Assistive Robotics Empower Independence for Individuals with Disabilities

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I. Abstract

The study investigates the development and implementation of a dual-component assistive robotic system designed to enhance the quality of life for Claudia, a 54-year-old with severe glaucoma, diabetes, and mobility challenges. The social assistive component utilises the Pepper robot to provide companionship, medication reminders, and guided exercises, employing advanced voice interaction, natural language processing, and emotive communication to enhance Claudia's rehabilitation and sense of connection. The physical assistive component employs the TurtleBot 4, which navigates Claudia's home using cutting-edge object detection technology to assist her with daily tasks, thereby reducing her physical exertion. Implemented using the HARE (Human, Abilities, Robot, Environment) model, this study ensures a user-centered approach while addressing ethical considerations. Although the system shows promise in enhancing independence and reducing health complications, limitations such as Pepper's limited response to non-verbal cues suggest areas for future improvement. The report concludes with recommendations for broader integration into Ambient Assisted Living systems and emphasises the need for interdisciplinary collaboration to refine and optimise the deployment of such technologies.

II. Introduction

A. Motivation

The escalating need for assistive robotics is accentuated by shifting global demographics and the evolving demands of healthcare systems. By 2050, the elderly population (aged 65 and over) is projected to rise from 10% to 16% [1], while Europe's working-age population is expected to decrease by 25% from 1995 levels, significantly lowering the potential support ratio from 4.8 to 2.1 [2]. This demographic trend poses severe challenges for maintaining healthcare quality as it significantly reduces the workforce available to support an aging population. Concurrently, the NHS is experiencing critical staff shortages, with almost 105,000 vacancies that compromise patient safety and inflate operational costs [3]. Between 2018 and 2020, NHS trusts incurred expenditures exceeding £5.8 billion annually on temporary staff, emphasising the urgent necessity for assistive robotics as a sustainable solution to support healthcare services [3].

Assistive robotics significantly alleviate healthcare burdens and enhance the quality of life by providing essential physical and cognitive support for the elderly [4]. These technologies address the shortage in the care workforce [5] and are crucial for individuals with physical impairments and cognitive disorders, such as stroke survivors and those with autism spectrum disorder (ASD). Socially assistive robots not only facilitate early intervention but also significantly improve rehabilitation [6], [7] and educational outcomes for those with disabilities and autism [8]–[10], driving measurable enhancements in vital social skills [4].

B. Challenges in Assistive Robotics

Assistive robotics faces numerous challenges that must be addressed to maximise their effectiveness, while expanding rapidly—from USD 4.1 billion in 2019 to an expected USD 11.2 billion by 2024 with a 22.3% CAGR [11]—face significant challenges. Increased demand due to rising incidences of strokes and spinal injuries, along with expanded insurance for medical exoskeletons and robotic surgeries, underscores the sector's growing role in healthcare. However, high rates of device abandonment, with 19.38% of assistive technologies not retained by users [12], and ineffective utilisation, such as over 50% of wheelchairs for spinal injury patients [13] and 40% of devices in Italy never used [14], highlight urgent needs for better customisation, user engagement, and adoption strategies.

C. Persona

Claudia is a 54-year-old residing alone and facing significant challenges due to severe glaucoma and diabetes. She is partially sighted, with her visual impairment primarily caused by glaucoma—a condition characterised by increased fluid pressure in the eye leading to optic nerve damage, as shown in Figure 1 [15]. This condition has progressively diminished her vision, undermining her confidence and restricting her mobility. Formerly an active social worker, Claudia now works from home, and her situation is complicated by a recent fall that has exacerbated her physical frailty and diabetes-related circulatory issues.

Her isolation is further deepened by geographical distance from her daughter in Australia, intensifying her loneliness. Claudia's daily life is complicated by difficulties in locating everyday objects, a challenge intensified by her visual impairment. To enhance her independence and effectively manage her environment, Claudia seeks the assistance of an assistive robot.

Claudia falls into Category 4 (Vulnerable) on the Clinical Frailty Scale (CFS), marked by her severe glaucoma and diabetes, leading to partial sight loss and decreased physical stability. Her recent fall indicates declining strength and

stability, limiting activities beyond routine walking. These health challenges, compounded by her daughter's absence, intensify feelings of isolation, affecting her emotional and physical well-being. This aligns with CFS Category 4, characterised by limited activities despite not being fully dependent on daily assistance [16].

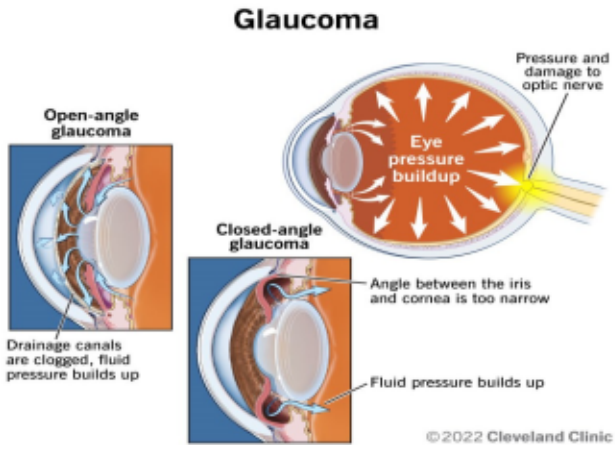

Fig. 1: Glaucoma-affected eye, showing both open-angle and closed-angle types, characterised by blocked drainage canals causing fluid pressure buildup and optic nerve damage [15]

D. Experiment Goals

This study is dedicated to crafting a robotic system that not only attends to Claudia's social and physical needs but also prioritises the ethical and safety aspects of its design. To achieve this, comprehensive hazard analysis, as detailed in the appendix, is employed. This ensures that the system's functionalities are not only effective but also mindful of potential risks, thus safeguarding Claudia's well-being throughout interaction.

*1) **Socially Assistive Task**:* The social assistive task will utilise the Pepper Bot to deliver companionship, facilitate communication, and involve Claudia in cognitive activities aimed at sustaining her mental well-being and social adeptness. Leveraging interactive elements such as voice recognition, natural language processing, and emotive communication, the Pepper Bot will emulate a social presence, encouraging regular interaction and maintaining Claudia's ties to her social circle. Crucially, these tasks are designed to collectively bolster Claudia's confidence and foster her independence. The implementation strategy follows a phased approach, allowing Claudia to gradually assume greater responsibilities as her familiarity and confidence in the robotic system grow in table I.

*2) **Physically Assistive Task**:* For the physically assistive task, our strategy involves deploying the TurtleBot 4 platform [17] with user specific robotic system to navigate Claudia's home efficiently. The bot's objective is to locate, retrieve, and deliver objects that Claudia may find challenging to locate due to her vision impairment. Equipped with cutting-edge SLAM [18] navigation using YOLOv9 [19] and for object recognition technologies, TurtleBot 4 inherent sensors and onboard computation will adeptly maneuver around the house, minimising Claudia's physical exertion and mitigating the risk of falls I.

