

Development and Deployment of a Mobile Manipulator for Assisting and Entertaining Elders Living in Supportive Apartment Living facilities

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Abstract—In this paper a novel telescopic manipulator was adapted to a mobile robotic base to perform manipulation tasks in an elder care facility. As indicated by our previous work, leisure activities and engagement in socialization were desirable among elders, and a physical game assisted by the robot was chosen to investigate both its acceptance and interaction with the older adults. The robot was deployed at an assisted living center and performed multiple interactions. The manipulator was able to successfully retrieve items from different heights as part of the game and results from post-interaction surveys with elders indicated high perceived usefulness and comfort in having the robot as an assistant in the game.

I. INTRODUCTION

The elderly population worldwide is growing and trending towards home and community-based services [1]. However, there is a disparity between such growth and the number of working-age adults, and a possible crisis in the healthcare segment is imminent. For this reason, creative robotic solutions capable of assisting elders with tasks such as Activities of Daily Living (ADLs) and Instrumental Activities of Daily Living (IADLs) are welcome. Our previous work [2], [3] sampled clinicians, caregivers and older adults by means of focus groups and confidential surveys, providing a number of tasks these stakeholders would like to see in a future service robot. From these tasks, hydration and hydration reminder, as well as walking exercise were chosen to be implemented in a mobile only robot.

For this present work, we investigate usability and acceptability of the robot in addressing a wider range of highly ranked tasks (according to our need finding study [2]). Fetching objects on the floor or high cabinets or leisure activities (such as playing games) emerged in the focus groups and surveys, and are also found in the literature. To address such these tasks, the Savioke Relay mobile base was modified, adding a low-cost, lightweight telescopic manipulator (Fig. 1). The arm has two degrees-of-freedom (DOF) with two additional DOFs from its non-holonomic mobile base. The

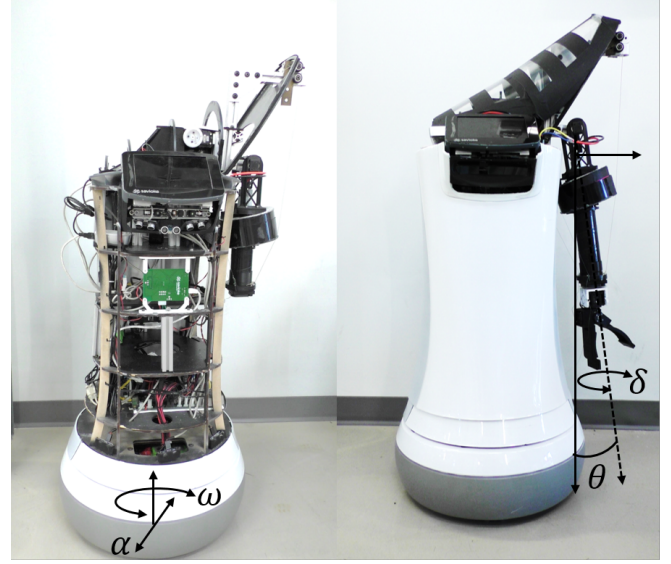


Fig. 1: A telescopic manipulator is mounted on the Savioke Relay base, with the mobile base (ω, α) and manipulator (δ, θ) degrees of freedom.

telescopic feature of the arm allows easy access to high cabinets and also to ground level, increasing the reachable workspace compared to a conventional manipulator. Due to its light weight, this mechanism is also safer to be operated near humans compared to conventional robotic arms.

In this paper, our contributions are:

- New applications for a novel low-cost manipulator in elder service centers
- Deployment of a mobile manipulator in a real PACE (Program of All-Inclusive Care for the Elderly) center
- Evaluation of human robot interaction for manipulation tasks with older adults

This paper is organized as follows: Sec. II presents relevant literature. Sec. III presents a detailed description of the manipulator adapted on the mobile base. Sec. IV describes the methods applied to investigate elders behavior towards the robot during the deployment. Results from the investigation are shown on Sec. V. Conclusion and future work discussed on Sec. VI.

