Assistive Robotics Group Report

Ben Allen
22071020

Oliver Girling
19009076

Finlo Heath
22071796

Thomas Rowland
18007687

***Abstract*—Assistive robotics holds significant promise in revolutionising home-based care for individuals with diverse needs. This study investigates two distinct applications of robotics, addressing both physical and social challenges. First, a TurtleBot equipped with YOLOv3 object detection and SLAM navigation capabilities was utilised in simulation to search an environment and locate a specific object. The robot successfully found the object in 2 minutes and 12 seconds, illustrating the viability of this approach for assistive tasks. Secondly, a Pepper robot was programmed to serve as a physical rehabilitation instructor, offering basic conversation and leading an exercise routine through both demonstration and verbal guidance. This socially assistive implementation of Pepper was aimed to provide social interaction and encourage behaviours that improve users' mobility and confidence. Pepper engages users with a social introduction, inquires about their well-being, and reminds them of daily tasks, while guiding them through a seated exercise routine. The robot utilised verbal communication, images, and physical demonstration to accommodate users with various limitations, such as poor sight.**

The successful implementation of both the TurtleBot and Pepper underscores the potential for assistive robots to be integrated effectively into home environments. However, before these systems can be widely adopted, it is essential to address outstanding challenges related to safety, effectiveness, adaptability, ethical considerations, and user preferences to ensure seamless and responsible integration into people's lives. The choregraphe and python files created as part of this study are publicly available on the authors' GitHub for researchers to access at the following link: GitHub Resources

I. Introduction

The UK faces many challenges in healthcare, but among the most prominent is the ongoing shortage of National Healthcare Service (NHS) healthcare workers [1] in the face of an ageing population [2]. With the shortage particularly prevalent in nursing staff, researchers across various disciplines are considering systems to support the assistive requirements of the elderly and those with disabilities. Roboticists have the opportunity to lessen the strain on the NHS by designing systems which can serve as contextual alternatives to human carers or assist them in their roles. In this study, we propose, develop and test two methods of robotic assistance - physical and social - tailored to the needs of a specific, imagined end user.

Our solutions focus on the persona of Claudia: *At 54 years old, Claudia lives independently despite being partially blind because of severe glaucoma and diabetes. She is employed part-time as a social worker, and though she once made house calls, her deteriorating vision led to a loss of confidence, prompting her to work remotely. A few months ago, Claudia experienced a fall and has since been less active. This decrease in mobility, coupled with her diabetes, has caused her to become increasingly fragile, with poor circulation and swelling. With her only child residing in Australia, loneliness affects Claudia significantly.*

We concluded that Claudia would require physical assistance in aspects of her life revolving around her loss of sight, allowing for the reclamation of her independence and autonomy. By introducing the Turtlebot [3], a small mobile robot with onboard object detection, Claudia is provided assistance in finding useful items around her home. Regarding social assistance, Claudia will benefit from the companionship of a social robot, given she currently experiences loneliness and lacks the confidence to leave her home. In addition, a social approach to her exercise to aid recovery from her fall may be more successful, because of the increased motivation and guidance as shown by H. Hawley [4]. To demonstrate this, the Aldebaran Pepper robot [5] was programmed with a bespoke exercise routine; performed seated given Claudia's frailty. The aim of this research is therefore to leverage assistive robotic systems to restore independence and capability to the user where recovery is possible and to provide functions for the user where it is not. In further sections, we will refer to this persona interchangeably by name and as "the user".

II. Socially Assistive Robots

A. Methods

The aim of the socially assistive robot is two-fold. Firstly, it must provide some of the social interaction that the user is unable to acquire given they are mostly housebound. Secondly, the robot must encourage and assist with behaviours which will improve the user's mobility and confidence so that they are able to participate in a wider range of social activities in the future. These objectives are considered in the daily workout routine created for the Pepper robot to lead the user in a short seated exercise session. Pepper provides a social introduction to the interaction, enquiring about the user's well-being and offering reminders for daily tasks with the example of medication. During the verbal farewell, Pepper praises the commitment and effort of the user; with the intention of boosting confidence.

