Human-Robot Interaction Studies for Autonomous Mobile Manipulation for the Motor Impaired

Young Sang Choi and **Cressel Anderson** and **Travis Deyle** and **Charles C. Kemp**
Healthcare Robotics Lab
Georgia Institute of Technology
828 West Peachtree Street NW
Atlanta GA 30308

Abstract

We are developing an autonomous mobile assistive robot named El-E to help individuals with severe motor impairments by performing various object manipulation tasks such as fetching, transporting, placing, and delivering. El-E can autonomously approach a location specified by the user through an interface such as a standard laser pointer and pick up a nearby object. The initial target user population of the robot is individuals suffering from amyotrophic lateral sclerosis (ALS). ALS, also known as Lou Gehrig's disease, is a progressive neuro-degenerative disease resulting in motor impairments throughout the entire body. Due to the severity and progressive nature of ALS, the results from developing robotic technologies to assist ALS patients could be applied to wider motor impaired populations. To accomplish successful development and real world application of assistive robot technology, we have to acquire familiarity with the needs and everyday living conditions of these individuals. We also believe the participation of prospective users throughout the design and development process is essential in improving the usability and accessibility of the robot for the target user population. To assess the needs of prospective users and to evaluate the technology being developed, we applied various methodologies of human studies including interviewing, photographing, and conducting controlled experiments. We present an overview of research from the Healthcare Robotics Lab related to patient needs assessment and human experiments with emphasis on the methods of human centered approach.

Introduction

The Healthcare Robotics Laboratory of the Georgia Institute of Technology have been developing an assistive robot, named El-E, pronounced "Ellie", in close cooperation with the Emory ALS Center. We designed El-E to perform various object manipulation, such as locating, grasping, transporting, and handing everyday objects to users. The robot has a five degree of freedom robotic manipulator mounted on a vertical linear actuator. It can monitor an indoor space using an omni-directional camera and also view a specified area with higher resolution using a stereo camera. We built the robot system on a statically stable wheeled mobile base to navigate flat surfaces. The major breakthrough of this robotic system is the user interface, which utilizes a common, inexpensive laser pointer. The robot detects the laser point on the surface of an object with its cameras and determines the relative 3D location of the identified object (Kemp et al. 2008). This interace is analogous to the point-and-click interface used in personal computer 2D graphical user interfaces (GUI). The 3D point and click interface using a standard, off-the shelf laser pointer is expected to reduce the mental and physical burden of users when controlling the robot compared to direct control of traditional manipulation arms. The robot has been previously tested in a laboratory setting with very successful and promising results (Nguyen et al. 2008).

The primary target users are individuals with severe motor impairments, such as those suffering from amyotrophic lateral sclerosis (ALS). Because the target user population of the assistive robot suffers from severe motor impairments, it is necessary for the designers and developers of the robot to acquire familiarity with the needs and everyday living conditions of these individuals. Additionally, the developed robotic technology should be evaluated by the prospective users. Therefore, we believe involvement of prospective users throughout the design and development process through needs assessment and human evaluation is essential in improving the usability and accessibility of the robot. In this paper, we introduce the two human studies in developing an assistive robot with an emphasis on the methods of interviews, observation, and experimentation.

Background

ALS is one of the most common neurological diseases resulting in motor impairments. At any given moment, it is estimated that there are around 30,000 Americans diagnosed with ALS (The ALS Association 2004). ALS debilitates the function of motor neurons, which eventually affects all voluntary muscle movement of the entire body. ALS is a very severe, progressive disease, that starts with minor symptoms, such as muscle stiffness, and progresses to the loss of muscle movement across the entire body, eventually leading to death.

Although ALS is a deadly disease affecting the entire body, it is reported that the cognitive and mental abilities of the people with ALS remain relatively unaffected. In addition, a study with ALS patients reported that many of the patients often have a positive attitude regarding their condition and their life despite their tragic physical condition (Young and McNicoll 1998). Some patients interviewed during this study indicated that they think more about their family and social relationships even though actual contact with their loved ones has often decreased. The loss of contact with their family and friends is largely due to the loss of independence in their daily lives. Therefore, assistance via technologies, such as robotics, may also be beneficial for these individuals to help maintain their social relationships and eventually increase their quality of life.