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II. RELATED WORK

Our previous work [2], [3] considered results from focus groups and surveys with all stakeholders at a Supportive Apartment Living (SAL) facility (elders, clinicians and caregivers) to determine what priority tasks a mobile service robot could do that would benefit them. Based on these tasks, two deployments using a mobile robotic base without an arm took place at a PACE center apartment living facility. The results are presented in [4], and include design guidelines for the next iteration of the robot. Other studies [5] determined design guidelines for a socially assistive robot for elder care based solely on a focus group.

Helping elders with dementia improve their cognitive ability by interacting with robots was investigated in [6], [7], [8], [9] and [10]. In particular, [11] investigated older adults with dementia performing ADLs by interaction with a socially assistive robot. In [12] a *UMA* robot was intended to assist elderly and disabled people in the transport of objects over short distances. In this study, the robot was not deployed in an actual assistive living facility or used by elders. In [13] a mobile robot was developed to provide walking support to elders as well to carry relevant items to caregivers.

Robotic manipulation for assistance with ADLs has also been explored in the literature. SaM [14], a mobile manipulator, used visual servoing to autonomously grasp objects for people with mobility limitations based on user input on the robot's screen. For people with mobility problems, some solutions regarding manipulation of objects include workstation systems (where a manipulator can be mounted on a desk for accessing objects), stand alone manipulators (lighter versions of workstation manipulators), wheelchair mounted manipulators and mobile platforms [14]. In [15] a manipulator that can be controlled through a GUI by the user was described. *Mary* [16], a mobile manipulator with vision capabilities, was intended to assist elders in tasks such as fetching items. However, the testing scenario did not include real users or an environment like a PACE Center. More recently [17] used a *PR2* robot and a head tracker device to perform manipulation tasks in a home environment.

Exercise for older adults can delay numerous diseases, helps advance performance in daily routines, improve their independence and quality of life [18]. Extensive research has investigated different ways to motivate and promote exercise among elders. In [19] a mobile treadmill had its speed amplified depending on the user walking pace input. In [20] seated exercises were motivated by an anthropomorphic robot that engaged elders through games.

Virtual or physical games stimulate brain activity in elders, and have been seen in some instances to even improve their cognitive ability. Embedding assessment algorithms to evaluate the cognitive improvements of elders while interacting with the game was investigated in [21]. A system for monitoring elders that includes a game that can be played individually by the elder or with their peers (which is also investigated in this paper) was introduced in [22]. Promoting exercise for low-income elders through games and

also monitoring their current health state through daily alerts in a mobile application was presented in [23]. However, the study did not present data from real end-users. In [24] a human-like robot promoted adaptive games in which the user has to follow a sequence of actions to progress further. The study stated that users who requested help from the robot progressed further in the game, compared to those who did not.

III. SYSTEM DESCRIPTION

The same mobile base deployed in [4] was adopted and modified in this present work. The Savioke Relay robot has a touchscreen monitor, 21 liters of storage space, and uses Lidar and sonar sensors to navigate autonomously. The manipulation task requirements were established based on our previous work [2], [3].

Requirements for the manipulator can be summarized as:

- Arm able to reach down to the ground, retrieve objects weighing up to 2 lbs, and hand them to a nearby human.
- Manipulate objects in limited workspaces in a PACE Center, such as common areas and kitchen.
- Safely be operated around elders and staff in a PACE Center and so avoid sharp edges, fast motions, or heavy high torque manipulators.

1) *The Arm*: Based on these requirements, we have chosen a two DOF manipulator that utilizes the spiral zipper extension technology [25] with a single rotational joint. This configuration is advantageous for its low cost and complexity. The spiral-zipper arm is light weight, retractable and human safe even if it comes in contact with a person. The arm can retract into a canister when not in use, improving the robots ability to avoid collisions in dynamic or cluttered environments. Most of its components are lasercut or 3D printed ABS plastic and there are only two actuators. The arm itself costs about \$1000.