As shown in the HARE Model, Fig. 1, the user's ability limitations also include poor sight. For this reason, Pepper primarily communicates verbally to the user, utilising images

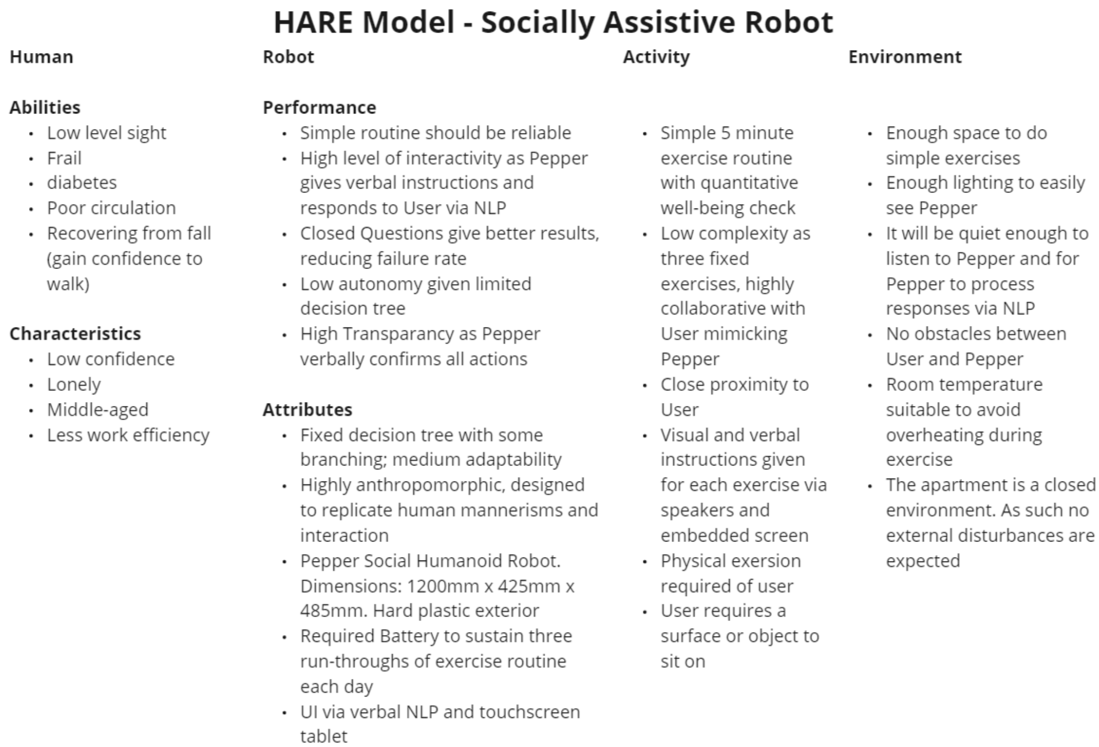


Fig. 1. HARE Model for the socially assistive exercise routine performed by the Aldebaran Pepper robot.

on the screen to emphasise its spoken instructions for each exercise. Pepper also imitates the exercise as accurately as mechanically possible. This sets the speed for each exercise and repetition and may help a user with low confidence to perform the movement. The user must be able to hear Pepper clearly and Pepper must be able to clearly record their replies. To improve communication between Pepper and the user, Peppers questions detail reply prompts such as "How are you feeling today on a scale of 1 to 5?". This significantly reduces the possible replies from the user and improves the likelihood of Peppers speech recognition understanding the response. The volume has been set with the consideration of the deployment environment - the user's home. Our full socially assistive routine was constructed with the following flow diagram displayed in Fig. 2.

B. Results

The exercises chosen were taken from the NHS seated exercise guide [6], designed to improve mobility and strength to recover from and prevent falls. As noted in Fig. 2, the three exercises allow demonstration of the range and limitations of Pepper's instruction capabilities. Pepper can directly demonstrate arm raises (Fig. 3 (a)) and can analogously demonstrate leg marches (Fig. 3 (b)) using corresponding arm movements, but can only instruct ankle raises verbally, via reference to an image on its chest-screen (Fig. 3 (c)). During the well-being survey and farewell, Pepper's eyes are set to turn green. This is choice is based on colour psychology. While a user's reaction to different colours is inherently subjective, the literature broadly agrees that different colours can be used to leverage specific emotional responses. Green can signify a sentiment of calm and positivity [7], ideal for the objective of improving the user's mood and inspiring them to raise their confidence.