III. Part A - Social Assistive Robots

We utilise the HARE model to comprehensively address the design and evaluation of robotic systems, focusing on four critical components: Human (including Abilities and Characteristics), Robot Performance and Attributes, Environment, and Task or Activity. This approach ensures a user-centered design tailored to Claudia's abilities and environmental dynamics, enhancing interaction between her and the robot.

A. Methods

The socially assistive robot is assigned two primary tasks. Firstly, Pepper will provide companionship to the user, compensating for the user's daughter who lives abroad and addressing the user's loneliness. Secondly, it aims to motivate the user by boosting their confidence and enhancing their mobility following their recent fall. This is achieved by leading the user through three seated exercises, These activities are designed to inspire the user to transition from working at home to participating in an regular environment. Each morning, Pepper will initiate interaction by asking the user how they feel and reminding them of their daily tasks, such as taking their daily medication and a exercise routine involving an eye exercise, breathing exercise and leg exercises.

The eye exercises aim to improve Claudia's vision and reduce eye strain, particularly important given her partial sight loss due to severe glaucoma. These exercises may include eye movements, focusing on different distances, and blinking exercises, all of which can help maintain eye health and prevent further deterioration [20].

The breathing exercises are tailored to promote relaxation, alleviate stress, and improve respiratory function, all of which are beneficial for Claudia's well-being. Given her recent fall and limited mobility, these exercises offer a gentle yet effective way to enhance her overall physical condition, increase oxygen flow, and support her recovery. Deep breathing exercises, in particular, can induce a calming effect, potentially alleviating anxiety and enhancing Claudia's emotional well-being [21]. Considering Claudia's condition, which restricts engagement in external aerobic activities like running, cycling, or swimming, these simple breathing exercises serve as an accessible and practical alternative to promote her physical and emotional health. [22]

Lastly, the seated leg exercises are crucial for sustaining and enhancing lower body strength, balance, and mobility. Opting for seated exercises minimises the risk of Claudia losing her balance and experiencing another fall. Given her decreased physical stability post-fall, these exercises assume a pivotal role in averting future accidents and bolstering her confidence in movement. By strengthening leg muscles, overall stability is reinforced, significantly diminishing the likelihood of falls—an imperative consideration given Claudia's vulnerability. [23]

The design also involves Pepper providing verbal praise and clinical communication [24] to acknowledge the user's efforts and offering motivational quotes to boost their confidence.

Following the HARE model outlined in Fig. 2, our methodology integrates tailored strategies to optimise in-

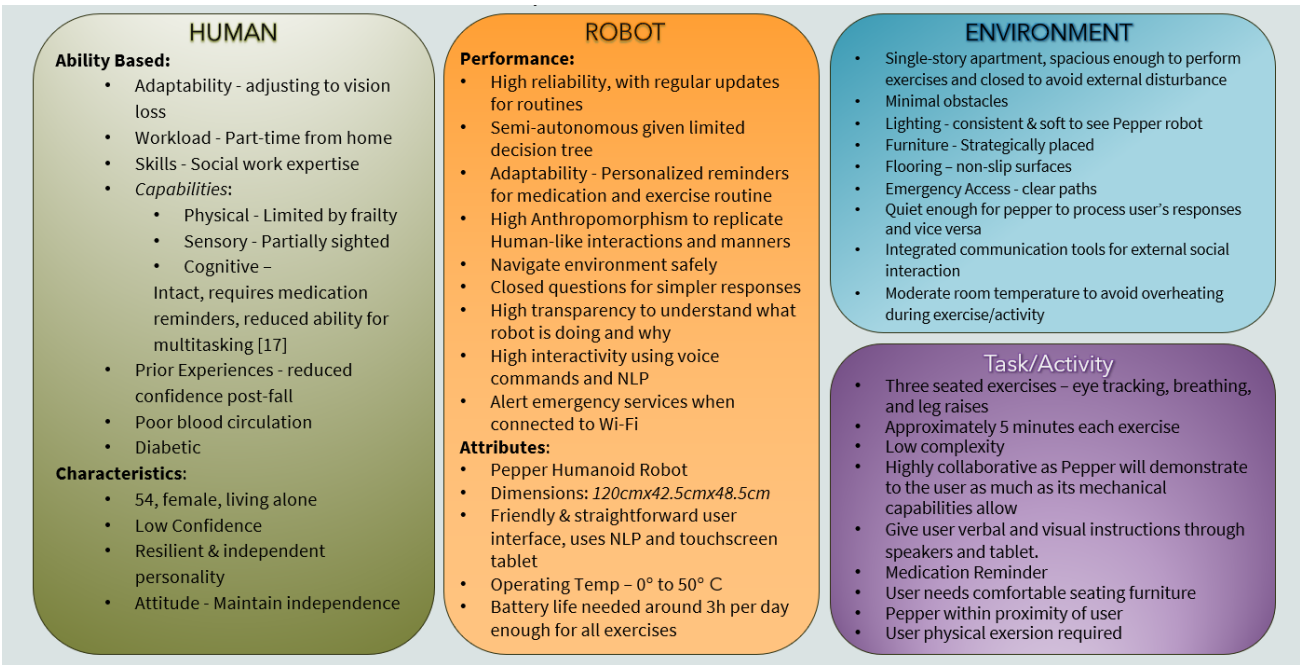

Fig. 2: HARE model for social task performed by Pepper robot considering persona mentioned in II-C. Reference [25] in the image the shows that glaucoma patients have reduced ability to divide attention and multitask.

