Shared Control of Assistive Robotic Manipulators

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***Abstract*— The continuum of controlling an assistive robotic manipulator (ARM) ranges from manual control to full autonomy. Shared control of an ARM operates in the space between manual control and full autonomy. This paper reviews the status quo on shared control of ARMs. Though users and ARMs can divide responsibilities for a manipulation task in different ways, most research in this area focus on maximizing robot autonomy and minimizing user control, while other work split the responsibilities more evenly between the ARM and the user. User studies in this area are very limited. More research is needed to investigate the overall performance, workload, and satisfaction across different levels of autonomy for the shared control of ARMs.**

Keywords—assistive robots, shared control, human robot interaction, autonomy

I. INTRODUCTION

Individuals with upper limb impairments due to injury, neuromuscular disease, or other severely physically disabling conditions often have difficulties in performing activities of daily living that require object handling and manipulation. Assistive robotic manipulators (ARMs) have emerged as a potential solution to mitigate the difficulties, frustration, and lost independence experienced by these individuals [1-2]. ARMs can be mounted on powered wheelchairs, on mobile platforms, or along fixed tracks in the environment to increase their workspace. Currently, there are two popular commercially available ARMs on the market, i.e., *i*ARM (Exact Dynamics, Netherlands) and JACO^{TM} (Kinova, Canada). In additio to the manual control or teleoperation of an ARM, research has been done to investigate shared control of an ARM where a certain level of robot autonomy is incoporated into the user control so that the robot and its user can work together to achieve the manipulation tasks. This paper presents a review of the status quo on shared control of ARMs and discusses its challenges and potentials.

II. SHARED CONTROL OF ASSISTIVE ROBOTIC MANIPULATORS

Unlike industrial robotic manipualtors that work in carefully controlled settings, ARMs are supposed to work in highly unstructured environments alongside people with physical impairments. Previous research evaluated user performance and satisfaction with manual control of an ARM, and found that most users are able to operate an ARM after training and complete certain manipuation tasks [3-4]. Howevers, under human control ARMs often move slowly and lack dependability, and for some users it can be cognitively and physically demanding to manually control an ARM [5].

To address the issues with the manual control of an ARM, research has been conducted to investigate introducing different levels of autonomy to ARMs to strategically reducing the complexity exposed to the user while keeping the user in the control loop [5]. This combination of direct user control and robot autonomy is terms as shared control, semi-autonomous control, collaborative control, or shared autonomy. There are a a variety of strategies for sharing control between a user and an ARM. One of the common strategies is to miminize user input and maximize robot autonomy. Under this strategy, users only need to indicate an object of interest by clicking on a computer screen showing images of the scene or pointing to a physical object, and robots then take full control by using a vision-based system (i.e., an “eye-in-hand” camera and/or an “eye-to-hand” camera) along with other sensors such as force and tactile sensors and a laser range finder to autonomously guide the robot to the target object.

Tsui et al. developed a vison-based system for a wheelchair-mounted ARM where the manipulator had the full autonomy to retrieve objects and the user only needed to indicate the object of interest by pointing to the object on a touch screen where an over the shoulder video feed was displayed. The manipulator took over the rest of the task by reaching towards the object, grasping it, and bringing it back to the user, which requires algorithms for estimation of 3-D object locations, alignment of the gripper position, object recognition, and fine grasping planning. They evaluated this system with 12 individuals who had various physical and cognitive impairments, where they were asked to retreive objects from a three-level bookshelf (two objects on each level). There were a total of 198 trials. The participants were able to make the correct selection most of the time (91.4%). The system was able to successfully retrieve an object in 129 of the 198 trials (65%). Of the 69 unsuccessful trials, 56 (81%) were due to algorithm failures [6].

Chen et al. described a similar “point-and-click” system for a mobile-based dual manipulators, i.e., Willow Garage PR2 robot to assist an individual with high-level spinal cord injury on manipulation tasks near his body such as scratching his face and shaving his cheek and manipulation of objects remotely such as tidying the house, answering the door, or fetching objects [7].

Jain et al. developed EL-E, an assistive mobile manipulator, that can autonomously fetches objects from the flat surfaces. Users can indicate an object of interest by selecting the object

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on a touch screen or pointing a laser pointer to the object. The system has been evaluated by 8 individuals with amyotrophic lateral sclerosis (ALS) who were able to command the EL-E to pick up an object with a 94.8% success rate [8]. In another test on EL-E's ability to approach and grasp objects from the 25 object categories that were ranked most important for robotic retrieval by ALS patients, EL-E successed at least once with objects from 21 out of 25 of these categories with varied reliability [9].