A full recording of the routine is provided at the following web address: **Routine video**. The Choregraphe file dictating peppers Pepper's behaviour is available on the GitHub linked in the abstract.

C. Discussion

Our study aimed to explore the extent to which socially assistive robots could be used to improve physical health in addition to the well-being of our persona, Claudia in the context of a care setting. The experience produced, reached the goals set out by the specification to increase her confidence while aiding Claudia's recovery process through seated exercises. However, throughout the development and implementation of these solutions, we found many limitations that could be improved upon.

There was a distinct lack of adaptable reactivity and branched responses in our socially assistive use of the Pepper robot. Our solution to the problem has been programmed with pre-defined responses resulting from certain stimuli. Pepper lacks the ability to adapt to responses that Claudia or other end-users may have, for example, humans have a large set of verbal or non-verbal cues which Pepper will ignore in the current iteration - unable to adjust its responses based on the previous answers or actions. This makes the

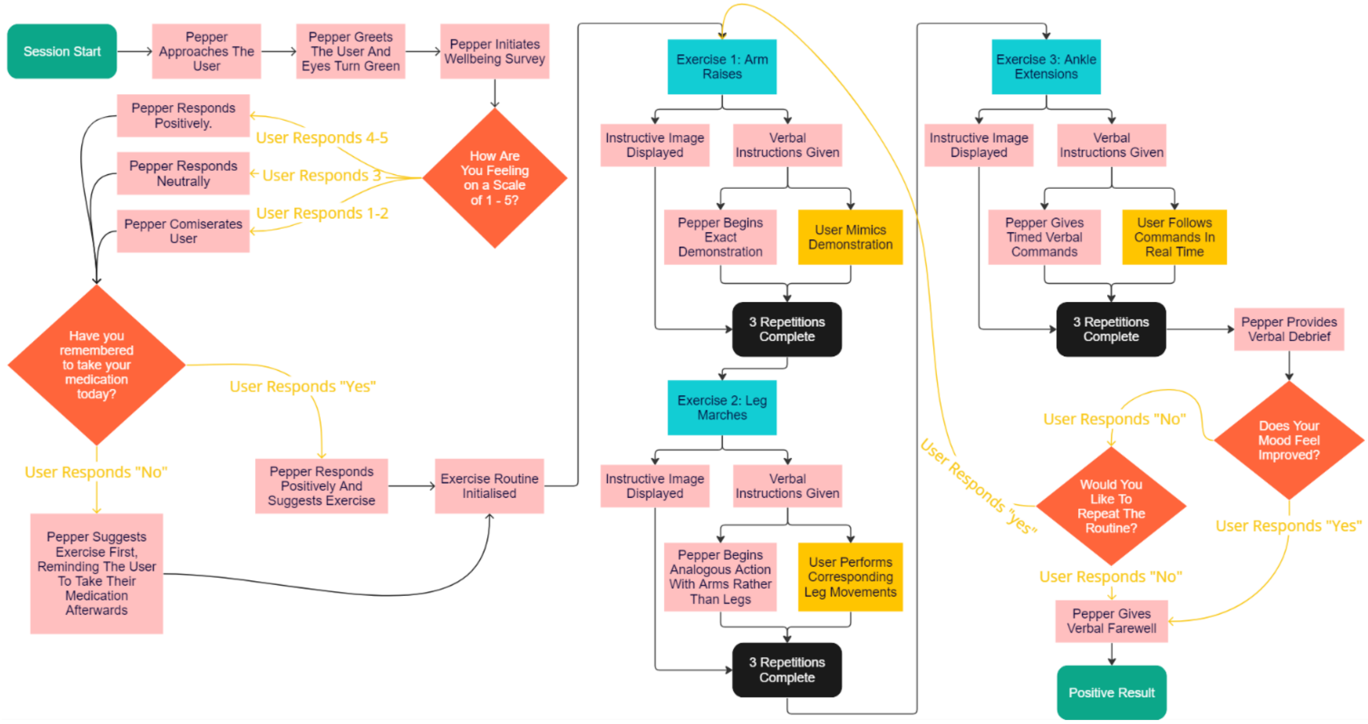
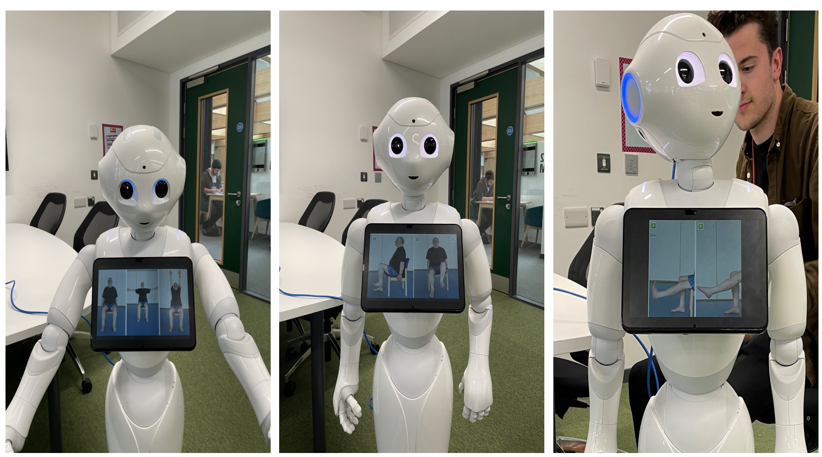


