Enhancing Elderly Health Monitoring: Achieving Autonomous and Secure Living through the Integration of Artificial Intelligence, Autonomous Robots, and Sensors

Andrea Antonio Cantone [1], Mariarosaria Esposito [1], Francesca Pia Perillo [1], Marco Romano [2,*], Monica Sebillo [1] and Giuliana Vitiello [1]

1   Department of Computer Science, University of Salerno, 84084 Fisciano, Italy; acantone@unisa.it (A.A.C.); m.esposito281@studenti.unisa.it (M.E.); fperillo@unisa.it (F.P.P.); msebillo@unisa.it (M.S.); gvitiello@unisa.it (G.V.)
2   Faculty of Political Science and Psychosocial Studies, Università degli Studi Internazionali di Roma—UNINT, 00147 Roma, Italy
*   Correspondence: marco.romano@unint.eu

Abstract: The use of robots in elderly care represents a dynamic field of study aimed at meeting the growing demand for home-based health care services. This article examines the application of robots in elderly home care and contributes to the literature by introducing a comprehensive and functional architecture within the realm of theInternet of Robotic Things (IoRT). This architecture amalgamates robots, sensors, and Artificial Intelligence (AI) to monitor the health status of the elderly. This study presented a four-actor system comprising a stationary humanoid robot, elderly individuals, medical personnel, and caregivers. This system enables continuous monitoring of the physical and emotional well-being of the elderly through specific sensors that measure vital signs, with real-time updates relayed to physicians and assistants, thereby ensuring timely and appropriate care. Our research endeavors to develop a fully integrated architecture that seamlessly integrates robots, sensors, and AI, enabling comprehensive care for elderly individuals in the comfort of their homes, thus reducing their reliance on institutional hospitalization. In particular, the methodology used was based on a user-centered approach involving geriatricians from the outset. This has been of fundamental importance in assessing their receptivity to the adoption of an intelligent information system, and above all, in understanding the issues most relevant to the elderly. The humanoid robot is specifically designed for close interaction with the elderly, capturing vital signs, emotional states, and cognitive conditions while providing assistance in daily routines and alerting family members and physicians to anomalies. Furthermore, communication was facilitated through an external Telegram bot. To predict the health status of the elderly, a machine learning model based on the Modified Early Warning Score (MEWS), a medical scoring scale, was developed. Five key lessons emerged from the study, showing how the system presented can provide valuable support to physicians, caregivers, and older people.

Keywords: socially assistive robotics; elderly; artificial intelligence; home-based healthcare; IoRT; user-centered approach

1. Introduction

The use of robotics in elderly care is a burgeoning area of research that seeks to address the escalating demand for home and healthcare services. This article explores the implementation of robots in elderly home care and provides a valuable addition to the existing literature by presenting a comprehensive and operational framework within the *Internet of Robotic Things* (IoRT) domain, which is generally finding wide use in various sectors [1,2]. This framework integrates robots, sensors, and Artificial Intelligence (AI) to effectively monitor the health conditions of the elderly. In recent years, people have been facing a

number of challenges affecting mental health in which technology is providing support, such as ADHD [3,4], dyslexia [5], and other disorders. The elderly population is characterized by vulnerability, with the aging demographic showing an increased prevalence of chronic diseases, physical impairments, mental disorders, and other co-morbidities [6–8]. Several factors influence this scenario, including:

- Social considerations: often, adult children are forced to leave their parents' home in search of employment, leaving their elderly parents isolated without support [9,10].
- Insufficient knowledge and awareness of risk factors: there is a lack of knowledge and understanding of the determinants that contribute to adverse health outcomes in elderly population [9].
- Dietary and nutritional requirements: given that nutritional deficiencies are significant risk factors for age-related chronic diseases, addressing the current predicament of inadequate nutrition requires the implementation of nutritional interventions that promote healthy lifestyles [11,12].
- Prescription requirements: Older people tend to rely on an extensive list of medications to be taken at specific intervals. This increases the complexity associated with appropriate medication intake, administration, and adherence [13].
- Psycho-emotional concerns: isolation, mental strain, and challenges associated with time management are notable psychological and emotional issues facing older people [14].

There are several types of robots, but in our study, we focus specifically on a class of robots known as social robots. In particular, these are a category of robots designed to interact and communicate with humans in social environments and in the smart home [15–18]. They are equipped with AI and have face, voice, and gesture recognition capabilities, enabling them to understand and respond to human interactions in a natural and engaging way. These robots can be used in a variety of social contexts, such as hospitals, schools, care homes, autism support, rehabilitation therapy, and support in work environments, such as customer service and in the education sector. One of their main goals is to enhance the social experience of individuals by providing emotional support, entertainment, and enjoyable social interactions. One of the most promising applications of social robots is in elderly care. These robots can provide companionship, monitor the well-being of the elderly, and even help with daily tasks, such as meal preparation and medication management. Studies have shown that interaction with social robots can have a positive impact on the emotional and mental state of the elderly, reducing loneliness and social isolation [19–22].

This study explores the dynamic and emerging field of robotics in elderly care in response to the growing demand for home and healthcare services. The main objective is to present a comprehensive and sophisticated architecture that seamlessly integrates robots, sensors, and AI to enable continuous monitoring of the physical and emotional well-being of the elderly. Real-time updates are carefully transmitted to doctors and healthcare practitioners, ensuring prompt and appropriate medical attention.

Our research is contributing to a complete and functional architecture that harmoniously blends robots, sensors, and AI to provide comprehensive care for the elderly in the familiar confines of their own homes, reducing the need for hospitalization. The integration of AI helps the elderly population by assessing their health. This is done by continuously measuring vital signs using sensors and by classifying health status through the use of a trained ML model on a specific medical score table called the Modified Early Warning Score (MEWS) [23]. The MEWS score is a medical measure used for all types of people and is commonly used in intensive care units. It was suggested to us by various geriatric experts. Geriatricians are main care doctors who have additional training in treating older adults, especially those aged 65 and over. People in this age range often have multiple or complex health problems and need specialized care. Geriatricians have the training and experience to deal with these issues.

In order to realize this project, we adopted a resolutely user-centered approach and conducted interviews with eminent experts in the field of geriatrics, seeking to distill the

essential requirements derived from the most common challenges faced by older people, as identified by astute medical professionals. In-field research conducted with stakeholders comprehensively encompasses requirements analysis and requires iterative feedback mechanisms to ensure a thorough and complete understanding of the requirements, thereby increasing the likelihood of successful implementation.

The main contributions of this paper are as follows:

- Presentation of a working and complete system architecture involving four actors (including carers, doctors, and the elderly) and several technologies (including AI, sensors, and robots);
- Five key lessons emerged from the study.

The paper is structured as follows: Section 2 delves into the existing literature and related studies pertaining to the monitoring of elderly health or the utilization of robots and sensors in healthcare. Section 3 provides a description of all the materials utilized in the research. It thoroughly explores the overall architecture of the system, encompassing both the robot and the external Telegram bot. It presents an analysis of the selected robot, including its technical specifications and functionalities. This section also outlines the set of vital parameters used to assess the health status of the monitored elderly individuals. Section 4 focuses on a comprehensive presentation of the external Telegram bot. This explains the functioning of the bot and the diverse functionalities it offers. Detailed instructions were provided on how users can interact with the bot to receive information about the health status of monitored elderly individuals, showcasing its potential applications in the healthcare domain. Section 5 offers practical examples and use cases of the system in action. It demonstrates how the robot and Telegram bot integrate to collect and provide health-related data for elderly individuals. Finally, Section 6 highlights the strengths and limitations of the system while discussing the implications of the results. This section outlines the potential avenues for future research and improvement.

