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An Architecture for the Integration of Robots and Sensors for the Care of the Elderly in an Ambient Assisted Living Environment

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Abstract: In this paper, the development of an assistance system for the elderly that combines robots with a network of sensors and actuators is described. The architecture was developed with the aim of interaction. With this reason, the system incorporates particular solutions that are adaptable to the needs of the user, such as a pyramid interaction system, a telepresence robot, a biometric bracelet, and others. In the software, the system is composed of two servers: local and web. The local server is in charge of different modules that interact with direct users and their needs. The web server provides different facilities to external users to access the system remotely. A use case is analyzed where the proposed system is validated.

Keywords: robot architecture; telerobotics; human-machine interaction

1. Introduction

According to [1], people who reach an advanced age usually need care such as emotional support and well-being, mood, quality of sleep, social activities, cognitive functions, personal hygiene, healthy eating, and regular medical check-ups. An important part of the care of the elderly is the monitoring of their vital signs. Consequently, it is very complicated to monitor a person 24 h a day. Besides, many people with advanced age are prone to fall, and may not have a person who can help them in these cases immediately.

In that regard, it could be derived that domotic, telecare systems, among others, facilitate the independent life of the elderly in their homes. Examples of this technology can be found in [2–4]. However, insufficient progress has been made in the area of improving the social and emotional well-being of these persons. In this context, robotics is shown as part of the solution for the care of the elderly in their homes. In particular, social robotics is an effective complement to home automation systems, especially in the case of the elderly, as they have difficulties using technological devices. The integration of robots and advanced interfaces, together with other domotic devices, allows reducing the technological gap of older people to the use of new technologies. These resources can be used together in the framework of adequate planning, oriented to satisfy the needs of the users.

In this context, there are different projects, especially from the European Community, where the care of the elderly through robots and IoT is approached. To mention some projects: TERESA (Telepresence Reinforcement-learning Social Agent), is a project of the University of Oxford and consists of a telepresence robot with social characteristics connected to an intelligent environment [5]. Another project recently closed in 2018 is MARIO (Managing active and healthy aging with use of caring service robot), in which social assistance robots are developed in conjunction with the geriatric evaluation whose proposal uses the Kompai platform [6]. The RADIO project (Robots in assisted living environment, unobtrusive, efficient, reliable and modular solution for independent aging), focusses the development of robots that assist in conjunction with an AAL the needs of the elderly, in turn, tha effectively monitor vital signs [7].

On the other hand, the idea of having intelligent environments and robots in the fields related to health and medical care has been widely considered in the literature. According to [8], you can perceive certain common problems within such projects, such as unreliability, lack of human interaction, high costs, lack of experience when using, etc. The aforementioned problems reflect that a deficit persists concerning previous studies (some studies have begun to study how healthcare robots are perceived by professionals [9]), so it is important to analyze the potential of service assistance robots with IoT environments from the perspective of real satisfaction of the user's needs.

The main contribution of this article is an architecture and assistance services for the elderly that integrates home automation and robotic systems-oriented into interaction. The remainder of this document is structured as follows: Section 2 deals with IoT structures and robot, in addition to different technologies related to the proposed work; Section 3 presents the concept of the system; Sections 4 and 5 refer to the hardware and software developed for its implementation; Section 6 analyzes the operation of the system; and finally Section 7 presents some evaluation and results.

2. Technologies Related to Smart Environments

Some trends can be identified within different works related to the focus of this work. They are focused on the areas of health, safety, social interaction, and physical condition. Subsequently, a brief analysis of the technologies developed in these areas is presented. Inside the technologies of assistance to the elderly, those that provide support to health have a priority. These technologies are classified as those that can respond to emergencies, detect falls and monitor physical variables. A variety of technologies are described and compared in [10].

Security indoors can be understood as a great variety of alternatives among which the control of alarms and novelties, devices of doors and beds, etc. can be mentioned. Moreover, the monitoring of activities can help the early detection of cognitive or physical deterioration. Studies and examples of these systems can be found in [11].

Social participation is also a key element. There are two main branches of the technologies oriented to this participation: the robots dedicated to taking care and the robots that facilitate interaction (such as telepresence robots). An example of the first is PARO ([12]), a baby seal robot with different sensors (touch, light, audio, temperature, and position which uses to feel its location and perceive where users speak) that allow it to interact with the environment and people. As for the robots that facilitate social interaction, we can mention the Giraffe [13] robot, which incorporates an interface for communication with family members or doctors, and also provides a system that allows monitoring the patient's activities.

In some elderly people, the physical condition is reduced. Technology can help compensate for this deficit through daily activities or provide auxiliary functions in physical rehabilitation (through walkers or therapy elements). In fact, as for the use in daily activities, domestic robots can help in common household tasks (cleaning, cooking, etc.). Some examples of these types of robots are the Roomba [14], Moley ([15]), etc. Regarding support robots, we can mention the LEA project ([16]), which is a robotic walker that provides stability and support through a posture detection system.

In all the technologies described above, numerous factors must be taken into account for acceptance by the user. According to certain models and experiences such as [17–19], the main elements to take into consideration are functionality (perception of use), usability (ease of use), Appearance, safety, cost, and reliability.

3. Concept of the Proposed System

In this section, the initial idea of the proposed solution with its different characteristics is analyzed. Furthermore, the general structure of the system is described, as well as its main elements, both local and on the web.

3.1. Initial Idea

The development of an assistance system that combines autonomous robots with sensors and external actuators forming an intelligent network managed by a planner is proposed. The robots add to the traditional IoT architectures different aspects to be considered: on-site validation through the robot, better interactions with users, more complex operations, flexibility, and recovery, among others. The proposal is integral in that the core of the interaction is the user, taking into account the user's physical and social needs. We seek to promote the independence and safety of the users through a natural and intuitive interaction, non-invasive in terms of controls.

Another aspect to comment on the proposed structure is that resources work in a decentralized manner: robots within the system that can perform their own actions without the need for external resources, but these actions are being suitable, planned, monitored and analyzed. This allows the system to make changes dynamically in the plans or activities, even allowing the user to make certain modifications in the plans, change states within the system, etc. It also incorporates a web management system that allows tasks to both local and external users remotely, in activities such as video calls, vital signs review, among others.

