Robots for Humanity

Using Assistive Robotics to Empower People with Disabilities

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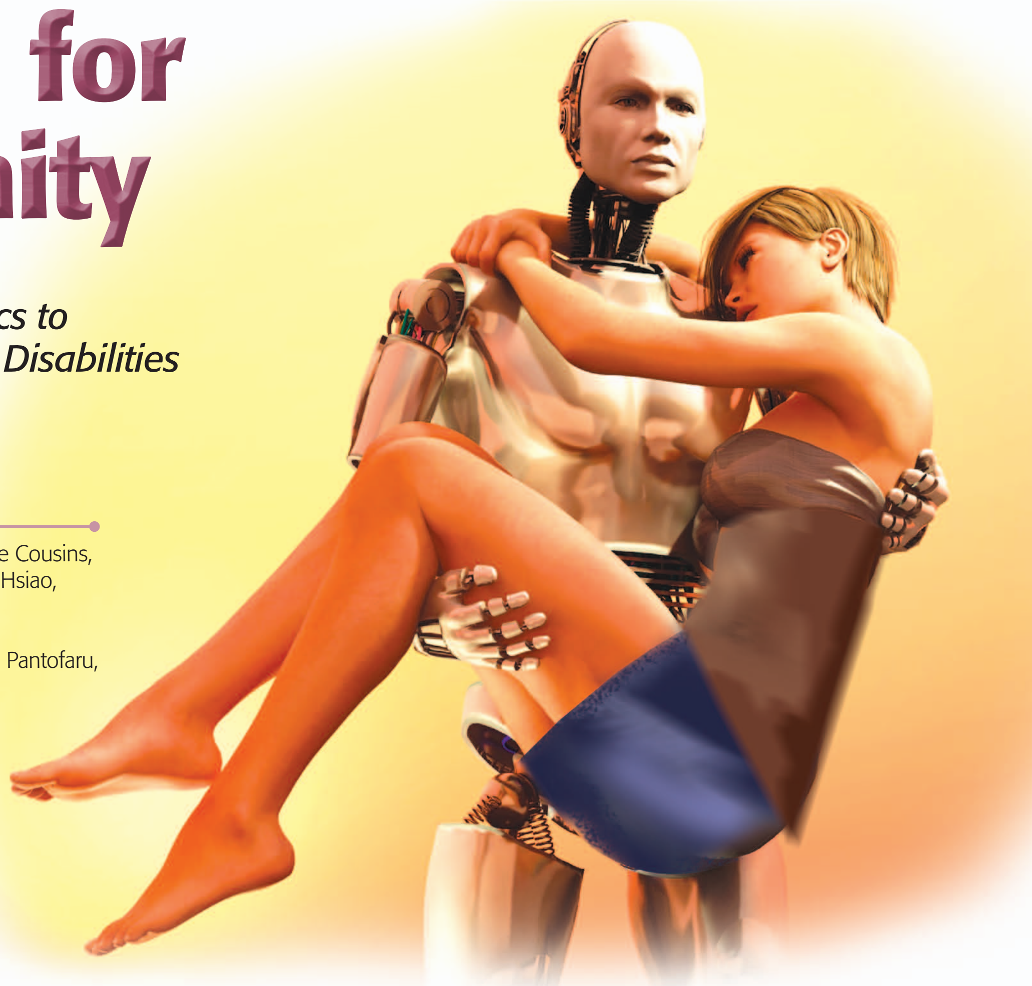

Assistive mobile manipulators (AMMs) have the potential to one day serve as surrogates and helpers for people with disabilities, giving them the freedom to perform tasks such as scratching an itch, picking up a cup, or socializing with their families.

Project on Assistive Robotics

"I was lying in bed, watching TV as usual, when I saw a technology special on a mobile robot. I immediately imagined controlling it as a surrogate for my own body," recounts Henry Evans as he describes how our project on assistive robotics first started. As a result of a brainstem stroke, Henry is mute and quadriplegic. After extensive therapy, he regained the ability to move his head and use a finger, enabling him to use a computer. When, in October 2010, Henry saw a TV interview of Georgia Tech Prof. Charlie Kemp demonstrating research with the Willow Garage PR2 robot, he immediately saw the opportunity for people with severe motor impairments to use mobile manipulators as assistive devices. Henry was motivated by the possibility of using a robot as a surrogate for his paralyzed body, and he believes thousands of others with severe motor impairments could benefit as well.

Shortly after learning about the PR2, Henry contacted our research team, kicking off the project that he has dubbed "Robots for Humanity." The goal of this multidisciplinary project is to empower people with severe motor impairments to interact with the physical and social world, thereby enhancing their quality of life through the use of an AMM.

Over the past year, we have been engaged in a participatory design process with Henry and his wife and primary caregiver, Jane Evans. The research team, Henry, and Jane have gathered four times (in March, June, and October 2011 and February 2012) for multiday research workshops to design, develop, user test, and iteratively improve upon robotic software and hardware tools. In this article, we introduce our project and give a first project report describing our approach, the results we have achieved so far, and lessons we have learned.

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Assistive Mobile Manipulation

AMMs are the mobile robots that physically manipulate the world to provide assistance to people with disabilities. As opposed to other assistive systems, AMMs can operate when they are away from their user, do not require donning and doffing, do not directly encumber the user, and have a large dexterous workspace due to their mobility. General-purpose AMMs have the potential to provide assistance with a wide array of tasks for people with diverse conditions, whether they are in bed, in a wheelchair, or ambulatory [17]. An AMM could also be suitable as a shared resource for multiple users living together.

