33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Direct Interaction with an Assistive Robot for Individuals with Chronic Stroke

Brandon Kmetz, Heather Markham, and Bambi R. Brewer, *Member, IEEE*

Abstract—**Many robotic systems have been developed to provide assistance to individuals with disabilities. Most of these systems require the individual to interact with the robot via a joystick or keypad, though some utilize techniques such as speech recognition or selection of objects with a laser pointer. In this paper, we describe a prototype system using a novel method of interaction with an assistive robot. A touch-sensitive skin enables the user to directly guide a robotic arm to a desired position. When the skin is released, the robot remains fixed in position. The target population for this system is individuals with hemiparesis due to chronic stroke. The system can be used as a substitute for the paretic arm and hand in bimanual tasks such as holding a jar while removing the lid. This paper describes the hardware and software of the prototype system, which includes a robotic arm, the touch-sensitive skin, a hook-style prehensor, and weight compensation and speech recognition software.**

I. INTRODUCTION

Hemiplegia is a common result of stroke, and even four years after a stroke, approximately half of all individual have a non-functional arm and hand [1]. While these individuals often learn to compensate using the opposite arm and hand, bimanual tasks remain difficult. For instance, an individual may have difficulty stabilizing a jar while using the non-paretic hand to open it. Tasks such as putting a glove on the non-paretic hand may also be difficult.

A number of robotic systems have been proposed to assist individuals with disabilities, including stroke. These include simple systems designed for a single task, such as feeding systems [2], as well as more complex systems capable of a variety of tasks. An example of the latter is the ASIBOT system, a manipulator that can dock at various stations and assist individuals with disabilities in a variety of daily tasks [3]. However, many previous robotic systems have required user interaction via a joystick or keypad, which can be challenging and slow for individuals with disabilities. In addition, previous systems have not focused on the types of bimanual activities that become difficult as a result of stroke.

The goal of the work described here is to enable individuals with chronic stroke to interact in an intuitive manner with a robot in order to accomplish tasks that are typically performed with two hands. The most intuitive interaction with an object is through touch; we have developed a method of direct interaction with the robot by creating a skin for the robot arm. This skin acts as a switch that is closed by touch. When the skin is touched, the robot moves compliantly and compensates for the effect of gravity on the robot and any object that it is grasping. Thus, the user can easily position the robot using the non-paretic arm. When the user releases the arm, the switch is opened, placing the robot into a fixed mode. This keeps the robot in place and enables it to stabilize an object to be used by the individual. For instance, the robot can stabilize a glass while the user pours water into it using the non-paretic arm.

This paper describes the components of our prototype system, which is shown in Figure 1. This system consists of a robotic arm, touch-sensitive skin, and a prehensor. We also describe the software used with this system, including weight compensation and speech recognition algorithms. This testbed will enable us to investigate how individuals with chronic stroke can use direct interaction with a robotic arm, providing valuable information about how these individuals can successfully and easily interact with assistive robotic systems.

Figure 1. A prototype system for investigating direct interaction with an assistive robotic arm. When the individual grasps the touch-sensitive skin, the robot moves compliantly. When the skin is released, the robot remains fixed in position.

Manuscript received April 15, 2011. This work was supported by a supplement to the Quality of Life Engineering Research Center, NSF EEC-0540865.

Brandon Kmetz is with Rose-Hulman University, Terre Haute, IN, USA (e-mail: kmetzbs@rose-hulman.edu).

Heather Markham is with the University of Pittsburgh, Pittsburgh, PA USA (email: hcmarkham@gmail.com).

Bambi R. Brewer is with the University of Pittsburgh, Pittsburgh, PA USA (phone: 412-624-6475; email: bbrewer@pitt.edu).

978-1-4244-4122-8/11/$26.00 ©2011 IEEE

II. ROBOTIC PLATFORM

The robotic arm used in this prototype system is the 4 degree of freedom Whole Arm Manipulator (WAMTM) from Barrett Technologies (Boston, MA). This robotic arm has a payload of 4 kg and a workspace volume of 3.5 m2 [4]. While this robot may be too large for home use, this commercially available system will enable us to test the concept of direct interaction with individuals with chronic stroke and use their feedback to inform future versions of the system.