Figure 1 shows the system concept where the user's interaction can be seen with different elements of the system. It is based on a heterogeneous network of sensors and actuators which has an IoT structure. The relationship of the robot that can interact with both the environment and the user can be also seen. And finally, it is understood that the services of the network for both direct and indirect users are present within the architecture.

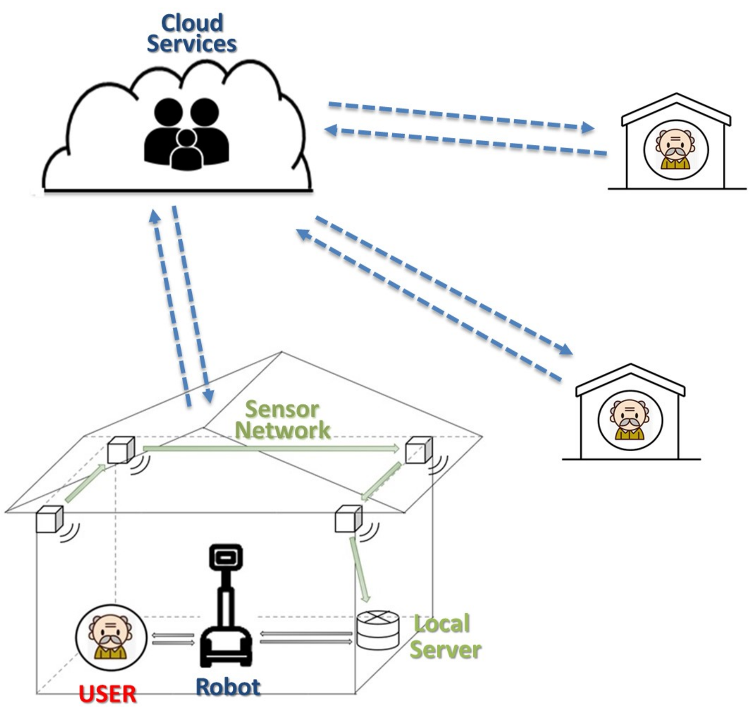

Figure 1. Concept of the proposed system.

The system has three important characteristics: modularity, adaptability, and integrality. The system is modular because it allows the integration of a wide variety of devices. These modules can be responsible for health, communications, and interaction, among others. For example, you have a biometric bracelet that is responsible for measuring certain physical variables such as heart rate, temperature among other variables.

Regarding the adaptability of the system, it is manifested in the fact that it is not a rigid structure but rather focuses on the individualities of the users. To achieve this, the system periodically evaluates the actions carried out either through metrics (response time, activities carried out successfully, detection of dangerous situations, among others), surveys or external evaluations. This information allows the system to generate customized solutions depending on the tastes and needs of the user. A clear example of the adaptability of the system is that you can have different user profiles (where you can change the number of users, activities, calendars, etc.) and modes of use (surveillance, vacations, among others).

Finally, the system proposed intends to have integrality, because it does not focus solely on a specific need of the older person but presents different solutions within the biological, psychic and social aspects.

3.2. General Structure of the System

The complete architecture of the system can be seen in Figure 2. The system is composed of two servers: one at the local level, in charge of the needs of the direct user and another with web services, which is used to provide different facilities to external users. Also, in Figure 2 it can be seen different elements that interact in the local server through the users, such as sensors, robots, interaction systems, etc. These elements can have their structure and code but share information about their states and certain properties such as location, activities in execution, etc.

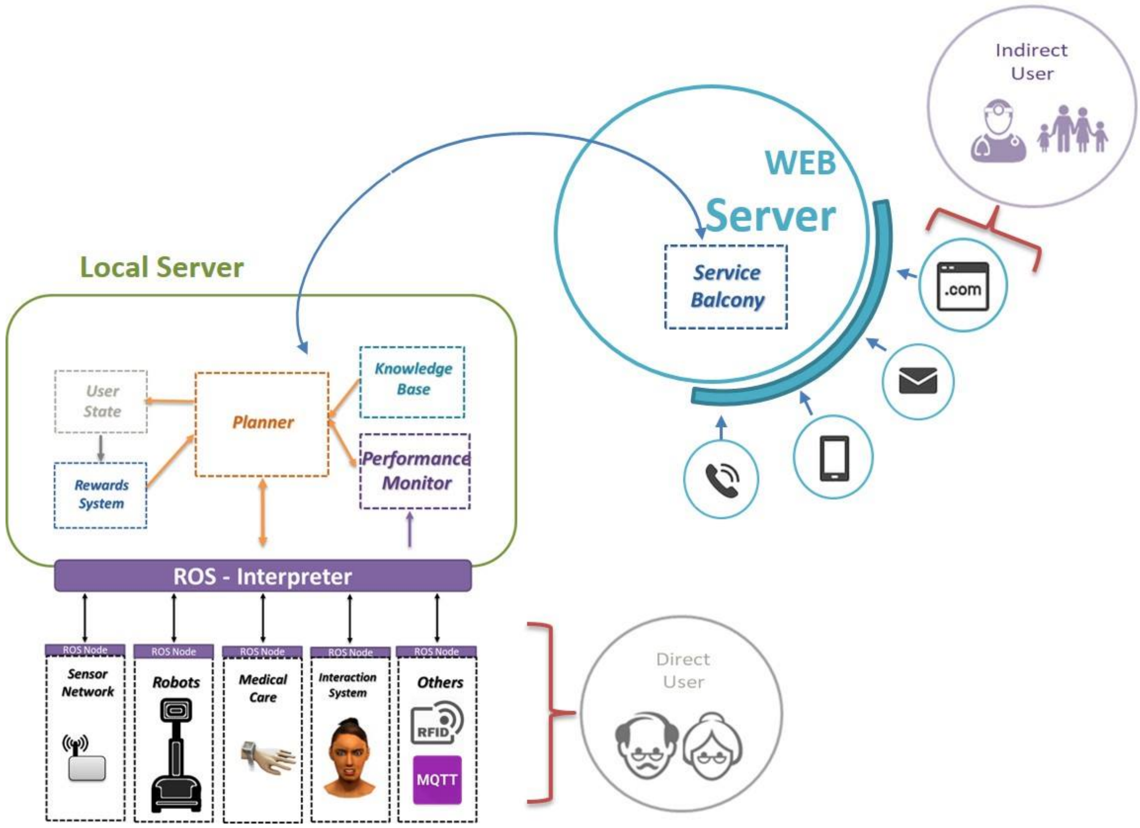

Figure 2. Proposed architecture.

