Mobile Assistive Robot in an Inclusive Space: An Introduction to the MARIS Project

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Abstract. Elderly or infirm persons who live alone may encounter difficulties in carrying out the instrumental activities of daily living. Often such persons who would prefer to live independently are forced to rely on outside assistance from family, friends, or social workers, or possibly even to leave their homes. A potential approach to address this social issue involves the use of an assistive robot to provide help within the home. However the challenges involved in achieving a satisfactory robot design for reliable operation within the typically unstructured domestic environment remain difficult to meet. To date, attempts reported in the literature to mitigate this problem by developing a more amenable home environment – a robot-inclusive space – remain sparse and preliminary. In this work, a new systematic engineering approach is taken to address this problem. A structured data collection exercise has been carried out with samples of older adults and of associated allied healthcare professionals to first identify those regular tasks within the home that are typically problematic for the elderly. These tasks are then analyzed to extract those specific steps, movements and performance skills that could benefit from facilitation through a combined approach of environment-redesign and robot assistance. A new conceptual design for a robot-inclusive kitchen has been generated, and an associated prototype six-degree-of-freedom tele-operated domestic robot has been designed and constructed.

Keywords: Domestic robot · Robot-inclusive space · Assisted living

1 Introduction

Over the last several decades, a steady growth has been observed in the older adult (OA) population, and as life expectancy increases more seniors are living alone in their own house [1]. The OAs living alone however are an at-risk group, and due to frailty and/or health problems often experience difficulties in performing the basic activities of daily living (ADLs, e.g. bathing, transferring), and/or the instrumental activities of daily living (IADLs, e.g. telephone use, food preparation). This often leads to dependence of the OA on outside help from family, friends, or social workers, and/or ultimately to relocation of the OA to a nursing or rest home. However, surveys have consistently shown that the majority of OAs would prefer to remain in their own homes and communities-at-large as they age, rather than moving to a retirement home [2, 3].

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Many researchers are working on new robotic assistive technologies that can help the OA with simple tasks required to continue living independently at home, which would otherwise be carried out by a caregiver (e.g. [4, 5]). However, the dynamic and highly unpredictable nature of everyday living spaces presents a challenge for an assistive robot that must work efficiently and safely around people. Thus, practical and widely capable assistive robots still remain an unmet promise, despite the significant advances made in associated sensor and control technologies.

A key realization is that one of the root causes of this problem involves the fact that in the traditional (and intuitive) domestic robot scenario, the robot must adapt to an environment which was not designed for it. To address this issue, the general concept of universal design of the environment, normally understood to indicate accessibility to all people regardless of age, disability or other factors, was extended in [6] to include accessibility to robots. This holistic approach has been explored by a small number of other research teams (e.g. [7–10]), and has led to the definition of the robot-inclusive space (RIS) [11, 12]. The results so far however have been mainly conceptual and/or very exploratory, and a lot of work remains to be done to bring the concept to a successful and wide demonstration, and ultimately to application and general use.

The end objective of this work is to take a more extensive and structured approach to address this problem, by exploring in a systematic manner how the home environment can be designed/converted to be amenable to use by both humans and robot(s), and then to evaluate the concept by developing a test environment and an associated early prototype robotic device for domestic support. The overall project (and the robot) have been given the acronym MARIS – *Mobile Assistive Robot in an Inclusive Space*.

The MARIS project is intended to be an ongoing research activity within the Robotic Systems Laboratory (RSL), of the Department of Mechanical Engineering at the University of Malta. This paper gives a summary of the results that have been achieved in the first phase of this project, mainly (1) the targeted and empirically derived understanding, analytical description, and categorization of the needs and preferences of OAs who live independently; (2) an early concept design for a robot-inclusive kitchen that is derived from the empirical and analytical results; and (3) the development, simulation and evaluation of a first prototype of an assistive robot capable of functioning within this space. Items (2) and (3) are addressed only very briefly in this introductory report.

2 Data Collection, Analysis and Interpretation

2.1 Objectives of the Data Collection Process

Various studies in the literature have investigated and/or reviewed the problems with independence faced by OAs, and the potential for acceptance of robotic assistants by OAs. In [13], a survey of 44 OAs who lived independently indicated that the tasks that presented the most difficulties involved cleaning (e.g. laundry, washing dishes), outdoor work (e.g. gardening), and home upkeep (e.g. air conditioner maintenance, replacing a light bulb). In [14], a literature survey as well as a focus group based study carried out on 113 participants (41 OAs, 40 professional caregivers, and 32 informal caregivers) indicated that the main areas of difficulty involved activities related to mobility, self-care and social isolation, although no single activity could be identified as the main threat to independence. A literature survey carried out in [15] concluded that users' characteristics such as age, needs and experience with technology/robots play a crucial role in the user's acceptance and preferences for a robot assistant. These results for robot acceptance were in general consistent with the results of a Eurobarometer survey taken across the EU member states, which showed that demographic attributes such as older age and lower education level tended to negatively affect acceptance. An extensive literature review in [16] found that acceptance of robots by OAs, is likely to be better if robots use humanlike communication and if they meet the users' emotional, psychological, social and environmental needs.

