MUTUALLY ASSISTIVE ROBOTICS

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September 12, 2023

ABSTRACT

Mutually assistive robotics is an approach to robotics in which robots and people work together and can be especially useful for people with disabilities. The robot is able to complete physical tasks like moving objects that the user may be physically unable to do, while users contribute their knowledge of the environment. This collaboration facilitates daily activities and independence for wheelchair users. There are many existing robots and control systems in place that implement a mutually assistive approach, including ones that utilize augmented reality (AR). As technology improves, mutually assistive robots for wheelchair users could transform how people with mobility challenges navigate the world and enhance their quality of life.

MUTUALLY ASSISTIVE ROBOTICS

I. INTRODUCTION

The project I worked on this summer is Mutually Assistive Robotics, which involves using AR specifically for disabled users. I did this work under Jivko Sinapov in the Multimodal Learning Interaction and Perception Lab at Tufts University. The question we are trying to answer is: How can augmented reality facilitate better interaction between disabled users and their assistive robots? This topic is important because over 25% of Americans suffer from some form of disability. Assistive robotic technologies can help improve the quality of life for disabled people by enabling them to participate more actively in work and leisure activities and to feel more independent (Schwartz et al., 2007).

In this project, we use a strengths-based approach to assistive robotics in which the user and the robot assist each other. The user is able to understand and control not just the high-level tasks, but low-level aspects of the robot's movement and behavior as well. This practice is different from many assistive robots, which typically take a deficit-based approach to disability, meaning they simply allow the disabled user to provide high-level goals, and then the robot completes the task entirely autonomously. This method removes all control from the user, which can be problematic from an ethical standpoint when control over the robot's actions is the goal itself. Another difference is we want the robot to be able to perform not only basic chores and tasks, but activities like art, makeup, and other hobbies. Although these tasks are not necessarily medical or survival necessities, our goal is to help disabled people have a more fulfilling life. By allowing the disabled user's intelligence to guide the robot, we can have a user-robot system that is constantly evolving and adapting.

One important technology we employ is AR. The goal of AR is to help users understand the information the robots are using to make decisions. For example, AR can be used to display the mental models of the robot, which are used to explain the robot's behavior. By having a better understanding of how the robot works, the user then will be able to influence it in an informed manner. Understanding the robot will allow them to change its behaviors more effectively. The robot we use is a Kinova Jaco arm, which is designed to be mounted on a wheelchair. Its sensing will be done with depth cameras (Intel RealSense D400 depth camera), microphones (MiniDSP directional microphone array), and proprioceptive sensors.

II. EXISTING TECHNOLOGIES

A. ROBOTIC ARMS

Robotic arms are a useful technology that can empower disabled individuals with greater independence and improved quality of life. Robotic arm wheelchair attachments are designed to be mounted on wheelchairs, providing enhanced reach and manipulation capabilities to wheelchair users. These arms allow their users to interact with their environment, from grabbing objects on shelves to opening doors; these attachments extend the user's reach beyond the confines of their chair. There also exist smaller-scale robotic arm assistive devices that can aid users in specific tasks. For instance, assistive robotic arms can be used to assist eating, by helping individuals with physical disabilities to bring food from the plate to their mouth independently. These devices can also assist in personal care tasks, like brushing teeth or combing hair (Park et al., 2020). These examples are simply a few of the many existing robotic arms that can assist disabled users in their daily lives.

Robotic arms can be controlled in many different ways, including manually or using artificial intelligence (AI). With manual control, operators have real-time control over the robotic arm's movements, often using devices like joysticks, controllers, and touch-screen interfaces. This hands-on approach offers precise control, making it more user-centric than other approaches. AI-controlled arms utilize algorithms and machine learning to perform tasks autonomously. This approach reduces the need for constant human supervision, leading to increased efficiency in repetitive tasks compared with a user driven approach. There are advantages and considerations for each approach, for example, manual control offers direct operator interaction, intuitive manipulation, adaptability, and immediate decision-making. However, it relies on human attention and skill, and may not be ideal for longer or repetitive tasks. AI-controlled arms, on the contrary, offer autonomy, efficiency, and complex decision-making capabilities. They excel in tasks requiring data analysis and minimize human risk in hazardous environments, but they demand skilled programming and training. In order to focus on our goal of a user-centric control system of the arm, I further explore manual ways to control robotic arms.