III. TOUCH-SENSITIVE SKIN

A. Design

The skin we developed is a fabric switch, which consists of an external and internal cover, two conductive surfaces, and an insulator which prevents unintentional contact (Figure 2). Our design criteria included: 1) continuous activation surface, 2) less than 1N of force required to activate, and 3) a large and consistent voltage change between non-activated and activated states. The external and internal covers are comprised of basic poly/cotton material. Zelt, Tin/Copper coated plain weave nylon fabric, is the conductive material used. The insulator selected is a very thin foam material with rectangular perforations measuring 6.5mm x 8mm, set 1.20mm to 2.20mm apart depending on orientation, and a maximum thickness of 1.25mm. The skin pieces measure 13-1/2" x 12-1/2" and 11-1/2" x 12-1/2 for the two links of the WAM arm. Two wires (data, power) are attached securely to each side of the upper link switch by using a separate small piece of conductive material as a pocket for the wires. Inside the elbow joint, the two links of the robotic arm are electrically connected using Stretch Conductive Material (medical grade Silver plated 92% Nylon 8% Dorlastan). The elbow covering was constructed so that it is not possible to activate the skin by touching the joint.

An input voltage of 5 V is applied across the skin, and the output voltage was measured using a USB-6218 data acquisition card (National Instruments). The output voltage is approximately 5 V when the switch is open, moving towards 0 V when the skin is touched.

B. Testing

The force required to close the switch was measured using a Nano17 sensor (ATI Industrial Automation) with a ¼" round tool attached to the flat end. The Nano17 has a resolution of 0.003 N and measures both forces and torques in the x, y, and z directions. A USB-6218 data acquisition card (National Instruments) was used to record the forces and torques measured by sensor and the output voltage across the skin. Measurements were made at 100 Hz.

The skin was tested in two configurations: laid flat on the table and secured on the WAM. A grid was oriented with the first row aligned with a seam edge. The proximal (relative to the base) linkage of the robotic arm was tested using a 12 x 12 grid, and the distal linkage of the robotic arm was tested using a 10 x 12 grid. Each grid point was pressed a minimum of 25 times.

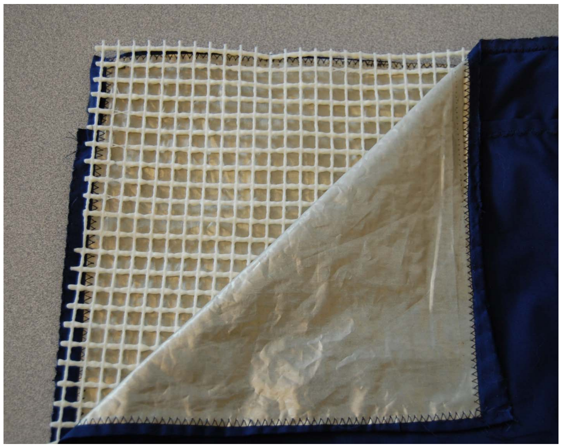

Figure 2. The touch-sensitive skin, which is composed of two conductive layers separated by a perforated insulator.

The threshold was set to a value relative to the maximum voltage measured (V_{max}) and the minimum voltage measured (V_{min}).

$$\text{Threshold} = V_{min} + 0.005(V_{max} - V_{min}) \qquad (1)$$

For each time that the switch was closed at each test point, we found the first voltage value under the threshold and identified the force at that timepoint. We call that voltage the "activation voltage"; and the force at that timepoint, which is the minimum amount of force required to activate the switch, we call the "activation force".

C. Results

The activation force and voltage are shown in Table 1 for both links of the robotic arm. The activation force was approximately 1 N for both links, though the activation force was slightly larger for the distal link than for the proximal link. The activation voltage for both links was less than 0.05 V with a small standard error, indicating a reliable voltage change when the skin is touched.