To effectively help those with motor impairments, it is essential to identify which tasks of daily living are the most difficult to perform and the most important or critical. It is equally necessary to discover which needs can be met with technological solutions. Additionally, it is important to understand the expectations of, concerns regarding, and feelings or anxiety toward the use of assistive robots or other technology. Researchers in rehabilitation robotics and orthotics conducted a number of surveys to understand the needs of potential users (Stanger et al. 1994; Rahman et al. 1996; Hillman et al. 2002). Many of the surveys focused to find out which tasks of daily living should be prioritized in developing assistive manipulation technology by asking people with motor impairments and clinical personnel who helped them. Object retrieval is one of the task these studies found to be prioritized. However, we need to investigate the specific needs related with the object retrieval task. In this study, we met people with motor impairments and observed their environment to gather information regarding the objects, environments, and expectations of the people regarding the mobile autonomous manipulation robot.

In addition to limited mobility which can be aided by powered wheelchairs, object manipulation presents difficulty to those with motor impairments. Those with limited arm and hand strength and dexterity have difficulty with lifting, carrying, and controlling everyday objects. People with lower limb disabilities also have problems with object manipulation because they cannot reach some objects, such as those dropped on the floor. As many people with motor impairment use wheelchairs, wheelchair-mounted manipulator arms have been developed and commercialized (Kwee and Stanger 1993). However, wheelchair-mounted robots have limitations in flexibility of use, such as reaching objects located physically close to the human user. Additionally, because direct control of a robotic manipulator requires significant efforts with regard to learning and upper limb mobility, a number of studies have focused on the development of technologies for autonomous manipulation (Caselli et al. 2003; Graf et al. 2002; Graf, Hans, and Schraft 2004; Kemp and Edsinger 2005; 2006).

The User Needs Assessment

In order to investigate the needs of object manipulation in the daily lives of the target population, we recruited 8 patients through bi-monthly clinics held in the Emory ALS center. After introduction and initial surveys at the clinic, we asked the patients and their caregivers to bring home data collection instruments including a digital camera. We asked them to record incidences over a period of about a week where the patient experienced difficulty while manipulating an object. Then an interviewer visited their homes to conduct in-depth interviews regarding these experiences as well as their expectations of manipulation assistance robots to be developed.

Table 1: Demographic information

Variables	Values
Gender	Male (6), Female (2)
Ethnicity	White (6), African American (2)
Age	39 - 62 (average 53.5) years
Diagnosis	16.73 months ago (average)
Caregivers	spouses (5) family (2) paid personnel (1)

Participants

We recruited eight participants for the user needs assessment study with help from the Emory ALS clinic in February 2008. A short introduction of the research project was given by a registered nurse or a physician who provided treatment. If the patient indicated interest in participation, the interviewer entered the exam room. The demographic profile of participants is listed in Table 1. Although the relatively small number of eight participants is not representative of the overall ALS participation, the composition of ethnic and gender differences is in line with national statistics. In addition, the progression of disease and physical capability limitations showed reasonable variability.

Procedures

The ALSFRS-R (Revised Amyotrophic Lateral Sclerosis Functional Rating Scale) is an assessment method used to determine the level of ALS symptom progression. This test assesses the physical condition of a patient based on 13 assessment items scored from 0 (most severe impairment) to 4 (normal condition, without any impairment). The last four items are related with breathing problems and need to be tested by respiratory specialists, while the other nine items cover a general health assessment. The scores are combined to generate an overall score. The ALSFRS-R score has often been used to predict the survival time of a patient and empirical study has demonstrated the efficacy of this score as a predictor of remaining lifetime (Kaufmann et al. 2005). A registered nurse in the Emory ALS Center administered the assessment on the day of the clinic.