On the other hand, it is important to mention that indirect users can interact with the system through different equipment and platforms (phones, tablets, dedicated applications, etc.) that allow a more natural and effective communication through the webserver. For this, a set of tools has been developed that allows the communication between web-user (web-interpreter) and intelligent-user-environment (user-interpreter). In its operation, the interpreters take this information from specialized nodes installed within each device that is developed according to a set of standard protocols (MQTT, COAP, etc). The information shared with the system can be varied and ranges from global variables to energy levels or failures.

In Section 7 we work with an example of the capabilities of the system. It concerns when a resident in their daily routine will have different needs. The modules of the system and their different execution are presented in the use case.

4. Sensors and Actuators Network

The sensor and actuator network implemented in the system consists of a set of devices that can be connected to the local server through a protocol. Through this network, the sending and receiving of information are managed, where the data can be transferred from multiple nodes through a gateway. The devices are implemented for the sensing and control of lights, blinds, doors, and temperature. The information captured by the sensors is sent to the acquisition card and through the wireless network; they also send data to the local server. This central server manages the information and, based on the received data, sends it to the devices that require it, actuators or services within the system.

For communication between devices, the MQTT "Message Queuing Telemetry Transport" [20] protocol is used, which allows sending and receiving information through a central intermediary. Once the information is sent to the cloud, it can be viewed by the users who have access to it, whether by a computer, phone, smartwatch or other intelligent devices that have access to the system.

4.1. Network Design

To work with the proposed network, the design of an IoT architecture that allows the inclusion of robots and different devices need to be designed. There are IoT solution providers. However, the purpose of the research is to propose an own architecture oriented to the sensor network, the robot, and the system's own devices. An IoT architecture is composed of the following elements: devices (sensors and actuators), communication (protocols), cloud services and layers (administration, security, application). The scheme shown in Figure 3 is proposed, where different components that conform to the system are shown:

- Devices: This section shows the different sensors and actuators that are part of the IoT network proposed for the AAL that includes: control of lights, blinds, door opening, and temperature.
- Communication: For communication between devices it is important to define the network and protocol to be used, in this case, the implementation of the MQTT protocol that works with the WiFi wireless network under port 1883 is proposed.
- Cloud services: The services provided by the cloud and that will be used for the implementation will be oriented to the management of the information acquired by the sensors through storage and database.
- Applications: Are those that allow direct contact with the end-user. That is why among the applications of visualization NodeRed is used, which will allow the control and monitoring of the devices, as well as a chatbot created in Dialog Flow for the interaction of people with a virtual avatar projected on the holographic pyramid.

The robot can connect to the Internet-of-things, either in passive or active mode. In passive mode, the robot is not connected to the Internet but can be identified uniquely through an RFID tag. Other things connected to the Internet with RFID reading capabilities can identify it and publish information related to the robot, for example, robot location information. In an active mode, the robot is connected to the Internet, which allows the traffic of sending information in real-time through Internet services.

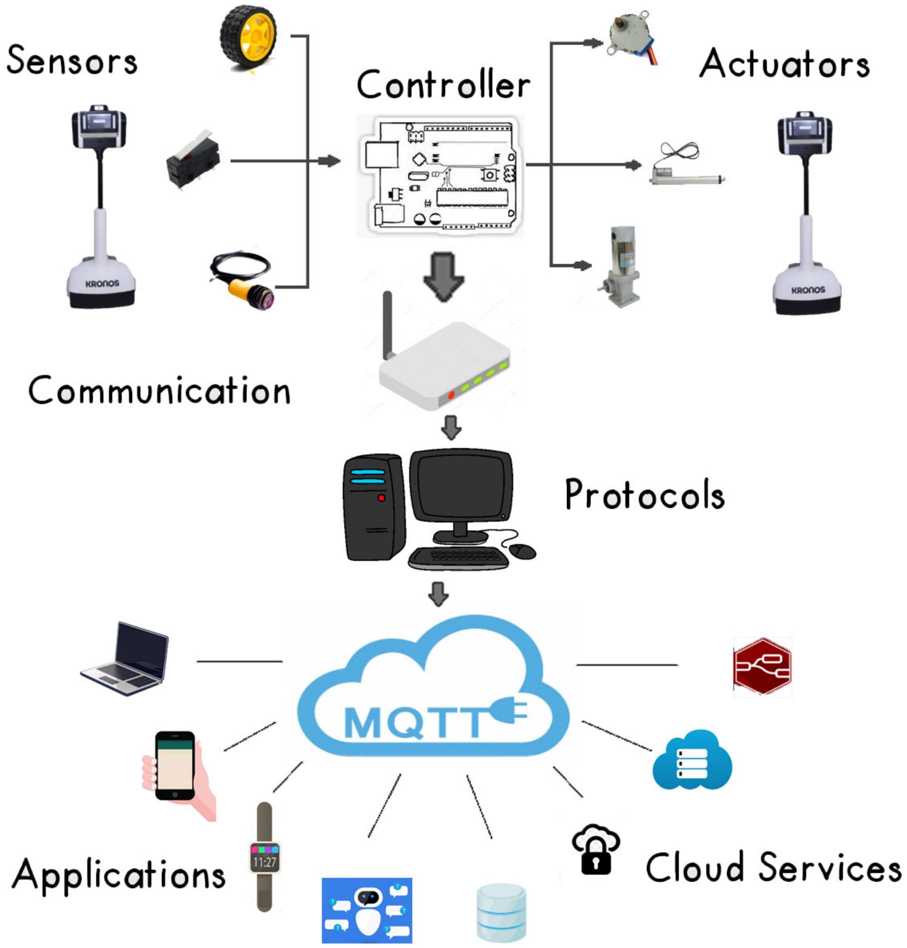

Figure 3. IoT Scheme.

