ARoMA-V²: Assistive Robotic Manipulation Assistance with Computer Vision and Voice Recognition

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Abstract: We have designed and developed a handy alternative control method, called ARoMA-V² (Assistive Robotic Manipulation Assistance with computer Vision and Voice recognition), for controlling assistive robotic manipulators based on computer vision and user voice recognition. Potential advantages of ARoMA-V² over the traditional alternatives   include: providing completely hands-free operation; helping a user to maintain a better working posture; Allowing the user to work in postures that otherwise would not be effective for operating an assistive robotic manipulator (i.e., reclined in a chair or bed);   supporting   task specific commands; providing the user with different levels of intelligent autonomous manipulation assistances; giving the user the feeling that he or she is still in control at any moment; and being compatible with different types of new and existing assistive robotic manipulators.

Keywords: rehabilitation robotics, assistive robot manipulator, alternative control, human machine interaction, computer vision, voice recognition, intelligent system

1. INTRODUCTION

Successful object manipulation is critical for efficient activities of daily living (ADL). A study monitored the ADLs of an able-bodied individual for five days and identified 3,964 activities based on the International Classification of Functioning, Disability and Health (ICF) [1]. Among these activities, the most frequent tasks for self-care included carrying, moving, and handling objects such as lifting, putting down objects, manipulating, and carrying in the hands. However, individuals who have severely impaired motor functions, such as high-level spinal cord injury (SCI), have difficulties in performing ADL that require object handling and manipulation. With the technology advancement and cost reduction in commercial robotics technology, assistive robotic manipulators hold great potential to assist these individuals with a range of everyday manipulation tasks [2-7]. The University of California conducted a long-term study with three participants with physical disabilities to test the Rancho Los Amigos Manipulator using a proportional joystick that sequentially drove each joint motor and tongue-actuated switches [8]. Participants completed the peg-in-hole test within 4 minutes after using the manipulator for 13 hours. The University of Medicine and Dentistry of New Jersey conducted a long-term study of six participants, who were all wheelchair users without functional movement of the shoulder and elbow but with finger excursion for pressing push buttons [9], using two industrial robotic manipulator mounted on a stand fixed to the lap tray to evaluate two user interfaces: keypad and joystick. The keypad consisted of 12 touch-sensitive buttons on a circuit board to control the motors geared to shoulder, elbow, wrist, and terminal device functions. The joystick user interface consisted of two joysticks and two toggle switches. One joystick and two toggle switches were designed for selecting commands using scanning mode, and the other joystick was used to activate the robotic manipulator. A study conducted by the Forschungs Institut Technologie Behindertenhilfe in Germany explored the capability of users with different disabilities to operate the Manus ARM after a short training period [10, 11], using the standard 4×4 keypad. The participants performed simple tasks of driving to a work position and building a tower of three wooden pieces. But, five participants were unable to finish this task within the requested time, and a negative response in switching menus with the standard keypad led to refusal or rejection in most participants. An exploratory study was conducted by DuPont Hospital for Children in Wilmington with nine participants with severe physical disabilities to measure the effective manipulation performance of individuals with disabilities using a desktop-mounted robotic manipulator (UMI-RTX) [12], using Intelli-keys and/or WiViK scanning software. Three functional assessment measurements were used: Jebsen Hand Test, Block and Box Test, and Minnesota Rate of Manipulation Test: in all the three functional assessments, all participants were not able to complete the tests. A study with 27 participants by the Center for Interdisciplinary Research in Rehabilitation and Social Integration evaluated the usability of the JACO robotic manipulator [13] using its proprietary 3D joystick control. Participants were asked to complete six tasks: grasping a bottle located on the left side on the table, grasping a bottle located on the right on a surface near the ground and bringing it on the table, pushing the buttons of a calculator, taking a tissue from a box on the table, taking a straw from a glass on the table, and pouring water from a bottle into a glass. Among these 27 participants, 5 participants could not

completed the tasks, and the success rate of the other 22 participants for the tasks was also not very high for the relatively difficult tasks. A larger sample-sized (n = 31) study of the same manipulator reported a similar success rate, easiness, and importance [4]. A multi-center study was conducted to evaluate the efficacy of a graphic user interface with a panoramic camera to identify out-of-sight objects to be retrieved by Manus ARM automatically with 20 participants with disabilities and 24 able-bodied control participants [14]. Participants were asked to grasp six objects previously placed around their wheelchair, using a computer access technology they were comfortable with (12 with trackball, 6 with a simple mouse, and 2 with head tracking). Significant higher success rate was found in control group (88.7% for control group and 81.1% for people with disability). Significantly longer completion time was found in the disability group (71.6 seconds) in comparison with the control group (39.1 seconds). Personal Mobility and Manipulation Appliance (PerMMA) [15], a wheelchair-mounted dual robotic arms on a curved track, was evaluated by 15 users with both lower and upper extremity impairments. None of the participants were able to complete all five tasks within a single session, but participants rated that PerMMA could potentially help them achieve important goals at 7.2±3.0 in a 10-point scale [16].