To understand the personal experiences and needs related to assisted object retrieval, interview participants were given a digital camera to photograph instances in which objects were dropped and/or were otherwise unreachable. Participants were asked to photograph such instances over the period of a week. A Kodak C613 digital camera equipped with an 1 giga byte Secure Digital memory card was provided attached with a pen and memo pad to record these events. The home survey, used to summarize events in which participants experienced object retrieval difficulty, contained the following entries with examples:

- *Object:* Standard sized single volume spiral notebook, blue
- *Location:* Living Room
- *Orientation:* Fell flat on floor about one foot between both the edge of the sofa and myself.
- *Method of Retrieval:* Brother picked it up
- *Time Elapsed until Retrieval:* 30 minutes

After the photographing and recording period in the patient homes, researchers visited participants in their homes to ask questions on their experiences with object retrieval. The photographing session was also designed to help remind patients of these experiences although some participants could not take pictures because of their physical limitations. In instances where participants had taken photographs, questions regarding these photographs were asked first to understand the situational context. The interview questions consisted of object identity, location, return method, and other as below:

1. *Drop Frequency*
   - On a daily basis, how often do you drop objects?
   - What objects do you drop most frequently?
   - Do you ever experience tremors?
   - Do you ever experience increased/sudden stiffness or weakness in your arms or hands?
2. *Object Identity*
   - Of the objects you drop, which do you find most important to retrieve?
   - Are there any objects that you avoid using out of fear of dropping them?
   - What objects?
   - Are there any everyday tasks that you can no longer do or have difficulty performing?
3. *Location Identities*
   - In order to avoid impeding your mobility, what distance is required from objects and people?
   - Are there specific places that make maneuvering more difficult than others?
4. *Method of Return*
   - What is the most convenient way for you to receive from a caregiver?
   - What locations are most accessible to you for retrieval?
   - Between a caregiver returning or placing in a location, which is more valuable to you?
5. *Use of Laser Pointer*
   - How familiar are you with laser pointers?
   - Can you hold the pointer?
   - Can you point at the dropped object?
   - How comfortable are you using a laser pointer?
   - Is there an easier way for you to point objects?
6. *Other Questions*
   - Is there someone to help you with daily chores?
   - Would an object retrieving robots be valuable to you?
   - How much would you like to spend on such a robot?
   - Do you have any specific devices that you use to interact with objects?
   - Can you imagine a task where you would want a robot to help you?

Results

The results of ALSFRS-R assessment show that the group of participants had considerable variability in the extent of disease progression. The summation score of the 13 ALSFRS-R sub-scores ranged from a minimum of 19 to a maximum of 37, with an average of 27 and standard deviation of 6.85.

Photographing Six out of eight participants took 36 pictures and/or recordings in total of instances of object manipulation difficulty by themselves or with help of their caregivers. Since many of the participants had significant difficulty in upper limb mobility, the results far exceeded the expectations of the research team.

As shown in Figure 1 to Figure 4, various objects were photographed by participants which actually presented difficulties in their daily lives with respect to object manipulation. Everyday objects, such as TV remotes and cellular/regular phones, were initially expected during the planning of this study. As anticipated, participants dropped these objects on the floor and were faced with challenges to retrieve them. However, additional objects, such as the walking stick shown in Figure 3, were not anticipated. The walking stick presented a challenge to the current robot design because the gripper was not appropriate to grab long objects and objects exceeding weight capacity. As shown in Figure 4, small objects such as small screws, which a participant used for a hobby, and medicine pills were also reported to be dropped on the floor. Small objects also presented challenges in robot design to develop a gripper to grasp them.

Six participants could record the elapsed time between when the object was needed and when they finally retrieved the object, either by themselves or with help from caregivers. The collected time was used to help indicate the urgency for assistance with object retrieval. In 22 cases, it took 9.4 minutes in average with high variability from 1 minute to 120 minutes with standard deviation of 25.4 minutes. This result implies that when a care giver is present, object retrieval typically takes less than five minutes. Object retrieval assistance by robots should complete the task under five minutes. We hope robotic assistance can provide patients with a level of independence by reducing the need for constant care giver presence.