4.2. *Comunication*

Once the devices are defined, the next step is to define the means for communication, the first step is the selection of the network, which must be wireless since a wiring system would be anti-aesthetic and impractical for implementation. WiFi is the selected network for acceptance in households. Concerning protocol, as previously mentioned, there are different protocols for IoT applications. However, the selected protocol has been MQTT due to the advantages it presents for its implementation. MQTT consists of a messaging protocol based on a system of publications and subscriptions, in which the devices that are part of the architecture send and receive data through a central server or broker that is responsible for managing the information.

5. Hardware

As mentioned in the introduction, there is a diversity of needs of the characters, who have their own particularities. Due to this fact, some special elements with specific functions have been designed, constructed and implemented. Figure 4 shows three of these elements: a biometric bracelet, an interactive pyramid, and a telepresence robot. This is due to a network of sensors and actuators distributed by the environment explained in the previous section. All of them have valuable information about the environment that after receiving and processing it, according to each device, it is sent to the local server through the ROS-interpreter. These elements are described below.

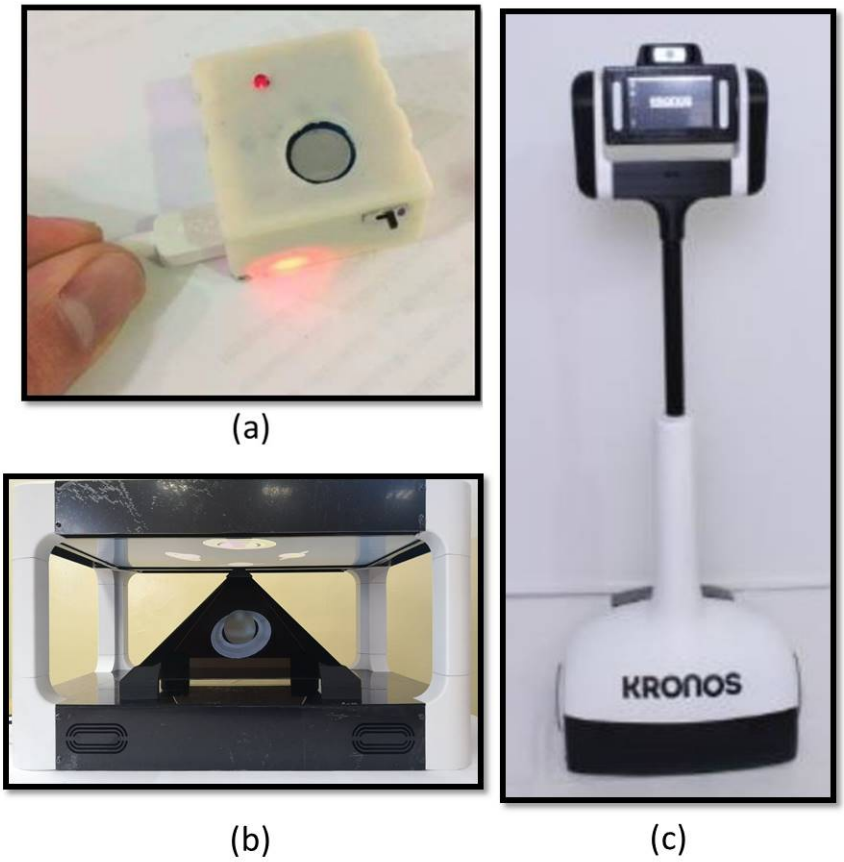

Figure 4. System hardware (**a**) Prototype of biometric bracelet; (**b**) Interaction pyramid and (**c**) Telepresence robot.

5.1. Interactive System-Holographic Pyramid

The holographic pyramid proposed in [21] is used as a channel of interaction with the elderly person. Its operation is based on the effect of Pepper's ghost technique and an animated avatar is projected. It is an interactive system, easy to replicate, and with which a natural interaction can be achieved. It is basically composed of three subsystems: the holographic retroprojection subsystem that uses the pyramid as a means of projection, the subsystem of gestures that is responsible for the different expressions and visemes of the avatar and finally the interaction subsystem that includes the modules in a vision set, chatbot and others. The pyramid has been integrated into the proposed architecture and provides a natural interaction through voice commands.

The holographic pyramid receives information obtained from the interaction between the avatar and the user, which is connected to the system through ROS ("Robot Operating System") [22]. This avatar is in charge of making the direct contact of the system with the user and through which a direct link can be established between the two. The information is received by the pyramid through the camera and the microphones that the device has, to be processed and converted into appropriate data that the interpreter can process.

5.2. Telepresence Robot

The telepresence robot developed in [23] has dimensions of 500 × 500 × 1500 mm and a weight of 35 Kg. The robot has a mobile platform of differential configuration, a system of height regulation and a mechanism of two degrees of freedom for the screen, to improve the user's visual field when making video calls. It also has an infrared sensor system to avoid possible collisions with its surroundings.

The system can self-locate within the environment, avoid obstacles and be teleoperated in a simple way. Also, its features include face recognition [24] that allows the robot to focus on the user during the interaction. It has a system based on IP addresses that allows knowing its approximate location(as long as it is connected to the webserver).

In summary, the telepresence robot is built in a differential platform that integrates other parts like a microphone, screen, and camera. Also, It can be located in its surroundings, teleoperate remotely through the internet in safe mode, avoid obstacles and make calls through its interface. Its integration into the system is simple because of its software is developed in ROS.

The telepresence robot is connected to the system through the ROS-interpreter to which information obtained by its sensors, such as obstacle detection, request for video calls, facial recognition, among others, is sent. The information received from the environment or the user is converted into adequate information to be sent to ROS-interpreter. Also, the robot through the ROS-interpreter sends the necessary information so the actuators can start operating and performing the actions for which it was implemented as moving forward, back and side, as well as rotating in both directions and allowing adjustment of its screen on the vertical axis.

