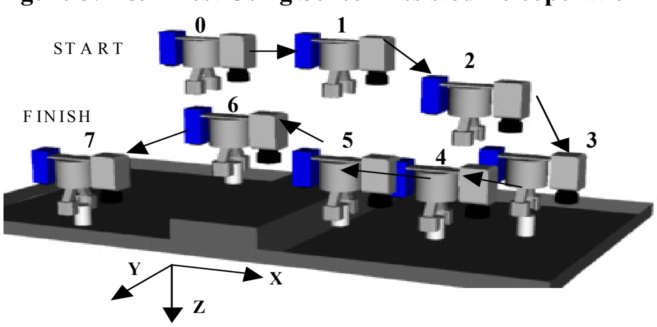

Figure 6: Stages of Scaling During Task Execution

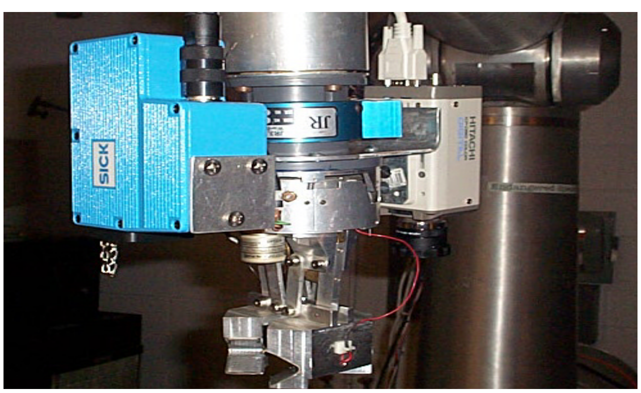

Figure 7: Sensors Mounted on End-Effector

The third stage assists the manipulator when the vision system can no longer see the goal object. Finally, once the object is grasped, the fourth stage assists the operator in avoiding the wall obstacle. The fifth stage is activated when the range data is too close to an object. The sixth stage involves the vision system, and enhances the movement in the horizontal plane to clear the wall horizontally. The seventh stage simply frees the user to place the object down on the correct side of the box.

SIMULATION EXPERIMENTS

The experiments were implemented using the PHANToM haptic device and the GHOST software development kit. Figure 8 shows the interface GHOST window provided to the user for MRMT task.

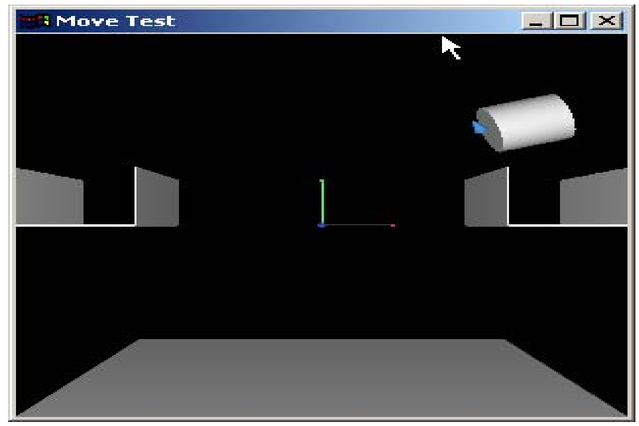

Figure 8: MRMT testing Interface

The experiments were run implementing the various forms of assistance functions designed. In addition, two different filters (low pass first and second order filters) were designed to eliminate any tremor coming from the user.

The operators were instructed to start the tasks at the origin of the workspace (Home position) and simply guide the Phantom to perform the various tasks to be executed. Position data in X, Y and Z coordinates, and the time taken to execute the tasks were recorded for further analysis.

Three different operators, without disabilities, ran the set of experiments. Test-retest methods were used to study the practice effect in the execution of the tasks. The results are discussed in the following section.

We now have the data for persons with disabilities. It will be used in future publications.

RESULTS

Comparison is made between the execution of the tasks with no assistance and with the use of the various forms of assistance functions designed. Filtering of tremor inputs in implemented in all the cases.

Minnesota Rate of Manipulation Test

The time results are shown in Figures 9-11. In these Figures:

From left to right the forms of assistance functions are:

1-Filtered (1^{st} order) No Assistance Provided

2-Filtered (2^{nd} order) No Assistance Provided.

3-Position Assistance Provided. Scaling Factor=0.5

4-Position Assistance Provided. Scaling Factor=1
5-Velocity Assistance Provided. Scaling Factor=0.5
6-Velocity Assistance Provided. Scaling Factor=1
7-Velocity and Rotations Assistance. Scaling Factor 0.5
8-Velocity and Rotations Assistance. Scaling Factor 1
9-Velocity Assistance with Variable Scaling Factor.
10-Force Assistance Function.