The experimenter took additional pictures of the participants' home environments during the final interview. Compared to controlled laboratory environments, actual places of residence can present significant challenges to the mobility and object detection capabilities of the robot. Because the robot is built on wheels, stairs and uneven surfaces would present a limitation for the robot's movement. However, as shown in Figure 5, most of the home environments visited were either flat or contained smooth slopes to accommodate wheelchair mobility. Although the homes of par-

Figure 1: TV remote

Figure 2: Cell phone

Figure 3: Walking stick

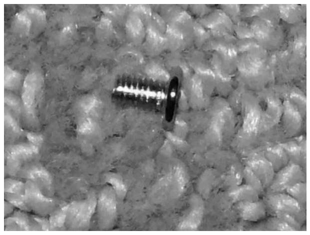

Figure 4: Small screw

ticipants cannot fully represent all possible environments in which individuals with motor impairments might live, the observation of modifications to the living environments for wheelchairs suggests the viability of using mobile robots on wheeled bases. The pictures also illustrate some potential challenges for the development of the assistive robot. In Figure 5 the sunlight was reflected by the tiled floor creating a bright glare which would make it difficult for the robot to visually segment the object from background. Figure 6 shows a desk with many objects placed in cluttered fashion which might make it difficult for the robot to distinguish which object is actually the target object.

Figure 5: Shining sloped floor

Figure 6: Cluttered space

Other than object retrieval, different tasks were also reported as difficult through the participants' photographs and recordings. A participant had difficulty in holding and moving a hairbrush due to limited hand dexterity. Similar to this, putting on socks, shirts, and shoes was one of the common tasks with which participants experienced difficulty. Opening food containers and controlling switches were also reported as a source of difficulty for some participants. Although the robot developed for this study focuses on the object retrieval, these additional tasks and needs can provide direction for future assistive robot development efforts.

Final Interviews

Final interview questions were structured into categories of objects, location, receiving methods, the laser pointer interface , acceptable performance, and other questions. The participants frequently dropped objects (e.g., on a daily basis) and tried not to use breakable or heavy objects for fear of dropping them. The most common objects were phones and paper materials, the latter of which may be difficult for retrieval with the current robot design. Phones and walking sticks were rated high with respect to retrieval importance. Participants experienced difficulty and/or were no longer able to perform tasks such as dressing, bathing, and carrying heavy objects. These areas need to be further investigated to identify possible robotic solutions to help individuals with motor impairments with these tasks of daily living.

The ability of the robot to follow the user into a room, between rooms, opening doors, and traveling in automobiles were perceived as useful. Increasing the mobility and portability of the robot would be one future direction of assistive robot development. Participant answers regarding the preferred receiving method, illustrate a split preference between direct handing to the user and putting the object on a nearby surface. These mixed results may be dependent on the exact context of the object and situation. Therefore, developing technologies for both methods of returning objects to the user would be preferable.

Because the primary interface for controlling the robot, via indicating the target object to be retrieved, involves the use of a laser pointer, the interviewer brought a laser pointer and asked participants to practice using it. Six out of eight participants could effectively aim the pointer to an object, but only three individuals were comfortable during use, which implies the need of better design of controlling interface. A head-mounted laser pointer was suggested by one participant, which seemed ideal as all participants could move their head freely. We developed ear-mounted laser pointers as a result of these findings, which can be hooked on the ear of the user and directed by head movement rather than hand movement.

Controlled Human Experiments

Based on what we learned from the needs assessment, we developed an ear-mounted laser pointer as a robot controlling interface in order to help ALS patients having difficulty in using standard laser pointer. The ear-mounted laser pointer is expected to decrease the upper-limb mobility needed to control the robot. We also developed a touch screen GUI for robot control to compare the novel laser pointer interfaces with a traditional interface technique. We evaluated and compared the efficacy of all three interfaces through a study involving eight patients recruited from the Emory ALS Clinic. The eight subjects participated in a lab-based experiment with three user interfaces: 1) an ear-mounted laser pointer, 2) a touch screen graphical user interface, and 3) a hand-held laser pointer. We asked the participants to command the robot to pick up an object from the floor by selecting it with the interfaces, which involves illuminating the object with a green laser or touching the image of the object on the touch screen. During this study, participants used the three interfaces to select everyday objects to be approached, grasped, and lifted off of the ground. By within-subject design, each partipant performed experimental tasks using all the three interfaces as their motor capability allowed. We experimented with three everyday objects of a cordless phone, a medicine bottle, and a plastic medicine box, in random order placed in two different locations on the floor. In this paper, we present an overview of the user study focusing on the experimental methods. See (Choi et al. 2008) for details of the study.