2. Related Works

In this section, we review and summarise previous studies, research papers, and academic articles relevant to our research objectives. We discuss the conclusions of these papers, and assess their strengths and weaknesses. A review of current literature and relevant studies related to our research topic is presented. In the context of elderly care, it is very important to consider the ethical factor regarding the perception of healthcare robots for the elderly. In fact, according to a study by Boch et al. [24], the introduction of healthcare robots raises various ethical concerns and opportunities that require a holistic analysis from the perspective of both AI ethics and bioethics. An ethical approach to design can help prioritise the well-being and safety of users, avoid harm, respect user autonomy, promote equity in healthcare, and ensure transparency and accountability in decision-making processes. Boch et al. emphasise the importance of ensuring that systems developed in the healthcare sector respect AI ethical principles such as beneficence, non-maleficence, autonomy, justice, and accountability, bringing together the perspectives of AI ethics and bioethics. The article acknowledges that there will be specific ethical requirements within the subfield of AI, which may vary depending on the domain, culture, and users involved.

Mintrom et al. [25] consider the development of autonomous robots in public places and the associated policy implications. They highlight how rapid technological advances are making robots more efficient and autonomous, opening up new possibilities for interaction with people in public spaces. However, they also highlight the risk that robots may influence public spaces and social interactions in undesirable ways. The article draws attention to the paucity of public policy discussions on this issue and calls for more exploration by researchers and policy experts.

A range of technologies are currently being used in the care of the elderly, including the use of medical and environmental sensors. According to a systematic review by Alboksmaty et al. [26], there is limited evidence on the impact of the use of environmental sensors in

healthcare for older people. It has been shown that environmental sensor technologies can lead to cost savings, but further research is needed to assess the impact on health outcomes.

The research by Aminosharieh et al. [27] developed and tested a sensor system for smart chairs with 40 participants. The system is innovative and versatile due to the small number of sensors and optimised design. It transmits data via Wi-Fi without initialisation or cables and offers 30 hours of continuous operation. It can be used to identify emotions and behaviour.

One such technology is remote monitoring systems, which allow real-time tracking of vital signs and other critical health information, such as blood pressure, heart rate, oxygen saturation, and blood glucose levels [28]. These systems provide continuous, instantaneous monitoring of health status, enabling rapid diagnosis and intervention. They have the potential to minimise hospital admissions and frequent doctor visits, thereby increasing convenience for the elderly. However, the main limitations of these systems are their cost and the need for a robust Internet connection. Moreover, some elderly may find the use of continuous monitoring devices inconvenient [29].

In the field of preventive measures and health monitoring for the elderly, wearable devices such as smart watches, bracelets, or necklaces are often used to monitor physical activity, sleep patterns, and various parameters [30]. These devices provide continuous monitoring of daily activities and vital signs, encouraging a healthy and active lifestyle. Some devices also incorporate alarm features to address emergencies or falls [31]. Conversely, some elderly may not immediately comprehend the output provided by such sensors, necessitating professional evaluation to accurately interpret the data collected [32].

Telehealth is another technology used in this area, enabling the elderly to communicate with healthcare professionals or caregivers via video calls or online platforms [33]. This facilitates access to medical advice, rehabilitative therapies, or emotional support [34]. Telehealth allows direct and immediate communication with healthcare providers or caregivers, thereby reducing the need for physical travel. It can provide remote emotional support and medical advice [34]. However, some elderly may prefer human interaction and find it challenging to engage in virtual communication [35].

Home automation technology offers solutions to improve safety and make daily activities easier for the elderly. For instance, voice commands or smartphones can be employed to control lighting, temperature, or window shutters. Systems can also be implemented to detect open doors or windows, gas leaks, or flooding [36]. This type of technology promotes a safe and comfortable environment for the elderly, and streamlines their daily tasks. It promotes a sense of independence and autonomy while reducing the risk of domestic accidents [37]. However, configuring and installing home automation systems can be costly, and some elderly may find it difficult to adapt to using complex technology or may prefer a less automated environment [38].

Assistive robots are another potential technological solution, capable of assisting the elderly with various daily activities, including meal preparation, medication management, lifting or transferring, as well as providing companionship and social interaction [39]. These robots increase independence and overall quality of life, by providing companionship and emotional support. Some robots are even designed to provide personalised care and emotional support [40]. It is important to consider the significant costs associated with purchasing and maintaining robots, as well as the potential discomfort some elderly may feel when interacting with robots or their preference for human assistance [38].

In addition, many mobile applications and software are specifically designed for the elderly and their caregivers, including medication reminders, chronic disease management, physical activity monitoring, cognitive games, and online including services [41]. These applications are easy to install on smartphones or tablets. However, older adults may have difficult using apps independently due to their limited familiarity with technology or cognitive limitations [42].

Based on the review of the existing literature, our study has identified specific gaps and limitations in the current body of knowledge. These gaps highlight areas for further

investigation and provide a compelling rationale for our research. For instance, our analysis revealed that a prominent challenge associated with wearable devices is the understanding of the output generated by such sensors by the elderly population. In response, our proposed system aims to address this gap by focusing not on enabling the elderly individuals themselves to understand their health status, but rather on providing caregivers with comprehensive situational awareness of the health status of the elderly individuals under their care.

Furthermore, our review of the literature has shown that a subset of older adults express a preference for direct interactions with healthcare professionals or caregivers, as opposed to virtual communication methods. In light of this finding, we propose the use of a humanoid robot as opposed to a conventional device. By incorporating a humanoid robot into the care paradigm, older people can cultivate a higher level of trust in the device [43–48]. This trust-building process is paramount in facilitating effective communication and engagement between the elder and the robot, ultimately improving the overall care experience.

A study by Gasteiger et al. [49] investigated the experiences and perceptions of elderly people who had the robot textbfBomy in their homes for a week. The results showed a positive acceptance of the robot and its value as a daily care assistant, to the extent that the participants perceived Bomy as a companion. Daily care robots, including the one under consideration, have thus shown promising potential in caring for the elderly, particularly in providing medication reminders and monitoring health and well-being. According to Gasteiger et al, the future design and development of daily care robots should focus on quiet, friendly, and customised technology to meet different daily and healthcare needs, such as measuring vital signs.

A study by Kolstad et al. [50] investigated the use of robots in three different Japanese care facilities to assess their impact on care and to collect positive and negative experiences reported by the elderly and the staff involved. The interviews focused on communication robots. The results of the interviews suggested that all types of robots studied had a positive impact on the mental health and well-being of patients.

3. Materials and Methods

The purpose of this section is to examine the architecture and design of the proposed system and to provide a concise overview of the materials and methods employed throughout our research. By detailing the tools and techniques used, this chapter establishes a basic framework for the following sections and provides a clear understanding of the context in which our study unfolds. The architecture of the proposed system is outlined below, with a focus on the four main stakeholders involved. Moreover, the rationale for selecting a humanoid robot with an ergonomic design is explained, and the methodology for monitoring the vital parameters of the elderly is highlighted.