The scaling factors for the various assistance functions are the degrees of constraint that is provided to the slave in the non-desired directions by scaling the transformation matrix of the constraint frame.

The results are presented in Figures 9-11. In the case of the Placing Test, it is noticed that the various forms of assistance functions help to reduce the execution times of the tests.

The assistance functions that reduced the execution times the most were the Velocity mapping with a variable scaling factor and the force assistance function. It is noticed also that for the various forms of assistance that required a constant scaling factor, the execution times were shorter when there was some constraint in undesired directions (scaling factors of 0.5) than when there was a total free motion on these directions (scaling of 1).

In the case of the Turning Test, which required a flipping of the object once grabbed, it is noticed that the rotations assistance reduced the execution times, especially when entered a scaling factor of 0.5. Still in this case, the velocity assistance function with variable scaling and the force assistance function performed better.

An analysis of variance (ANOVA) with a critical value α of 0.05 was performed for the results presented in Figures 9 and 10. An ANOVA p value of 0.1607 was obtained for the Approach part of the test, indicating that the forms of assistance functions were not very significant in this case. However, the same analysis for the Move part of this test (longer distance) presented an ANOVA p value of 0.0033, indicating that the forms of assistance functions had a significant effect in the difference in the average execution times for this part of the test.

The Flip part of the test (Figure 11) resulted in an ANOVA p factor of 0.0007, demonstrating again that the effect of the assistance provided to the user is considerable.

Jebsen Hand Test

In Figures 12-13, the forms of assistance functions are presented from left to right as follows:

1-Filtered (1st order) No Assistance Provided.
2-Position Assistance Provided. Scaling Factor=0
3-Position Assistance Provided. Scaling Factor=0.5
4-Position Assistance Provided. Scaling Factor=1
5-Velocity Assistance Provided. Scaling Factor=0
6-Velocity Assistance Provided. Scaling Factor=0.5
7-Velocity Assistance Provided. Scaling Factor=1
8-Velocity Assistance Provided. Scaling Factor Variable.

The experiments were run for empty and heavy cans. Since similar results were obtained for heavy cans, only the results for empty cans are presented in this paper (Figures 12 and 13).

Again, it is noticed that the forms of assistance provided reduced considerably the execution times with the best performance obtained with the Velocity assistance function with variable scaling factor. Also, in the assistance functions that required a constant scaling factor, it can be noticed the need for scaling since the total or no motion constraints results provided longer execution times.

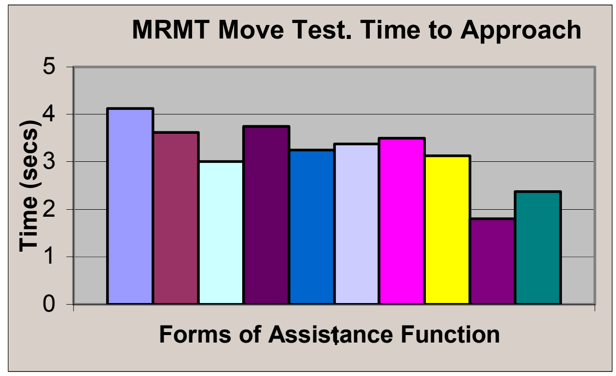

Figure 9: Time to Approach the Object

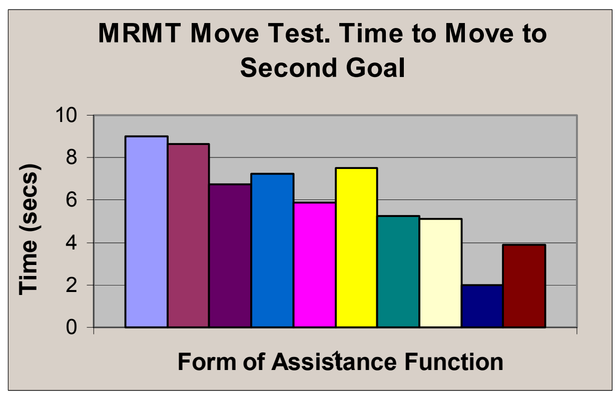

Figure 10: Time to Move the Object to a Different Location

An analysis of variance (ANOVA) test with a critical value α of 0.05 was run for the mean times presented in Figures 12 and 13. ANOVA p factors of 0.00041 and 0.00045 were obtained for the approach and move part of the test respectively. This indicates a considerable effect that the assistant functions have in the execution times.