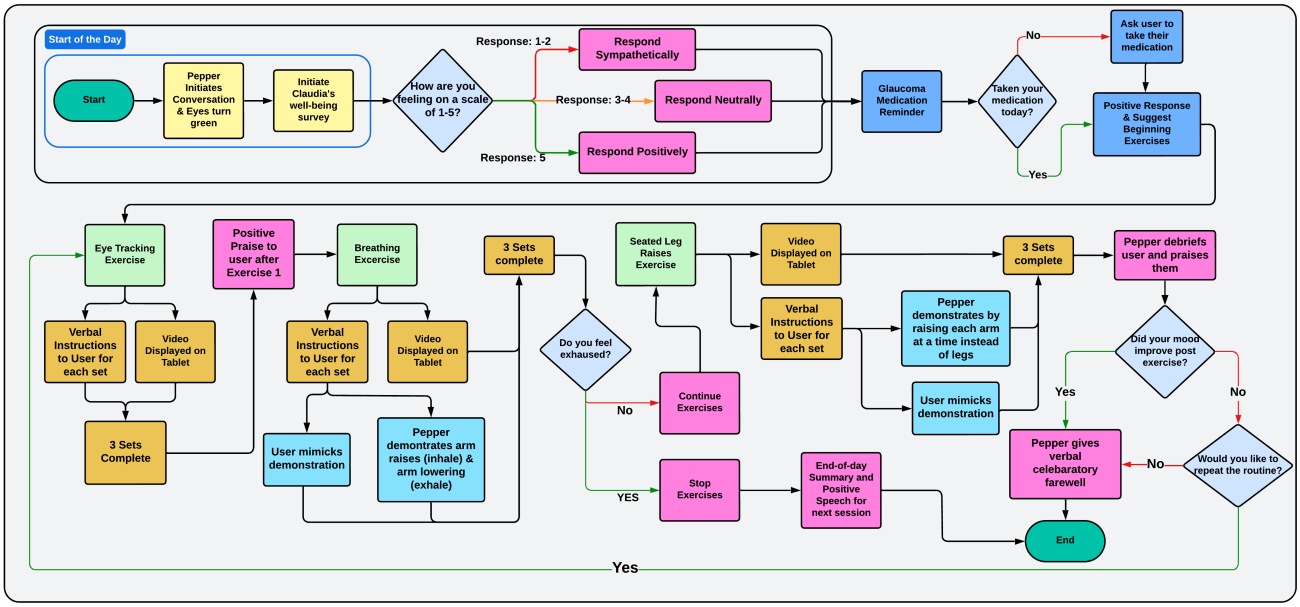

Fig. 3: Flow diagram for social task comprising of a medication reminder and 3 seated exercises implemented in Choregraphe software.

teraction between Claudia and Pepper, the socially assistive robot. Pepper's design emphasises high reliability, adaptive communication, and safe navigation in Claudia's environment, considering her partial sight and medication needs. Its anthropomorphic features facilitate engaging interactions, while its mechanical capabilities enable it to perform exercises alongside Claudia, boosting her confidence. The environment is arranged to minimise obstacles, allowing Pepper to navigate easily and facilitate low-complexity seated exercises. Each session begins with structured routines, enhancing interaction clarity. Leveraging voice commands and natural language processing, Pepper reinforces instructions and prompts user engagement through its tablet interface. Careful volume configuration and periodic fatigue checks ensure safety and alignment with Claudia's needs. A comprehensive flowchart (Fig. 3) illustrates the interaction task.

B. Results

Aerobic exercise is highly beneficial for patients with glaucoma, as activities that elevate the heart rate can be enhanced by aerobic breathing techniques [26]. Authors in [27] suggest a beneficial link between overall cardiovascular health and eye health, stating that what is good for the heart and brain is also favorable for managing glaucoma. Seated leg raises, also known as ankle stretches, have been

Fig. 4: Pepper's eye turns green

Fig. 5: Eye Exercise

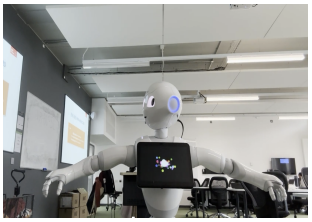

Fig. 6: Breathing Exercise

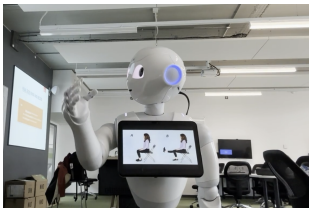

Fig. 7: Leg Raise Exercise

Fig. 8: Exercises demonstrated by the Pepper robot to enhance user mobility and wellness

shown to lower intraocular pressure (IOP) and improve blood flow to the brain and eyes [28], [29]. This reduction in IOP is crucial for glaucoma patients as high IOP is a major risk factor for the progression of this eye condition. Therefore, engaging in regular aerobic exercises, complemented by proper breathing, can significantly benefit the health of glaucoma patients by mitigating one of the key risk factors of the disease. In our design, Claudia was asked after the first two exercises if she feels exhausted and is able to continue the routine or not. The flowchart in Figure 3 details the subsequent responses.

Given that Pepper lacks mechanically functioning legs and cannot demonstrate seated leg raises, this limitation was addressed by programming Pepper to raise one arm at a time to mimic the leg raise for the user, as illustrated in Figure 7 and shown in the design in Figure 3. Additionally, although perceptions of colour can vary significantly across different cultural contexts, the colour green is generally associated with calmness and relaxation. Therefore, in the interface design, Pepper's eyes are programmed to turn green when inquiring about the user's well-being, as shown in Figure 4, to evoke a sense of tranquility. This design choice is grounded in the principles of colour psychology [30]. Regarding the first exercise shown in the flowchart of Figure 3, Pepper cannot physically demonstrate the eye-tracking exercise to the user. Therefore, only verbal instructions along with a video displayed on the tablet, depicted in Figure 5, were delivered to the user. Finally, the breathing exercise was demonstrated to the user by Pepper raising both arms for inhaling and resting for two seconds before lowering its arms to show the exhaling process. This is depicted in Figure 6.

C. Discussion

This study explored the extent to which socially assistive robots can improve physical health and emotional well-being. We provided our persona with a comprehensive design aimed at enhancing her quality of life, despite her physical and emotional restrictions. The primary goal was to boost Claudia's confidence and encourage her to improve her physical abilities through a seamless recovery process. However, through meticulous design, development, and implementation, we identified numerous limitations that could be addressed in future enhancements.

Firstly, humans utilise a rich array of verbal and non-verbal cues, such as facial expressions, body posture, and gestures, which are integral to communication and cognitive processes [31], [32]. In this aspect, Pepper exhibited a limitation in adaptability to the user's non-verbal cues. While Claudia may express emotions or subtleties typically understood in human interaction, Pepper, constrained by its programming in Choregraphe, responds primarily to pre-coded keywords. This scripted nature of the interaction, although transparent, diminishes the robot's anthropomorphism. To address this, incorporating machine learning algorithms will allow Pepper to learn from Claudia's behaviours and preferences over time, adapting its responses and suggestions based on her changing needs. This can help the robot become more responsive to changes in Claudia's condition or routine.

The robot utilised three teaching methods—direct demonstration, analogous movements, and verbal instructions—to enhance its instructional capabilities. However, it is essential to acknowledge that individuals have diverse learning preferences. While our approach was effective for Claudia, others might benefit from a more hands-on learning style, akin to physiotherapy. Given that our users are often elderly and potentially vulnerable, it is crucial to adopt a range of teaching strategies to ensure a safe and effective learning environment. Tailoring the educational experience to each user's preferences through individual consultations could optimise their interactions with Pepper or other socially assistive robots.

In designing the Pepper robot for socially assistive tasks, several ethical considerations have must be meticulously addressed to ensure the responsible use of this technology. First, privacy and data security are paramount; all personal data collected by Pepper, including health information and daily routines, are to be encrypted and stored securely, adhering to privacy laws like GDPR [33]. Informed consent is a core principle, with the user having the ability to control, modify, and withdraw her consent regarding data use at any time. To prevent dependency, the robot's functionalities encourage Claudia's independence, promoting her ability to perform tasks on her own as much as possible, while still providing necessary support when needed. This means that the Claudia should not solely rely on the robot to replace her social interactions with other humans, such as her daughter as assistive robots are meant to assist and not replace humans. Transparency must be maintained in all of Pepper's operations, ensuring that Claudia understands what the robot is doing and why, through clear, understandable explanations. The robot's design must also be inclusive, avoiding discrimination by being adaptable to diverse user needs and ensuring equitable assistance. Finally, safety and error handling should be rigorously implemented; Pepper should be equipped with robust error detection mechanisms and safety features that minimise risks and provide clear protocols for Claudia to summon human assistance in case of an emergency.