Fig. 2. Flow diagram visualising the choregraphe code dictating Pepper's behaviour in the socially assistive solution.



(a) Arm Raises (b) Leg Marching (c) Ankle Extensions

Fig. 3. Images taken during the socially assistive routine. These display the three exercises led by Pepper via direct demonstration (a), analogous demonstration (b) and verbal instruction (c).

scripted nature of the interaction with Pepper transparent to the user, especially in Claudia's case where she may be interacting with a socially assistive robot multiple times a day.

The use of learning methods such as direct demonstration, analogous movements and verbal instruction only, broadened the robot's ability to teach the user how to complete each exercise. Despite this, it is important to recognise there are limitations. Different people have varying preferences when it comes to learning new tasks so in Claudia's situation our method may have worked effectively although others may prefer a more hands-on approach to learning similar to physiotherapy. While our solution used three different ways it is important to consider a variety of teaching approaches to cultivate a safe and effective environment especially given our users are elderly and potentially vulnerable individuals. This could be achieved by assessing each individual's needs through consultation as to what they would prefer for their experience with Pepper or another socially assistive robot.

It is imperative that ethical issues are considered during the development and implementation of socially assistive robots. In the context of our project, the robots are collecting and processing a large amount of sensitive data from the end-user potentially discussing their health, daily routines and any medicine they may be taking. This data must be kept confidential and protected assuring that it will not be accessed by an unauthorised source or misused under the data protection act. We also need to ensure that the ethical issue of social isolation and dependency is considered, our solution can provide Claudia with valuable support however this should not replace her interaction and socialising with other humans such as her daughter. It is important that robots are implemented to assist and not replace human care or support, so they do not contribute to the social isolation or dependency of vulnerable users.

Although there were limitations of our solution, there were clear advantages attributable to the routine developed. Claudia would regain companionship after her daughter moved out, she may have felt isolated as a result of limited social interactions. Socially assistive robots can be used to improve her emotional well-being, especially in Pepper's case as a result of the encouraging voice lines and calming eye colour that were implemented into our code boosting Claudia's confidence.

Another advantage we developed was increasing Claudia's exercise consistency. Avoiding exercise after her injury lead to a decline in physical health and mobility. Pepper was used to provide motivation and reminders for our user to exercise which help increase the probability that individuals will engage with regular exercise importantly improving their overall physical health.