B. AR DEVICES FOR CONTROLLING ROBOTIC ARMS

There are many existing AR devices that are currently being used to control robotic arms and assist disabled users with daily tasks. AR technology merges the physical world with digital information, empowering users to interact with their surroundings effectively and excitingly. AR devices can be adapted and customized to cater to the specific needs and abilities of disabled users, promoting accessibility and inclusion. One common AR device is AR glasses. AR glasses are equipped with cameras, sensors, and advanced image recognition software. The glass can be used as an AR display system, a control system, or both. One way they can control a robotic arm is through gesture recognition. The glasses are able to track the user's hand and arm movements. By recognizing specific gestures or motions, the glasses can interpret the user's intentions and translate them into commands for the robotic arm. For those without upper body or arm mobility, AR smart glasses can also display menus or buttons in the user's field of view. The user can select different commands or actions by focusing on specific options by gazing or making gestures in front of them (Makhataeva & Varol, 2020).

Another way to employ AR to control a robotic arm is using a tablet or computer screen. This control system is what I worked with this summer. The AR software superimposes a 3D virtual representation of the robotic arm onto a live video feed of the arm displayed on a tablet screen. Users can see the virtual robotic arm as if it is actually present in their physical environment. The virtual arm's position, orientation, and movements are synchronized with the real robotic arm's actions. The tablet screen displays a control interface that allows users to manipulate both the virtual and physical robotic arm. Users can first move the virtual arm to test for collision or other issues that may arise before they actually move the physical arm. This visual feedback allows the user to determine if the AR arm's movement is actually the desired movement of the physical arm. This process helps minimize the risk of collisions or errors, particularly in confined spaces or complex tasks. With AR, users can gain insights into their surroundings they might not have previously noticed.

C. NON-AR DEVICES FOR CONTROLLING ROBOTIC ARMS

Robotic arms are controlled in many ways besides AR. Traditional joysticks and controllers offer a straightforward method of controlling robotic arms. Joysticks offer a tactile approach, wherein users can manipulate the robot's movements by intuitively tilting and maneuvering the joystick in various directions. Remote controllers are typically a handheld device with buttons and controls that allow users to command the robotic arm's actions like they would a video game. Both options grant operators the ability to navigate the robotic arm's motions smoothly, making complex tasks such as picking, placing, and manipulating objects accessible and efficient (Aspelund et al., 2020).

A novelway to control robotic arms is Brain-Computer Interface (BCI) technology which establishes a direct link between the human mind and machine movements, offering a groundbreaking solution for individuals with severe physical disabilities. There are two distinct types of BCIs: invasive and noninvasive. An invasive BCI captures brain signals through a device that is surgically implanted in the brain, as opposed to a non-invasive device that can simply sit on a user's head, like a hat would, to capture signals. The signals from an invasive BCI are usually stronger, but implantation is less practical for most people. The most common technique for reading brain activity in a noninvasive BCI is through electroencephalography (EEG) signals because they measure brain activity faster and for longer periods than other methods. By harnessing brain signals, users can control the movements of the robotic arm merely through their thoughts (Aljalal et al., 2020). BCI technology is not only used to control robotic arms, it can control many other technologies, such as electric wheelchairs. The BCI translates EEG signals into motion commands that are sent to the device (i.e., wheelchair) to move it as the user desires (Kulkarni & Bhosale, 2018).