Pepper into Claudia's daily life would provide a vital social interaction, effectively reducing feelings of lone-

liness and isolation. By engaging in regular, structured conversations and activities, Claudia would experience a sense of companionship that enhances her emotional well-being.

Furthermore, Pepper's implementation of a structured exercise routine would lead to notable improvements in Claudia's physical health. These exercises, tailored to her capabilities, not only will aid in her recovery process but also promote long-term physical health benefits. By encouraging regular movement, the risk of further physical deterioration is mitigated, and her overall mobility would be enhanced.

Additionally, Pepper's ability to provide consistent reminders for medication and daily tasks could foster an environment of safety and routine for Claudia, crucial for her cognitive health. This regular prompting helps maintain Claudia's medication adherence and daily activity schedule, which are vital for her overall health management.

IV. Part B – Physical Assistive Robots

To effectively assess the impact of physical assistive robots for individuals with disabilities, our study focuses on the daily living scenarios of Claudia, a 54-year-old with severe glaucoma and mobility issues, by focusing on her daily living scenarios. We emphasise independence in robotic support, using the HARE Model to address her specific needs and ensuring ethical and safety considerations. The optimal solution facilitates Claudia's independent retrieval of objects, accommodating her sight limitations and promoting physical activity for rehabilitation. By informing her of item locations, the system minimises unnecessary movement, enhancing usability and improving the quality of life for those with similar disabilities, as outlined in the HARE Model in Fig10.

A. Methods

The HARE model informs our assistive robotics development with a focus on human-centered design and explicit objectives. It emphasises understanding patients' needs, aligning robotic systems with their preferences, and ensuring ethical considerations such as privacy and safety. Claudia, who recently experienced a fall, is ranked as a moderate impairment (level 4) on the CSF scale [16]. Consequently, we have established four key objectives for the assistive technology designed to support her [34]:

- Medicine Management
- Object detection and retrieval
- Navigation
- Safety monitoring with immediate response

Testing the robotic system within Claudia's daily routines, we designed task scenarios to cover all her needs and allow adaptation to other routines, enabling a critical assessment of the robot's performance in realistic settings.

Comprehensive Assistive Tasks

- **Medication Monitoring:** After Claudia takes her medication, the robot evaluates her health by asking about her sleep, pain, and overall feelings. Claudia's responses are recorded for health monitoring and alerting healthcare providers if needed.
- **Navigation Assistance:** The robot helps Claudia navigate to her home office and retrieve items such as work files and a phone, using voice commands for guidance and object detection for precise item retrieval.
- **Safety Checks:** Regular well-being checks ensure Claudia's health and safety. The robot uses verbal questionnaires to assess her mood and physical state, analysing responses to detect trends and trigger alerts to healthcare providers in case of concerning symptoms.

To ensure comprehensive task completion, the platform TurtleBot 4 enhanced with a manipulator system leverage its existing sensors and onboard computation powers since growth of mobile robots in assistance [34], an RGB-D camera, and a LiDAR sensor, has been meticulously designed following insights from the HARE Model. The inclusion of the LiDAR sensor is pivotal for its navigation capabilities, enabling the robot to effectively implement Simultaneous Localisation and Mapping (SLAM) techniques [18]. This technology allows the robot to create a detailed map of its environment while simultaneously tracking its own location within that space, crucial for accurate and efficient navigation throughout the apartment.

Fig. 9: Robot Design System [35]

The robotic system is strategically programmed to traverse every designated key area within the apartment at least once, ensuring no space is overlooked. It is equipped with distinct auditory alerts—different tones are emitted based on whether an object is detected or not, providing clear and immediate feedback on search outcomes.

The robot employs an RGB-D camera paired with the YOLO v9 algorithm for object detection, initially trained on the RGB-D Object Dataset. This dataset, known for its extensive collection of 300 household items, provides a robust base for accurate object recognition. To enhance specificity for Claudia's environment, the system will receive additional training using customised data from her daily surroundings. This targeted approach ensures precise and personalised object detection, significantly boosting the robot's effectiveness in performing assistive tasks within her apartment.

A user-friendly interface in Fig 13 and voice assistance enable Claudia to easily interact with the robot, which autonomously delivers items or notifies her of their locations based on her preferences, enhancing her daily activities and independence. For hazard mitigation and to further support her autonomy and safety, her home has been modified by rearranging furniture to create clear pathways, enhancing

lighting, making kitchen essentials accessible with anti-slip mats, organising the bedroom with night lights, and installing grab bars and rubber mats in the bathroom. Additionally, rugs and cords have been secured, smart plugs have been installed to simplify appliance control, and clutter-free doorways and hallways ensure unobstructed access throughout her home Fig. 16.

B. Results

The results section highlights the successful design of the robotic system, illustrated through detailed flowcharts for each task. These flowcharts intricately depict how the wide range of sensors integrated into the system enables seamless execution of various tasks, catering to Claudia's specific needs and preferences Fig 10 By incorporating these flowcharts into the narrative, a clearer understanding of how the design effectively fulfills the requirements outlined for the persona, ensuring an enhanced user experience and efficient interaction with the robotic system Fig. 12

When crafting the user interface and experience (UI/UX) for Claudia, who has partial sightedness and glaucoma, simplicity and accessibility are paramount. The interface insights were drawn from [36]should prioritise large, high-contrast text and graphics to enhance readability for Claudia. Clear and intuitive icons, buttons, and navigation menus streamline the user experience, ensuring Claudia can easily understand and navigate the system. Customise font sizes and contrast settings allow Claudia to adjust the display according to her preferences and comfort level, while audio feedback and voice commands provide additional accessibility options, enabling Claudia to interact with the system effectively through auditory cues.

In addition to visual accommodations, minimising visual clutter and complexity in the UI [37] design reduces cognitive load and enhances usability for Claudia. Consistent layout and design patterns across different screens promote familiarity and ease of use, while incorporating tactile feedback through vibration or tactile markers on touchscreens can provide additional sensory cues for Claudia, aiding in navigation and interaction Fig.15. By prioritising simplicity, clarity, and accessibility we also did the focus analysis for the UI displayed in 17 and 18 in the UI/UX design [38], the system ensures that Claudia can easily understand and use the technology, empowering her to engage with it independently and confidently. The **Preview [38]** can be accessed. the

C. Discussion

The proposed physically assistive solution demonstrated satisfactory performance in achieving its design specifications, successfully assisting Claudia in her daily task for medical well-being and reminders, navigating around the house, object detection and retrieval on command within a flat environment. However, Yet for optimised functionality and elevate user satisfaction, it's imperative to discuss various shortcomings.