In this project, we aim to address two questions that are critical to the success of this emerging assistive technology. The first question is: How can people with severe motor impairments effectively use general-purpose mobile manipulators for self-care, household activities, and social interaction? Our goal is to empower motor-impaired users to take full advantage of AMMs to effectively perform a wide range of tasks, including new tasks from their own imaginations.

The second question is: How can mobile manipulators robustly provide assistance given the large variation found in the real world? Robots are notorious for coping poorly with environmental variations, and homes encompass diverse materials, illumination, clutter, objects, mechanisms, pets, people, and more, all of which can negatively impact the robot's performance. Our goal is to enable AMMs to handle the real-world variation found in homes and to inform the design of future AMMs.

Shared Autonomy

In our article, we attempt to address these challenges by using shared autonomy, leveraging the capabilities of both the robot and the user. Robot autonomy has the potential to make mobile manipulators more accessible and more capable by strategically reducing the complexity exposed to the user. Humans have the potential to make mobile manipulators operate more robustly in real homes through the use of their domain knowledge and superior scene and situation understanding.

There are a vast number of options available for shared autonomy, as humans and robots can divide responsibilities for a task in many different ways. Our approach in this project is to develop a diverse suite of software tools with overlapping capabilities. Each tool provides a particular coherent capability to the user, such as grasping a selected object or reaching to a selected three-dimensional (3-D) location. The tools vary in their degree of autonomy and their task specificity. For example, one tool attempts to autonomously perceive and grasp an object, while another asks the user to show it where to grasp an object. In general, we expect to give users multiple ways to achieve the same goal through tools with overlapping capabilities. We intend to empower users to decide how they want to achieve their goals, including goals that were not anticipated by the research team.

User-Centered Design

Given the numerous tasks that an assistive robot might perform and the numerous technologies relevant to the assistive robots, a large project such as ours could become lost in interesting but impractical research questions. We believe that one of the strengths of our effort is that it has been user-centered from the beginning. Our research questions have been driven by the users and the capabilities they value.

Our goal is to empower motor-impaired users to take full advantage of AMMs to effectively perform a wide range of tasks, including new tasks from their own imaginations.

Many user-centered design projects have begun with researchers seeking out inspiration and feedback from a target population of end users through methods such as contextual inquiry for interaction design [2], user and task analysis [8], and other types of user research such as surveys, focus groups, user interviews, and more [16]. In contrast, this project began with Henry's own initiative and has continued with a participatory design process in which Henry and Jane offer ideas, user feedback, and the use of their home for testing. As extreme users [14], Henry and Jane are able to quickly assess the strengths and weaknesses of our software and hardware.

The key design choice that Henry influenced is the system interface mode. Henry is able to control a cursor on a screen through a headtracker, so all of the on-screen interfaces presented in this article use a two-dimensional (2-D) input device with a button click. Due to the prevalence of personal computers that expect mouse input, a diverse array of assistive interfaces exist that can provide the input our system requires, which bodes well for its accessibility. We also believe that in the future, our tools could contribute to the general use of robots by nonexperts through widely available interfaces, such as mouse cursor control.

We have organized our project around three broad categories of robotic assistance: with manipulation near the user's body, with manipulation of objects in the environment, and with social interaction. Each type of assistance entails distinct research challenges. They are also closely related to the activities of daily living (ADLs) (e.g., feeding, using the toilet, transferring between bed and wheelchair, dressing, and maintaining hygiene), the instrumental ADLs (IADLs) (e.g., housework, food preparation, and shopping), and the enhanced ADLs (EADLs) (e.g., hobbies and social activities), which have been shown to be important for quality of life but are difficult for many people with motor impairments [18], [15].

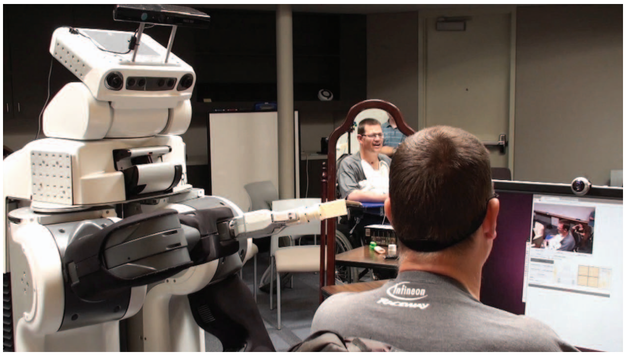

Figure 1. Henry controlling the PR2 from a GUI to scratch his face.

(a) (b)

Figure 2. Henry commands the PR2 (a) to scratch his face and (b) to shave his cheek.

Figure 3. Henry operating the PR2 robot to perform a remote manipulation task in his home with the Interactive Manipulation interface.

Figure 4. Henry (bottom right, using Interactive Manipulation running on laptop) giving Halloween candy to children with the PR2.

Our first workshop with Henry and Jane included an assessment of needs. During a visit to their home, Henry and Jane walked the team through a day in their lives and participated in interviews. They also both filled out a questionnaire rating the value and usefulness of the robot assisting with various tasks on a Likert scale. This process led us to identify tasks that both Henry and Jane considered to be high priority and acceptable for robot assistance. Including both Henry and Jane in this process was valuable, since they did not always agree on tasks. For example, Henry wanted the robot to feed him, but Jane considered the task too dangerous for any food except yogurt (because of choking hazards). In general, involving both the care receiver and the caregiver has been valuable for our participatory design process. Involving caregivers in robot development may also be important to the future success of AMMs, since caregivers are likely to use and interact with AMMs in distinct ways.