Kim et al. instrumented a wheelchair mounted robotic arm with a wide-angle stereo camera system in the gripper and used the visual servoing technique to automate the reaching and grasping functions of the arm [10]. They further tested this control mode against a user control mode. Ten individuals with SCI were randomly assigned to two groups with each group focusing on one type of control for three weeks. A pick-and-place task setup was designed where 6 objects were placed on two shelves. At the end of the three weeks, both control methods had comparable task completion times while user effort required for operating the robot in autonomous mode was significantly less than that for the manual mode. However, user statisfaction with the automous mode was lower for the group who expeienced the autonomous mode. The authors speculated that individuals with disabilities prefer the manual control because they feel in control, while the robot in automous mode is merely an agent that does their work for them just like a caregiver [11].

Our research group has also been working on shared control of ARMs with a focus on splitting the responsibilities more evenly between the robot and the user. We have developed a prototpye voice-controlled semi-autnomous system for the JACO^{TM}. A user can start a manipuation task by giving the manipulator a voice command (e.g., "move up", "move down", "move left", "move right", "move forward", or "move backward; "rotate up", "rotate down", "rotate left", and "rotate right"). During the operation, when detecting an object within a set range based on a low-cost RGBD camera (Creative Sensez3D), the semi-autonomous controller automatically stops the manipulator and provides the user with possible manipulation options (e.g., "push it", "tap it", "pick it up" or "bypass") through a visual/audible text output. It then waits until the user selects one option by a voice command. The system then drives the manipulator autonomously until the given command is completed or the user interrupts it, based on the orientation and proximity of the object in the environment provided by the camera.

We have also developed an assistive interface for ARMs that takes advantage of the manipulation knowledge from both computation and the user. The assisitve interface works with a wheelchair mounted ARM with vision input, the software for planning and object recognition, and the user input interface. It blends the inputs from the calculated trajectory via vision input and path planning algorithm and the user, and provides a way for the user to correct the calcuated trajectory when necessary, or control the speed of the ARM moving through the planned trajectory.

We have also developed an overhead track mounted assistive robotic system called KitchenBot (Figure 1) [12-13]. The fixed installation of the Kitchenbot makes it easier to obtain relative position of the robotic manipulator with respect to various kitchen components (e.g., cabinets and appliances), which greatly facilitates the implementation of autonomous functions for typical kitchen tasks. Based on a focus group with 11 users with physical impairments, the development prority was set to investigate a co-control strategy where users select a task from a task repository that includes step-by-step instructions for each task. They can work together with the Kitchenbot on the task by completing certain steps on their own and asking the Kitchenbot to complete certain steps autonomously such as retreiving items from top cabinets and stabilizing the pan during cooking.


Figure 1 Kitchenbot

III. DISCUSSIONS

During shared control, though users and ARMs can divide responsibilities for a manipulation task in different ways, most research has focused on maximizing robot autonomy and minimizing user input. The limitations of relying on robot autonomy include additional required components (e.g., sensors and display), the lack of robustness and reliability of system performance due to algortihm and sensor failures, and possibly low user statisfaction due to the lack of involvement and tolerance of robot mistakes. Dragan et al. conducted an intersting experiment where they manipulated three factors including agressiveness of robot assistance, difficulty of task, and correctness of robot policy. They found task difficulty and policy correctness could influence the mode of assistance. All participants in the study favored aggressive robot assistance on difficut tasks when the robot's policy was correct. They also clearly preferred less robot assistance on tasks when the robot's policy was wrong. Opinions were split on easy tasks, depending on how much they wanted to remain in control [14]. Unfortnately, user studies on shared control of ARMs are very limited. Existing studies often evaluate ARMs with discreet and structured tasks that do not resemble the tasks users often encounter in everyday life, and thus system performance and user satisfaction with the ARMs and the shared control strategies cannot be accurately assessed.

Shared control could potentially benefit from greater user involvement. Users' knowledge and situation awareness could make robot autonomy operate more robustly in real homes. Interestingly, in another domain of designing robotic system for life science processes, Kaber et al. developed a general autonomy cost function by taking into consideration of a number of factors such as operator perceived mental workload, operator situation awareness, number of errors by an operator, and number of task completed by an operator. They showed that the overal autonomy cost has a U shape indicating an optimal intermidiate level of autonomy can be identified for system design from an operator perspective [15]. Clearly, more research is needed to investigate different levels of autonomy for shared control of ARMs.

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