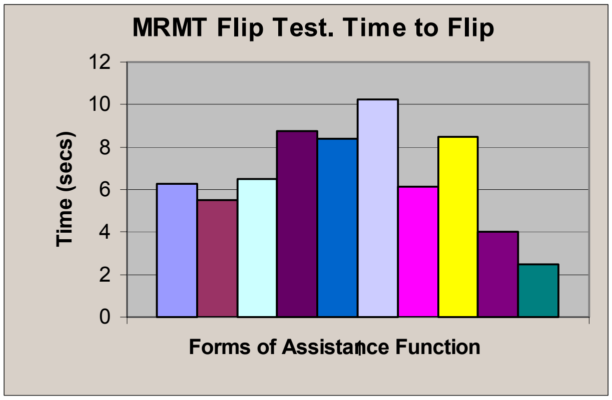

Figure 11: Time to Flip the object once is grabbed

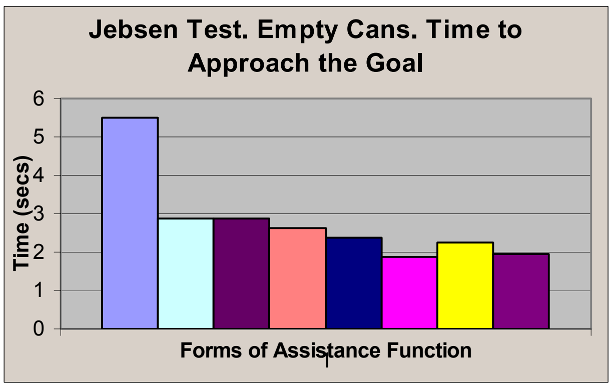

Figure 12: Jebsen Test. Empty Cans. Time to Approach.

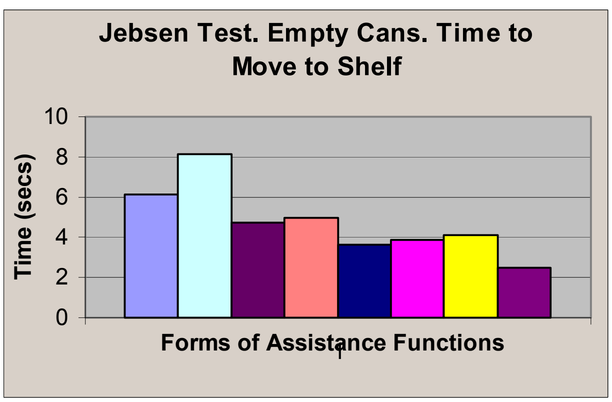

Figure 13: Jebsen Test. Empty Cans. Time to Move to Shelf

Box and Blocks Simulation Test

A sample of time executions for seven cubes was taken. The average times were 10.33 secs without assistance, and 5.66 secs with assistance. Also, it is important to note that the standard deviation was smaller when assistance was provided (reduced from 0.81 to 0.50).

Box and Blocks Test Using Sensor Based Assistant Function

The following results show the trajectory of the position of the slave with no assistance versus the slave with assistance. According to Figure 14, the trajectory with assistance is a smooth curve approaching the object, and then avoiding the wall obstacle. The curve shows how the user was guided toward the object. The trajectory with no assistance shows that the user has a random approach to the object, while showing many uncertain and unnecessary movements.

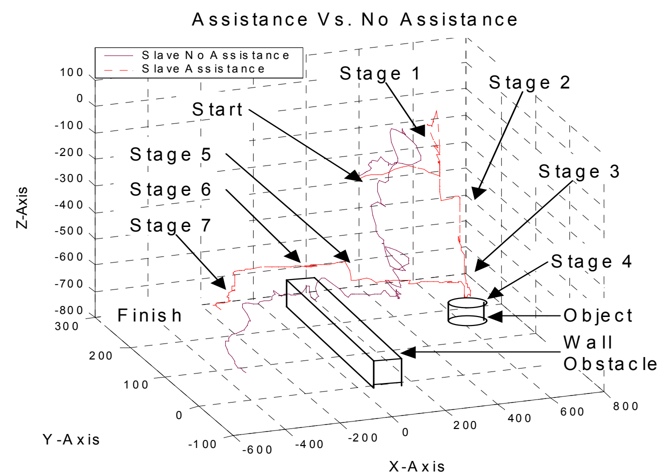

Figure 14: Trajectories During the B&B Task Execution

Figure 14 also shows the effect of each stage of scaling. Stage one constrains in the x-y plane to point toward the object. Stage two increases the z-axis velocity while still continuing toward the goal. Stage three constrains the motion in x and y directions. Stage four shows upward z-direction movement, while stage five stopped the end-effectors motion in the X-Y plane, and scaled in the upward z-direction until the end-effector was high enough to clear the wall obstacle vertically. Stage 6 shows how the end-effector was constrained in the Y-Z plane to increase the movement to clear the wall obstacle horizontally. Stage seven shows how the end-effector has passed the obstacle and the user could release the object on the other side of the box.

An able-bodied individual performed the Box and Blocks test with and without the SAF to determine the effect of the assistance. The person performed the test 30 times with assistance and 30 times without assistance. Table 1 shows the results of the tests.