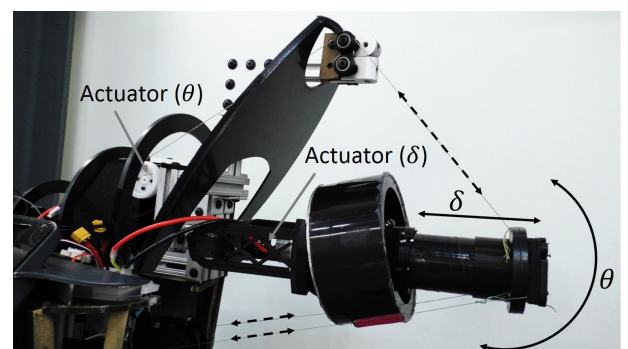


Fig. 2: Degrees of Freedom of the arm (continuous arrows). The tethers attached to the arm are shown as dashed arrows.

The arms rotational joint is actuated via a single tether that runs to the top of the arm (Fig. 2). When the cable retracts, the arm is rotated upward. The effective workspace is about 120 degrees where resting position is straight down. The arm can extend up to 80 cm, and retract to 20 cm (Fig 4). To evenly distribute the load along the arm column, additional

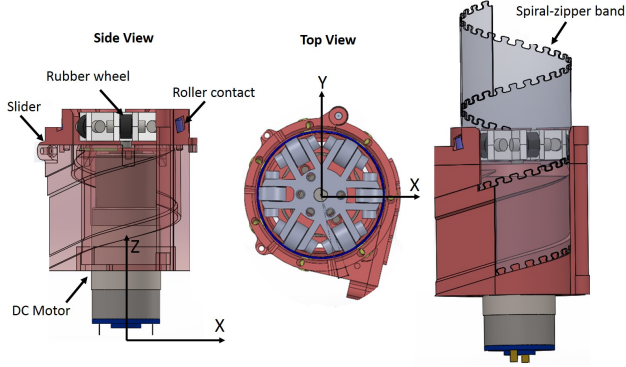


Fig. 3: Spiral zipper arm extension. The DC Motor spins a rubberized omniwheel, locked frictionally to the zipper band. Rollers on the omniwheel allow band to extend as the system rotates.

cables were routed underneath to the end of the arm, as it can be seen on Fig. 2. The cables run directly to a pair of constant force springs (simulating a 2lb load) that balance the moment produced by the top cable on the column and makes the spiral zipper mechanism perform more robustly.

The mechanism (see Fig. 3) is driven upward by a motor embedded at the center of the meshing block, which we call the slider. The motor interfaces with the band via a rubberized omniwheel oriented along the axis of the helix. The omniwheel rollers grip the band as it rotates by, spinning it upward. The rollers on the omniwheel then passively counterrotate downward in order to maintain vertical position relative to the motor. Because the system operates on the basis of friction, if the band is under a heavy load, the friction wheels will slip on the surface of the band and the band will not rotate upward acting as a clutch.

Consequently, we include the ability to adjust the normal force between band and wheel to guarantee that the transmissible torque through the wheel to the band is higher than the expected downward load on the arm itself. The advantage of this particular style of manipulator is its simplicity and safety. The arm does not possess more DOF than necessary. Between the two DOF embedded in the design plus two from the Savioke base itself, the arm can reach any object in its direct field of view (Fig. 5).

Finally, the arm is easy to retract into a low profile which is a useful attribute in the cluttered living environments people often inhabit. The robot can travel in these environments more easily without increasing the chances of the system bumping into or getting caught on its surroundings. The extension is also useful since it can reach over cluttered spaces to pick up a desired object from far away without having to come up with a strategy to get closer without bumping into things.

2) *The End-Effectors*: With the purpose of facilitating robot interaction with older adults during manipulation, and investigate different designs for future deployments, we use two end-effectors. The first (Fig. 6 left) facilitates magnet-

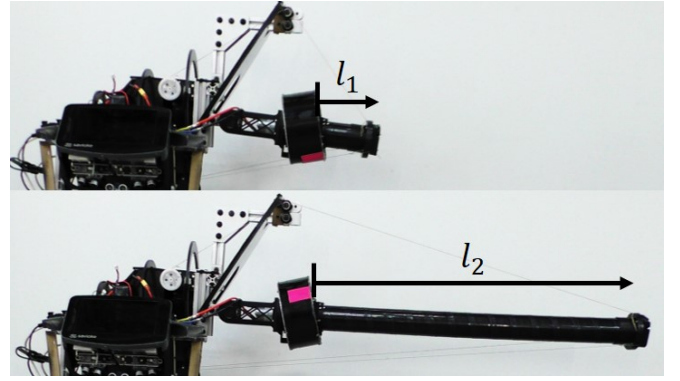


Fig. 4: Spiral zipper arm extension, from $l_1 = 20\text{cm}$ to $l_2 = 80\text{cm}$.