5.3. Biometric Bracelet

The biometric bracelet consists of a device for monitoring and interpretation of vital signs of elderly people, which is integrated into the system through Openhab [25] according to [26]. The device can monitoring and interpreting vital signs such as body temperature and heart rate. It has a fall detection system and automatically emits emergency alerts and, if necessary, sends an alert by pressing a button located on the top of it. It transmits information gathered wireless using the MQTT communication protocol.

For the detection of falls, the behavior of the angular acceleration in the x, y, z axes of a gyroscope and accelerometer in relation to the reference system of a standing person is studied. This device was created with an ergonomic structure made by additive manufacturing methods. Besides, the energy autonomy in continuous operation is about 15 h. The used electronic circuits are in the smallest possible size obtaining an embedded and non-invasive system which uses free software for programming.

The biometric bracelet is connected to the system using ROS-interpreter to which is sent the information obtained through their sensors. Upon receiving the data, this is processed through the internal logic of the interpreters and converted into adequate information for the user's interpretation.

6. Software

As shown in Figure 3, the system has two servers: one at the local level (communication with the elderly) that controls all the in-situ elements and an online system (communication with relatives, doctors, etc.) that manages the service point. Below is a description of the different elements of the system.

6.1. Local Server

The local server (Figure 5) is a set of modules that can perform the following activities: receive requests from the environment, plan different activities, manage system resources and make requests to web services, among others. The functions of the local server can be decomposed into three groups: social interaction (user status, reward system), organization (ROS scheduler and interpreter) and performance (performance monitor and knowledge base).

The elements that make up the local server are ROS-interpreter-, planner, knowledgebase, performance monitor, user status and reward system. These elements are described below.

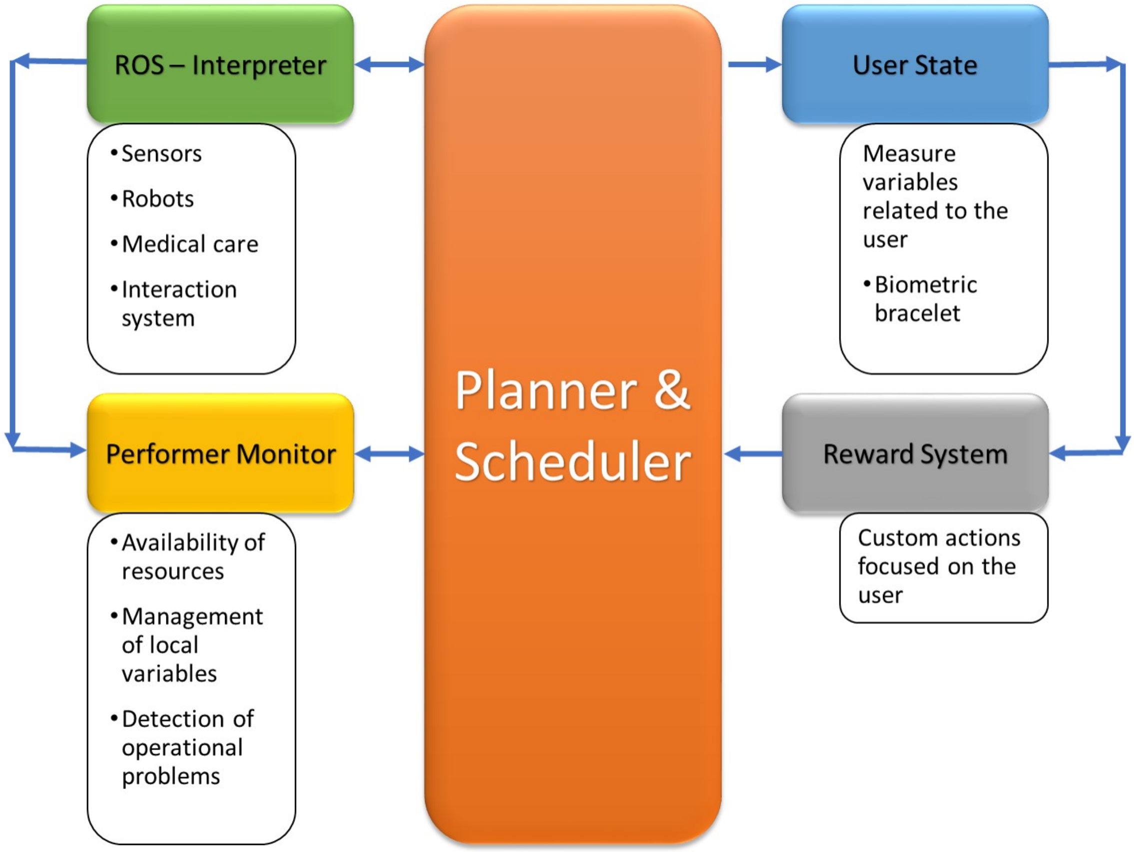

Figure 5. Structure of the Local Server.

6.1.1. ROS-Interpreter

ROS-Interpreter allows the communication of the different devices connected locally with the server in situ. The system works by the connection between nodes both in the computers and in the local server, these nodes specify several elements within which we can specify three types: head, internal services, and external services. The head contains the main characteristics of the equipment as well as the overall identification within the system. The second element is the internal service, which has functions and operations that the device performs internally for its correct operation and in which the architecture has no interference or control. Finally, external services are actions that the device can perform and report to the architecture to contribute a planner's objective.

An example of how the system interprets the different elements can be seen in Figure 6, where all the elements of the telepresence robot are described by the three groups, previously analyzed as head, internal and external services. For example, in the case of "head", the dimensions and the weight of the robot are described, it is also interesting to note that each group can associate particular functions, in this case, the telepresence robot can call the following functions: go to a point, call or reload, etc. Each function has a message type associated with its structure in ROS inside the robot for that matter.

Currently, elements are supported in MQTT and ROS In the future, it is proposed to include other types of protocols (such as COAP) and other types of identification (such as RFID). The main idea of having an interpreter will be to group by common types to build own nodes that perform these functions.

The ROS-interpreter connects to each of the elements registered in the system and turn, connects within the architecture with the performance monitor and the scheduler. The program will update the elements through its tags and the planner structures the different actions to be carried out. The system has subroutines that allow the installation of the different devices quickly and easily.

