Simplifying Wheelchair Mounted Robotic Arm Control with a Visual Interface

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Abstract

Wheelchair mounted robotic arms can assist people that have severe physical handicaps with activities of daily life. Manufacturer-provided direct input devices may not correlate well to the user's motor skills and may require a high level of cognitive awareness. Our goal is to provide methods for independent manipulation of objects in unstructured environments utilizing a wheelchair mounted robotic arm for manipulation. We hypothesized that users would prefer a simple visual instead of the default interface provided by the manufacturer and that with greater levels of autonomy, less user input is necessary for control. An experiment was designed and conducted to investigate these hypotheses.

Introduction

Activities of daily life (ADL) such as picking up a telephone or drinking a cup of coffee are taken very much for granted by most people. Humans have an innate ability to exist in and manipulate environments. Moving from one location to another, acquiring, and manipulating an object is something most of us do without much effort. We are so adept at these tasks that we almost forget how complex they can be. However, people with neuromuscular impairments (e.g. spinal cord injury, stroke, multiple sclerosis, etc.) may be confined to wheelchairs and rely on others for assistance. For them, executing an ADL is anything but trivial. Traditionally, a dedicated caregiver is needed, thus the disabled person cannot absolutely control when an ADL is aided or performed for them. Prior research has shown that users are very interested in tasks that occur regularly in unstructured environments. These include pick-and-place tasks such as lifting miscellaneous objects from the floor or a shelf [Stranger et al. 1994].

Our goal is to provide methods for independent manipulation of unstructured environments to wheelchair-confined people using a wheelchair mounted robot arm for manipulation. We want a simple interface where the user can specify the end goal such as picking up a glass of water by pointing to the glass. Another example is navigating to a hotel room. From the hotel lobby, we need to navigate to the elevator lobby, call for the elevator, locate and push the desired elevator button, proceed to the hotel room itself, open the door, and enter. However, instead of micromanaging each section of the task, the user could simply specify "Room 304" as their destination. In this initial phase of research, we investigate the use of a visual interface as a source of input.

Background

Industrial robot arms were developed to quickly accomplish high precision, pre-programmed specific tasks. The automobile industry has used the Programmable Universal Machine for Assembly (PUMA) on the assembly line since 1961 [Marsh 2004]. Robotic arms have also been used for non-assembly tasks, such as the Telegarden [Kahn et al. 2005] and as assistive technologies.

In the realm of assistive technology, robot arms have been used for rehabilitation and as workstations. Fixed-point devices enable some severely physically impaired people gain employment, eat, and perform other specific tasks. Stanford University's ProVAR [Van der Loos et al. 1999] is an example of a vocational desktop manipulation system. It features a PUMA-260 robotic arm and a human prosthesis end-effector. The arm is mounted on an overhead track that provides an open range of access for object retrieval and placement near the user.

Workstations have proven useful to some degree. Schuyler and Mahoney found that 45% of 12,400 severely disabled individuals were employable with vocational assistance [Schuyler et al. 1995]. However, by definition, workstations manipulate a fixed area. This limits when and where the user is able to operate the robot. Alternatively, robot arms can be mounted on mobile robots or on power wheelchairs.

The University of Pittsburgh's Human Engineering

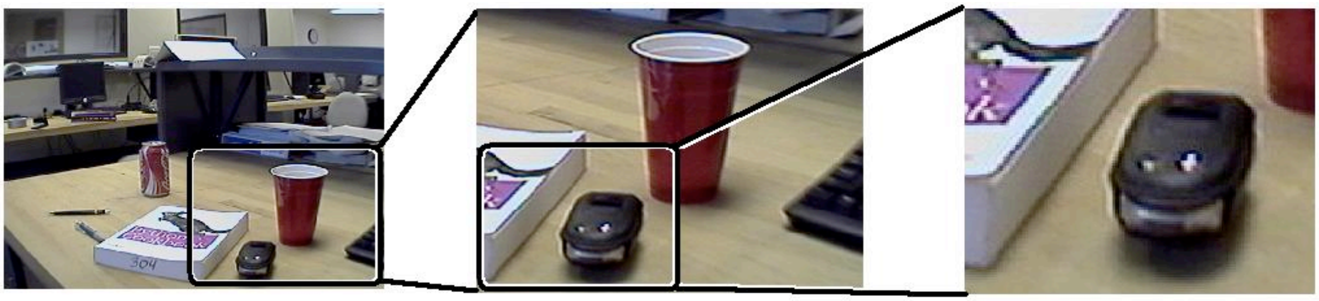

Figure 1: Progressive quartering for single switch scanning on the visual interface.