III. Physically Assistive Robots

A. Methods

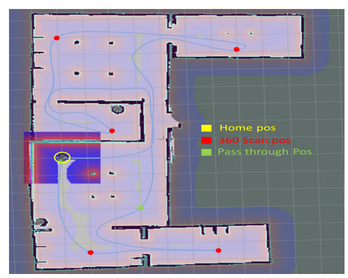
The prior examination of the user showed that a solution which could locate objects for her and then persuade her to go and grab them herself would be optimum. It would compensate for her reduction in sight by locating the object but promotes movement to help with her rehabilitation after her fall. However, knowing where the item is reduces the overall movement as she will not have to search around so should allow for an incentive to use the system. The HARE Model in Fig. 5 shows the initial considerations around the system.

From this HARE Model, a series of instructions were extracted to start designing the program for the TurtleBot. The robot needed to alarm if an object was found and then alarm with a different sound if not. The robot needed to actively search for the object so would have to view the full apartment and the robot would need to identify the correct object which would be set through a user interface input. Key positions were chosen in the map of the flat to make sure each area of the flat was viewed at least once.

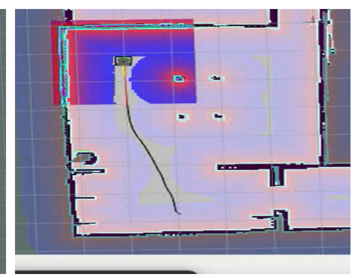
The object recognition will be performed using YOLO v3 [8]. The YOLO family of object detection models are capable of real-time inference and are computationally inexpensive when compared to other real-time object detection models such as Faster R-CNN [9]. YOLOv3 has been pre-trained on the MS-COCO dataset making it already is capable of accurately detecting 80 categories of object but this could be fine-tuned for our use case with further training later in development. The quick inference speed and low computation requirements make it a good choice for this application on the TurtleBot. The movement plan will also try to overlap views as much as possible to give several chances for recognition of the object. The flow chart given in Fig. 6 provides a visual representation of the code behind the simulation.

B. Results

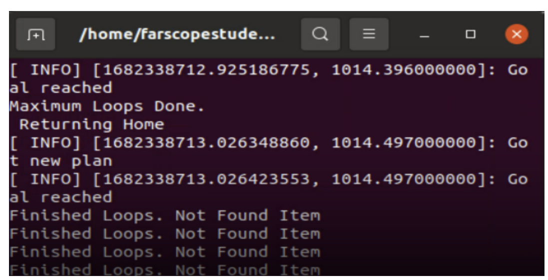
Fig. 4 displays the resultant simulation for our physically assistive solution. A full recording of the simulation is provided at the following web address: **Simulation Video**. The python file dictating the navigation goals is available on the GitHub linked in the abstract.



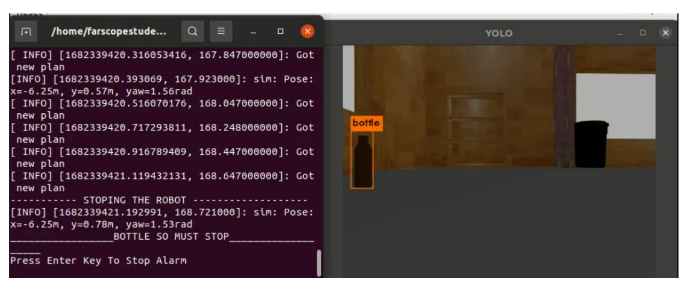
(a) Search Positions and Robot Path



(b) Robot Navigating to Position



(c) Object Not Found, Failure Alarm



(d) Object Found, Robot Alarms

Fig. 4. (a) & (b) display the robot movement through the user's apartment. (c) & (d) display negative and positive results respectively, for the search task.