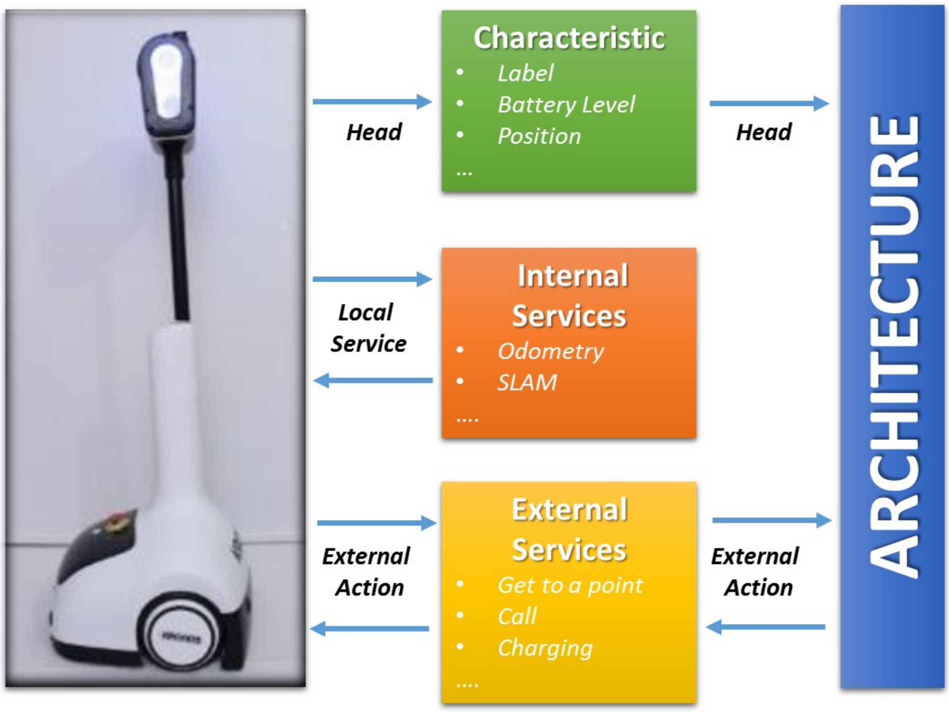

Figure 6. Configuration of the KRONOS robot in the architecture.

6.1.2. The Planner

The planner works as the main entrance of the system and has the functions of finding a plan to solve each particular task if this is possible.

The planner of the system is a partially observable probabilistic action [27]. This characteristic makes to generate temporary planes (taking in account actions with dependencies of time and relative time between actions) and the probabilistic character (the actions may not be carried out or lead to different results) which also generates other plans.

The input for the planner is a group of tasks divided into discrete time intervals (the planner's expansion to handle different users, equipment and robots is part of future work). The planner produces a plan according to the objectives of the system, the state of the environment, the restrictions imposed by the sequence of actions of the human being and the cost of the actions.

The plan obtained is a conditional type, which will obtain secondary goals as the plan progresses. For example, if a robot is asked to clean the house, the system will verify that the user is not at home or if the time is adequate for that task. Once this milestone is completed, the robot will be able to complete the task and notify the planner when it has finished, completing a plan structured in stages.

The planner communicates with all the elements of the local server. It works in conjunction with the performance monitor looking at feasible devices and completing the different stages of the plan. It has direct communication with the knowledge base because it has information about the user and the system. Finally, it is connected to the web-server through information exchanged with indirect users.

6.1.3. The Performance Monitor

The performance monitor supervises all the activities that are being executed at all times by the different elements of the system. The activities of the monitor are: record the availability of resources, manage local variables of the system, detect operational problems and continuously review the proper functioning of the devices. Also, it performs the installation of new elements in the system taking its main characteristics and storing them as local variables or actions.

The performance monitor provides continuous control over the execution of the system plan, taking into account the resource limitations (number of operational units available in the system), time (for tasks, and the established order of the process) and security (if any activities involve a risk to users). If there are inconsistencies, the monitor can stop the execution and request a new generation of plans.

The importance of the monitoring capacity is based in synchronizing all the elements of the system (including the monitoring of critical variables of the health of the users) and maintain a consistent plan over time. At all the time, the system must know the general situation, to analyze and perform actions that do not interfere with users, the environment and even other robots.

The performance monitor is connected to the ROS-interpreter from which it receives data from the different media, and it once has a connection with the planner who receives the information about the execution of the plan.

6.1.4. The Knowledge Base

The knowledge base is oriented to different aspects: personal information, calendars, schedule, and requirements. The node keeps personal information (identification of family and friends, care people, etc), as well as routines (medicines, schedules of exercises or therapies, events, etc.) that must be performed at specific times. Each database has unique information of the patient and can only be modified by authorized personnel.

The development of the system has not reached a point where must disclose patient information. However, it is planned to implement rules and policies to balance data privacy versus information that is relevant to the ongoing research.

The knowledge base is linked to the planner so that the planner can make use of it.

6.1.5. User Status

The node will take into account two situations: (i) the homeostatic variables, with which we can evaluate the health and mood of the users and (ii) the recognition of user plans, which will help in the activities of the users.

The user status corresponds to certain variables related to its health. These internal variables are acquired through different sensors, in our case the biometric bracelet.

The recognition of the human plan is a large area of research and there are many possibilities. In the work, The use of external detection systems is proposed. These systems will be installed in places to recognize common activities (such as eating, bathing, washing dishes, etc.). These activities will allow establishing patterns of behavior that can be used for planning.

The user state module is directly dependent on the planner and it updates the state periodically, share information with the reward system in case of having a newness based on the internal variables.

6.1.6. The Reward System

The reward system is a group of personalized actions that depends on the user. The personalizing of these actions refers to providing options that allow certain characteristics of the system to be adapted based on service evaluations, user preferences, limitations, and personal skills.

The reward system is connected to the user state to obtain user information and provide periodic information to the planner in case it would be necessary.

6.2. Web Server

The web server (Figure 7) represents all the online services currently available in the system: video calls, conference, others. The server allows the interrelation between the local user and the external user. To this end, it has a communication system based on a balcony of services, which allows receiving information from different devices (tablets, mail, applications, and others), and then converting it into information and services that end in the local server or queries at the online base.