Henry has already been able to use a PR2 robot, and the open source software we have developed, to perform a variety of tasks for him for the first time in ten years under carefully controlled conditions. These include scratching his face and shaving himself (Figures 1 and 2), performing remote manipulation tasks in his own home (Figure 3), and giving out candy to kids on Halloween at a mall near his home (Figure 4). In the following sections, we describe these results in more detail, along with the software and hardware that enabled them and the lessons we learned along the way. While these examples are only first steps, they suggest the diverse ways in which people with motor impairments could benefit from AMMs.

Assistance with Manipulation Near One's Body

A person's ability to perform ADLs is predictive of his or her ability to live independently. When human caregivers assist with ADLs, they often make contact with the care receiver's body. The AMMs that physically assist with these critical tasks may also need to make contact with the care receiver's body, either directly or indirectly via manipulated objects.

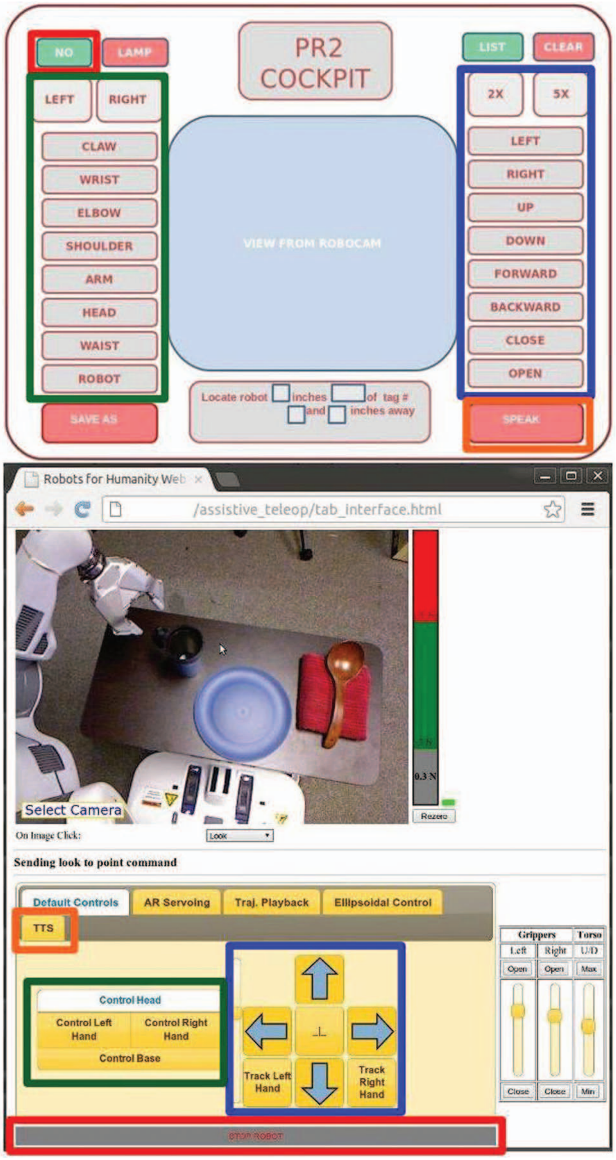

Figure 5. An interface developed through iterative design with the user. At the top is the original interface layout provided by Henry, and at the bottom is a later version of the interface after repeated iterations between Henry and researchers. Analogous components retained throughout the design process are highlighted in each version: a context menu for selecting components of the robot (green), scalable command buttons (blue), live video feed, text-to-speech (TTS) (orange), and stop button (red).

During the initial needs assessment, Henry and Jane each rated scratching (average rating of 6) and shaving (average of 5) as useful tasks on a 7-point Likert scale that ranged from "1—extremely not useful" to "4—neutral" to "7—extremely useful." In contrast, they rated brushing hair (average of 1) as not being useful. We chose to focus on scratching and shaving tasks because of Henry's and Jane's preferences, the tasks' suitability for AMMs, and the potential to generalize these tasks to other ADLs that involve manipulation around the care receiver's head (i.e., feeding and maintaining hygiene). We are using scratching and shaving as challenge tasks to develop general methods for assistive tasks performed around a person's head.

During the first workshop, before the needs assessment, Henry tested a Web-based graphical user interface (GUI) for the PR2 to pick up objects and brush his hair. Since then, we have continued to iterate and elaborate on this Web-based interface for which Henry provided the first design via PowerPoint (Figure 5). From his computer at his home in California, Henry tested and gained experience with the Web-based interface by remotely controlling a PR2 robot located in the Health-Care Robotics Lab at Georgia Tech. For example, he used the PR2 to remotely perform mock assistive manipulation tasks with a medical mannequin in a wheelchair. When Henry used a PR2 in person at Willow Garage or in his home, we took several steps to reduce the risks, including using low velocities and low joint stiffnesses when controlling the robot's arms. We also had an able-bodied observer with a run-stop button to carefully watch all activities and to stop the robot if something went wrong.

A simulation environment allowed Henry to practice complex tasks in the comfort of his home.