TABLE I
ACTIVATION FORCE AND ACTIVATION VOLTAGE FOR THE TOUCH-SENSITIVE SKIN

	Proximal Link (144 points)		Distal Link (120 points)	
	Flat	On WAM	Flat	On WAM
Activation Force (N)				
Mean	1.2609	0.9860	1.4374	1.0828
Standard Error	*(0.2736)*	*(0.2624)*	*(0.2284)*	*(0.1692)*
Activation Voltage (V)				
Mean	0.0047	0.0017	0.0192	0.0038
Standard Error	*(0.0180)*	*(0.0025)*	*(0.0089)*	*(0.0030)*

Figure 3. The prehensor used in this system, the Electric Terminal Device (ETD) from Motion Control.

IV. SYSTEM PREHENSOR

The prehensor used in this system is Electric Terminal Device (ETD) from Motion Control, which is a 1 degree of freedom electric hook-style prosthesis (Figure 3). It has two lyre-shaped metal fingers. One finger is stationary, and one can be opened or closed based on an electric signal. Thus, objects can be grasped between the fingers or the closed hook can be used to lift objects. The maximum grip force of the ETD is 25 lb. The ETD is typically controlled by myoelectric signals in the context of a prosthesis, but in this system, it is controlled by pulses of DC voltage. A pulse of 6.5 V with a duration of 1 s closes the hook, while the same duration with opposite polarity opens the hook. To increase grip force, the close command can be executed multiple times. The hook is opened and closed by voice commands, as described below. When a voice command is received, the appropriate voltage pulse is applied to the hook using the USB -6218 data acquisition card and custom circuitry including two AC-to-DC power adaptors.

One advantage of a hook-style prehensor is its simplicity. Only a single degree of freedom must be controlled, and there is no need for grasp planning. In addition, because the fingers of the hook are thin, the object being grasped is not occluded by the prehensor. This provides better visual feedback to an individual using the system to grasp an object.

V. SYSTEM SOFTWARE

The WAM is controlled by an external PC with the Ubuntu 7.10 operating system. Programs for the WAM are written in C using custom libraries supplied by Barrett Technologies. The touch-sensitive skin and the ETD are controlled by a PC running Windows. Programs in Windows are written in Visual C++ using libraries provided by National Instruments to communicate with the data acquisition card. The main application is executed in Windows and communicates with the WAM PC via an Ethernet connection.

A. *Weight compensation*

TABLE II
ACTUAL AND CALCULATED OBJECT MASS FOR THE WEIGHT COMPENSATION SOFTWARE

Actual Object Mass (kg)	Calculated Object Mass(kg)
0.2220	0.3060
1.3270	1.4390
1.7370	1.9380
2.8770	2.7750

The WAM uses its own software model to implement active gravity compensation, allowing the robot to be manipulated as if the arm itself is weightless. However, compensating for the mass of the payload is also necessary in order for individuals to be able to effortlessly move the arm when it is grasping and object. The current method for weight compensation operates the WAM in Cartesian mode, which allows the algorithm to directly measure the weight of the payload from any position while stationary. The user grasps the desired object with the prehensor, then executes the lift command (see below). The software then uses position control to lift the object a short distance (approximately 5 cm). The distance of the lift is limited and performed slowly to avoid startling the user. After the lift, the robot measures the mass of the payload. The program then recalibrates the software model of the robot using the newly measured payload mass. The user can then move the WAM and the object being grasped as though both are weightless. A comparison of the object mass calculated by this software relative to the actual mass of the object is presented in Table II.

B. *Speech recognition*

The speech recognition system was designed using Microsoft's Speech API. The recognition engine runs on the Windows PC. Three phrases are recognized: "hook open", "hook close", and "robot lift". Each recognition phrase begins with a keyword; in this system the keywords are "hook" and "robot", which enable the recognition engine to clearly differentiate between grasping and lifting commands. Execution of the “hook open” command automatically resets the software model of the robot to remove the payload mass.

VI. DISCUSSION

This system has been developed as a testbed; we do not expect to employ this exact system in a home environment. Our goal with this testbed is to investigate a method that individuals with chronic stroke can use to interact easily, quickly, and intuitively with an assistive robot. We expect that the results of these studies could be deployed on a number of robotic systems. Specifically, we plan integrate these techniques with other assistive robotic systems in development at the Quality of Life Technology Engineering Research Center [5-6].