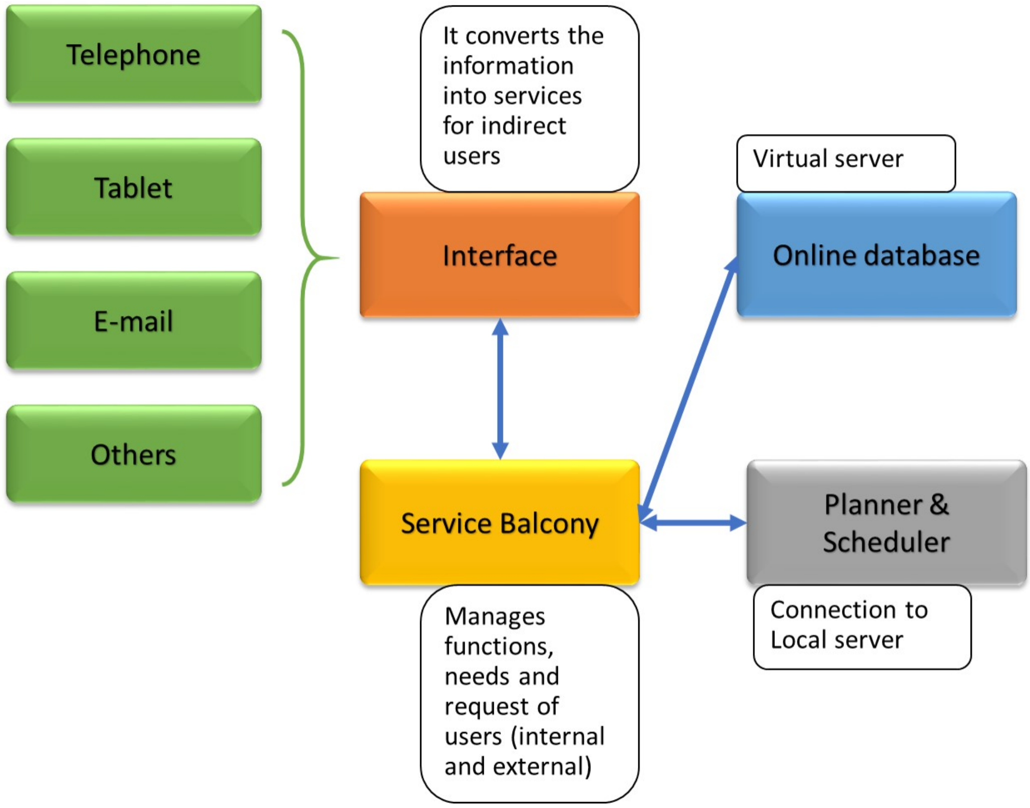

Figure 7. Structure of the Web Server.

In this layer, access interfaces for users are developed. This layer acts as an interface that provides the modules used for the control and monitoring of different aspects of the architecture. The implemented applications allow users to view and analyze the current state of the system. In this case, NodeRED application has been implemented to allow different users to access information from various devices that have access to the Internet.

The Web server is directly connected to the local server and the different devices through the interface, with which it exchanges information through the application.

7. System Operation

For the system operation, a use case has been proposed in which the role of components of the proposed architecture in Figure 2 are identified. The use case proposed contains 3 stages (a); (b) and (c), identified in Figure 8:

Stage (a):

- It starts when the senior citizen (direct user) interacts with the projection pyramid, which is the main interaction system in the architecture. The pyramid is managed through verbal communication and is allocated in a local server that provides the system greater fluidity for operation.
- In a regular scenario, the interaction would begin with basic questions such as time, date and weather information; then continues with more specific questions such as information about medication, schedules, prompts (visits of relatives, medical appointments, consultations), recommendations (drink water, walk and rest often, sleep at prudent times) . If the user suffers from hearing impairment, the option of subtitles or other simpler means of communication can be enabled, such as the use of easy-to-remember figures and symbols, in order to give the elderly a sense of autonomy and independence, which is what he/she often need and miss.

- In Figure 8a it can be observed that a user is interacting with the pyramid conversationally. She just asked the time because she needs medication for her legs discomfort and is following a pain therapy that consists on doing a small walk of 2 min in her room every 20 min, between 9 and 11 AM, which the pyramid has the responsibility to inform.

Stage (b):

- In this stage, simple conversational communication that the user had with the pyramid is left and the system starts to carry out direct actions and requests such as turning on lights, movement of the telepresence robot for objects manipulation, control and monitoring of other devices, etc. It is a great help for users who had mobility impairments or users who need to rest with limited movement. The robot can be placed within the environment, so it can locate the user at all times if it requires it.
- Once the action between the user and the pyramid has been validated, the state of the other devices needed for the plan is updated. If there is any conflict with the required action, a replanning occurs; in case the action is not possible the user is informed. If there is a major problem like a health risk, an update can be sent directly to a web server, which can send notifications directly to emergency or close relatives of the senior citizen.
- In Figure 8b it can be seen that the user performed the action of calling the telepresence robot. Due to impairment by strong pain in her legs when she was going to pick up her medicines, which did not allow her to get up, she requested help from the pyramid to call the telepresence robot and bring her said medicines.

Stage (c):

- This stage allows the use of some additional features of the webserver, such as video-call, telemedicine, etc. to be integrated into previous services.
- The local server is connected to a web server, which not only serves as a backup of the user's status information but also provides access tools for real-time monitoring and the external operation (indirect user) of the environment in which the user is. The indirect user can be a family member or a personal physician since the system can detect a health problem through sensors integrated into the wristband. This data is updated in the user state module.
- Continuing with the example, in Figure 8c it can be observed the user personal physician looking with surprise at the cell phone when receiving a notification of the patient vital signs. Apparently, her pressure went up and her heartbeat was unusual. The physician immediately contacted the user through the projection pyramid. The user informed that the pain did not stop and she had already taken the pills as she had been instructed. Fortunately, she received immediate attention from the doctor and there were no unfortunate side effects.