As shown in the above, the most widely adopted solution for assistive robotic manipulator is to use a traditional 2D/3D joystick combined with buttons and/or knobs, keypad, touchscreen, and switch scanning interface. However, the conventional control methods not only demand fine motor control and good dexterity, as well as cognitive and physical workload, but the performance also is significantly slower with large variance. Vision-based full autonomy as an alternatives to this issue has long been investigated [14, 17-20], because it transfers the loading in positioning and fine adjustment to the computer. However, the current vision-based full autonomy also has its own limitations and trade-offs: The primary drawback includes lack of robustness [21, 22] due to uncertainty, inability to keep users engaged and in control [20, 23]. In addition, most importantly, the current level of intelligent algorithm to implement full autonomy is too premature to cover everyday scenarios like household chores [24].

2. ARoMA-V²

As a viable solution to the above issues, we have designed and developed a handy alternative control method, called ARoMA-V² (Assistive Robotic Manipulation Assistance with computer Vision and Voice recognition), for controlling assistive robotic manipulators to enable people with severe physical disabilities to independently control an assistive robotic manipulator, based on automatically recognizing user speech and intelligently planning a path to the object of interest using a low-cost 3-D camera input rather than physically activating conventional control devices such as joysticks and/or keypad.

Using voice recognition to control the assistive robotic manipulator can not only provide completely hands-free operation, but also helps a user to maintain a better working posture and allows him or her to work in postures that otherwise would not be effective for operating an assistive robotic manipulator (i.e., reclined in a chair or bed). The RGBD camera, which can efficiently identify the characteristics of the target object and its surroundings through 3D mapping, allow us to implement important safety features (i.e., automatic error correction, collision avoidance, autonomous navigation in challenging environments such as narrow and cluttered space). Thereby, it can enable the robotic manipulator to provide the user with task specific semi-autonomous intelligent manipulation assistances (i.e., picking up an object, opening door, and dealing with something to drink). For example, the user start operating a robotic manipulator using direction-based voice commands (e.g., "move up", "move down", "move left", "move right", "move forward", and "move backward; "rotate up", "rotate down", "rotate left", and "rotate right"). During the operation, when detecting objects within a set range, ARoMA-V² automatically makes the robotic arm stop, and provides the user with possible manipulation options (e.g., "open hand", "close hand", "push it", "tap it", "pick it up" or "bypass") at that moment through a pop-up windows or audible text output. Then it waits until the user selects one by saying a voice command. Once the task context/specific command is provided, the ARoMA-V² drives the robotic arm autonomously until the given command is completed or the user interrupts it, using orientation, proximity and relation to objects in the environment as environmental cues based on the 3D map. ARoMA-V² allows the user to overrule the vision-based intelligent controller at any time when he or she disagrees with the decision of the controller or when he or she feels confident enough about his or her operation at that moment.

3. PROTOTYPING & INITIAL ASSESSMENT

We have designed and developed a prototype ARoMA-V² based on a commercially available assistive robotic manipulator (Kinova's JACO Robotic Arm) combined with Microsoft Speech API for speech recognition and a low-cost 3-D depth sensing camera (Creative Senz3D camera) (Figure 1) for intelligent path planning and its control software.

Fig 1. Prototype ARoMA-V²

In order to more reliably recognize the user's voice commands, the prototyped ARoMA-V^2 adopted command-and-control approach which has smaller vocabularies, consisting of command words and phrases, because it does not necessarily require the users to train the system prior to use [25]. Two types of voice command sets were provided in ARoMA-V^2: direction-based and task-based commands. Direction-based commands are used to make translational/rotational movements of an assistive robotic manipulator (e.g., "move up", "move down", "move left", "move right", "move forward", and "move backward; "rotate left", "rotate right", "head up", "head down", "head left", and "head right"). Task-based commands are used to perform primitive robotic manipulations (e.g., "open hand", "close hand", "push it", "tap it" and "stop"). As a result of testing the developed speech recognition module for ARoMA-V^2, while almost all (>98%) commands spoken by seven adults (3 female and 4 male) speakers with normal voice were successfully recognized for both types of voice commands, it was found that the recognition quality of the system was significantly compromised (<50%) with the commands spoken by a child with high pitched voice.

An object identification algorithm was developed using a low-cost 3-D depth sensing camera to more efficiently identify the distance and pose of objects and establish the path and motion planning strategy. Specifically, to more efficiently localize the object in 3D space and to automatically plan a path toward the object, we adopted position-based visual-servoing approach [26], in which the 3-D sensor is mounted on the fixed position, the robot shoulder or base, to provide a better perspective of the object and its surroundings. The primary advantage of this approach is to find a path and to establish grasping plan even when the object is occluded from the starting location or folding position [27]. In general, the quality of object identification highly depends on the model created by object learning algorithm requiring various poses such as front side, backside, and all possible 3D rotations of the object. However, using a 3-D camera can significantly simplify this process by automatically generating a unidirectional 3D model. This kind of 3D model-based object identification method is less dependent on diverse lighting conditions, as well as invariance to rotations. As shown in Figure 2, multiple objects can be successfully identified; the algorithm is robust to occlusions, as big as 50%; and the algorithm is invariant for rotations up to 10-15 degrees.

Fig 2. ARoMA-V^2 Object Identification

Integrating the above two into one module, ARoMA-V^2 infers the current context based on user voice representing the user's intention and the 3-D camera input rendering environmental features to provide the user with context sensitive task assistance (i.e., picking up an object, opening door, and dealing with something to drink). In recent lab trials with four human testers, we found the prototype ARoMA-V^2 demonstrated significant improvement in manipulation efficiency measured by task completion time, compared to both a conventional 3D joystick control and a voice-only control.

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