Initially, RFID technology was considered for object tracking in Claudia's environment, but we opted for machine vision due to its higher accuracy, flexibility, and real-time adaptability [39]. Machine vision offers advantages over RFID in non-invasive operation, aligning with healthcare safety standards. Research highlights RFID's limitations, including susceptibility to interference and false detections [40]. Looking ahead, leveraging machine vision promises to enhance Claudia's assistive system, improving her interaction with the environment and daily tasks' safety [39], [40].

One of the notable features of the robot is its RGB-D camera, strategically positioned at a height of 50 inches, distinct from the LiDAR sensors on the TurtleBot-4 platform used for SLAM [17], [18]. This deliberate placement ensures a wide range of vision, empowering the robot to detect objects situated at elevated positions, such as shelves or tables. By having this dedicated camera configuration, the robot excels in object detection tasks across various surfaces and elevations, enhancing its versatility and functionality in diverse environments.

Incorporating a 360-degree camera presents a promising opportunity to enhance the robot's environmental awareness. By expanding the viewing range, the robot can conduct a more thorough scan of its surroundings, leading to improved object detection efficiency. However, the current challenges with the YOLOv9 object detection system impact search duration and battery consumption. This uncertainty about task completion can induce anxiety for Claudia as she awaits the robot's status updates. Balancing object detection and retrieval will always involve trade-offs. Addressing these concerns is crucial to ensure a smoother and less stressful user experience.

Improving the robot's manipulation and grasping abilities is crucial for its effectiveness. One avenue is to incorporate soft grippers designed to handle a diverse range of objects. By utilising soft grippers, the robot gains versatility in retrieving various items, as these grippers can conform to different shapes and textures more effectively. This approach not only enhances the robot's grasping capabilities but also improves its overall performance in object retrieval tasks.

From a user interaction perspective, the robot's protocol to halt upon detecting an object and prompt for retrieval, or providing audio cues for its location, while effective in a controlled demonstration, proves less practical in cluttered or spacious environments. This approach could lead to user confusion if the robot stops far from the detected object. However, leveraging an RGB-D depth camera [41] helps the robot gauge optimal interaction range, ensuring more precise positioning before halting. An additional strategy could involve displaying a possible map of previously detected objects on Claudia's app, enabling her to view and retrieve items independently. If the object isn't at the indicated location, Claudia can instruct the robot to sweep and detect the object, conserving robot battery and promoting her independence.

Moreover, safety considerations regarding the manipulator around the user are paramount, especially given Claudia's partial sightedness. There is a potential risk of collision if the manipulator's movements aren't carefully monitored. To address this, integrating motion sensors that detect nearby motion within a few inches can prompt the robot to retract its arm, minimising any obstructions to Claudia's movement and ensuring a safer interaction

Human Abilities:

Ability

- Moderate visual loss
- Social interaction difficulties
- Level 4 frailty
- Glaucoma
- Poor blood circulation
- Recovering from a fall with limited mobility

Characteristics:

- Elderly
- Lacks confidence
- Experiences isolation issues
- Values companionship
- Prone to fatigue
- Exhibits slow reaction times

Robot Performance:

Performace

- Reliable and safe deployment to minimize the user's risk of falling.
- The robot assists the user without fostering dependency.
- Clear audio cues are provided when an object is detected, simplifying the task.
- Improved field of vision with a camera positioned at the top.
- Navigation avoids rapid movements to enhance safety.
- Adaptive map generation enables movement and storage of previously detected objects' locations for easier retrieval.
- The conversational interface is clear and slow-paced to accommodate visual impairments.

Attributes:

- Low anthropomorphism
- Battery life sufficient for five sweeps of the apartment before needing to return to the charging dock.
- Emotive speech output
- User interface accessible via mobile app and voice commands, tailored for elderly users.
- Compact design with a 14-inch diameter and 50-inch height to navigate tight household spaces and cover a wide range.

Activity:

- The robot initiates daily greetings and conversations to promote engagement.
- Scheduled reminders for medication and well-being checks are set.
- Users select preferences for sensory detection and object recognition.
- Audio cues are used by the robot to signal successful detection.
- Users can request the robot to retrieve or locate objects based on their mood.
- Equipped with a manipulator, the robot grasps and retrieves objects on command.
- Highly dexterous and capable of detecting a wide range due to strategic camera placement throughout the apartment.

Environment:

Home Setting:

- Indoor environment with minimal obstacles
- Stable Wi-Fi for real-time data processing and remote monitoring
- Living areas like the lounge, kitchen, and bedroom accessible to the robot

External Factors:

- No pets or children present that could startle the robot
- Adequate lighting for the robot's visual sensors
- Soundproofing considerations to enhance audio interactions

Fig. 10: Refined HARE Model for the Robot physically assistive search, detect, and retrieve routine.

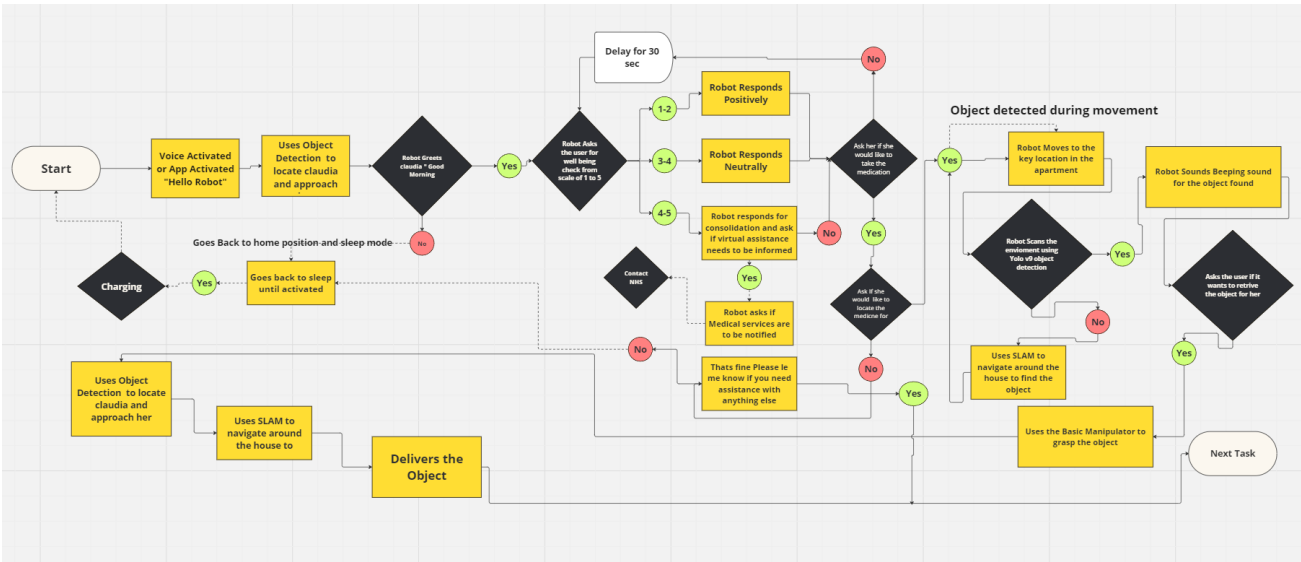

Fig. 11: Flow diagram for Physical assistive task comprising of a medication reminder and object detection and Retrieval

environment.