Table 2 shows the results of the test when the PHANToM workspace was constrained to better simulate a person with disabilities. The range of motions has been constraint in order to better represent a person with disabilities.

Table 3 shows the comparison of the performance of an able-bodied person and the performance of the simulated disability. The table shows as you limit the input the performance of the Sensor Assist Function improves. The performance of the Box and Blocks test shows a decrease of necessary input motion, idle time, and execution time when using the developed computer assistance.

Table 1: Comparison of Averages for Box and Blocks Test Using No Workspace Constraint

Average Test Data-All Positions	No Assistance	SAF Assistance	% Decrease
Total Distance	11.571	9.143	20.98%
Times Repositioned	11.500	8.967	22.03%
Time Spent Repositioning	15.184	11.755	22.58%
Total Completion Time	52.006	43.034	17.25%

Table 2: Comparison of Averages for Box and Blocks Test Using Workspace Constraint

Average Test Data-All Positions	No Assistance	SAF Assistance	% Decrease
Total Distance	11.872	9.886	16.73%
Times Repositioned	43.800	23.800	45.66%
Time Spent Repositioning	22.561	9.656	57.20%
Total Completion Time	76.625	50.243	34.43%

Table 3: Comparison of Amount of % Decrease Using a Workspace Constraint vs. No Constraint

Average % Decrease	% Decrease No Constraint	% Decrease Workspace Constraint	Improvement
Total Distance	20.98%	16.73%	-4.25%
Times Repositioned	22.03%	45.66%	23.63%
Time Spent Repositioning	22.58%	57.20%	34.62%
Total Completion Time	17.25%	34.43%	17.18%

The performance of the Box and Blocks test shows a decrease of necessary input motion, idle time, and execution time when using the developed computer assistance.

CONCLUSIONS

It was shown that the use of a robotic haptic interface with the incorporation of assistance functions can help reduce the execution times for the occupational therapy tests chosen. Even though the experiments were run with people without disabilities, these results indicated that these or similar tasks can be used to train individuals with disabilities, specifically those with pathological tremor.

The advantage of implementing these techniques is that users can still be in control of the task execution since the haptic device and the assistant functions enhance the their movements rather than override them. In this manner, this methodology prompts for more unstructured operations.

Able-bodied persons initially performed the sensor based test to show the effect of the assistance concept. The results show how the desired motion was kept, and sometimes augmented, and the unwanted motion was reduced. This system provides a faster means to complete the task by extracting the correct input motion and enhancing the motion capabilities of persons with disabilities. The current experiments run by people with various forms of disabilities have shown promising results.

Furthermore, the information obtained from these or similar experiments can be used to identify the appropriate assist functions for various applications of the haptic interface.

REFERENCES

1. Schuyler, R. Mahoney. “Job Identification and Analysis for Vocational Robotics Applications”. Proceedings RESNA 1995.
2. J. Hollerbach. “Some Current Issues in Haptics Research”. Proceedings of the 2000 IEEE International Conference on Robotics and Automation. San Francisco, 2000.
3. K. Maclean. “Designing with Haptic Feedback”. Proceedings of the 2000 IEEE International Conference on Robotics and Automation. San Francisco, 2000.
4. D. Gloss and M. Wardle. Use of the Minnesota Rate of Manipulation Test for Disability Evaluation. “Perceptual and Motor Skills”, Vol.55, p.527-532, 1982.
5. J. Schuyler, R. Mahoney. “Assesing Human-Robotic Performance for Vocational Placement”. IEEE Transactions on Rehabilitation Engineering. Vol. 8, No 3, September 2000.
6. R. Jebsen, N. Taylor, R. Trieschmann, M. Trotter, L. Howard. “An Objective and Standardized Test of Hand Function”. Arch. Phys. Med. Rehab, pp.311-319, June 1969.
7. N. Turro, O. Khatib, E. Coste-Maniere. “Haptically Augmented Teleoperation”. International Conference on Robotics and Automation. 2001.
8. K. A. Manocha, N. Pernalete, R. Dubey. Variable Position Mapping Based Assistance in Teleoperation for Nuclear Cleanup. Proceedings of the 2001 IEEE International Conference on Robotics and Automation. Korea, 2001.
9. S. E. Everett. *“Human-Machine Cooperative Telerobotics Using Uncertain Sensor and Model Data”*. Doctor of Philosophy in Mechanical Engineering, University of Tennessee, August 1998.
10. Rosenberg, L.B. Virtual Fixtures: Perceptual Tools for Telerobotic Manipulation. Proceedings IEEE Virtual Reality Annual International Symposium, 1993
11. Bettini, A., S. Lang, A. Okamura, and G. Hager, "Vision assisted control for manipulation using virtual fixtures." Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, Maui, Hawaii, pp. 1171-1176, 2001.