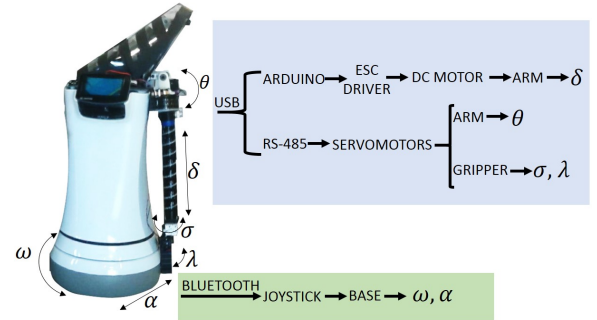


Fig. 5: The controlled mechanism and respective DOF of the system.

ically grasping items with embedded ferrous material. For tasks such as fetching single objects on the floor or on high cabinets and handing them off to the elders, we use a custom-made conventional 1 DOF two-fingered gripper with a 1 DOF wrist (Fig. 6 right).

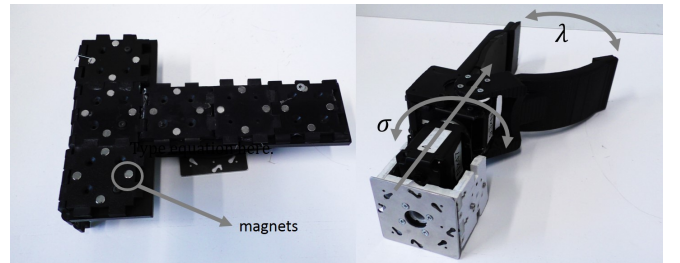


Fig. 6: End-effectors used for the study: (left) a magnetic gripper with no actuators, named "Gripper 1" and (right) a conventional 2 DOF angular gripper (λ aperture and σ the wrist joint), named "Gripper 2".

IV. METHODS

In order to provide a practical application scenario for the mobile manipulator in an elder care PACE center, as well as to better engage the elders, a corn-toss game was used to investigate human-robot interactions where the robot would be remote controlled to hand the bean bags to the

elders. The game set-up includes a game board and two bean bags per participant. The bean bags have been modified to magnetically adhere to the robot's end effector. Two cameras, one mounted on top of the robot arm and the second one on a tripod in the corner of the room, captured the robot's interaction with participants. Each game was done in pairs to allow for competition to increase engagement. To play the game, the bean bags have to be retrieved from a high cabinet and then be tossed and retrieved from the ground. This tested the usefulness of the manipulator in reaching objects in both high and low areas. For comparison, three different approaches to the game were tested (Fig. 9):



Fig. 7: Study setup at the PACE center (left). The game bean bags were initially placed in the cabinet. A modification ramp was added under the board so that bean bags would be ejected when scored, facilitating its retrieval by the robot.

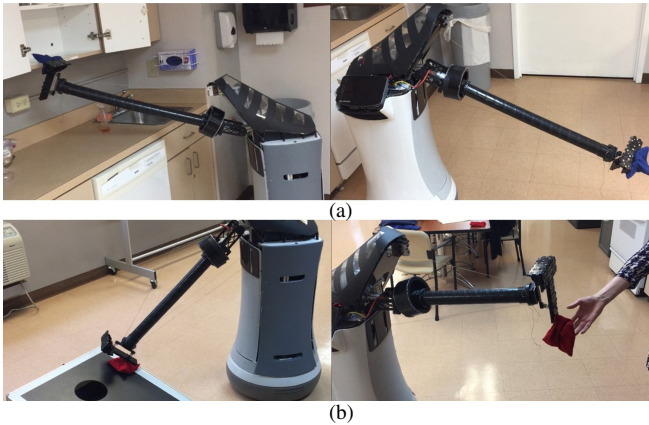


Fig. 8: The robot retrieved bean bags(a) from a high cabinet to handle to the elder or (b) after thrown by the elder.