The above important works, and other similar studies, have served to determine those activities and preferences of OAs that require focus, however the results obtained to date remain mainly qualitative and generic. In the present work, the objective of the data collection exercise is to obtain more specific and detailed information on the actual tasks and movements that OAs encounter difficulties with, with the aim of applying the analyzed results to the design of a RIS, and of an associated assistive robot. A boundary that was set in this research was to target only those OAs who have no difficulties with the basic ADLs (i.e. whose potential difficulties lie only with their performance of IADLs), and who have no cognitive impairment. The data collection exercise also aims to acquire specific information on preferred appearance, level of autonomy, and size of an assistant robot, within the local population, and also information about whether they would be willing to make changes to their home to accommodate a robot.

2.2 Method

The original intended approach to the data collection involved the acquisition of data exclusively from OAs, with participants to be recruited from among the elderly who are active in various community centres. However a pilot survey conducted on ten OAs revealed problems with this approach, in that (1) the OAs from this demographic tend not to have significant problems with performing IADLs; and (2) in spite of the requisite information and consent forms, the OAs were reticent to give detailed and truthful answers to survey questions being posed by researchers who they are unfamiliar with.

The approach was therefore modified to recruit OAs only from among relatives and friends of the core research team, or where a friend or acquaintance of a team member could serve as intermediary; and to acquire data also from allied health care professionals (AHCPs), in this case occupational therapists and physiotherapists who work with OAs. Thus two versions of a survey questionnaire were prepared, one targeting the OAs and the other the AHCPs. Each version was divided into three parts, with Part 1 addressing demographic and classification data; Part 2 addressing difficulties and assistance requirements with IADLs; and Part 3 addressing preferences with regard to assistive robots and willingness to make changes in the home.

Part 1 of the OA questionnaire collected data on gender, age, marital status, living companions (if any), availability of family or friends' assistance and frequency of the assistance, community services used, health problems, whether assistance is needed for

ADLs and/or IADLs, and experience with technologies such as mobile phones, computers, or other electronic devices. Part 1 of the AHCP questionnaire collected data on AHCP gender, age, education, occupation, place of work, and years of experience; as well as general information about their patients: ages, health problems, ADL/IADL abilities, family/friends assistance, and experience with technologies.

Part 2 first inquired whether the OAs experience lack of hand dexterity; or weak muscles in their hands, forearms and shoulders. The survey then examined the difficulties that OAs encounter when they perform 23 important day-to-day activities, chosen from the Assessment of Motor and Process Skills (AMPS), Task Challenge Hierarchy [17] (a list of tasks through which an occupational therapist can assess the OA's functional status). The activities chosen cover five different domains of function (responsibility for own medication, telephone use, meal preparation, housekeeping and laundry) from the Lawton-Brody IADL Scale [18], which is an instrument used to assess a person's independent living skills. The list of performance skills was based on the motor skills that occupational therapists use in the AMPS evaluation [19] and the classification of manipulation activities in everyday activities defined in [11].

Parts 2 and 3 of the questionnaire were almost identical across the two versions (apart from necessary differences in syntax), except that the OA version used 3-point Likert scales in Part 2 where applicable, while the AHCP version used 5-point scales. For the OAs, the questionnaire was filled by the researcher (or person known and trusted by the OA) in an interview setting at the OA's home. For the AHCPs, the survey respondents and responses were solicited over e-mail through the director of a local long-term care facility: selected AHCPs all had experience and ongoing work with outpatients who live independently, and the survey questions addressed issues pertaining to these outpatients. The data collection was conducted in Malta during early 2018.