Research Laboratories evaluated the effects of a Raptor arm on the independence of twelve severely disabled people. The Raptor, a wheelchair mounted robot arm manufactured by Phybotics [Phybotics 2006], has four degrees of freedom (DoF) and a two-fingered gripper for manipulation; it moves by joint reconfiguration, does not have joint encoders, and cannot be preprogrammed in the fashion of industrial robotic arms [Alqasemi et al. 2005]. Significant ($p < 0.05$) improvements were found in seven of sixteen ADLs. These improved tasks included pouring or drinking liquids, picking up straws or keys, accessing the refrigerator and telephone, and placing a can on a low surface [Chaves et al. 2003].

However, there were nine ADLs, including making toast, which showed no significant improvement, which the researchers ascribed to several factors. One possibility was the task complexity in the number of steps to completion and/or the advanced motor planning skills required. The researchers also believed the joystick input device for manual control did not correlate well to the users' motor skills [Chaves et al. 2003].

Hardware

Our choice of robotic arm is another commercially available wheelchair mounted robotic arm – the Manus Assistive Robotic Manipulator (ARM), manufactured by Exact Dynamics [Exact Dynamics 2006]. The Manus ARM has a two-fingered gripper end-effector and is a 6+2 DoF unit with encoders on its joints. A user may manually control the Manus ARM by accessing menus via standard access devices, such as a keypad, a joystick, or a single switch. The Joint menu mode allows the user to manipulate the Manus ARM by moving its joints individually. The Cartesian menu mode allows the user to move the gripper of the Manus ARM linearly through the 3D xyz plane. In Cartesian mode, multiple joints may move simultaneously in preplanned trajectories unlike the Joint mode. In addition to manual control, the Manus ARM can be controlled by communication from a computer, and thus is programmable. As with manual control, joints may move collaterally in Cartesian mode or individually in Joint mode.

To improve user interaction with the Manus ARM, we have added a vision system with two cameras. A camera at the shoulder provides the perspective of the wheelchair occupant for the interface. A camera mounted within the gripper provides a close up view for the computer control.

Process

The trajectory of a human arm picking up an object is two separate events: gross reaching motion to the intended location, followed by fine adjustment of the hand [Woodworth 1899]. Our current focus is gross motion. The gross motion is accomplished with explicit and implicit input. The user explicitly designates the end goal, and computer vision techniques control movement implicitly using a multithreaded vision system developed in our lab, known as Phission [Thoren 2006].

A large part of our target population does not have the fine motor control necessary to point directly to an object from in a scene as it is displayed on a touch screen. Therefore, we have designed a method for selection compatible with single switch scanning (see figure 1). In this method, the user is presented with an interactive image of the shoulder view, divided into four quadrants. When the quadrant that contains the majority of the object the user desires to manipulate is highlighted, the user clicks the switch to select it. Then the quartering procedure is repeated a second time providing a view that is one-sixteenth of the original image area.

The Manus ARM then moves in the xy plane towards the center of the selected quadrant emulating human motion control. The gripper of the Manus ARM is physically centered on the view's xy position (figure 2). For the purposes of the experiment in this paper, the depth z was fixed. (Current research is investigating the best methods for moving in this third dimension.)

Figure 2: The Manus ARM is shown reaching for the target (orange ball) in computer control.

Hypotheses

We designed an experiment to investigate several of our hypotheses about this initial system. These intuitions address the appropriateness of vision-based input and the complexity of the menu hierarchy.

Hypothesis 1 (H1): Users will prefer a visual interface to a menu-based system.

From our own interaction with the Manus ARM using direct control, we found the menu-based system to be unintuitive and frustrating. After the initial learning phase, simple retrieval of an object still takes on the order of magnitude of minutes; more complex tasks and manipulation take time proportionally longer. Also, while directly controlling the Manus ARM, it is necessary to keep track of the end goal, how to move the end-effector towards the goal, the current menu, the menu hierarchy, and how to correct an unsafe situation; these requirements can cause sensory overload.

Hypothesis 2 (H2): With greater levels of autonomy, less user input is necessary for control.

As discussed in H1, there is a lot to keep track of while controlling the Manus ARM. Under direct control, the operator must be cognitively capable of remembering the end goal, determining intermediate goals if necessary, and determining alternate means to the end goal if necessary. By having the user simply and explicitly state input of the desired end goal, the cognitive load can be reduced. Our target population can be expanded to include disabled people with some cognitive impairments, such as loss of short term memory.