D. OTHER AR DEVICES FOR PEOPLE WITH DISABILITIES

For those facing mobility impairments, AR can offer real-time navigation and guidance, significantly improving their ability to move around with confidence. There are many studies on different technologies that implement AR to assist users with disabilities navigate daily life. For example, smart canes or walkers with AR that can detect obstacles and display navigation paths, helping users navigate their environments more safely and efficiently (Mostofa et al., 2021). A different study implemented augmented reality to control home electrical appliances for those unable to physically do so. The user can control a physical switch by pointing their smartphone's camera at it from a distance, then different virtual switches will appear using AR on their smartphone. They are able to use the virtual switches to control the object just as they would with the physical switch (Tang et al., 2015). A similar study was done to allow individuals in wheelchairs to engage with objects positioned out of their immediate reach. Using a combination of AR and Radio Frequency Identification (RFID) technology, researchers created an interactive AR application that functions across various interfaces. This application enables users to digitally interact with physical items positioned on shelves by accessing real-time inventory data from an RFID system. Through this interactive interface, users can gain information about the currently available items and their precise in-store and on-shelf locations (Rashid et al., 2017). AR devices hold immense potential to transform the lives of individuals with disabilities by promoting accessibility, independence, and inclusion. From aiding mobility and communication to enhancing learning and social interaction, AR technology can break down barriers and empower users with disabilities to thrive in various aspects of life.

III. AR MODEL OF KINOVA ROBOTIC ARM

Displaying a robotic arm in AR offers a range of valuable advantages that enhance understanding, interaction, and learning. By displaying the robotic arm in AR, users can observe and understand how the arm responds to different commands and inputs before actually executing them. What I focused on in my research was displaying information from the arm in an AR model. The arm would send information, such as joint position, joint temperature, and more, in real time. I worked to display this information in my AR model so the user was able to understand this information in a simple manner. They would then be able to use this information to help them better control the arm and allow it to execute their desired tasks more effectively.

To do this, I used Unity Technologies, a popular game development engine, which offers many tools and capabilities for building interactive AR experiences. Using an existing 3D model of the arm, I was able to display the joint temperatures and joint positions relative to their maximum and minimum position. Around each joint are green rings representing how far each joint can turn in either direction. I also included a pointer at each joint that indicates the joint's current orientation. The pointer travels around the ring as the joints move. The rings and pointer are used to see how much farther each joint can turn in either direction. The arm is also a heat map. Each motor's temperature can be seen by the color of each joint, which allows the user to see if part of the arm is overheating, which could cause problems.

IV. POURING STUDY

I also assisted Andre Cleaver, PhD student and research coordinator, in his robot pouring study. Pouring liquids showcases the contrast between humans and robots. Humans, with our advanced sensory perception, possess the ability to discern various properties of liquids in order to adjust their pouring technique accordingly. We are also able to learn and refine our pouring methods over time, making us intuitive and responsive pourers. The finesse of human motor control helps ensure the safe pouring of liquids, even from fragile containers. In contrast, robots, while capable of precise and consistent pouring, lack the nuanced sensory perception and adaptive learning that humans exhibit. Their programmed instructions and reliance on data-driven decisions constrain their ability to navigate unanticipated variables. Although robots excel in maintaining accuracy and uniformity, they have yet to fully emulate the intricacies of human intuition, sensory finesse, and dynamic motor skills that define pouring liquids.

In this study, the robotic arm would pour the source container with a set amount of water into the target container. First, participants would look at physical and AR visuals and predict if there would be a spill. The second part was when we allowed human participants to adjust the parameters on the robotic arm in order to prevent a spill. The parameters included: rotational angle limit, rotational velocity, vertical position, and horizontal position. The human participants were able to visualize the pour using AR and then were able to use the visual feedback to adjust the arm accordingly. Before the trials, the research coordinator carefully selected 10 pouring configurations using 10 different pouring containers, including a soda can, a water bottle, and a mug. These arrangements led to either a verified spillage, meaning there is visible water reaching the surface of the table, or a successful pour, where all water is transferred from one container to the other. The study was not completed by the end of the summer research period.

V. CONCLUSION

The use of mutually assistive robotics and AR has the potential to bring real change to the lives of people with disabilities. Augmented reality's intuitive interface and robotics' assistive capabilities combine to offer solutions that enhance mobility, daily tasks, social interaction, and other opportunities. The collaboration between these technologies holds immense potential for promoting inclusivity and improving the overall quality of life for individuals with disabilities. As research and development in this field continue, the prospect of a more accessible and equitable future becomes increasingly tangible.

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