2.3 Participants

In total, seventeen OAs were interviewed, having ages in the 60s (23.5%), 70s (35.3%) and 80s (41.2%), with 82.4% of the respondents being female. The respondents suffered from the following health conditions: arthritis (58.8%), chronic heart failure (29.4%) and fractures (23.5%). Almost half the OAs were married (47.1%), closely followed by widows (35.3%), widowers (11.8%) and single (5.9%). Just over half of the OAs (52.9%) lived alone, with the rest living either with their spouse or family member. Most of the participants (93.8%) required assistance, mainly with IADLs, which is to be expected since the OAs participating in this survey were ones who were able to perform their ADLs. The community service mostly used was Home Help Services (35.3%), with 29.4% of the OAs hiring private helpers to assist them with housekeeping. Other commonly used community services were Telecare + (23.5%), CommCare (17.6%) and Meals on Wheels (17.6%) [20].

Meanwhile, twenty-two AHCPs (50% occupational therapists and 50% physiotherapists) took part in this study, having between one and twenty-five years of experience (Mean = 9.4 years, SD = 8.8 years). The participants surveyed mainly interact with people who are over 60 years old having health conditions such as arthritis (90.9%), post-stroke (77.3%), chronic heart failure (77.3%) and fractures (72.7%). The majority of respondents (63.6%) stated that OAs who live independently at home mainly require assistance with IADLs and 90.9% said that the majority of OAs have family members or friends to assist them with these activities. However, the required assistance depends on the severity of the disease, which impacts not only the OAs' quality of life but also that of their family or friends.

From the interviews carried out with the OAs, 94.1% said that they used mobile phones, closely followed by electronic appliances (88.2%). The use of computers was less common with a rate of 52.9%. This was observed to be quite similar to the responses given by the AHCPs, in that among the OAs, the use of mobile phones and electronic appliances is more popular than the use of computers. Most of the AHCPs (90.9%) stated that the majority of the OAs they interact with have experience using electronic appliances, while 68.2% said that the OAs have experience using mobile phones. Meanwhile, only 9.1% of the AHCPs thought that the majority of the OAs have experience using computers.

2.4 Results and Analysis on IADL Assistance

The responses obtained from both the OAs and the AHCPs for Part 2 of the survey were analyzed using SPSS Statistics Software [21]. Due to the higher robustness of the AHCP data (larger sample size, smaller error bars, higher consistency in the responses) it was later decided to base the decisions on the designs of the RIS and the robot on the results from these data, and these are summarized herein.

The responses to the first inquiry of Part 2 (see Sect. 2.2 above) were subjected to the Friedman statistical test, and demonstrated a significant difference between the two mean scores (Q = 5.444, P = 0.02), i.e. that the AHCPs were more likely to encounter OAs who suffer from weak muscles in hands, forearms and shoulders, than OAs who suffer from reduced hand dexterity. The mean rating scores for the assistance needs queried are shown in Fig. 1 in order of decreasing importance, and the frequencies of encountering OAs with the queried performance skills problems are shown in Fig. 2.

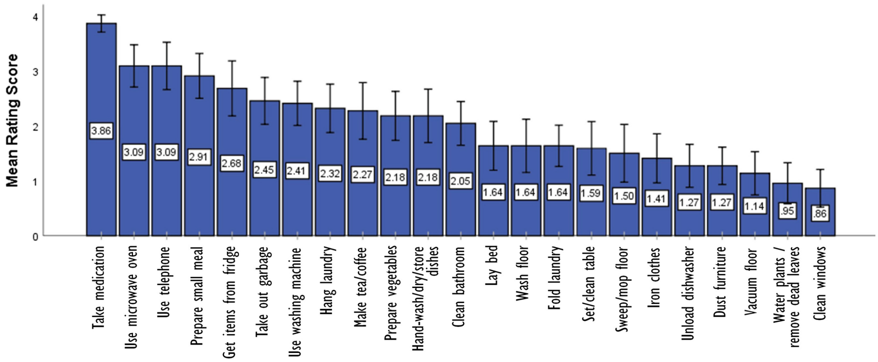

Fig. 1. Importance of assistance in IADLs according to AHCPs (Error bars: 95% CI)