Software Tools for Shared Autonomy

Over the course of the first four workshops, we iteratively tested and developed various capabilities to enable Henry to command the robot to scratch and shave him. In the first iteration of the interface, Henry used buttons to move the robot's base and control the arms while holding a tool. Buttons were available for incrementally translating the robot's gripper in the robot's frame of reference (Cartesian control) and rotating the gripper. Although Henry successfully used this basic interface, the tasks were challenging to perform. Since then, we have developed a number of software tools for shared autonomy with overlapping capabilities.

Point-and-Click Reaching

For the second workshop, we developed a tool that enables a user to click on a live video feed from a Kinect sensor on the robot's head to command the arm to reach toward a 3-D location. The robot estimates the surface normal at this location and attempts to move the tool a specified distance away from and perpendicular to the surface. The robot can either hold its pose or move toward the surface until a force-torque sensor detects contact. The user can then command the tool to advance toward the surface or retreat and can also use Cartesian control. Henry was able to use these methods to move a scratching tool near his face and then scratch himself by moving his head, as seen in Figures 1 and 2. He was able to shave his cheek in the same manner.

Task-Specific Coordinate Systems for Control

When using Cartesian control to move a tool, such as an electric razor, properly mapping the (robot-relative) motion to the movements around one's own head can be challenging.

Our experiences with Henry highlight the importance of tools that allow end users to author robot behaviors–the gestures that Henry has created have been creative and unexpected.

Keeping the tool in a useful orientation can also be difficult. To address this issue, for the third workshop, we developed an interface that moves the tool with respect to an ellipsoidal coordinate system registered with the user's head in a neutral pose. The tool moves tangent to or normal to the surface of an ellipsoid while staying perpendicular to its surface. This helps the user more easily follow the contours of his or her head. To register this ellipsoidal model with the user's head, he or she adjusts and then confirms the coordinate system's placement (Figure 6) after the robot has attempted automatic registration. This human-in-the-loop perception step reduces the chance of error.

Recorded Task-Specific Poses

For the third workshop, we provided buttons such as "middle cheek" and "chin" that move the tool to a position recorded with respect to the ellipsoidal coordinate system. These recorded poses serve to efficiently perform coarse positioning of the robot with respect to the named facial feature, after which the user can perform finer positioning with a task-specific coordinate system or command the robot to move until contact. Similarly, in the fourth workshop, we attached ARTags to Henry's wheelchair and recorded poses of the robot's mobile base with respect to his wheelchair. Henry can interactively command the robot to visually serve to these recorded poses. This allows Henry to situate his head in a more kinematically suitable workspace for the robot, which would be difficult for him to achieve manually.

Detecting Inappropriate Forces for a Task

Although Henry was able to shave his cheek and part of his chin in the second workshop, it resulted in some abrasions. To better understand the forces applied by the robot during shaving, we recorded the forces from a force-torque sensor mounted to the razor as Henry shaved himself, and compared them with the forces when Jane used the same razor to shave Henry. We found that Henry was applying much more force than Jane while performing the task. We also conducted a small study in which we measured the forces that the able-bodied people applied to themselves and to a medical mannequin while using the same type of electric razor (Figure 6) [10]. The study enabled us to determine an upper-bound force threshold for completing the shaving task. For the third workshop, we enabled the robot to use this threshold to monitor Henry's safety on the basis of the readings from a force-torque sensor mounted to the PR2's wrist. While shaving, Henry went above the threshold several times at the start, which caused the robot to retreat, and he soon adapted to applying lower forces. As a result, Henry was able to use this system effectively to shave his cheek and chin without nicks or abrasions. When the razor was off, Henry also used this response to intentionally push the robot's hand away from his head. Haptic communication like this could be beneficial, especially since tasks involving the head can conflict with use of a head tracker.

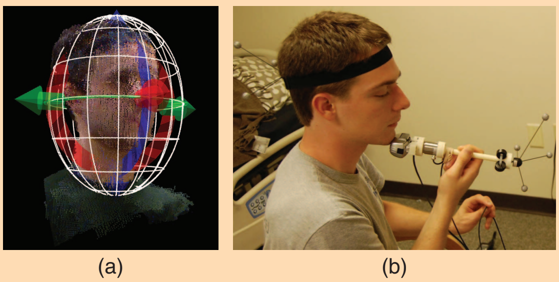

Figure 6. (a) An ellipsoid model registered to a point cloud of a subject's head with controls for adjusting the fit. (b) The force distributions were collected from able-bodied subjects using an instrumented electric razor.

Remaining Challenges and Future Work

Although Henry has successfully used our system to scratch and shave himself, many challenges remain. For example, feasible kinematic configurations that both avoid contact with the care receiver's body and reach the entire surface of the face (e.g., underneath the chin and the far side of the face) are difficult to achieve with the PR2. Characterizing the kinematic requirements for robots to perform assistive tasks could be beneficial. Similarly, characterizing the statistics of the forces involved in common tasks could help robots better regulate forces and help with the design of future AMMs.

Many opportunities remain for improving manipulations both around the head and around the body in general. We have presented examples of software tools that Henry has successfully used in the context of shaving, but further research will be required to understand their strengths, weaknesses, and generality. Testing our system with other people with motor impairments will be especially important to ensure that our software tools can benefit others. For example, people with more limited head motion than Henry may require more autonomy on the robot's part.

Assistance with Object Manipulation

In addition to having the robot manipulate objects near his body, Henry has also expressed a strong interest in tasks that involve manipulating objects remotely, such as tidying the house, answering the door, or fetching objects.