Hypothesis 3 (H3): It should be faster to move to the target in computer control than in manual control.[1]

We expect that participants will be able to get closer to the target with direct control since they have the ability to move in the z plane, but predict that it will take them longer, even after the learning effect has diminished. However, we hypothesize that the ratio of distance to time, or overall arm movement speed, in manual control will be slower than computer control.

Experiment

During the summer of 2006, a preliminary system was developed using color tracking. This system was the basis for the experiments performed in this paper. To execute the task, all users were guided through the system with text prompts. The user turns on the Manus ARM, and the initial shoulder view is presented. The user selects the desired target using the two step quartering process for single switch scanning, waits for the arm to open, and color calibrates to enable movement to the desired quadrant.

In our manual control runs (control experiments), we asked the participant to maneuver "sufficiently close"[2] to the desired object with the gripper open. While this does add user subjectivity, the researcher verified the arm's closeness to the object, thus allowing for consistency across subjects. Since we have only developed the gross motion portion of the pick up task for computer control, we needed to design a use of the manual control that would be similar to the task that could be completed by computer control.

Experiment Participants

Twelve physically and cognitively capable people participated in the experiment: ten men and two women. Participants' ages ranged from eighteen to fifty-two inclusive. With respect to occupation, 67% were either employees of technology companies or science and engineering students. All participants had prior experience with computers; including both job related and personal use, 67% spend over twenty hours per week using computers, 25% spend between ten and twenty hours per week, and the remaining 8% spend between three and ten hours per week. One-third of the participants had prior experience with robots. Of these, one works at a robot

[1] The Manus ARM moved at 9 cm/sec during manual control trials; its velocity was only 7 cm/sec during computer control trials. Despite the Manus ARM moving faster in manual trials, we still hypothesize that computer control will allow the task to be completed more quickly.

[2] "Sufficiently close" meaning near or approaching the desired object.

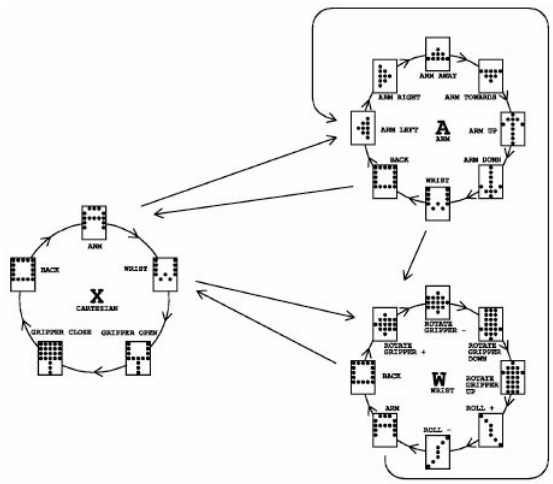

Figure 3: Cartesian menu using single switch control. Copyright Exact Dynamics 2002.

company, but not with robot arms. Three, including the aforementioned participant, had taken university robotics courses. The remaining subject had used "toy" robots, though none were specifically mentioned.

Experiment Design and Conduct

Two conditions were tested: manual control and computer control. We define manual control as the standard interface, which is the commercial, end-user configuration. The input device was a single switch, and control over the Manus ARM used the corresponding menus (figure 3); movement was restricted to only the Cartesian menu. Computer control involves the method described in Section 4. The input device was also a single switch. Users were prompted using text to execute a series of steps to designate the end goal.

Users first signed an informed consent statement and filled out a pre-experiment survey detailing background information about computer use and previous robot experience. The participants were then trained on each interface. Training was necessary to minimize the learning effect. Training for manual control was the ball-and-cup challenge. An upside-down cup and ball were placed on a table. Users were asked to "put the ball in the cup," meaning that they were to flip over the cup and then put the ball in it. Training for computer control was an execution of the process on a randomly selected target, walked through and explained at each step.

Suspended balls represented the center of quadrants that could be marked using single switch scanning and indicated a desired object. Targets for the trials were computed prior to all experiments. They were randomly generated and selected taken from the left view of the shoulder camera from quadrants two and three (figure 4). Half of the participants were randomly selected to begin with manual control (and in the subsequent trial use computer control, then manual, and so on); the other half, by default, started with computer control. This partition also occurred prior to the start of all user testing. Each user participated in three trials per interface.

Figure 4: Representation of approximate centers of single switch scanning quadrants.