HARE Model - Physically Assistive Robot

Human

Abilities
- Low level sight
- Frail
- Diabetes
- Poor circulation
- Recovering from fall (gain confidence to walk)

Characteristics
- Low confidence
- Lonely
- Middle-aged
- Less work efficiency

Robot

Performance
- Simple algorithm should be reliable and minimise risk of tripping User given her prior fall
- Highly Automated, user need only select the object they wish the robot to locate
- Robot actions must be clear, it gives a distinct signal if it detects the required object and a different signal if the object has not been found, making success or failure transparent to user
- Failure and false alarms will be more or less common depending on where items are typically left, given the robot's field of view is limited to near the ground

Attributes
- Little adaptability, only a set list of objects available for detection
- Low anthropomorphism
- Turtlebot is a wheeled, mobile robot, with YOLO, SLAM and obstacle avoidance. Dimensions: 138mm x 178mm x 192mm, cylindrical hard plastic chassy
- Battery life must be long enough to perform three sweeps of the apartment before returning to docking station, at a minimum
- User interface via mobile app or voice commands

Activity
- User selects item for search and detect task on a fixed route within the apartment
- Robot uses audio alarms to signal a successful or failed task
- User confirmation of receiving the alarm signals robot to return to dock
- Fixed routine with object as only variable means low task complexity with timing dependant on object location
- Collaborative only to initiate and complete the task
- No external materials required beyond robot and UI app
- Highly physical and large proximity as robot traverses the whole apartment

Environment
- No external disturbances, apartment is a closed environment
- Reasonable ambient lighting to enable object detection via YOLO
- It will be quiet enough for user voice commands to be detected
- No permanent obstacles
- Temperature consistant and will not affect robot performance

Fig. 5. HARE Model for the physically assistive search and detect routine performed by the Turtlebot.

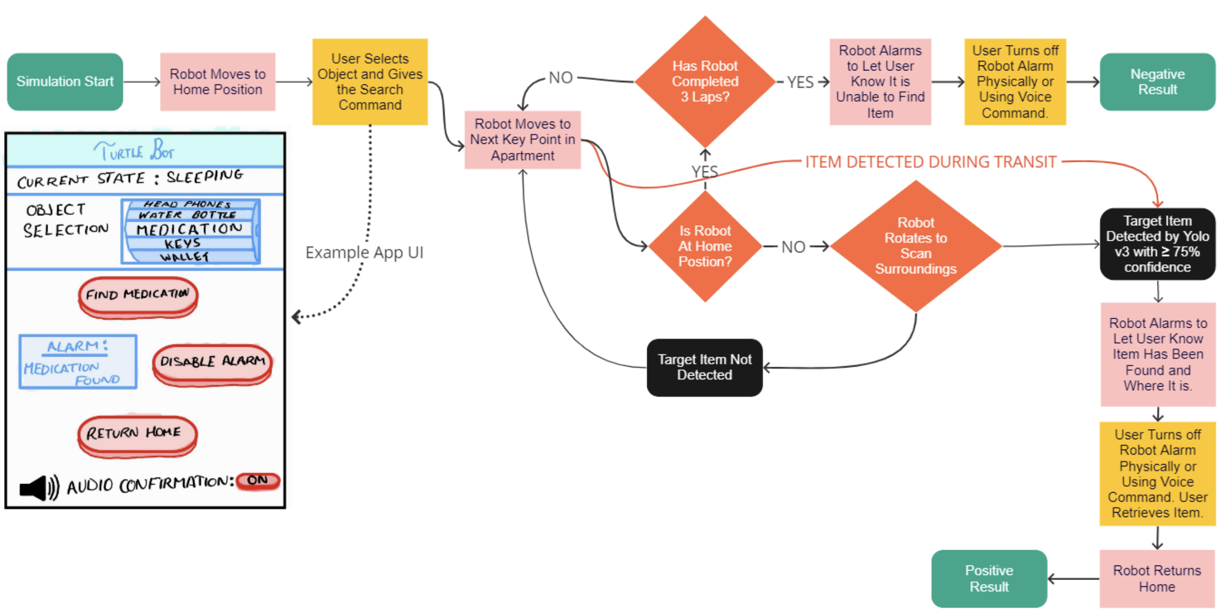


Fig. 6. Flow diagram visualising the code behind our ROS simulation of the Turtlebot Physically Assistive Solution. This includes a paper prototype of the companion app UI.