We conducted interviews with experienced geriatricians to gain insight into the critical elements required for comprehensive clinical assessment of elderly. Analysis of the interviews revealed the most relevant Functional Requirements (FRs), which can be categorized into two main areas: monitoring and communication.

3.1. Interviews and Requirements Analysis

Involving stakeholders, especially geriatricians, in the early stages of the project was crucial to its success. Their insights and feedback helped us to define clear project objectives and to develop a coherent strategy. Interviews with doctors provided valuable input and validation of design ideas, highlighting best practice in medicine. In particular, we interviewed ten individuals with experience in geriatrics and internal medicine, ranging in age from 35 to 68. The participants were selected on the basis of their expertise in geriatrics and internal medicine, and had extensive publication records and participation in scientific studies and conferences. Table 1 shows a matrix of the participants in the interviews.

Table 1. Explanatory matrix of the participants in the interviews.

Participant ID	Age	Sex	Specialization	Readhesion
1	35	M	Geriatrician, cardiologist	x
2	51	M	Geriatrician, internist	
3	56	F	Geriatrician	x
4	39	M	Geriatrician, angiologist,	x
5	45	F	Geriatrician, cardiologist, hepatologist	
6	67	M	Geriatrician, cardiologist, internist	
7	46	M	Geriatrician, angiologist,	
8	49	F	Geriatrician, cardiologist	
9	68	F	Geriatrician, cardiologist, hepatologist	x
10	37	M	Geriatrician, cardiologist, internist	

Geriatricians were asked targeted questions to understand common health problems in older people and their management, monitoring of vital signs and common signs of concern. The aim was to gather information for timely and accurate assessment and to ensure high-quality home care for this specific population.

The interviews provided a comprehensive picture of doctors' practices in managing the health of older people, focusing on the main health problems of older people, monitoring of vital signs, and challenges faced. Key questions explored doctors' receptiveness to intelligent tools for data processing and optimal health management solutions.

Assessing doctors' attitudes towards the use of intelligent tools is of paramount importance, as it guides the design of a monitoring system that meets the needs and preferences of the medical community.

The interviews allowed us to identify the main functional requirements of the project, with a focus on the monitoring of vital signs and the use of AI in the medical field. Some doctors are concerned about technology replacing their role, but they are trying to build a solution that maintains the necessary medical prognosis based on the experience of specialists. The interviews confirmed the importance of monitoring vital signs, and a possible classification system to distinguish between patient requests was discussed. The impact of the pandemic on the social isolation of the elderly and the increase in healthcare costs are also being considered. Based on the interviews, it is proposed to restructure home healthcare to improve monitoring and efficiency in caring for the elderly.

The requirements that emerged from the interviews can be grouped into two macro-categories:

- Monitoring: the aim of the proposed system is to ensure constant monitoring of the elderly person's health by capturing his or her vital parameters, as well as his or her emotional state. Wearable sensors make it possible to measure vital signs. It should be remembered that the parameters to be measured refer to the MEWS table. This table provides for the measurement of the response to stimuli. Such a measurement has not yet been carried out, and we will address this issue in future work. It is also essential to monitor the correct intake of medication therapy in order to avoid possible complications. With regard to this functionality, it is good to specify that currently the monitoring of medical therapy is done through a series of questions that QTrobot asks the elderly person at a specific time. We will discuss possible further implementations in future developments.

- Communication: the purpose of the proposed system is to provide accurate information on the health status of the assisted person by detecting vital parameters and generating an alarm if any problems are detected, with the necessary additional transmission of the vital parameters that led to the emergency call. It would also be desirable to display appropriate manoeuvres to be performed in the event of a delay in the arrival of help, should this be necessary.

The proposed system consists of four actors: (1) QTrobot, capable of interacting with the (2) elderly person in need of assistance. In addition, continuous updates are provided to (3) caregivers and (4) doctors to ensure full control of the elderly person's health and mental state. Table 2 shows the functional requirements.

Table 2. Functional requirements with the indication of category and actors: Q indicates QtRobot, E elderly person, C caregiver, and D doctor.

Category	Requirement	Actor
Monitoring	Display the current status of the parameters;	E C D
	Display of parameter history (weekly, monthly, annual);	E C D
	Monitoring of daily therapy or a specific date;	E C D Q
	Display of the list of prescribed medicines;	E C D
	Detection of elderly person;	Q
	Management of therapy;	C D Q
Communication	Automatic submission of help requests in case of alarming vital signs;	Q
	Emotional state detection and management;	Q
	Automatic forwarding of generic help requests, allowing the elderly to request assistance in case of non-specific need.	C Q

3.2. The Architecture of the Proposed System

Below is an overview of the proposed architecture. As shown in Figure 1, it consists of two Docker containers:

(1)　**NodeRed Container** is responsible for collecting the vital signs data collected by the sensors. This container acts as an interface for data collection and processing, ensuring accurate transmission to the system.

(2)　**AI Model Container** plays a crucial role in the workflow of the system. It receives vital signs from the NodeRed container and uses the $ML_{physical}$ model to predict the health status of the elderly person. These predictions are based on an evaluation of the vital signs captured by sensors, using the MEWS table, allowing early detection of any signs of deterioration. The $ML_{physical}$ model, trained using synthetic data, assists in determining health status. Synthetic data refers to artificially generated data that reflect the statistical properties of the original dataset without revealing any personally identifiable information. The generation of synthetic data is becoming increasingly important in various fields, particularly healthcare. Accurate categorisation and representation of the data is essential to provide reliable input to the classification algorithm. The generation process must be representative to ensure effective learning and accurate classification of the health status of elderly individuals. Synthetic data has shown promise in the field of AI and is seen as a prominent technology for the future, capable of mathematically and statistically replicating real events with precision [51,52].

Based on the processed data, QTrobot interacts in interactions with elderly, doctors, and caregivers through a Telegram bot interface. This allows doctors and carers to stay informed about the clinical and psychological status of the elderly person.In addition, the elderly person can interact with the robot using machine learning algorithms for face and voice recognition.As a result, the robot can respond and interact with the elderly person based on their current emotional state.The robot sends messages to the Telegram bot providing updates on the elderly person's physical and mental state, ensuring continuous real-time monitoring of their clinical and psychological condition.The Telegram bot facilitates bi-directional communication between relatives and doctors within the robotic system. For example, relatives can access current parameters, view historical data of all