- The elder would get the bean bag from the cabinet, throw it towards the board and also pick it from the ground with no assistance.
- A caregiver would hand the bean bag to the elder to start and retrieve the bean bag from the floor after it is tossed.
- The robot would get the bean bag from the cabinet (using either of its end-effectors), hand it to the elder, and also retrieve it from the ground and hand it back to the elder.

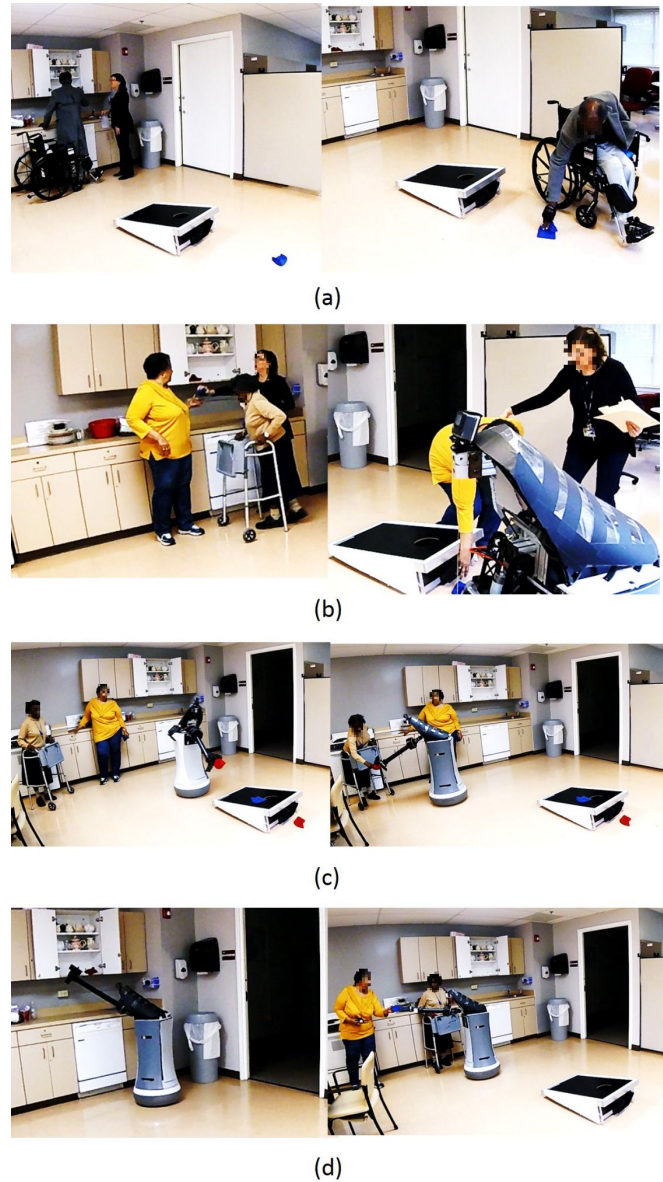


Fig. 9: Different scenarios for retrieving the bean bag for the game (a) Solely by the elder (b) With caregiver help and (c) and (d) with the help of the robot.

The setup is illustrated in Fig.7. The board was modified so that bean bags would be ejected and not remain under the board when scored, facilitating its retrieval by the robot. Allowing the elder to first grab the bean bags from the cabinet and ground would allow observations on the level of difficulty they have on reaching these regions. The location chosen for the robot deployment was a PACE center in Pennsylvania. As in our previous work, all subjects provided informed written consent and the confidentiality of participants was maintained. The study was approved by the Institutional Review Board of the University of Pennsylvania.