Ethical considerations are paramount, particularly regarding the privacy and security of user data. Given the robot's reliance on mapping the user's home and processing visual and audio data, it's imperative to implement stringent measures to safeguard data integrity and privacy. This entails robust protocols to prevent unauthorised access or misuse, thereby upholding the trust and confidence of users in the system's operation.

There's a critical concern regarding potential dependency promoted by the robot, particularly for users like Claudia recovering from physical ailments, which could hinder mobility and impede recovery. To address this, a selective approach for essential item retrieval can be implemented. The robot assists with precise retrieval of listed critical items while providing navigational support through audio cues for common objects, encouraging Claudia's active involvement and fostering independence essential for her recovery journey.

To overcome these limitations, it's crucial to implement thoughtful design adjustments and conduct rigorous testing. This approach ensures that the assistive solution not only fulfills its functional objectives but also adheres to stringent safety, privacy, and ethical standards. By prioritising user trust and acceptance, we can create an environment where individuals feel confident in relying on the technology to

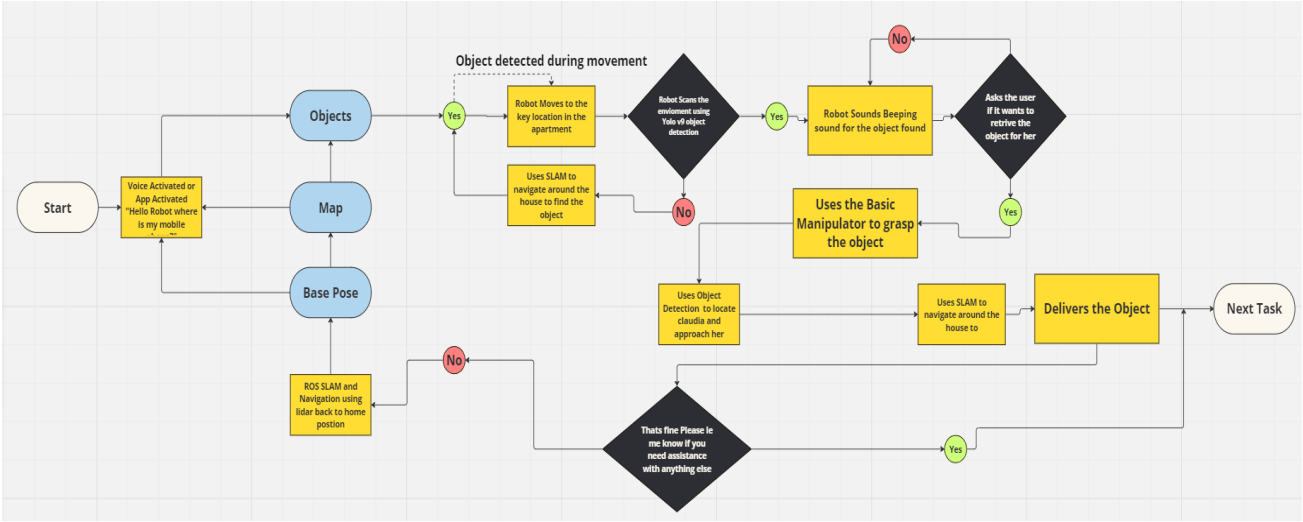

Fig. 12: Flow Chart For Object Detection and Retrieval Prompt using SLAM and Object Detection.

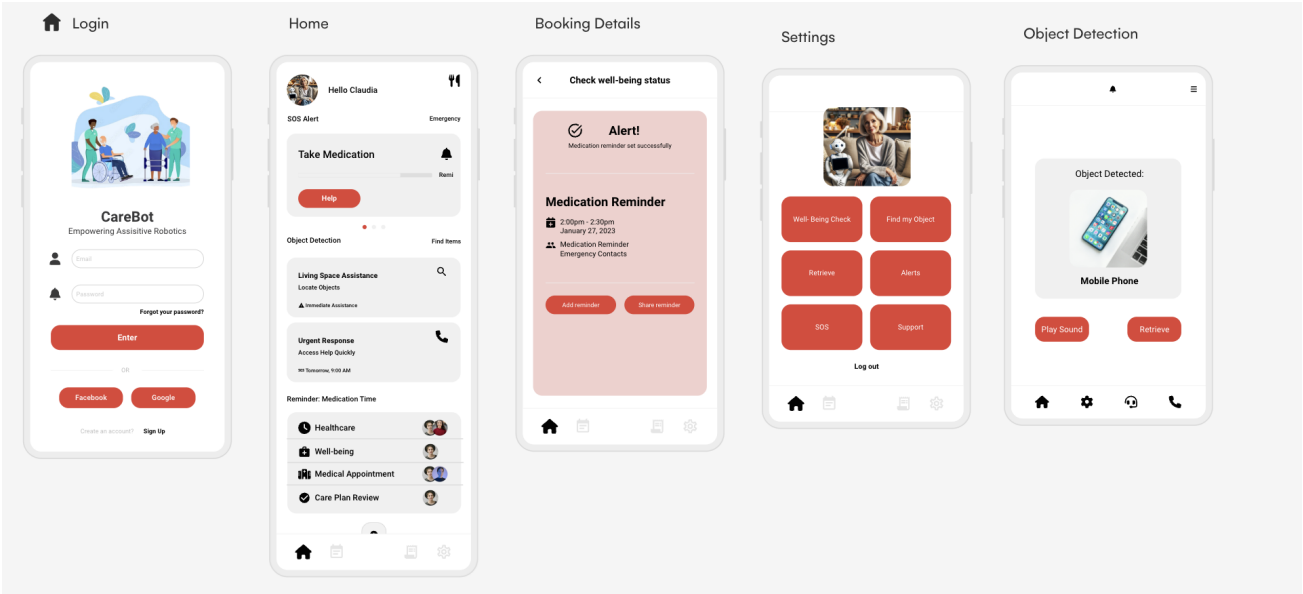

Fig. 13: Accessible and User-Friendly Mobile App Interface for Claudia

improve their quality of life without compromising their well-being or privacy.

D. Reflection

During the development of our assistive robotic solutions, we encountered a notable disparity in team member contributions, particularly regarding technical involvement and health technology support.

In programming the Pepper robot for socially assistive tasks, there was a lack of input from the health tech side, limiting our ability to integrate advanced health-related functionalities that could have enhanced the robot's interaction capabilities.

The initial design discussions for the TurtleBot, intended for physical assistance and object detection using RFID, lacked significant valid arguments to substantiate their case and input from health tech perspectives. This missed opportunity could have enriched our solution with health-specific considerations, enhancing the robot's utility and safety.

In terms of report and presentation efforts, Pruthvi and Yazan primarily undertook tasks such as developing HARE models, designing flow diagrams, and recording demonstrations. Mosses contributed literature relevant to the project's introduction and the significance of exercises for the persona.

However, Queen, Fadumo (who attended only one lab session), and Andy did not contribute to critical elements of the project. We request fair marking, where students who did not contribute face penalties.