Implementation

Figure 7 shows the implementation of the assistive robot, El-E. A vertical lift is used for vertical movement of a carriage holding a 5 DOF (degree of freedom) manipulator, a 1 DOF two finger gripper, a laser range finder, and a camera. A mobile base, with two driven wheels and a passive caster, holds other robot components. On the top of the vertical lift, the head part of the robot works as a visual system for the robot, containing two different types of camera systems. The hyperbolic mirror near the top of Figure 7 and a monochrome camera constitute an omnidirectional camera system. Due to the shape of the mirror, the camera has a comprehensive view of the local surroundings horizontally 240 degrees with a small blind area blocked by the linear actuator and vertically from the floor to the ceiling. This enables El-E to monitor most of a room. The robot uses a stereo camera system, mounted on a pan and tilt unit, to obtain detailed color images of the room and to compute estimates of 3D locations. The two-finger gripper is equipped with force-torque sensors for grasping objects. A laser range finder with a 4 meter range is mounted on the carriage, which allows the laser range finder to scan across the surfaces of planes of various heights, such as floors and tables.

During this study, when given a 3D location, the robot moves towards the location and uses its laser range finder to look for an object close to the 3D location. If it finds an object that is sufficiently close to the 3D location, it moves to the object, moves its gripper over the object, uses a camera in its hand to visually segment the object, aligns the gripper at an appropriate angle, and then moves its gripper down to the object while monitoring the force-torque sensors in its gripper. Once it makes physical contact with the object, it stops the grippers descent and begins closing the gripper. In the event that it does not successfully grasp the object the first time, it will try again, up to four times.

The mobile base is built from a commercially available mobile robot. It transports the other hardware components of the robot and is controlled by an on-board computer with a wireless link. An on-board computer of Mac-Mini with Linux operating system performs all computation required for the robots autonomous operation.

The hand-held laser pointer is a standard off-the-shelf laser pointer with a green laser that is commonly used for slide presentations. Although a hand-held laser pointer provides an easy and intuitive method to unambiguously point

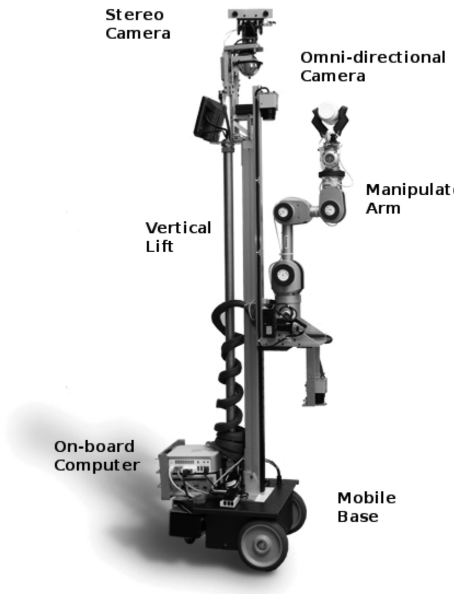

Figure 7: El-E and its components

Figure 8: A hand-held laser pointer being held by a participant

to a real world object within the three dimensional world, handling it requires strength and dexterity of the upper-limbs. As shown in Figure 8, a participant with limited hand dexterity uses both hands to point the pointer and press its button.

The hand-held and ear-mounted laser pointer interfaces use a point-and-click style of interaction analogous to the interaction style used in common graphical user interfaces. This interface enables the user to point to an object in the three dimensional world with a conventional laser pointer, similar to the use of a mouse pointer on the two dimensional screen of a PC interface.