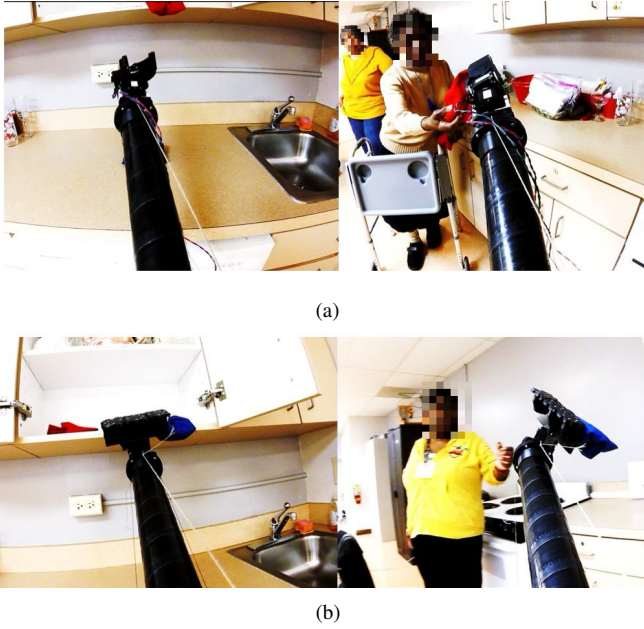


Fig. 10: Retrieving the objects with two proposed end-effectors (a) two DOF angular gripper and (b) magnetic with no actuation .

V. RESULTS

The robot was deployed at a PACE center in order to confirm the arm functionality and effectiveness in retrieving items at different heights and also handing them over to the participants. A total of six older adults gave consent to participate in the corn-toss game (see Appendix A for demographics). The PACE center includes over 400 older adults with an 8th-12th grade education level who qualify for Medicaid and who have limited previous access to technology (although all older adults had a cellphone), and the majority exercised daily (see Appendix B). Prior to each interaction, the older adult gave consent and was instructed on the robot's sequence of actions. All interactions were recorded by the two cameras and the reactions of participants were evaluated by an observer including the following criteria:

- Facial expression of older adults during interaction
- Participation and physical engagement in the game
- Object retrieval from either robot end-effectors
- Robot errors during interaction
- Request for robot to return by older adult
- Observer intervention during interaction

The six participants were grouped into four corn toss games, two being done with two participants paired and two done with participants playing alone. Both end-effectors from Fig. 6 were used for retrieving the bean bags off the shelves or the floor and handing them to the elders (Fig. 10).

A. Observations

General observations between the participant and the observer can be seen in Fig. 11. During the corn toss game, the elders were very invested in the game, becoming upset when

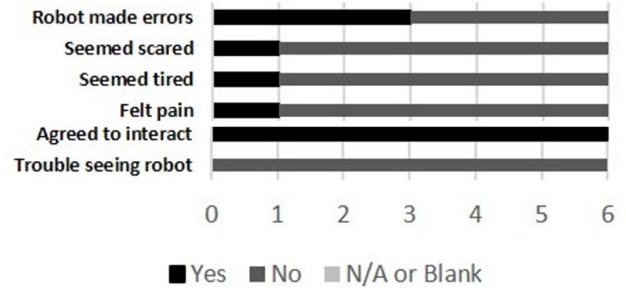


Fig. 11: General observations of participants interacting with the robot from the point of view of the observer (percentages of from N = 6).

they did not score, though most did not keep score during the game. One third of the participants were incapable of retrieving the bean bags from the floor, but only one could not retrieve it from the cabinet. Many of the participants complained that the robot speed was too slow and that they preferred when they could do something on their own. General observations about the corn toss game can be seen in Fig. 12.