parameters in daily, weekly, monthly or yearly formats, and review prescriptions issued by the doctor.
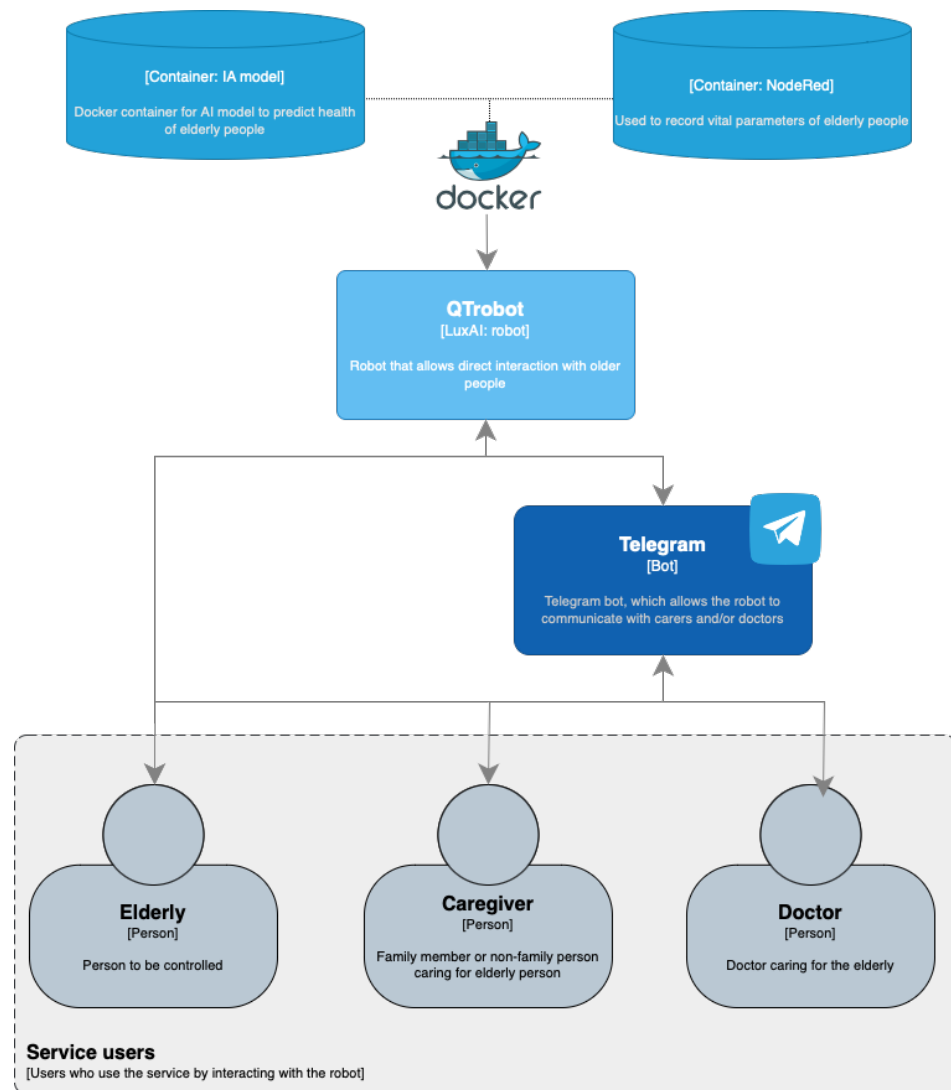

Figure 1. Proposed system architecture.

Our proposal encompasses a system that involves four key actors, each serving a 318 distinct role. These actors are described below:

(1) **Humanoid robot:** This actor interacts with the elderly person, using machine learning (ML) algorithms, specifically the ML_{mental} algorithm, to assess their emotional state. In addition, the humanoid robot employs sensors to measure the vital signs of the elderly. These vital signs serve as input to another ML algorithm, referred to as $ML_{physical}$, which categorises the measurements and determines whether the elderly person is in a healthy or unhealthy state.

(2) **Elderly people:** This actor represents the elderly population in need of continuous care, assistance, and companionship. The overall aim is to provide a system that ensures their safety and takes account of their health and mental state, enabling them to live independently in their own homes for an extended period of time.

(3) **Medical staff:** This actor is responsible for monitoring the vital signs and the decisions made by the $ML_{physical}$ algorithm. By continuously monitoring these factors, medical staff can ensure the elderly person's well-being.

(4) **Caregiver:** The carer is an additional person who can monitor the elderly person around the clock. Their responsibilities cover a wide range of tasks, including manag-

ing the elderly person's prescribed medical therapy and keeping abreast of the elderly person's daily activities.

One of the main objectives of this work is to establish a simple and intuitive means of interaction between the system and the elderly person. The aim is to promote independence and safety, enabling older people to remain in their own homes for longer. It also aims to provide peace of mind to family members while addressing the issue of cognitive impairment through various cognitive training activities.

This study proposes the implementation of a system centered around an elderly care robot that integrates a Telegram bot to facilitate communication between the robotic system, doctors, and caregivers. The system aims to improve elderly care by optimising communication, enabling continuous monitoring, and issuing alerts when the elderly person's vital parameters or mental state deviate from the normal range.

The care robot acts as a virtual companion, providing emotional and practical support to the elderly person. It assists with medication management, provides reminders for medical appointments, and offers personalised advice to promote a healthy lifestyle. In addition, the robot collects health data such as blood pressure and heart rate, which can be transmitted to doctors in real time for accurate monitoring.

Another important aspect to consider is the acceptance factor associated with such a system. To assess this factor, targeted interviews were conducted with specialists in the medical and robotic fields. The aim of these interviews was to assess the acceptability of the proposed system and to obtain expert feedback that could significantly influence its development.

Successful implementation of robots in elderly care requires close collaboration between clinicians and researchers. This collaboration is essential to ensure effective implementation and use of the system. Only through this concerted effort can the challenges be overcome and the full potential of robotic home care for the elderly be realised, ultimately improving the quality of life of the elderly and their families.

3.3. Humanoid Robot Selection

The evaluation of the robot to be used for the research was crucial, as an appealing and friendly device is required to create an engaging and emotional experience. The robot should be an ideal companion for activities that the elderly person has to perform on a daily basis, promoting cognitive development, improving social skills, and providing emotional and physical support. The robot selected to address these challenges at hand is the QTrobot for Research V2 (https://luxai.com/product/qtrobot-research-platform/, accessed on 23 August 2023), developed by LuxAI, a company specializing in the development of humanoid robots. As shown in Figure 2, QTrobot has an appealing and friendly design, making it an ideal companion for therapeutic and recreational activities. Designed primarily for interactions with children, its interactive and customizable features allow it to adapt to the specific needs of its users, facilitating cognitive development, enhancing social skills, providing emotional support, and serving various other purposes. The ongoing development of our system exemplifies the integration of robotics, AI, and sensors, and demonstrates their potential to improve the quality of life and overall well-being of older people.

QTrobot is a remarkable example of an advanced robotics technology that integrates hardware with the use of AI. Its ergonomic design places it at the forefront of interactive robots. This robot consists of two devices: the QT Robot Platform (QTRP), located in the table, and the QT robot PC (QTPC, Intel NUC i5/i7), located in the body of the robot. The latter provides the necessary power to support rapid software development. The QTrobot hardware is easily expandable via USB-c and USB adapters, allowing for the connection of external monitors, keyboards, and mice. Further accessibility is provided by a rich set of Application Programming Interfaces (APIs) supporting various programming languages, such as C++, Python, and JavaScript. The QTrobot has been equipped with highly sensitive sensors to ensure good perception and interaction with the environment. These include