When a user turns on the laser pointer and orients it toward a specific object, the laser light emitted from the laser pointer is reflected off the surface of the object. When the user points to an object and illuminates it with the laser pointer for a few seconds, it is recognized as a click command. The cameras on the robot produce images of the scene. Because the laser light has a well-defined frequency, a characteristic shape, and predictable motion, the robot can

Figure 9: Ear-mounted laser pointer and a wired button

Figure 10: Ear-mounted laser pointer worn by a participant

readily detect the illuminated location. To enhance the detection of the laser spot with the omnidirectional camera and to increase the sensitivity, the robot uses a narrow-band green filter matched to the specific frequency range of the laser pointer. After detecting the spot, the robot looks at it and estimates its 3D location using the stereo camera.

We designed the ear-mounted laser pointer to appeal to users with limited upper-limb mobility. We connected a green laser diode, which emits light, to a control unit consisting of batteries and a push button, as shown in Figure 9. Separating the battery and button from the laser diode helps reduce the weight of the ear-mounted component, which is based on an off-the-shelf ear-hook style Bluetooth headset shown in Figure 10. We expect the ear-hook design to be less obtrusive than alternatives, such as a hat, a hair band, or a headphone.

We implemented the touch screen GUI on a computer separate from the robot and located in close proximity to the user as shown in Figure 12. The GUI has a large area in its center that displays images from the robot's right stereo camera. On the left and right side of the image, we included large arrow buttons to enable the user to look around the room by panning and tilting the stereo camera as shown in Figure 11. When using the interface, the user first orients the view of the camera toward the object of interest by pressing the arrows. Next, the user selects the object by touching the object in the image display area. The robot uses this selection to compute a 3D estimate of the objects location. The 3D estimate is then used by the robot in the same manner as the 3D estimate from the laser pointer interfaces. In experiments, the participants put the touch screen display on their laps and used the interface with both hands interface, as shown in Figure 12.

Figure 11: Touch Screen Interface

Figure 12: The touch screen interface being used by a participant

Table 2: Demographic information

Variables	Values
Gender	Male (6), Female (2)
Ethnicity	White (6), African American (2)
Age	35 - 67 (average 53.13) years
Diagnosis	25.16 (average for all) 15 months ago (for 7 ALS patients)

Participants

Eight participants took part in this study with demographic profile in Table 2. Seven of them were ALS patients and the other was diagnosed with primary lateral sclerosis (PLS) which is different from ALS but also causes severe motor impairments and can be categorized within the same family as ALS. Five of the seven ALS patients previously participated in the needs assessment study. We recruited participants by meeting them in the Emory ALS clinic and telephone telephone calls. Participants had considerable variety in the extent of their impairments from slight difficulty in walking to a serious lack of limb mobility except only slight motion of a single hand. The subjects volunteered to come to our laboratory.

Experimental Setting

In the experiments, a patient sat on a wheelchair or a chair beside the robots initial position similar to the position of the wheelchair or chair. We chose this relative positioning of the robot and the user to emulate the use of a service dog. In this sense, one can think of the robot as a companion robot that stays by the side of the user. For this study, all objects were placed in one of two positions marked by tape. From the

Table 3: Direction and distances of object locations

Location	X offset	Y offset	Distance
A	1.964	0.195	1.975
B	1.54	-0.57	1.642

Figure 13: Objects; a cordless phone, a paper medicine box, and a plastic medicine bottle

users perspective position A is on the left and position B is on the right. The two positions were selected to represent different directions and distances from the robot as listed in Table 3. When placed in these two positions the objects were in plain sight of both the robot and the participant. 3D estimation of the point detected by the robot was compared with the object location to calculate the 3D distance between the objects actual locations and detected points.

To validate the performance of the robot with objects with different shapes, weight, and colors, we used three everyday health-related objects for the experiment; 1) a cordless phone, 2) a paper medicine box, and 3) a plastic medicine bottle, as shown in 13.