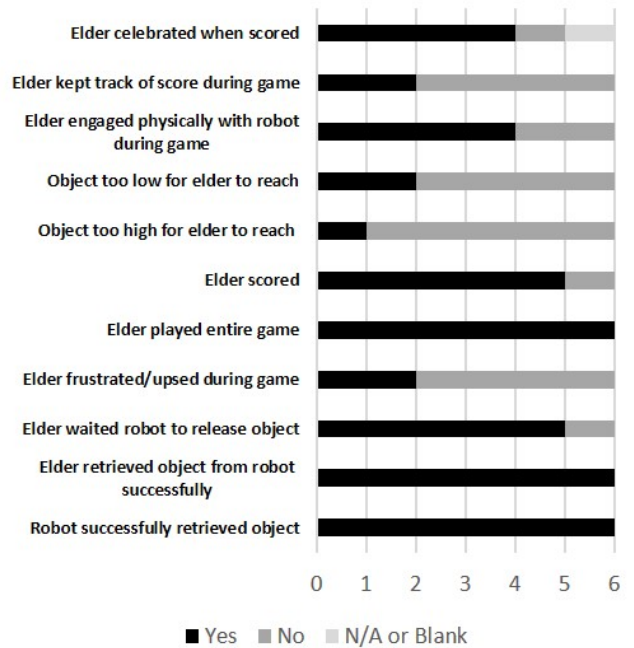


Fig. 12: General observations of participants interacting with the robot while playing the corn toss game, from the point of view of the observer (percentages of from N = 6).

B. Elder self-reported scores

Most elders had good interactions with the robot, as the majority found it simple to interact with it and felt

comfortable with the robot (Fig. 13). Playing the corn toss game did not prove very difficult to the elders, despite the difficulty for less than a third of them to reach the floor or the cabinet in picking up the bean bags. Gripper 2 was better ranked for level of satisfaction compared to Gripper 1, which could be related to its effectiveness when retrieving items from the cabinet (Fig. 14). Despite the slow speed of the robot when retrieving the bean bags, elders strongly agreed they were able to efficiently complete the game with it.

Additionally, difficulty levels were investigated regarding each approach to the game: elders independently playing, assisted by a caregiver or the robot with each end-effector (Fig. 14). As expected, the game assisted by a caregiver was rated the lowest difficulty score across all questions. For elders playing independently, retrieving and tossing the bean bags in the hole were the most difficult to do by themselves, but was improved when the game was assisted by the caregiver or the robot with Gripper one. For game assisted by the robot, retrieving bean bags from the floor was more difficult for Gripper 2 than Gripper 1, possibly because the latter was faster since it would only require normal contact with the bags. However, retrieving the beanbags from the cabinet was considered easier for Gripper 2, since the wrist joint could facilitate attaining a graspable position, whereas Gripper 1 would require constant repositioning of the arm and the mobile base. Lastly, tossing the bean bags in the hole was ranked less difficult by the elders when the game was assisted by the robot, compared to the caregiver assistance or no assistance at all.

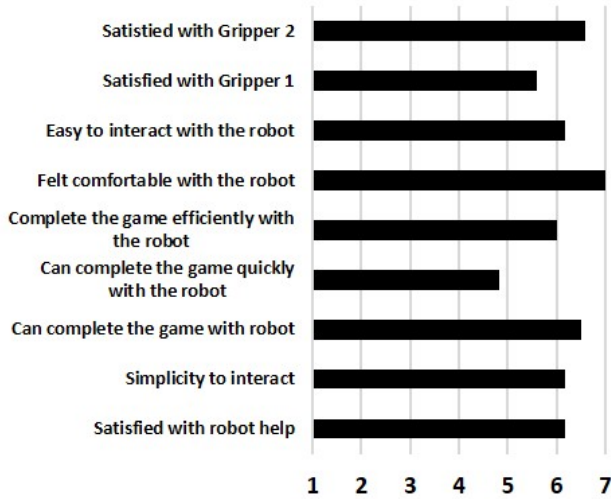


Fig. 13: Average Agreement score, where the participant scored in a scale from 1 to 7 how much they agreed with different statements. The number of participants that responded to each of the question varied and was taken into account when calculating the average. The number of participants who answered can be seen next to each bar (total participants was N = 6).

APPENDIX A - Participants Demographics

Gender	Male 2	Female 4	Total 6
Age	55-65 2	66-79 3	80 or older 1
Race	African American 4	Other 2	Total 6

C. Anecdotal Conclusions

All the elders generally reacted positively to the robot. Participants continuously talked to the robot and assigned either human or animalistic characteristics to it and two participants gave it the name "Butch". The robotic arm was noisy when it expanded and retracted which startled some of the elders (measured noise levels were up to 85 db at 5 cm distance). In addition, some showed some distrust in the robot, particularly when the robot was transferring the bean bags. The grippers were not always successful in obtaining the bean bags from the cabinet or the floor, in these cases the elders either ridiculed the robot or laughed at it. Often the observers had to encourage the participants to take the bean bag from the gripper, especially from gripper two, when the gripper did not fully open.