C. Discussion

The proposed physically assistive solution was able to achieve the desired specification and could successfully identify a bottle within the flat environment reporting its location to the user. However, there were several limitations to this solution. The first main limitation is the placement of the camera on the robot as it is mounted on the mid-front of the TurtleBot. This is a sensible location for the SLAM-based functions of the TurtleBot and its usual use case. For this scenario though it meant that the robot was unable to identify any objects which were more than around 30cm off the ground meaning that the bottle would not be discovered if it was placed on a shelf or table. This could be fixed by adding a central pole or extendable section to the robot to increase the height of the camera, but this would need to be carefully designed as itcould make the robot unstable or sway giving a blurry picture. Alternatively, a 360-degree camera such as in [10] could be used to allow for a wider view range and to alleviate the need for scans to speed up the search algorithm.

This gained speed could be useful as one of the other limitations was the robot's speed which was slowed down to accommodate YOLO. Although YOLO could be sped up by using later versions and would be faster if not running on a simulated environment, it still presents a speed limitation for detection. This means it took 12:16 minutes to perform 3 searches of the flat and still took 2:12 minutes to find the bottle when it was in the first half of the robot's path. The 360-degree camera could help speed this up as then objects are not just seen in one direction, so speed becomes less of an issue as they are less likely to come out of view. However, this will always be a limit so the system may not be suitable for time-sensitive location tasks such as medication detection.

The YOLO detection system has a few limitations namely that it only currently covers a handful of everyday objects so if more specific items were searched for, a dataset would have to be created added to the learning algorithm which may take time. This is a universal limitation for all detection systems but is important to make sure the user knows as they may overestimate the robot's potential, leading to disappointment and possible lack of trust. This lack of trust is already an issue in domestic robots [11] so should be carefully considered. The other main issue is that currently the robot simply stops once the object is detected which works as a demonstration but in a more cluttered environment becomes an issue as it may detect the object from a large distance so that it stops nowhere near the actual object. This may lead to confusion with the user and then does not solve the issue as the user will still have to search within that area. A better approach would be to add a depth sensor to the robot which can tell it the distance to the object so that once identified it moves towards it until an appropriate distance is reached. This can then be updated constantly so that if the object gets moved through pets or other means then the robot will continue to follow it until the alarm is cancelled by the user.

There are a few safety concerns with the solution as it is relatively low to the ground robot so it could become a trip hazard as it is relatively hard to spot being black. This could be reduced as an issue through brighter colours or a constant searching sound. There is also the concern of liquids and other debris in a home environment as there is currently no sensor for water or food spills [12] which if driven through could lead to damage to the LiPo Battery or electronics, in the worst-case causing fires. The lower end is that it could just spread the mess through the apartment which may then create more slip hazards for the user walking about which may result in more falls.

There are a few ethical concerns as well with the solution as it requires a map of the user's apartment to operate either having it constructed previously or creating its own. If this stays local, then it is not an issue but there have been problems with these house plans being sold to others [13] so there is a lack of trust in these systems. The captured footage for the object detection and audio samples for the voice commands will also have to stay local as this could contain private or sensitive information which should not be shared. Therefore, the images and samples should be deleted straight after the detection algorithm has been run on them. On a less technological side, the solution itself may cause more problems in the long run for the user. Especially in the case of Claudia this reduction in movement although helpful post recovery could result in her becoming dependent on it permanently reducing her movement time. This has the adverse effect of causing her to recover slower than expected and could lead to more severe injuries if another fall occurs.

IV. Reflection

The development of the two solutions differed considering one was performed solely in simulation. In this case, we found that only one of the four team members had a computer powerful enough to run the simulation software. This inhibited group work and as such, we recommend adapting the coursework so accessibility does not depend on having a powerful PC. We had more success with the social assistance implementation, developing different components of the routine separately and then bringing these together to create the overall exercise plan. This development ran smoothly for our team, allowing us to implement all desired features across the four practical sessions, resulting in a robust well-being and exercise routine.