This uneven distribution of work and the lack of health tech input posed significant constraints, limiting our project's scope and interdisciplinary approach. To address these issues, future projects should ensure balanced team involvement and incorporate health tech expertise from the outset. Implementing a checklist reviewed by the module leader during lab sessions can monitor and ensure equitable team contributions and health tech involvement, fostering a more collaborative learning environment.

E. Conclusions and Future Work

The combination of social and physical robotic technologies is transforming assisted living, significantly enhancing Claudia's independence and reducing her reliance on traditional healthcare systems. By staying in her own home, Claudia not only alleviates the burden on healthcare providers but also rebuilds her confidence. The robot offers support without fostering dependency, enabling her to handle daily activities on her own. This demonstrates the crucial role of assistive robots in boosting autonomy and improving quality of life, making healthcare more manageable and effective for individuals like Claudia.

Our proposed solution involved deploying two types of robots: the Robotic system, based on the TurtleBot 4 platform [17] for physical assistance, and the Pepper robot for social interaction and tasks. Both robots met their foundational goals through straightforward implementations.

The TurtleBot-4 platform with enhanced framework, equipped with YOLOv9 [19] trained on the RGB-D Object Dataset [42] for object detection of 300 household items and SLAM with Lidar for navigation, can autonomously locate and retrieve items within a home. It uses a robotic manipulator for retrieval and notifies users with audio cues, enhancing accessibility. Meanwhile, the Pepper robot serves effectively as a robotic rehabilitation coach. Utilising its natural verbal skills and physical movements, Pepper initiates exercise sessions with a mood-check conversation and medication reminders, followed by a structured exercise routine, thereby boosting user motivation and engagement during recovery.

F. ***Directions for Future Enhancements***

Robot Enhancements:

- Interactive Media: Add a Touch Display to Enhance Claudia's Interaction.
- Object Detection: Broaden the range of recognisable objects and refine the detection algorithms.
- Grasping: Introduce modular components to customise according to user needs. Enhancements could include advanced audio modules that not only provide clearer voice commands but also deliver more emotional and familiar tones, improving user interaction. Additional improvements could include enhanced grippers for more precise object manipulation and integrated automated medication dispensers within the robot's hardware.
- Safety Features: Include sensors to detect and warn against potential hazards like stairs and obstacles.
- Data Privacy: Enhance privacy by locally storing navigation data and ensuring secure data erasure.

Pepper Robot Enhancements::

- Conversational Abilities: Upgrade the natural language processing capabilities to support more complex and engaging interactions, potentially through enhanced dialogue management and adaptive learning algorithms.
- Machine learning: Enhance Pepper with machine learning to learn Claudia's patterns, predict her daily routine, and adapt dialogue accordingly. This will allow for more personalised and anticipatory interactions.
- Exercise Demonstrations: Enhance Pepper's ability to demonstrate a broader range of exercises, perhaps through better Interaction.
- Performance Monitoring: Integrate additional sensors to monitor user performance and provide corrective feedback, enhancing safety during exercises.
- Enhanced Security: Enhance privacy and security measures to robustly protect user data.
- Mobility Enhancement: Equip Pepper with better navigation sensors and algorithms that can handle diverse terrains and tighter spaces more effectively. This could involve the integration of more sophisticated mapping and obstacle avoidance systems.
- Software Improvements- Regular updates and bug fixes for the Choregraphe application to enhance stability and functionality. Improve natural language processing capabilities to better understand and respond to user commands, particularly in noisy environments or when the user has speech impairments.

Integrating both robots into an Ambient Integrated Living system would entail using multiple sensors and inputs from wearable devices like smartwatches to monitor the user's health and environment effectively. Future research should explore the long-term effects and ethical issues of using assistive robotics in residential settings. Collaboration among researchers, industry experts, policymakers, and users is vital to enhance the safety and effectiveness of these technologies. Such partnerships are essential for the responsible implementation of assistive robots to improve life quality and well-being.

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V. Appendix A: Hazard Analysis Worksheet Agent

Table I details the potential hazards associated with the deployment of the Pepper robot in a socially assistive task, the type of interactions involved, and the mitigation measures to minimise risks. Each component of the robot's functionality is considered, ensuring that both user safety and effective assistance are prioritised. This approach helps in developing a system that is not only beneficial but also safe for the user, aligning with ethical standards and safety engineering principles addressed in our Week 2 lecture materials.

VI. Appendix B: Hazard Analysis Worksheet Object

Table II thoroughly addresses the physical interactions and potential hazards associated with each component of the TurtleBot 4 as it operates within an interior space. The mitigation measures proposed aim to enhance safety and ensure that the robot effectively supports Claudia's needs without introducing new risks. This analysis is crucial for ensuring the TurtleBot 4's deployment is both beneficial and safe.

Component	Agent Type	Interactions	Hazardous Consequences	Hazard Risk Reduction / Mitigation Measures
Mobility	Autonomous Systems	Pepper navigates around Claudia's home to interact and assist.	Potential collision with user or furniture could cause injury or damage.	Implement obstacle detection sensors; apply speed control algorithms; conduct regular system maintenance.
Interactive Touch Screen	Automatic Systems	Claudia interacts with Pepper via touch screen for commands and feedback.	User frustration or incorrect commands due to unresponsive or malfunctioning screen.	Integrate responsive touch screen technology; provide manual override options; regular functionality tests.
Audio Communication	Social/Communicative Behaviour	Pepper communicates with Claudia using voice commands and responses.	Miscommunication due to high volume or unclear speech output, especially critical during emergencies.	Install volume control accessible to Claudia; use clear and concise language; incorporate advanced speech recognition.
Visual Sensors	Autonomous Systems	Pepper uses cameras to recognise and respond to Claudia's presence and gestures.	Misinterpretation of gestures leading to inappropriate actions; privacy concerns.	Employ redundant visual systems; regular updates to recognition software; ensure data privacy through secure processing.
Emotive Communication	Social/Communicative Behaviour	Pepper displays emotive responses to interact with Claudia.	Misinterpreted robot emotions could distress or confuse the user.	Design universally recognisable emotive expressions; update emotional AI responses based on user feedback.
Emergency Response	Autonomous Systems	Pepper detects emergencies (e.g., falls) and alerts services or caregivers.	Inadequate emergency response could exacerbate health situations.	Implement reliable detection algorithms; ensure seamless communication with emergency services; user training on emergency protocols.

TABLE I: Hazard Analysis for Pepper robot.