an Intel(R) RealSense TM Depth Camera D455 and a powerful 4-microphone system. This enables the QTrobot to recognise faces, emotions, and sounds. In addition, the built-in speaker system allows the robot to produce high-quality sound and converse naturally with users. Table 3 provides the capability matrix and is a summary of the QTrobot's technical details, covering its microcontroller, processors, sensors, actuators, mobility, and communication.
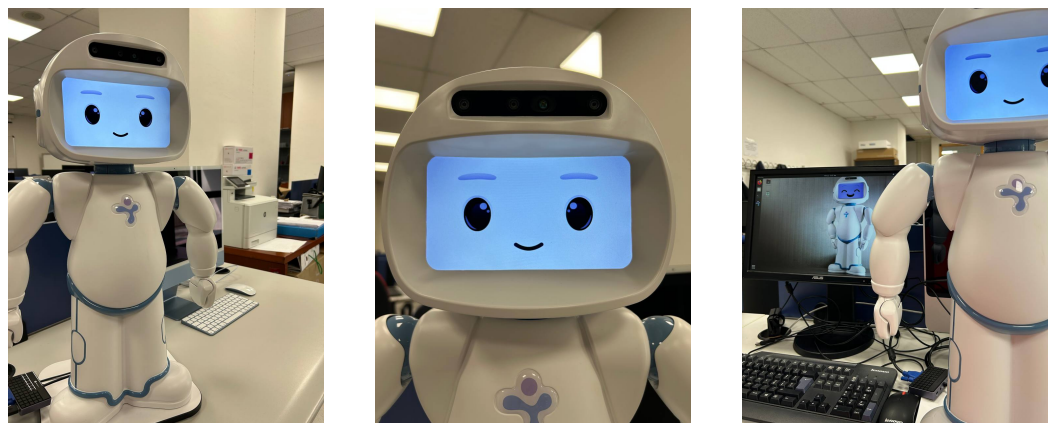

Figure 2. QTrobot in the HCI-UsE lab at the University of Salerno.

Table 3. QTrobot Technical Details.

Robot Name	Microcontroller/ Processors/OS	Sensors/ Actuators	Mobility	Communication
QTrobot for Research V2	Raspberry Pi 4 Model B; 8th Gen quad-core Intel (R) NUC 10 Core (TM) i5/i7 processor; Ubuntu - ROS Noetic	4× High Performance Far Field Microphone Array; RealSense(TM) depth camera D4555	none	USB-C USB 3.0; WiFi IEEE 802.22 Ethernet HDMI

Through the use of AI, QTrobot provides an interactive and engaging experience: it can understand and respond to voice commands, and recognise and interpret human faces. All these features enable effective and natural two-way communication between the user and the robot. QTrobot's behaviour can be customised and modified using QTrobot Studio, which includes a large set of generic and QTrobot-specific blocks that provide a simple and intuitive programming interface, and a Robot Operating System (ROS). By using ROS, developers have access to an ecosystem of modules, algorithms, and tools that allow them to create complex behaviours and integrate the robot into larger systems.

In summary, while QTrobot Studio provides an intuitive and accessible solution for customizing QTrobot behaviours, the use of ROS provides a greater level of flexibility and power, allowing developers to create complex behaviours and integrate the robot into more sophisticated environments [53].

The following main interfaces of QTrobot have been used during development:

- Robot Emotion: implements the expression of the robot's facial emotions. This allows the control and modulation of facial expressions to communicate specific emotions.
- Robot Speech: implements the robot's speech functionality. This allows text to be converted into speech using appropriate speech synthesis. Text can be sent to the robot through this interface for it to speak.

- Robot Behaviour: allows you to implement more complex behaviour by combining the basic functionality of the robot. Through these actions, such as the robot's facial expressions, voice, and movements, the robot's facial expressions, voice, and movements create a coherent and interactive behaviour.
- Robot Setup: implements some basic robot settings, such as controlling the volume of the robot's speakers. Through this interface, it is possible to change the robot's settings to suit the user's preferences or the environment in which the robot is located.

3.4. Understanding the Health of Older People

One of the main challenges is to determinate the clinical compliance of elderly patients. Therefore, the first step in our research was to understand how to assess the health status of the elderly population. To do this, we use the $ML_{physical}$ algorithm in conjunction with a specific medical scoring scale known as the Modified Early Warning Score (MEWS), as shown in Table 4. The MEWS is a systematic tool used in healthcare facilities to provide an early assessment of a patient's clinical deterioration. It assigns scores to various vital and clinical parameters, which are then aggregated to produce an overall score. This cumulative score helps physicians and healthcare professionals to identify patients at risk of clinical deterioration at an early stage, allowing timely implementation of necessary diagnostic and therapeutic measures. The parameters assessed by the MEWS include:

- Heart rate: measured in beats per minute (bpm).
- Systolic blood pressure: measured in millimetres of mercury (mmHg).
- Respiratory rate: measured in breaths per minute.
- Body temperature: measured in degrees Celsius (°C).
- Level of consciousness: assessed using various methods, our current approach involves the recognition of emotions and expressions exhibited by the robotic system employed. Specifically:
  - A denotes an "alert" level of consciousness, indicating an awake patient.
  - B denotes a "reacting to voice" level of consciousness, signifying a patient responding to verbal stimuli.
  - C denotes a "reacting to pain" level of consciousness, suggesting a patient responding to painful stimuli. However, further research is required to validate and refine this aspect.
  - D denotes an "unresponsive" level of consciousness.

Each parameter is evaluated and assigned a score based on predefined ranges of values. For example, heart rate is given a score of 0 if it is between 51 and 100 bpm, 1 if it is below 51 bpm or above 100 bpm, and so on for subsequent intervals. The same principle applies to the other parameters. Once the individual scores for each parameter have been obtained, they are aggregated to give the total MEWS score. For example, if a patient has a heart rate of 110 bpm (1 point), a systolic blood pressure of 140 mmHg (0 points), a respiratory rate of 20 breaths per minute (1 point), a body temperature of 37.5 °C (0 points), and a level of consciousness classified as A (0 points), the total MEWS score would be 2.

An intervention protocol is then determined based on the total score attained. For instance, a low score may only necessitate regular monitoring, while a high score may mandate immediate medical intervention, such as alerting the attending physician or activating the rapid response team.

The objective of employing this scoring system is to facilitate early intervention [23]. A study published in Critical Care suggests that the use of MEWS in preoperative assessments and patient follow-up can enhance care and reduce mortality rates. Preliminary findings indicate that the implementation of MEWS may yield positive impacts on patient care and mortality outcomes [54].

Table 4. MEWS table: the first row shows the weights; the first column shows the vital parameters.

Parameters	3	2	1	0	1	2	3
Blood pressure	≤70	71–80	81–100	101–199		≥200	
Heart rate		<40	41/50	51/100	101–110	111–129	≥130
Respiratory rate		<9		9/14	15/20	21/29	≥30
Temperature		<35		35–38.4		≥38.5	
Level of consciousness				A	B	C	D