The Interactive Manipulation Interface

We have thus created another interface, which we call Interactive Manipulation, that allows motor-impaired users like Henry to remotely accomplish arbitrary manipulation tasks in their homes. The interface provides navigation, perception, and manipulation capabilities through an extensive set of tools with varying levels of autonomous assistance. The user can use autonomous robot tools to carry out subtasks faster and more easily when autonomy is possible, but they can still take full control of the robot to carry out tasks when autonomy is not available.

Interactive Manipulation is a "point-and-click" GUI that provides the user with two primary displays: on one side is a live image from the robot's camera, and on the other is a virtual camera showing a rendered view of the 3-D scene, which can be rotated, translated, or zoomed to see the scene from any angle. The rendered view shows the robot in its current pose (according to proprioception), as well as any 3-D snapshots of the current scene from a Microsoft Kinect mounted on the robot's head. The user controls the robot through a set of conventional dialog windows, as well as through a variety of 3-D widgets (called "interactive markers") that the user can click on and drag to control either in the camera or in the rendered view. An overall picture of the interface is shown in Figure 7.

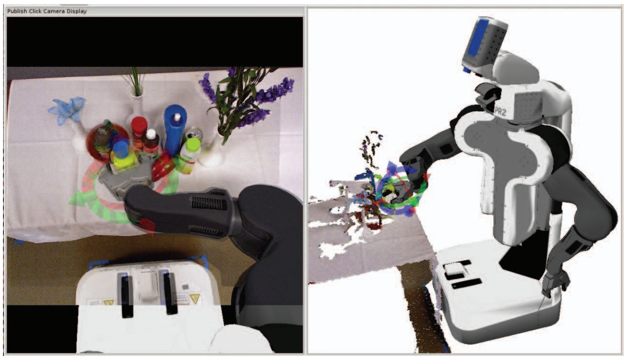
Figure 7. The Interactive Manipulation interface.

Figure 8 shows a variety of interactive marker tools for manipulating objects with varying levels of autonomy. For objects that the robot can autonomously segment and/or recognize, the user can ask the robot to use fully autonomous grasping capabilities [Figure 8(a)], as described in [3]. For the objects that the robot is unable to segment or recognize, the user can still specify a final grasping pose, and allow the robot to autonomously plan a collision-free path for pickup [Figure 8(b)]. For more arbitrary tasks, such as pushing objects or opening doors and drawers, the user can directly control the arms by dragging a rings-and-arrows interactive marker for rotating and translating the gripper in Cartesian space [Figure 8(c)].

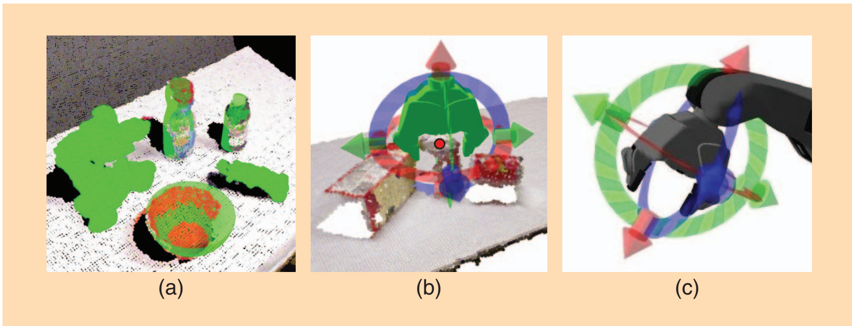

Figure 8. Tools for manipulation. (a) The segmented and recognized objects for autonomous pickup. (b) Specifying a final grasp pose for autonomous grasp execution. (c) The controls for directly moving the gripper.

Similarly, Figure 9 shows a variety of tools for navigating with varying levels of autonomy. The user can ask the robot to autonomously navigate using planned, collision-free paths [Figure 9(a)]. For moving right up next to obstacles, the user can carefully select a pose to perform an open-loop movement relative to a static, 3-D snapshot of the world [Figure 9(b)] or directly drive the robot using rate-controlled arrows [Figure 9(c)].

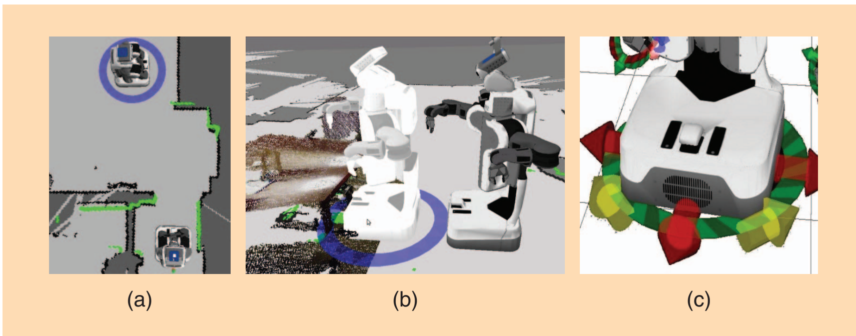

Figure 9. Tools for moving the base. (a) Navigating using a map. (b) Moving the base under a table open loop. (c) Moving with rate-controlled arrows.

Use of the Interface and Lessons Learned

Using Interactive Manipulation, Henry is able to perform tasks in his home such as the one shown in Figure 10, in which he controlled the robot to drive from the living room to the kitchen, open and close a kitchen cabinet door to examine its contents, open a drawer and remove a towel, and finally drive back to his wheelchair in the living room with the towel. This task was executed in a single continuous run, succeeded on the first attempt, and included the use of both autonomous and open-loop tools for base movement, grasping, and moving the arms.