For each run, the desired object was appropriately placed at the predetermined target. The Manus ARM's initial starting configuration is folded. Time began when the user indicated, and ended for manual control when the user indicated "sufficient closeness" to the target or for computer control upon prompt indication. Distance between the gripper camera and the center of the desired object was recorded. The Manus ARM was refolded for the next experiment, and the object was moved to the next predetermined target; total changeover time took approximately two minutes. At the completion of each trial, a short survey was administered. At the conclusion of the experiment, an exit survey was administered and a debriefing was conducted. The entire process took approximately ninety minutes per participant.

Data Collection

We collected data from questionnaires (pre- and post-experiment), video, and observer notes. Post-experiment surveys asked both open ended and Likert scale rating questions, and solicited for interface improvement suggestions. Video was filmed from two locations: capturing the Manus ARM movement towards the desired object, and capturing the interface display from over the participant's shoulder during use of computer control. An observer timed the runs and noted distance, failures, technique, and number clicks executed.

No failures occurred during manual control trials; all users completed the task, thus all time and distance data is complete. However, there were several failures during

	Manual Control						Computer Control					
	Time	**Distance**	**Time**	**Distance**	**Time**	**Distance**	**Time**	**Distance**	**Time**	**Distance**	**Time**	**Distance**
S1	422.718	13	160.331	10	279.265	9	72.718	15	64.996	10.5	96.878	23
S2	213.126	15	218.824	5	122.792	5	127.349	18	66.265	17	77.623	11
S3	286.855	5	217.359	4.5	184.624	3	114.63	20	75.721	10	74.736	16
S4	171.635	5	148.054	4.5	111.792	3	60.152	21	77.837	9	70	38
S5	259.655	5	135.4	8	157.039	3	56.823	18	50.135	16	51.575	10
S6	261.17	5	206.948	7	201.931	3	132.216	18	83.519	16	70.934	18
S7	146.663	16	39.78	12	121.758	8	52.678	NaN	58.31	NaN	54.03	NaN
S8	346.295	4	125.288	3	177.342	5	90.911	NaN	60.376	20	61.88	19.5
S9	185.343	3	128	7	197.971	5	104.439	NaN	101.327	10	60.838	NaN
S10	222.761	12	395.592	14	218.529	5	114.014	NaN	136.84	21	65.942	14
S11	208.789	4	196.855	3	90.704	5	70.175	34	65.92	16	66.095	17
S12	748	3	275.544	3	290.472	5	112.271	NaN	128.622	NaN	110.904	NaN
Average	289.418	7.5	187.331	6.75	179.518	4.917	92.365	20.571	80.822	14.55	71.786	18.5
Std Dev	47.261	1.428	25.766	1.058	18.297	0.557	28.723	6.214	27.694	4.375	17.096	8.359

Table 1: Times to complete the trials in seconds and distances from goal at end of trials in centimeters

trials of computer control. Users either did not color calibrate or did not color calibrate correctly (did not know where the view for calibration was, did not hold at optimal angle, etc). Time to failure was recorded, and distance has been designated as NaN (see table 1).

Results and Discussion

We expected that the visual interface of computer control would be preferable to the menu-based system of manual control (H1). Referring to manual control, one participant stated that it was "hard to learn the menus." However, in their exit interviews, 83% of the participants stated a preference for manual control. These ten participants preferred to be directly in control since they could control the accuracy of the end position of the gripper, but four of these ten offered that computer control was simpler. The remaining two participants preferred computer control; they felt it was a fair exchange to trade manual control for the simplicity and speed of computer control.

Participants were asked to rate their experience with each interface using a Likert scale from 1 to 5, where 1 indicates most positive. Computer control averaged 2.5 (SD 0.8) and manual control averaged 2.8 (SD 0.9). This suggests that participants had relatively better experiences with computer control despite their stated preference for manual control, although the differences are not significant. With the Likert scale, half rated computer control higher than manual control, three ranked them equally and three ranked manual control above computer control.

One possibility for this conflict may be the color calibration of computer control. The system used in the experiment used color tracking for arm movement. Periodic recalibration of the system is necessary, and we wanted to see how users would handle this. Six participants specifically mentioned having difficulties with the act of color calibration; ten of thirty-six runs failed because either the user forgot to or did not correctly color calibrate. We speculate that color calibration may have made computer control less preferable. Despite training, one user stated, "I felt confused about what I was actually doing. I didn't understand why I was doing the steps I was trained to do in order to accomplish the task." These results indicate that the system should be designed in a way to require as little calibration as possible for the user.