Previous systems designed to assist individuals with manipulation tasks have used a variety of methods to accept user input. Some, such as the Assistive Robotic Manipulator (ARM) from Exact Dynamics, can be controlled using commands entered with a joystick or keypad [7]. Other work has been done with the ARM to evaluate other interfaces including speech input [8], a wireless mouse [9]; and human-in-the-loop combined with computer vision processing [10]. El-E, a mobile robotic manipulator, autonomously grasps objects identified with a laser pointer [11]. The system described here differs from previous work in assistive robotics because we are focusing on the use of touch to allow individuals to directly position the robotic manipulator. This will make the system easy to learn to use and potentially accessible even to individuals with cognitive impairments due to brain injury. The simplicity of the prehensor will also increase the speed of the system by eliminating the need for grasp planning or control of multiple degrees of freedom. The result will be a system that is easy to learn, intuitive, and quick to use for individuals with disabilities.

While our target population is individuals with hemiparesis due to chronic stroke, we anticipate that the interaction technique may also be applicable to individuals with other disabilities. For instance, individuals with disabilities affecting strength in the upper extremities might use the weight compensation feature to assist them in moving objects in tasks such as unloading groceries from bags on the floor to shelves above waist level. This might be particularly helpful for individuals with limited leverage due to a seated position in a wheelchair.

VII. FUTURE WORK

We are currently beginning initial testing with individuals with chronic stroke. Individuals will come into the lab and attempt to perform a variety of bimanual tasks with and without the robotic system. We will determine whether the system affects which tasks can be completed or the completion time. We will also record user feedback about ease of use of the system and what improvements are needed.

Future modifications to the system will be based on the results of the initial user tests. For example, individuals with aphasia may prefer to operate the hook by a button or switch rather than voice commands. After modifying the system based on user feedback, we plan to employ a modified system for home testing.

ACKNOWLEDGMENT

We would like to thank Motion Control for their technical assistance, as well as Vinod Sharma for his assistance with circuitry. We would further like to acknowledge the contributions of Rachel Arnold, CCC-SLP, and Emily Eckel, DOT.

REFERENCES

[1] J. G. Broeks, *et al.*, "The long-term outcome of arm function after stroke: results of a follow-up study," *Disabil Rehabil,* vol. 21, pp. 357-64, Aug 1999.

[2] "Meal assistance robot: My Spoon," www.secom.co.jp/english/myspoon/index.html.

[3] C. Balaguer, *et al.*, "Proprio and teleoperation of a robotic system for disabled persons' assistance in domestic environments," in *Advances in Telerobotics*, M. Ferre, *et al.*, Eds., ed Berlin: Springer-Verlag, 2007, pp. 415-427.

[4] "Data Sheet - WAM," www.barrett.com/robot/DS_WAM.pdf.

[5] S. W. Brose, *et al.*, "The role of assistive robotics in the lives of persons with disability," *Am J Phys Med Rehabil,* vol. 89, pp. 509-21, Jun 2010.

[6] S. Srinivasa, et al., "HERB: a home-exploring robotic butler," Autonomous Robots, vol. 28, pp. 5-20, 2010.

[7] H. Eftring and K. Boschian, "Technical results from MANUS user trials," in 1999 IEEE International Conference on Robotics and Automation. 1999: Stanford, CA. p. 136-41.

[8] C. Martens, et al., "A FRIEND for assisting handicapped people.," IEEE Robotics & Automation Magazine, vol. 8(1), p. 57-65, 2001.

[9] P. Athanasiou, N. Chawla, and E. Leichtnam. "Assistive Robotic Manipulator interface," in Proceedings of the IEEE 32nd Annual Northeast Bioengineering Conference, 2006.

[10] K.M. Tsui and H. Yanco. "Simplifying wheelchair mounted robotic arm control with a visual interfac," in AAAI Spring Symposium on Multidisciplinary Collaboration for Socially Assistive Robotics. 2007.

[11] Y.S. Choi, et al., "Laser pointers and a touch screen: intuitive interfaces for autonomous mobile manipulation for the motor impaired," in Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility, pp. 225-32, 2008.