Henry has also used Interactive Manipulation to perform the user study done by the able-bodied users in [12], involving grasping objects from a highly cluttered shelf. Both Henry and the other study participants were able to grasp objects faster on average using a tool with more autonomous assistance [Figure 8(b)] than with a direct

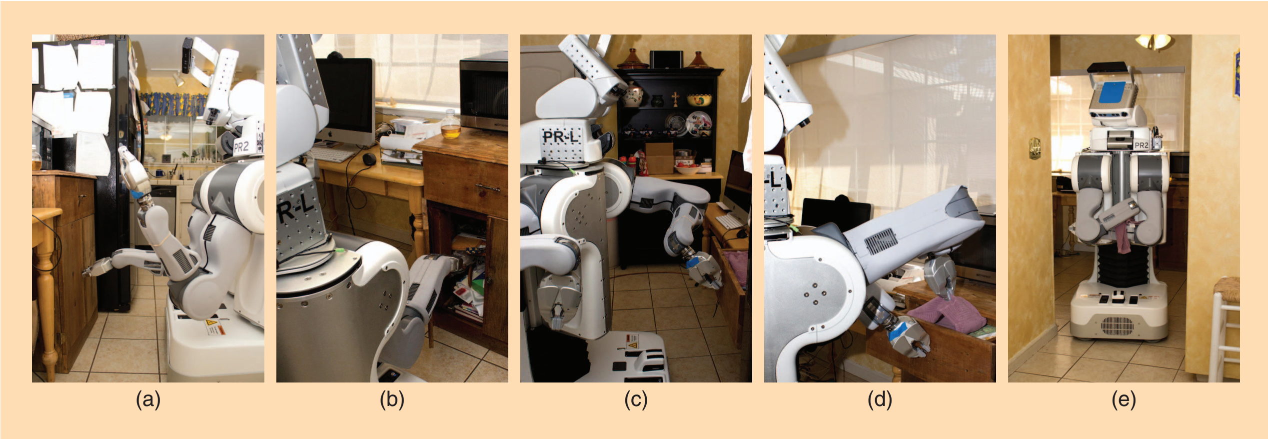

Figure 10. Henry fetching a towel from his kitchen with the PR2. (a) Grasping a cabinet handle. (b) Pushing open a cabinet door. (c) Opening a drawer. (d) Grasping a towel inside the drawer. (e) Navigating to the desired dropoff location.

control [Figure 8 (c)], highlighting the benefits of autonomous assistance.

However, our experiences in Henry's home also highlight the importance of providing tools for direct control when autonomy is either not applicable or fails outright. For instance, in an initial test, it was discovered that the robot's fan causes curtains to billow and register as obstacles in the robot's navigation map, which stops autonomous navigation. Also, during the towel-fetching task, a synchronization error between the robot's Laser Rangefinder and its computers caused most of the autonomous navigation attempts to fail. In both cases, the direct control was used to compensate. In other situations, autonomy is simply not applicable. For instance, Henry used the robot's forearm to push shut the cabinet door by directly controlling the gripper, a task for which no autonomous tool was available.

Like the remote training for the manipulation around the body tasks, we also found that training was a key enabler for using the object manipulation tools. In this case, a simulation environment allowed Henry to practice complex tasks in the comfort of his home. Even though the simulator cannot accurately capture the complexity of real-life situations, it can still help the operator become familiar with the interface and robot with no risk of injury or damage. We believe that both appropriate training mechanisms, and interfaces that provide a range of tools with varying levels of autonomous assistance, are key to allowing the assistive robots to successfully perform ADLs in real homes. More information about the Interactive Manipulation interface can be found in [4].

An Alternative Interface Method: Head Tracking

Although the Interactive Manipulation interface is effective, we would also like the opportunity to free Henry from always needing a computer monitor in front of him. With this in mind, we have begun experiments with a head-tracking system for contextual interactions with the robot such as selecting an object for manipulation in the real world. Using the system in [5] with the Kinect sensor, we track the 3-D position and orientation of Henry's head in real time and use this as a pointer for objects in the world. This is analogous to the Clickable World interface in [13]. We compute a vector normal to the coronal plane of the head and then intersect this with the robot's 3-D world model. This intersection point can be used to determine what Henry is looking at. A full overview and initial results are described in [11].

While initial experiments with this system have been encouraging, they have also highlighted a number of areas that need improvement. The tracked head pose is noisy, so we use a mean filter to trade off stability of the pose estimate against responsiveness. When making large head movements, responsiveness seems to be more important; when trying to dwell on an object, stability is more important. This implies that we need to make the tracker settings either more intelligent or more controllable.

To be useful as a pointing device, the system needs to offer feedback about what it thinks Henry is pointing at. In our initial prototype, we fixed a laser pointer to the robot's head for this purpose, but this is not a good long-term solution unless Henry can control when the laser is on.

Finally, we intend to make the sensor itself less obtrusive, either by using sensors that are already in widespread use (such as a Kinect mounted on a TV) or by mounting the sensor on the robot itself in a way that allows it to track Henry's head without interfering with normal robot operations.

Assistance with Social Interaction

Moving beyond manipulation tasks, we are using the PR2 to support EADLs such as socializing [15]. Henry has expressed frustration with the slow, inexpressive methods of communication available to him, which leave him an outsider in many conversations. The communication board that Henry and Jane use (Figure 11) requires the conversation partner to infer the gaze direction of the user to spell words [19], a task that requires patience and skill. Augmentative communication systems [1] such as text-to-speech (TTS) generators are functional but frustratingly slow.