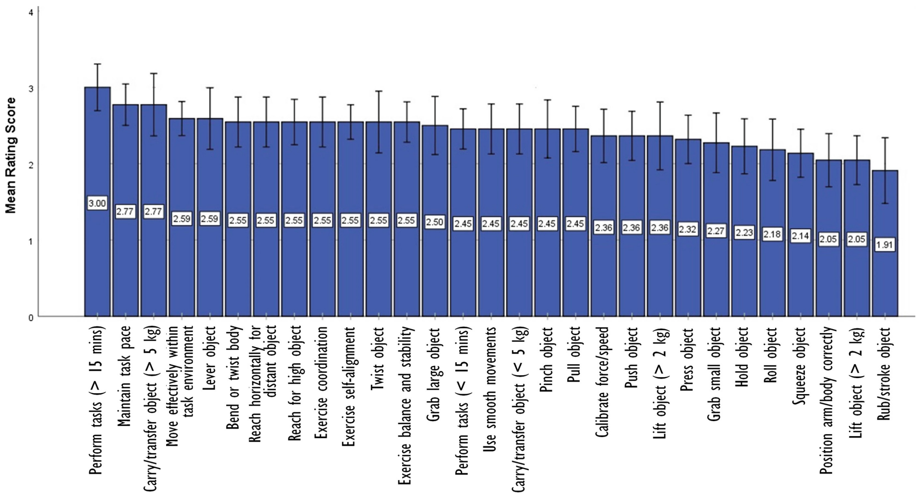

Fig. 2. Frequency AHCPs interact with OAs having the above problems during task execution (Error bars: 95% CI)

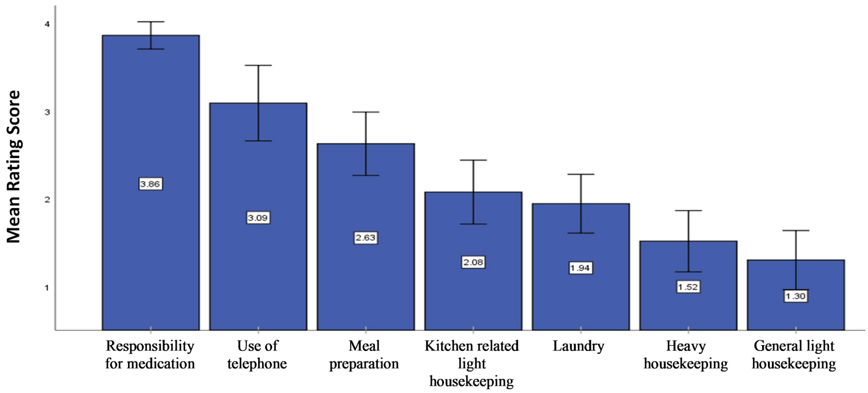

Fig. 3. Importance of categories of IADLs based on AHCP responses (Error bars: 95% CI)

The IADLs shown in Fig. 1 were grouped into seven categories: Responsibility for Medication, Use of Telephone, Meal Preparation, Kitchen-Related Housekeeping, General Light Housekeeping, Heavy Housekeeping and Laundry. The latter five categories were identified as unidimensional constructs extracted from a number of related activities: in each case the Cronbach's alpha was measured to verify an adequate internal consistency. The relative importance of the seven categories are shown in Fig. 3. In each case the mean rating score was obtained by averaging the rating scores given to the activities included in that category. The four highest ranked categories were selected for further analysis, as drivers for the RIS and robot design.

Each of the activities (e.g. prepare tea) within the four selected categories was analyzed in detail to extract the constituent steps (e.g. fill kettle with water), movements (e.g. reach for kettle) and action primitives (e.g. reach horizontally for distant object) [19], and to match the primitives to the list shown in Fig. 2. The degree of difficulty for each movement was extracted from the number of constituent action primitives and their associated degrees of difficulty (from Fig. 2), normalized to a fraction between 0 and 1. The priority score for each movement was then obtained through a weighted sum of this normalized difficulty (60%), the normalized degree of occurrence of the movement across all the selected activities (30%), and a binary score (1 or 0) that reflects whether or not the movement requires a relatively significant muscle strength in the hands, forearms and shoulders (10%), (percentage weightings shown in brackets). The highest scoring movements are shown in Table 1, and these were selected for consideration in the design of the RIS and robot.

2.5 Results on Robot-Assisted Living

The idea of robots and robot-assisted living was new for most of the OAs interviewed. However, once the concept and potential benefits were explained, the majority were hesitant but intrigued by the idea, especially if the robot is able to do tasks they can no longer perform, thus allowing them to continue living in their home independently. In fact, 70.6% of the OAs interviewed said that they would be willing to make changes to their home to improve the performance of the robot. The others, despite liking the idea, said that they would not be willing to go through the trouble and the required costs, and some were also concerned with the potential detrimental effect on the aesthetics of the environment. On the other hand, only 31.8% of the AHCPs thought that the OAs would be willing to make the necessary changes if they understood the purpose of the robot in their home. One of the common concerns was that the majority of the OAs they interact with do not have knowledge regarding robots and thus are unable to understand the use of the robot and the need to change their environment. Additionally, a number of the AHCP respondents commented on the reluctance of OAs to change their ways and environment. The large discrepancy between the two responses in this regard may be either because the OAs were questioned face to face and felt the need to agree with the surveyor, or because they were really more open to the idea. However, both the OAs and the AHCPs pointed out various important concerns which should be considered during the design of both the environment and the robot.