Our team members worked well together, with strong communication throughout the project. Work was divided according to member strengths and practicality. For example, Ben was the only member who had a laptop powerful enough to run the TurtleBot simulation and as such led development on the physically assistive solution; he also had prior experience with ROS. Tom developed both HARE models for our user and solutions, Ollie led on video editing for our group presentation and Finn composed the master Choregraphe file for the social routine, as he had significant experience from the HRI module. Finn created both flow charts for the two solutions. Tom's background in machine vision was utilised to support Ben in implementing the social solution, and as such Tom contributed significantly to this aspect of the report. Ollie has performed video editing in the Bio-inspired AI module to emphasise key moments in the solution. He also performed an extensive literature review of socially assistive robots in the first half of this module, and so suggested many of the features we used in our socially assistive routine.

Report writing was divided equally with all sections completed before multiple editorial passes were made by different team members. Finn acted as the organisational lead in this stage of the project and on the presentation, setting deadlines for a first draft, editing passes and submission. All team members attended all practical sessions and were responsive to messages outside of these sessions.

V. Conclusions & Future Work

The integration of both social and physical applications of robotics has demonstrated its transformative potential in assisted living environments. Proactively embedding such technological solutions in residential settings can enhance individuals' health while prolonging their independence from conventional healthcare systems. The ability to remain comfortably in one's own home not only elevates mental well-being but also mitigates the pressure exerted on our healthcare infrastructure [14].

This study has looked at two implementations, the physically-assistive TurtleBot and the socially-assistive Pepper robot and with relatively simple implementations the base objectives have been met.

By implementing YOLOv3 and utilising the TurtleBot's SLAM and path planning capabilities, a system has been created whereby a small wheeled robot can autonomously search a single floor of a property and alert the user to an item's whereabouts. The system was designed with a user-centred approach, prioritising accessibility and ease of use through features such as audible alarms and bold buttons and displays.

Similarly, the Pepper robot has shown the possible utility for a robotic rehabilitation instructor. The system utilised both Pepper's natural language capabilities and physical movement for leading exercise routines. This resulted in a 5-minute exercise routine prefixed with an introductory conversation where Pepper checked on the mood of the patient and prompted a reminder for medication. Each exercise was then verbally explained and demonstrated with Peppers movements where possible and otherwise with the onboard display. Pepper kept time and counted the repetitions, congratulating the user throughout. Interaction such as this has been shown to increase motivation and engagement when recovering from injuries [4].

A. Future Work

1) TurtleBot: Future work for the TurtleBot could come from several areas:

- **Object Detection:** Expanding the number of detectable objects and improving the object detection algorithm.
- **Camera Positioning:** Redesign the camera placement to allow the detection of objects above the floor level.
- **Modularity:** Modular components could allow for easy customisation based on the individual user's requirements. Examples include an improved audio module for voice control, a gripper attachment to allow picking objects or medication dispensers so that medication can be given at the prescribed schedule.
- **Safety Improvements:** Sensors could be included to detect dangers such as stairs, obstacles and slip hazards, and would warn the user when they collect the item.
- **Privacy and Security:** Ensure data privacy by storing maps locally and implementing secure data deletion to protect sensitive user information.

2) Pepper: Improvements to the Pepper robot could include:

- **Conversational Capabilities:** Enhance the natural language processing to facilitate more dynamic and engaging conversations with users. This could include advanced dialogue management or machine learning to adapt to the users preferences over time.
- **Exercise Demonstration:** Improve Pepper's ability to demonstrate a wider variety of exercises by incorporating additional visual aids such as an upgraded display or augmented reality projections.
- **Personalisation:** Personalised exercise routines and interactions dependant on the user profile such as age and ability.
- **Feedback and Monitoring:** Additional sensors to monitor the user performance and provide real-time feedback and corrections. This could reduce the risk of injury and ensure safe completion of the exercises.
- **Privacy and security:** More robust privacy and security measures to protect personal data.

Both systems could be used as part of an Ambient Assisted Living (AAL) environment where multiple sensing modalities are combined to give an accurate representation of the user's health and living situation. Future research should also address common challenges in assistive robotics such as the effects of long-term usage and the ethical integration of robots at home. Collaboration between researchers, industry, and policymakers is essential to ensure the safe and ethical integration of assistive robots into the homes of vulnerable individuals, ultimately promoting a better quality of life and well-being.

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