We hypothesized that with greater levels of autonomy, less user input is necessary for control (H2). The workload of computer control should thus be less than that of manual control. We recorded the number of clicks executed by participants per manual control trial; the number of clicks in computer control is fixed by design. We divided the clicks by the total time of a trial for normalization; workload is thus defined as average clicks per second. H2 was quantitatively confirmed using a pair of t-tests on the average normalized workload of manual control and computer control trials per user ($p < 0.01$). Qualitatively, eight of the twelve participants stated that manual control was "frustrating" or "confusing," which is indicative of the sensory overload we anticipated a user to feel.

Under manual control, we expected that users would be able to maneuver closer to the desired object than in computer control. The current design of the computer control system is for the gross motion portion of the task only in two dimensions, so the gripper is likely to end up farther away. On average, the gripper's final position was 6.4 cm (SD 1.3 cm) from the object in manual control and 17.9 cm (SD 3.1 cm) from the object in computer control. The differences in final placement are largely due to the computer control system only moving in the xy plane for this set of experiments.

The distance to time ratio is used as a means of cost analysis: moving X distance takes Y time. We hypothesized that the distance to time ratio of computer control would be greater than manual control (H3); with computer control, the Manus ARM was able to move farther in less time (despite the fact that the maximum arm speed was set lower for computer control than it was for manual control). All complete distance to time ratios (i.e., not evaluated to NaN) quantitatively validated this hypothesis ($p < 0.001$). Three users stated that computer control was “quick” or “fast.”

Conclusions and Future Work

Wheelchair mounted robotic arms provide greater independence to people with severe physical handicaps. We have developed a preliminary visual interface to control the Manus ARM. An experiment was designed and conducted to investigate several hypotheses. We had hypothesized that with greater levels of autonomy, less user input was necessary; we found the null hypothesis to be false.

We had hypothesized that a visual interface would be preferred to a menu based one (H1). We obtained mixed results on this hypothesis. When the participants were asked which interface they preferred, the majority indicated that they preferred manual control. However, the Likert scale results indicated a preference for computer control.

In our current research, we have removed color calibration from the computer control process. We plan to run this experiment on new able-bodied users and believe that H1 will be proven qualitatively as well. We have improved the computer control process' graphical user interface. A domain expert will evaluate our system for usability in the target audience.

Future work includes integrating the Manus ARM with our robot wheelchair system, Wheeley, (Wheeley is a redesign based on Wheelesley [Yanco 2000].) and depth extraction (optical flow, image registration between the gripper and shoulder cameras, motion filter) to increase gross motion accuracy. Fine motion control for gripper reorientation and grasp is active research with the University of Central Florida.

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References

Alqasemi, R., E. McCaffery, K. Edwards and R. Dubey, (2005). “Wheelchair-Mounted Robotic Arms: Analysis, Evaluation and Development.” Proceedings of the IEEE Conference on Advanced Intelligent Mechatronics.

Chaves, E., A. Koontz, S. Garber, R.A. Cooper, A.L. Williams (2003). “Clinical Evaluation of a Wheelchair Mounted Robotic Arm.” RESNA Presentation given by E. Chaves.

Exact Dynamics (2006). http://exactdynamics.nl, accessed September 30.

Kahn, P. H., Jr., B. Friedman, I. S. Friedman, N. G. Freier, S. L. Collett (2005). “The distance gardener: what conversations in the Telegarden reveal about human-telerobotic interaction.” Proceedings of the IEEE Workshop on Robot and Human Interactive Communication, ROMAN, pp. 13-18.

Marsh, A. (2004). “Tracking the PUMA.” Proceedings of the IEEE Conference on the History of Electronics.

Phybotics (2006). http://www.appliedresource.com/RTD/rtdindex.html, accessed October 10.

Schuyler, J. L., and R. M. Mahoney (1995). “Vocational robotics: Job identification and analysis,” Proceedings of RESNA, pp. 542-544.

Stranger, C.A., C. Anglin, W. S. Harwin, and D. Romilly (1994). “Devices for Assisting Manipulation: A Summary of User Task Priorities.” Proceedings of the IEEE Transactions on Rehabilitation Engineering, 2(4), pp. 256-265.

Thoren, P. (2006). “Real-Time Vision Procession System,” http://www.phission.org.

Van der Loos, H. F. M., J. J. Wagner, N. Smaby, K. Chang, O. Madrigal, L. J. Leifer, and O. Khatib (1999). “ProVAR assistive robot system architecture.” Proceedings of IEEE Conference on Robotics & Automation, pp. 741-746.

Yanco, H. A. (2000). “Shared User-Computer Control of a Robotic Wheelchair System.” Ph.D. Thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology.

Woodworth, R. (1899). “The Accuracy of Voluntary Movement.” Psychology Review Monograph Supplement, 3.