In contrast to these methods, AMMs have the distinct advantages of embodiment and physical presence. This has

Figure 11. Henry and Jane use a communication board.

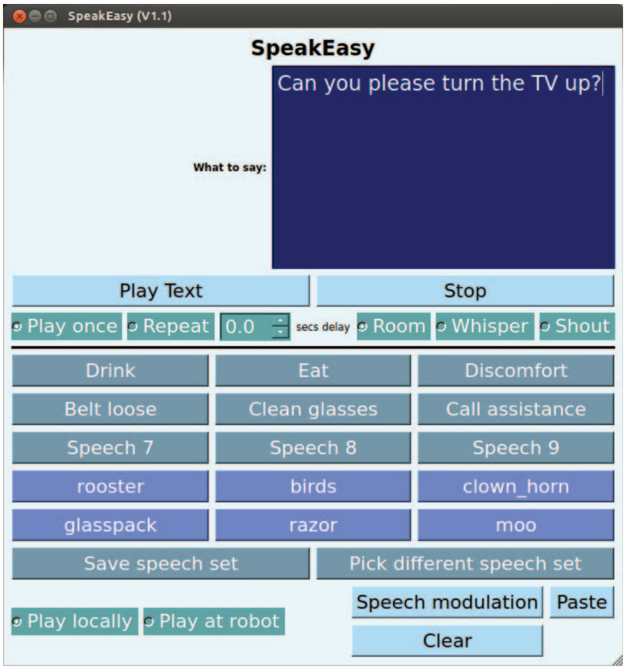

Figure 12. The SpeakEasy interface allows the user to control speech and sound onboard the robot and elsewhere. (Retouched for reproduction.)

inspired us to develop software capabilities and user interfaces that support social self-expression by people with both motor and speech difficulties (as can also occur for people with ALS [1]). Our goal is to allow a person to communicate and socially interact in a more satisfying way.

In this section, we discuss two interfaces that we have developed to facilitate social communication.

Audio Support

The first interface is called SpeakEasy and is shown in Figure 12. SpeakEasy allows a user to effectively control multiple speech engines simultaneously, for example, controlling one engine onboard the robot and another on the user's laptop. SpeakEasy is agnostic about the brands of the TTS engines.

The graphical interface is divided into five sections. Basic functionality is in the text entry section, which receives text entered via an onscreen keyboard, and the tape recorder buttons, which transmit the text.

To make the interface more efficient, the utterance program bank allows user-labeled buttons to be programmed with text of any length. The bottom row of the interface (see Figure 12) provides a method for storing and easily retrieving sets of buttons of preprogrammed utterances.

To make the interface more effective and interesting, the sound bank section stores sound effects that can be broadcast to standard audio players in multiple locations at once. A practical use of sound effects is using a warning sound when the robot drives around blind corners. Henry requested a more amusing sound effect; he wanted a powerful glasspack muffler sound for his electric wheelchair. This shows once again that utility is best measured by the user.

Creating Gestures with RCommander

Early on in the project, Henry explicitly expressed interest in performing a standup comedy routine using the PR2 as a proxy for his body. In spite of years of research with AMMs, this was not a task that we had previously considered. Gestural expressions can play an important role in standup comedy and in social interactions in general. Gestures can also be diverse, distinctive, and personal. As such, we wanted to empower people to create their own gestures, reuse those gestures, and share and adapt gestures created by other users in their communities.

With these goals in mind, we modified the RCommander robot behavior editing tool seen in Figure 13 to serve as a gesture-authoring tool. RCommander is a general tool that we are developing to enable nonroboticists like Henry to create their own behaviors for robots. As such, creating custom gestures has served as a first test case for enabling a person with severe motor impairments to create robot behaviors for himself.

Each set of robot actions that accomplishes a task is represented as a state machine with each state drawn as a circle representing one of a robot action. RCommander enables users to create new gestures through an iterative modify-and-test process, save gestures in a library, and create sequences of actions. The two classes of actions that Henry tested were splined trajectories for designing robot gestures and TTS generation.

The gesture GUI is structured as a keyframe animation tool in which interactive markers are used to create the keyframe poses. After a keyframe is posed, RCommander assists the user in debugging by highlighting the joint angles that are too close to the joint limits or that violate velocity constraints. Using interactive markers instead of physically posing the robot (as is typically done in learning from demonstration research), makes our interface accessible to Henry.

Henry has tested our interface multiple times. Each test begins with a tutorial, followed by an exploration period in which Henry has constructed gestures using a PR2's arms. After each session, we applied the lessons learned to iterate on the interface. For example, our sessions have highlighted the importance of quick access to behaviors during use,