Procedures

For this study we used a within-subject design in which all users conducted tasks with all conditions. The order of two factors; interface type and object type was randomized to minimize order effect and for counterbalancing. We used the following procedure to conduct the experiment with each participant

1. Participants read and signed consent forms and responded to surveys on computer experiences and upper-limb and neck mobility.
2. For the first interface type randomly chosen among ear-mounted laser pointer, touch screen, and hand-held laser pointer, the participant learned to use the interface and practiced until he/she indicated comfort and confidence.
3. For each of the three object types (in randomized order), the participant conducted two trials, one for each position (A&B) resulting in a total of 6 trials for each interface type.
4. We conducted a satisfaction survey to record the users experience with the interface.
5. Steps 2 through 4 were repeated for the other two interface types.
6. The participants answered final post-task interview questions.

The total time for each experiment was limited to 2 hours to prevent fatigue and lasted an average of approximately 1.5 hours. Separate from the experiment, an assessment of ALSFRS-R was conducted by a nurse in the Emory ALS Center to determine the extent of ALS disease progress.

Quantitative Performance Measures

Time to completion is a primary measure of assessing the performance of human-machine systems (Bailey 1996). In the experiment, we divided the total time to completion into;

1. Selection time: The time elapsed between when the user started to use the interface by notifying the experimenter to when the robot detected the targets 3D position.
2. Movement time: The time between the selection to when the robot approached the target and fixed its position.
3. Grasping time: The time from when the robot finished approaching to when the robot finished the task.

Out of these three decompositions, we expected the selection time to be the most relevant measure to detect differences among the three different user interfaces. We expected movement time to be highly correlated with the position of the objects and the grasping time to be dependent on the object types. The Euclidian distance between the objects actual 3D location and the 3D location used by the robot serves as a measure of accuracy for pointing tasks with the three interfaces. We recorded the 3D location in log files and calculated the distance as a measure of pointing error in the analysis.

Qualitative Measures

Human computer interaction researchers often conduct satisfaction questionnaires after experimental trials to measure the users satisfaction with a computer interface and has proven this method to be effective in long term user studies (Folmer and Bosch 2004). Because the purpose of this study is to evaluate the user interface for directing the robot, we used an existing satisfaction questionnaire developed for evaluating computer systems (Lewis 1995) to derive a questionnaire with 8 items. We asked the following questions to qualitatively measure participant satisfaction:

1. I could effectively use the system to accomplish the given tasks.
2. I am satisfied with the time between when I gave command and when the robot detected the object.
3. I am satisfied with the total time between when I gave command and when the robot finally picked up the object.
4. It was easy to find an object with the interface
5. It was easy to point an object with the interface.
6. It was easy to learn to use the system.
7. It was not physically burdensome to use the system.
8. Overall, I was satisfied to use the system.

The participants were asked to answer on a 7 point Likert scale from strongly disagree (-3) to strongly agree (3)

Results

In 134 trials in total, the participants commanded the robot to pick up an object with a 94.8% success rate overall with the three interface types. It took less than 10 minutes of learning to use each interface for all participants. Users could select objects 69% more quickly with the laser pointer interfaces than with the touch screen interface. We also found substantial variation in user preference. Users with greater mobility in arms and hands tended to prefer the hand-held laser pointer, while those with more difficulty in upper-limb movement tended to prefer the ear-mounted laser pointer. We also found that three patients preferred to use the touch screen interface even though it took apparently longer time to complete the task. These results indicate that assistive robots can enhance accessibility by supporting multiple interfaces and also demonstrate that the provision of 3D locations from a user to the assistive robot can serve as an effective abstraction barrier that enables the use of different interfaces to the robots while using the identical robotic functionalities.

Conclusion

From the needs assessment, we learned valuable information on the needs of prospective users with motor impairments such as frequency of dropping, types of objects, and preferences of delivery methods. The findings influenced design of the robot and interfaces which resulted in the evaluation by human experiments. The experimental results validated the performance of the robot and user satisfaction. We also found different preferences and performance impacts of interfaces. We hope the findings in the two reported studies be applied to future developments of assistive robotic manipulation and other robots for healthcare.

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