Table 1. Selected movements and their scores.

Movement	Score	Movement	Score	Movement	Score
Carry object	0.479	Open drawer/cupboard/appliance	0.388	Pour liquid	0.360
Open Tupperware-type container	0.427	Remove kettle lid	0.386	Turn on tap	0.357
Open dustbin	0.426	Reach for object	0.383	Cut/slice	0.354
Open medication bottle	0.402	Open bottle	0.380	Open can	0.352
Open store-bought container	0.397	Remove whistle cap	0.371	Open jar	0.349

With regard to the robot design, 52.9% (31.8%) of the OAs (AHCPs) interviewed preferred a machine-like robot; 23.5% (50%) preferred a robot with human traits; and 23.5% (18.2%) preferred a humanoid robot. A smaller robot was preferred by 70.6% (63.6%) of the OAs (AHCPs). With regard to level of autonomy, 47.1% (68.2%) of the OAs (AHCPs) preferred a semi-autonomous robot; 29.4% (13.6%) preferred a tele-operated robot; and 23.5% (18.2%) preferred a fully autonomous robot.

3 Prototype Development

3.1 Introduction to the Design of the Robot-Inclusive Space

The context selected for the first prototype RIS design was the kitchen, since this space is compatible with all the movements given in Table 1. Since all of these movements involve access and manipulation, the design effort focused on placing/modifying/selecting objects so that they are easy to reach, grasp and move; and on modifying activities such that they can be carried out with a single, low dexterity manipulator [11]. A concomitant objective was that the kitchen environment should also be functional, safe and aesthetically pleasing for human use (even in the absence of a robot).

A list of 27 individual steps, selected from the IADLs of Fig. 1, and containing movements from Table 1, was drawn up (e.g. throw away unwanted items; add water; cut sandwich). Each step was decomposed into its constituent movements, and a function means table [22] was used to brainstorm different concepts in which the environment could be modified to assist the robot. Morphological charts were used to formulate alternative methods to accomplish each step, and solution selection was based on established universal design guidelines for robots (e.g. [23]). The designs and/or selections address room layout, as well as various other details (e.g. door handles, utensils).

3.2 Introduction to MARIS, the Assistive Robot

The product design specifications for the robot included minimization of the degrees-of-freedom (DOFs); ability to reach standard countertop heights, as well as lower and higher cabinets; ability to handle standard or RIS re-designed kitchen objects; untethered operation; height shorter than an average person; and safe operation. A conceptual design approach similar to that of the RIS was taken. Ultimately the 6-DOF kinematic configuration of Fig. 4(a) was selected, and the embodiment and detailed designs, as well as a failure mode and effects analysis, were carried out. Commercially available items (3-DOF omni-directional mobile base, linear actuator spine, stepper motor for the 1-DOF wrist joint, and 2-jaw parallel gripper) were employed in the design. Tele-operated control was opted for in this first prototype, and a commercially available wireless controller was used. System control was built around an Arduino platform. System power was supplied by two 12 V sealed lead acid batteries. The constructed robot can lift a bottle weighing 2 kg, or a plate (from the rim) weighing 0.5 kg. It has a maximum horizontal linear ground speed of 0.25 m/s, a vertical stroke length of 0.8 m with speed 0.014 m/s, and a wrist rotation speed of 14.25°/s. In the fully extended position and at full load it can withstand a maximum angle of tilt of 12.25°, and has a vertical deflection of 3.16 mm at the gripper.

(a) (b) (c) (d)

Fig. 4. (a) MARIS kinematic configuration; (b) MARIS (retracted); (c) MARIS (extended); (d) conceptual elements of the RIS (top: wide rimmed plate; bottom: custom spoon handle)

The MARIS prototype is shown in Fig. 4(b) and (c). Figure 4(d) shows two conceptual elements of the RIS being handled by the robot.

4 Conclusion

Preliminary simulations of MARIS within a fully furnished robot-inclusive kitchen have been carried out in SketchUp with MSPhysics [24], and this exercise has indicated that it is possible to achieve a functional and aesthetically pleasing kitchen in which an appropriately designed domestic robot can operate. In a post project-phase evaluation exercise, a sample of 18 AHCPs have received favourably the new concept and system, although some have re-expressed concern on the actual willingness of OAs to implement changes in their home. Current work is focused on improving the RIS, on developing simple and low cost suggestions to convert typical kitchens to RIS, and on upgrading MARIS to more autonomous control.

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