4. Bot Telegram

To ensure comprehensive support for all actors involved in the system, an external Telegram bot has been provided, as shown in Figure 3. This Telegram bot provides the ability to communicate in real time with doctors, carers, and the elderly themselves. Its use extends the functionality of the bot, allowing immediate and accessible communication to all participants in the system. This allows doctors to receive timely updates and critical patient information, making it easier to monitor and manage prescribed therapies. Nurses can also receive real-time help and advice, providing immediate support. This real-time communication is particularly useful for managing urgent situations or providing timely instructions. Elderly people involved in the system can also interact with the Telegram bot to communicate their needs.
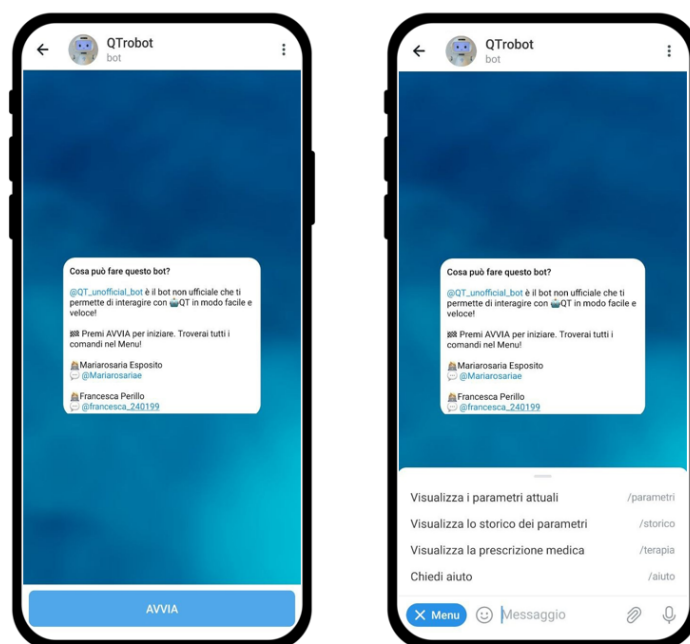
Figure 3. Telegram Bot.

The functioning of the bot on Telegram was based on two different and alternative modes of interaction:

1. Users can send commands through messages in a chat;
2. It is possible to send commands via inline requests, where the user enters the name of the bot, preceded by the '@' symbol, followed by a request into the Bot's command line.

The bot responds by sending the content to the user via chat, group, or channel, depending on the type of the interaction. The messages, commands, and inline requests sent by users are automatically transmitted by Telegram to the server running the bot software. Communication between the bot server and the Telegram takes place via Telegram bot API, which acts as a communication interface. This API is based on the HTTPS protocol and uses different encryption systems to guarantee communication security. In conclusion, by using

inline commands, messages, and requests and by using the Telegram bot API interface, it is possible to establish an efficient and secure communication flow between users and the bot.

Overall, the integration of the Telegram bot into the system ensures fast, effective, two-way communication between all stakeholders, helping to ensure comprehensive and personalised support for everyone involved in the care and support process.

4.1. Feature Overview

The Telegram bot is used by three categories of users: elderly people, doctors, and carers. It was therefore necessary to implement role management during conversations to allow each character to perform actions relevant to their needs. A master class was created to manage the connection to the bot and the specific actions that each actor could perform. The connection to the bot is made using a token provided during bot creation, while the available actions are entered in a drop-down menu.

Actions represent the functionality provided by the bot and can be performed using the following commands:

- */parametri*: Allows users to view current patient parameters, providing information on health-relevant measurements;
- */storico*: Users can access a history of patient parameters (weekly, monthly, and yearly), allowing them to examine trends and changes over time;
- */terapia*: Provides access to the patient's daily schedule of prescribed medications, enabling effective therapy management. Users can view medication intake times, record actual intake, and access a detailed history;
- */aiuto*: Offers users the ability to send requests for help and receive immediate assistance. It can be used to report emergency situations or request urgent information.

4.1.1. Parameter Visualization

The visualization of current and historical parameters is managed. Two main methods are used:

- send_params(...): Deals with sending the elderly person's current data and saving it in a json file;
- send_historical(...): Allows the user to choose which historian to view (weekly, monthly, or yearly) via a button menu; a list of parameters is displayed for each of the options, managed by three different methods:
  - weekly_report(...): Handles the weekly report by retrieving from the json file for all days of the week the parameters captured at a given time;
  - monthly_report(...): Handles the monthly report by fetching from the json file for all weeks of the month the parameters captured on a given day and time;
  - yearly_report(...): Handles the annual report by fetching from the json file for all months of the year the parameters captured at a given day and time of the month.

4.1.2. Visualization and Therapy Management

For therapy management, a menu is displayed that allows four main actions:

- View the medication list by taking from the diary the medication the elderly person is taking;
- View today's therapy report by taking from the diary the report for today's date;
- View the therapy report of a date of the user's choice by viewing a calendar, which allows the user to choose a specific year, month, and day by then picking up the report of the selected date;
- Manage therapy by removing, editing, or inserting prescriptions.

4.1.3. Help Request

The help request management allows elderly people to send a help request via the Telegram bot when QTrobot is absent or far away from the elderly person. At the same time, it allows doctors and caregivers to receive help requests immediately so that they can intervene promptly. This implementation ensures timely and direct communication between the elderly person, doctors and carers. It allows them to be aware of emergency situations or assistance needs at all times. This allows them to intervene quickly and provide the necessary support efficiently.

5. System Demonstration

To better understand the system, a demonstration is described.

5.1. Emotional State Detection and Management

If the elderly person shows signs of prolonged anger, the robot plays an active role in trying to help manage these emotions. In particular, QTrobot encourages the elderly person to contact a child or vice versa, depending on the circumstances, as shown in Figure 4. In particular, Figure 4 on the left shows how QTrobot is able to communicate with the elderly person in an active manner, prompting him/her to contact his/her son after seeing him/her a bit angry. The Figure 4 on the right shows the Telegram bot in action, which activates itself by sending a message to the elderly person's son, showing him the situation in which the parent currently is. The main goal is to provide emotional support to the elder and to encourage direct communication with a trusted figure, such as a child. Involving a close person who can provide listening, comfort, and support can help reduce emotional tension and improve the elder's well-being.
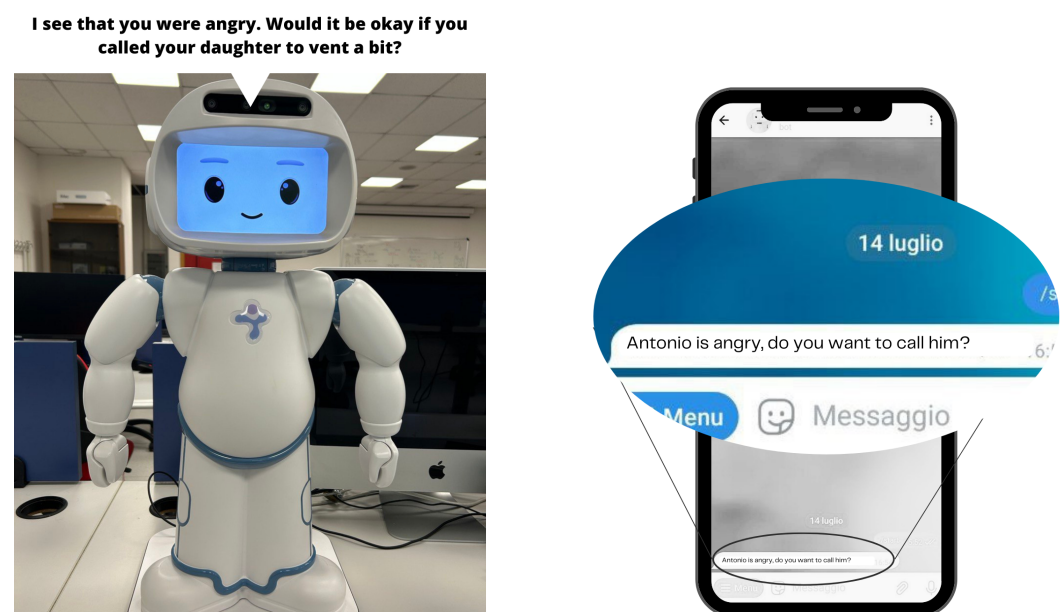

Figure 4. Detection and management of emotional state.