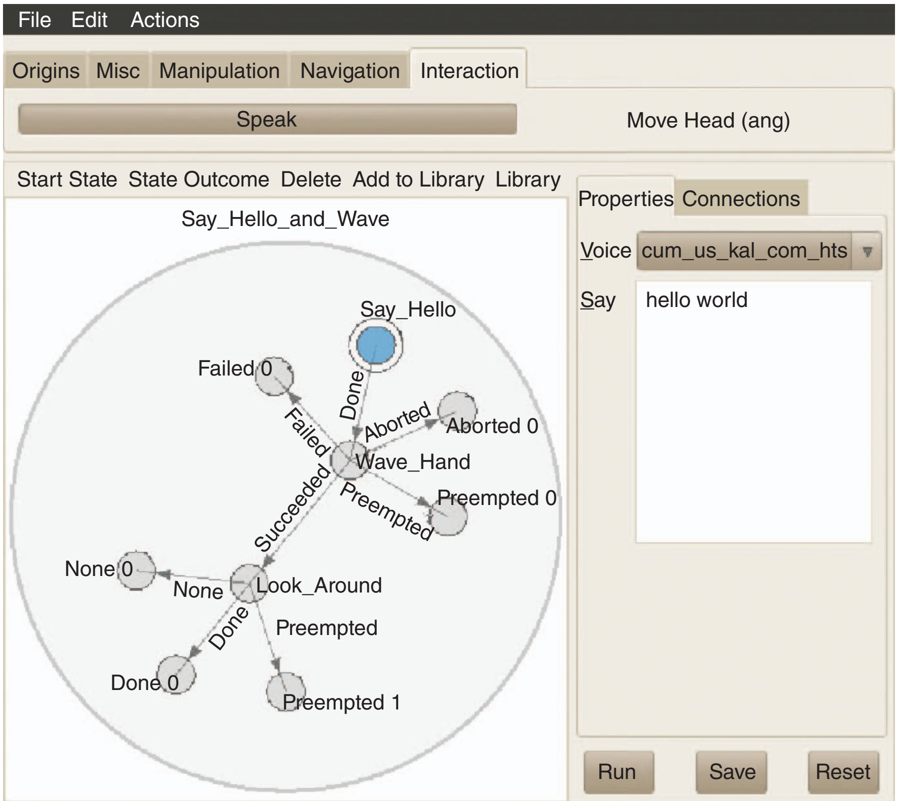

Figure 13. RCommander showing a sample sequence where the robot says "hello," waves, and looks around.

larger interface elements, robustness to accidental clicks, and coordination of both arms. Beyond the specifics of the interface, our experiences with Henry highlight the importance of tools that allow end users to author robot behaviors—the gestures that Henry has created have been creative and unexpected.

Accessible Run-Stops for AMMs

To date, Henry's use of the robot has been overseen by able-bodied people who can press a run-stop button if something goes wrong. We want to eventually enable Henry to use the robot on his own. Emergency-stop and run-stop buttons are generally accepted methods for reducing the risks of robots that work alongside able-bodied users [6]. Currently, however, there is no accepted method for people with severe motor impairments to stop a robot. In the context of AMMs, creating a reliable run-stop presents challenges. For example, when a spoon is in a person's mouth during feeding, he may be unable to use a head switch [9], and the robot's arm may interfere with fixed line-of-sight sensors.

We have been investigating methods by which Henry might reliably and efficiently command the PR2 to stop when alone. Since Henry has good control of his eyes, and his eyes are not directly involved in the tasks we are currently considering, we are investigating the potential for a wearable device to detect a voluntary eye gesture. For example, we have prototyped a novel concept for a run-stop that measures skin motion at the temple using optical mouse components mounted on glasses (see Figure 14). Our initial tests indicate that, when a person voluntarily closes his or her eyes tightly (winces), this device produces distinctive measurements. Henry has named this device the Wouse, which is a portmanteau of wince and mouse. We are continuing to evaluate its potential [7]. Similar technology may be useful for the able-bodied robot users as well. As the robots that work alongside people become more common, low-cost, intuitive, hands-free methods for stopping robots may become valuable, such as for workers in industrial settings.

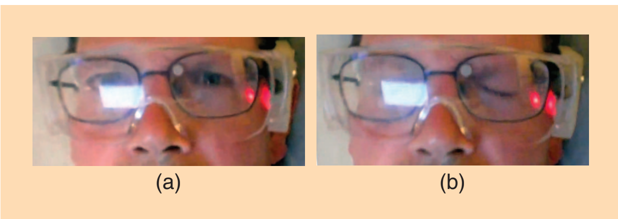

Figure 14. Henry voluntarily winces while wearing a prototype device called the Wouse that is designed to detect wince gestures to stop assistive robots. (a) Normal expression. (b) Wincing expression.

Conclusions

In this article, we introduced the Robots for Humanity project, a collaborative and interdisciplinary effort to empower people with disabilities through the use of the PR2 as an AMM. The goal of putting robots into real homes to help people with disabilities is a long-term vision for our project. By actively involving users Henry and Jane Evans in our participatory design process, we have made tangible progress toward assistive capabilities that are both useful and usable. We also anticipate that, by putting robots into the real homes of people with disabilities early and often, we can better direct our research to overcome the real-world obstacles to the use of mobile manipulators as an effective assistive technology.

Our efforts to date investigated a range of tasks, including ADLs, IADLs, and EADLs. Our methods enabled Henry to use the robot to scratch and shave himself, retrieve an object in his home, and socially interact through speech and gesture.

We are committed to creating a system that will generalize to other people with severe motor impairments and to the able-bodied users as well. The use of a general-purpose robot, the PR2, will allow users to explore a wide range of tasks. Using 2-D cursor-based interfaces provides accessibility for most users. In addition, the capabilities developed for the tasks explored to date generalize to the larger task spaces of manipulation close to the body (representing many ADLs), manipulation of the environment (representing many IADLs), and social interaction (representing many EADLs).

Our future challenges include enabling Henry and Jane to use a PR2 in their home for longer durations and evaluating our methods with other people with motor impairments. We are excited to address these challenges with the help of Henry and Jane Evans.

Videos and code associated with the project can be found at http://www.willowgarage.com/robotsforhumanity.

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