Environment Region / Domain	Object Type	Interactions	Hazardous Consequences	Hazard Risk Reduction / Mitigation Measures
Interior Space of Claudia's Home	Moving (as determined by natural forces e.g., battery operation)	TurtleBot 4 navigates to locate, retrieve, and deliver objects that Claudia struggles to find.	Collision with furniture or Claudia, leading to potential injury or damage to objects and robot.	Implement obstacle detection and collision avoidance systems; apply adaptive speed controls; regular maintenance and safety checks.
Interactive Components (Touchscreen, Buttons)	Movable (normally static but can interact when activated)	Claudia interacts with TurtleBot 4 using touchscreen or buttons for commands.	Incorrect operation due to user interface errors or failures, causing frustration or incorrect robot actions.	Design user-friendly interfaces with clear instructions and feedback; include manual override and emergency stop functions.
Navigation System	Moving (as determined by programming algorithms)	TurtleBot-4 uses SLAM technology to map and navigate the home environment.	Misnavigation leading to the robot becoming stuck or lost, failing to perform its tasks.	Use advanced SLAM algorithms; regular software updates; integrate manual control options for Claudia.
Battery and Power System	Fixed in the terrain (within the robot)	Provides power for movement and operations of TurtleBot 4.	Battery failure, overheating, or premature depletion could lead to interruptions in task completion or safety risks.	Incorporate battery management systems with temperature and charge level monitoring; provide clear battery status indicators to Claudia.
Object Detection System	Moving (as determined by sensor activation)	Utilises cameras and sensors to identify and interact with objects.	Failure to correctly identify objects, which could result in inappropriate actions or inability to assist Claudia effectively.	Employ redundant sensing systems; continual training of AI models on diverse objects; regular testing under various conditions.
Emergency Response Features	Fixed in the terrain (programmed responses)	Activates in case of detected falls or emergencies involving Claudia.	Inadequate response to emergencies, potentially worsening the situation or delaying necessary intervention.	Integrate reliable fall detection sensors; establish direct communication links to emergency services; frequent drills and updates.

TABLE II: Interaction and Hazard Analysis for TurtleBot 4 in a Domestic Environment.

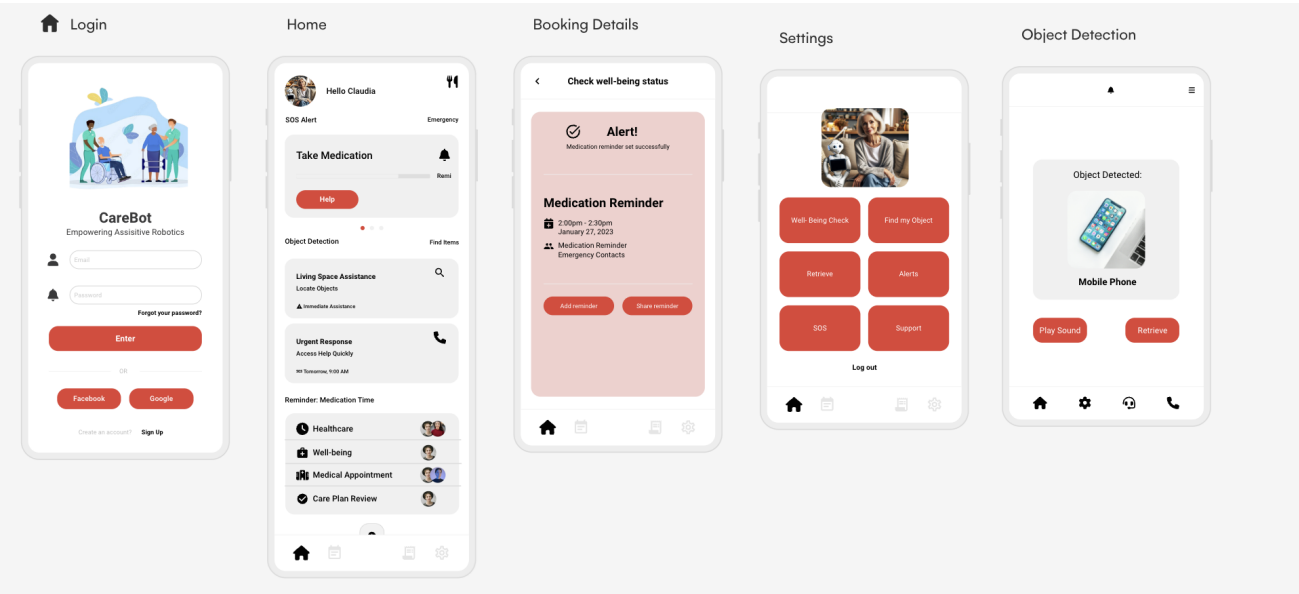

Fig. 14: User Interface Design for Claudia App

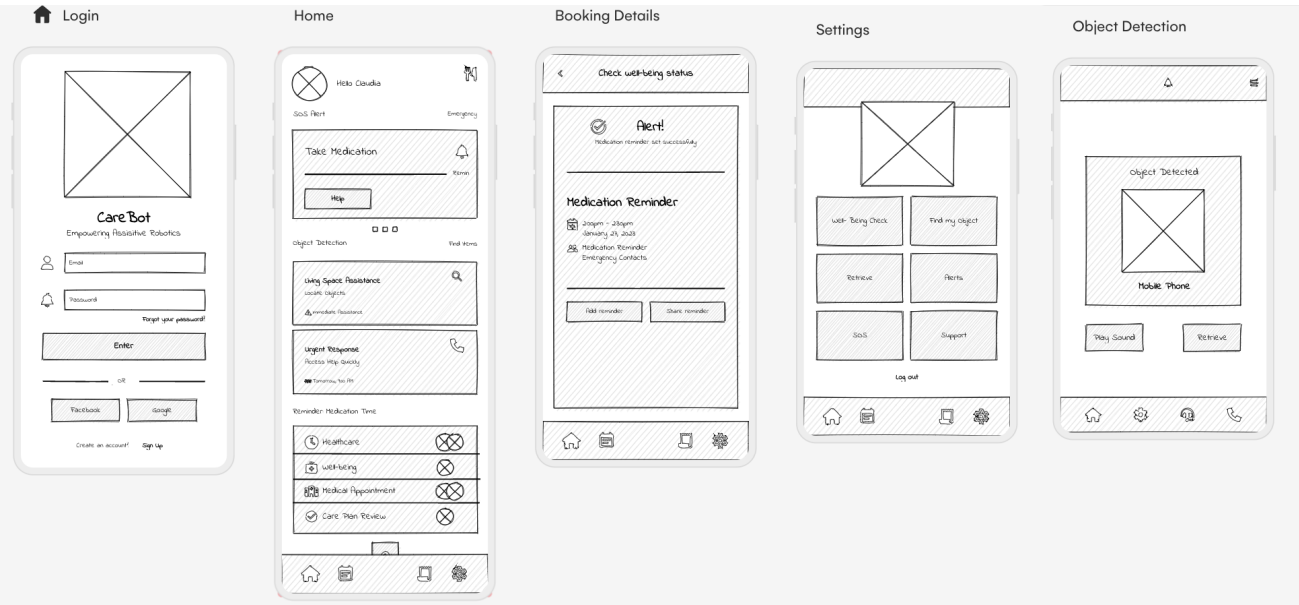

Fig. 15: Framework design of the App

Fig. 16: Modified House Layout for Claudia

Fig. 17: Focus prediction for page emphasis on Home page

Fig. 18: Focus Prediction for Living space assistant