VI. CONCLUSION

We have adapted a novel, affordable manipulator to a mobile robotic base and deployed it at an elder care facility in order to investigate the robot performance and aspects of human-robot interaction through a physical game played by the elders and assisted by the robot. Different levels of interaction and hardware configuration were proposed and results from post-interaction surveys with elders indicated high acceptance of the robot as an assistant in the game, despite being slower than a human for retrieving and handing off the objects. A future investigation with greater numbers of elderly population is intended, since their excitement for participating in the experiment could have influenced results. Future interactions will also include older adults with cognitive impairments. We also plan to improve the manipulator with additional sensing capabilities and provide some level of autonomy to it, such that object recognition and grasping can be done autonomously. Finally, we will further investigate the design and efficiency of object transfer between robot and human, considering the type of end-effector, object geometry and the dynamics associated with the transfer.

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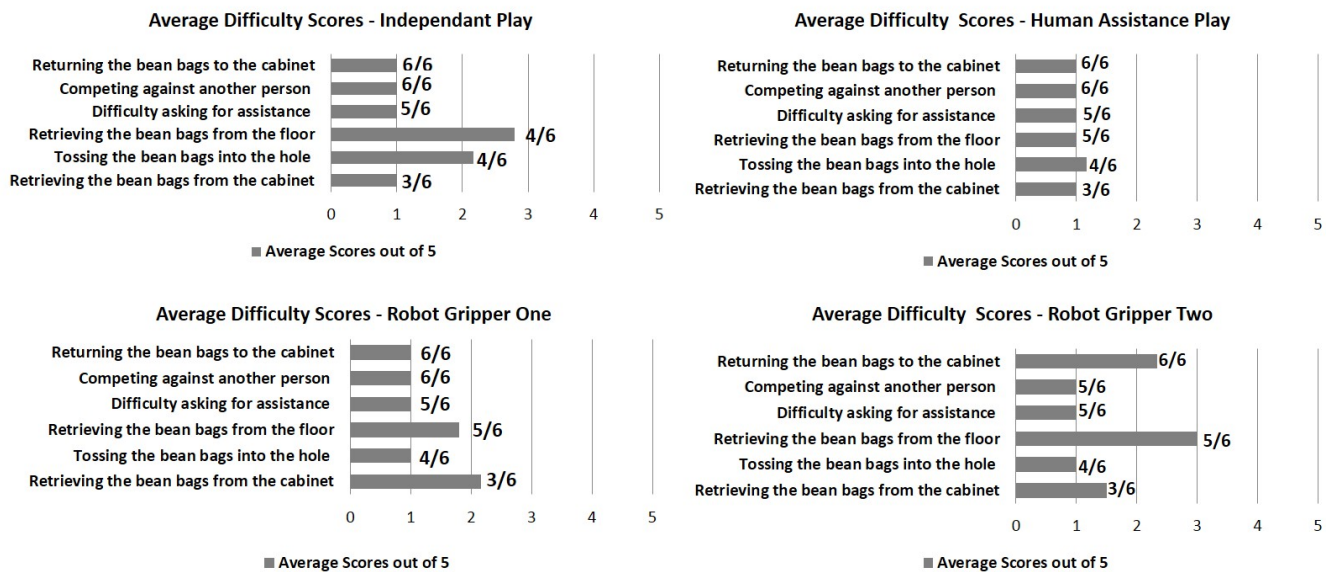


Fig. 14: Average difficulty scores, where the participant scored in a scale from 1 to 5 how difficult each of the statements were. The number of participants that responded to each of the question varied and was taken into account when calculating the average. The number of participants who answered can be seen next to each bar. Total participants was N = 6.

APPENDIX B -Technology and Exercise

Experience with or use a

Computer	3
Tablet or e-reader	2
Cellphone	6
Exercise daily*	4

Time of exercising

Morning	5
Afternoon	1
Evening	0

*Listed: 30- 30-60 and 60 mins

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