If the robot does not detect the presence of the elderly person for a certain period of time, it takes a proactive role by calling them back and at the same time alerting a relative of this situation. QTrobot is able to perceive the prolonged absence of the elderly person in the same environment in which the robot is located, and therefore asks the elderly person to join it. Figure 5 shows the Telegram bot in action, which is activated by sending a message to the elderly person's son, informing him of the elderly person's absence and suggesting that he contact him. The main objective is to provide emotional support to the elderly person and to encourage direct communication with a trusted figure, such as a child. The

involvement of a close person who can provide listening, comfort and support can help reduce emotional tension and improve the elderly person's well-being.

Figure 5. Detection of the elderly person by robot and reporting to the relative by bot.

5.2. Automatic Forwarding of Requests for Help in Case of Alarming Vital Parameters

QTrobot plays an active role in cointinuous monitoring the health status of the elderly person. When QTrobot processes a diagnosis with a negative outcome or detects any form of abnormality in the measured vital parameters, it immediately takes action to inform the physicians and caregivers responsible for care. This allows them to be promptly informed of the elderly person's critical situation and to take immediate steps to provide the necessary care, as shown in Figure 6.

5.3. Therapy Monitoring

The main objective is to remind the elderly person to take the prescribed medication correctly according to the prescribed schedule. This process occurs continuously and reliably due to the constant presence of QTrobot. In addition, QTrobot communicates the medication status to the caregiver and/or physician. This allows them to be constantly updated on the patient's adherence to prescribed therapy and to receive real-time notifications in case of missed medication or any problems encountered. QTrobot is able to ask the elderly person if they have taken their medication at the time it is to be taken. QTrobot will then wait for the elderly person's answer. Figure 7 shows the Telegram bot in action, which is activated by sending a message to the elderly person's child, by informing him or her of the correct intake of medication. To date, the taking of medication is handled in a relatively static manner by QTrobot's direct questioning of the elderly person. Communication of therapy status is critical to ensure effective monitoring and appropriate treatment management. Providing the nurse and/or physician with a comprehensive and timely view of the patient's adherence allows for timely intervention when needed, ensuring personalised and high-quality care.
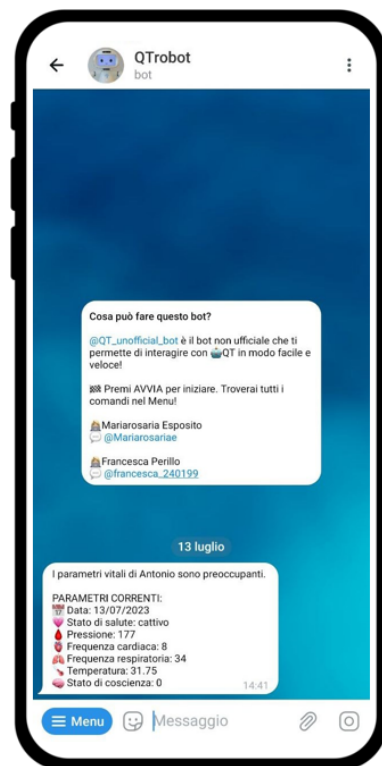
Figure 6. Sending alarming parameters via Telegram bot.

Figure 7. Detection of medicine intake by the robot and reporting to the relative by bot.

In case an elderly person has not taken the prescribed medication, the robot not only takes care of reminding him or her, but also asks about the elderly person's state of mind to get a more complete view of his or her general state (Figure 8).

Figure 8. Communication failure to take medication and emotional state.

5.4. Current and Historical Status of Parameters

System actors have the ability to access current health status information through two modes: by receiving a list of values for measured vital parameters and by consulting a weekly, monthly, or annual history (Figure 9).

- List of vital sign values: An up-to-date list of the current values of the measured vital parameters can be displayed, including vital information such as blood pressure, heart rate, body temperature, etc. This list provides an immediate overview of the user's current health status, enabling timely monitoring and preliminary assessment.
- Weekly, monthly or yearly history: For a more in-depth view, actors can access a history of vital parameters measured over time. This history can be viewed on a weekly, monthly, or annual basis as required. Access to a broader history allows for the identification of trends, variations, and significant changes over time, providing a more comprehensive assessment and understanding of the user's health status.

These two ways of visualising information provide system stakeholders with a clear picture of the user's current health status. This supports accurate assessment, informed decision making, and continuous monitoring to ensure the user's well-being over time.

5.5. Therapy Management

Through a specially created menu for users, the following features can be accessed (Figure 10):

- Monitor medication intake: users have the ability to check whether they have correctly taken their prescribed medications today or the past day, through direct questions that QTrobot asks the elderly person at specific times. This feature provides an easy way to keep track of intakes and promote proper medication compliance.
- View the list of prescribed medicines: users can view a complete list of medications they have been prescribed. This function provides a clear overview of the medications to be taken, helping to maintain complete control over the prescribed therapy.
- Update therapy: Users can make changes to existing prescriptions, such as adding or removing medications, or changing dosages or intake schedules. This flexibility allows for personalized and adaptive therapy management.

Through these features, the menu provides an intuitive and accessible interface to monitor medication intake, view the list of prescribed medications, and manage therapy

effectively. This helps to ensure proper medication adherence and facilitates communication between users and the system.

Figure 9. Current parameter status (**left**), menu for choosing history type (**center**), and an example of weekly history (**right**).
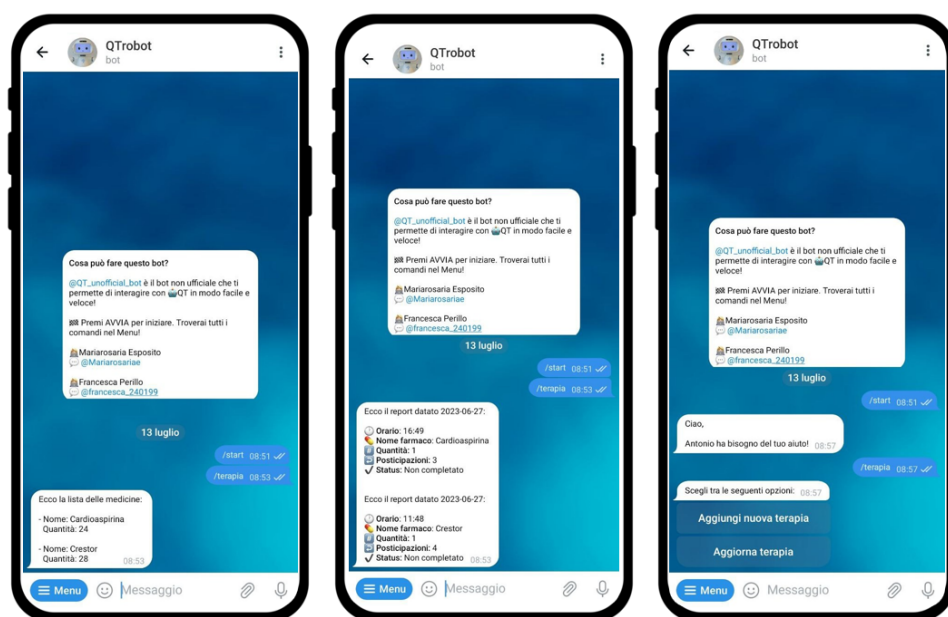

Figure 10. Therapy management screens.

5.6. Automatic Forwarding of Generic Help Requests

Through the Telegram bot, elderly people have the ability to make requests for help, which they would normally expose verbally to QTrobot, even when the robot is not nearby. This mechanism ensures an always-on communication channel for the elderly person, allowing them to report emergency situations or need assistance at any time, as shown in Figure 11. Thanks to the Telegram bot, caregivers and doctors can easily see these requests for help. This allows them to intervene as quickly as possible, offering immediate support to the elderly person and ensuring timely and appropriate care.
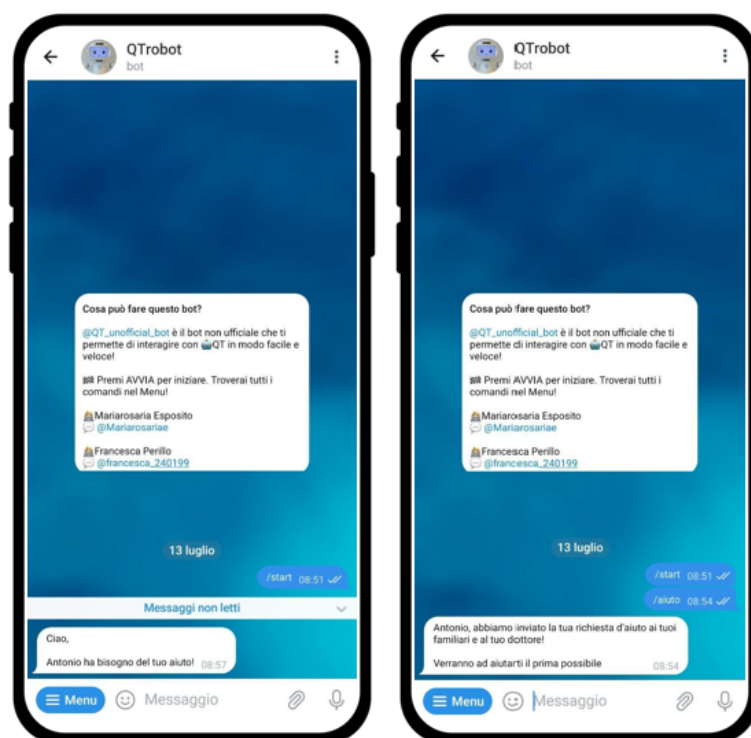
Figure 11. Receiving help request (**left**) and notice of sending help request (**right**).

6. Lessons Learned and Conclusions

As the care needs of the elderly population increase, so do the number of requests in hospital centers, which face ever greater numbers of people in emergency rooms. This research fits into the context of the IoRT and proposes to mitigate these issues through the use of a special type of fixed and small humanoid robot called QTrobot. The following lessons have been learned from this study:

- Highlighting the potential of integrating the Internet of Things (IoT) to improve healthcare for older people. Using a network of sensors, robotics, and AI, the research establishes a possible framework to facilitate continuous health monitoring, emergency response, and emotional support for the elderly population. This integration offers the prospect of promoting the independence and well-being of the elderly, preventing hospitalisation and allowing the elderly to remain comfortably in their homes for longer.
- Exploring the idea of combining technology with healthcare to help doctors care for older people using a special medical scoring system called MEWS. This helps to work out how well an older person is feeling.
- Emphasise the importance of addressing the social isolation of the elderly population through technological solutions. By incorporating emotional state monitoring and facilitating direct communication between carers, doctors, and older people, research suggests a possible way to combat loneliness.
- Illustrate the potential of technology to improve patient-centered care for older people. By offering real-time monitoring, personalised care and direct communication with carers and doctors, the research shows how the integration of robotics, sensors and AI can enable patients to become active participants in their care.
- Illustrate the potential of technology to improve patient-centered care for the elderly.

With the current idea, QTrobot, which is proposed as an intelligent companion robot combined with sensors and AI, can address the complex health management issues of the elderly, monitor their health, and provide assistance in daily activities. In addition, by

integrating a variety of sensors, QTrobot can promptly detect changes in the health status of the elderly, alert caregivers or indicate medical anomalies, and prevent risky situations.

This solution aims to improve the quality of life of older people and prolong their independence in their own homes, without necessarily having to resort to hospitalisation. This system will change the care of the elderly; this change will be evaluated when the system is actually used by all actors in the system, in future studies and work.

To date, the medication intake process has been relatively static, with QTrobot directly asking the elderly person questions. Our team is considering possible improvements, such as the use of smart medicine boxes and/or advanced camera systems. Again, with regard to the measurement of vital signs using wearable sensors, it will be of interest in future work where it is envisaged that this metric will be obtained through specific questions to the elderly person.

The proposed work contributes to research on a complete and functional architecture that integrates robots, sensors, and AI with the aim of improving the quality of life of older people in their own homes. The proposed architecture is universal; it can in fact fall into several contexts, not only the home. In fact, the same architecture could be used in contexts such as nursing homes or hospitals.

Thanks to a user-centered design methodology that involved various stakeholders in our design architecture, we understood how useful it was, in consultation with geriatricians, to constantly monitor the elderly person's vital signs through a specific MEWS score table, to monitor the medical agenda, to ensure that prescribed therapies were being carried out correctly, and to monitor the elderly person's emotional state. We have developed a system to monitor the emotional state of the elderly to prevent loneliness and provide ongoing support. In the event of an emergency, immediate direct communication with operators or doctors is possible to ensure a quick and effective response. The integration of an external Telegram bot also allows doctors and operators to communicate more efficiently about the elderly person's health. This facilitates the management of care for the elderly, who can feel reassured by the all-round support. By integrating robotics, sensors, and AI, our work aims to create a complete and integrated system for managing the health and well-being of the elderly. Overall, this work represents a promising approach to improving elderly care by integrating knowledge within the IoRT. It has a strong emphasis on promoting the independence of older people and providing timely and proactive health support, effectively preventing the imminent hospitalisation of older people. Instead, it enables older people to live sustainably and happily in their own homes for longer.

Despite the positive feedback from geriatricians and the promising initial findings of this study, there is still no formal evaluation of the acceptance and usability of the system by older people, carers, and doctors. For the future of this project, we are therefore planning a long-term longitudinal study in an authentic environment, working closely with medical professionals, carers, and older people. Such a study will enable us to collect both quantitative and qualitative data on the effectiveness of the system and its impact on stakeholders. There is also great value in introducing methods inspired by medical triage to assess the severity of the risks faced by the elderly. Currently, the system notifies of anomalies in vital signs without categorizing them according to a priority system that may or may not attract the attention of medical staff. The introduction of an alert code, for example, would allow a higher level of personalization based on the specific needs of each individual. This would ensure a more timely and targeted response in critical situations. In addition, the system is currently designed to monitor one elderly person per household. However, a more comprehensive monitoring framework that assesses the physical and emotional well-being of elderly residents within the same household would be beneficial.

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