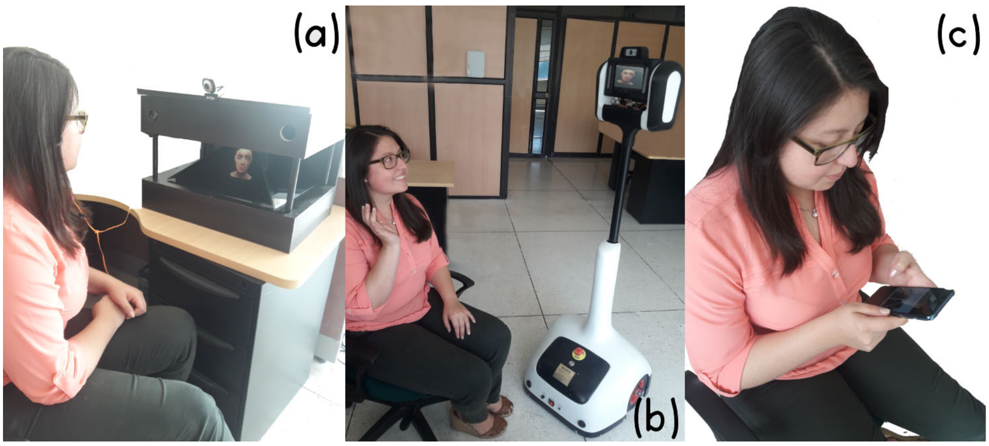

Figure 8. Use case.

Discussion

On the stages presented, you can see the various elements of the architecture in action. In stage (a), shows the system interacts naturally with the user through the pyramid. In stage (b), other elements of the architecture were introduced: sensor network and telepresence robot. The sensor network provides control over different elements in the house and telepresence robot help with the lack of mobility and needs of the user. Finally, stage (c) shows the web part of the architecture and the relation with the indirect user (physician).

A schematic view of the process is in Figure 9, where the different elements are shown: direct user (orange) hardware (yellow), local server (purple), web server (blue) and indirect user (green). On the part Figure 9a, the relations between different modules are presented with the current interactions in the use case (for example, the figure is about the question "What time is it?" and we can see the relation between ROS-interpreter, planner, and service balcony). Figure 9b shows the process that the robot of telepresence takes to come to the user (relations between the interaction system and telepresence robot). Finally, in Figure 9c, the planner considers the replanning of the actions by the medical alarm.

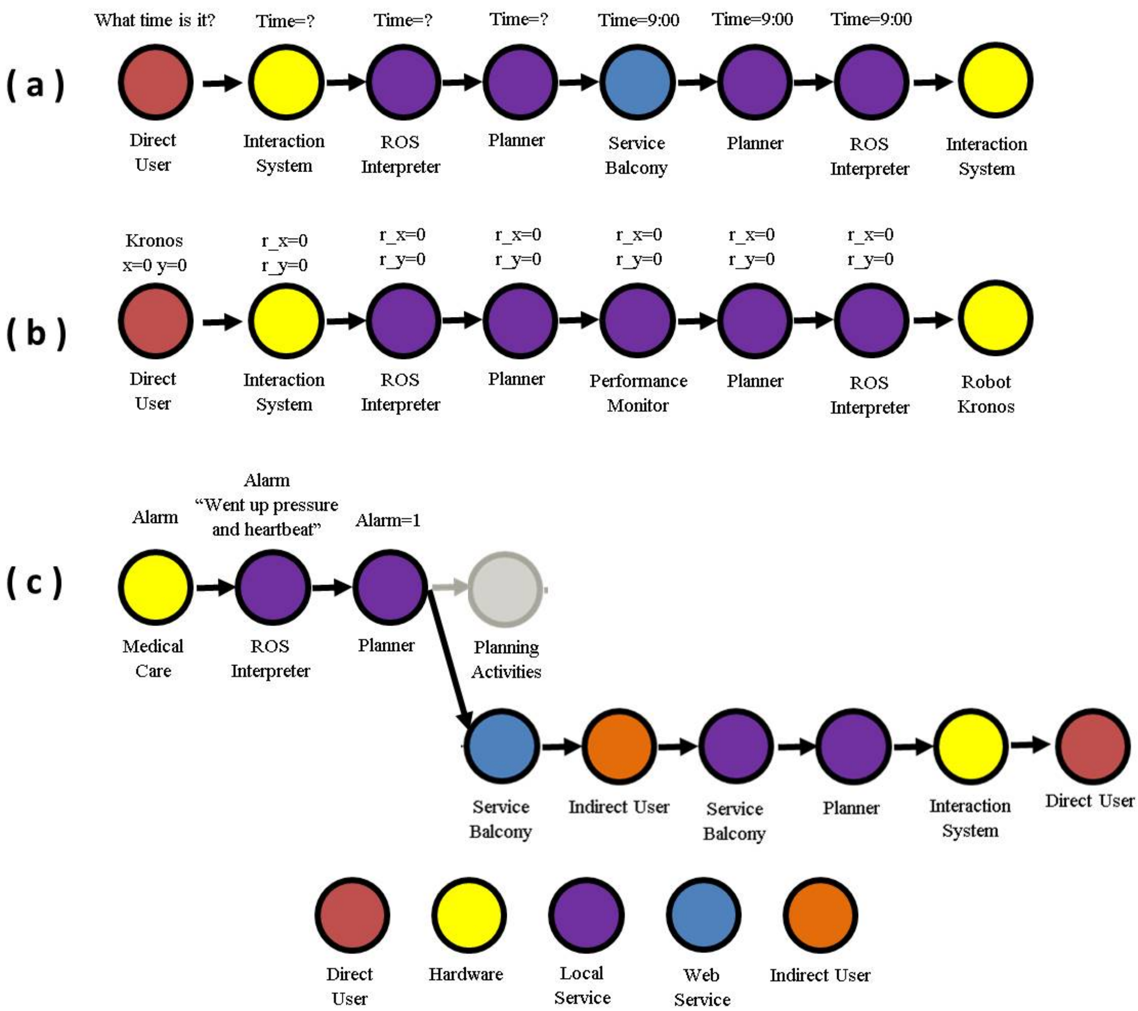

Figure 9. Flowchart about the case of use. (**a**) Simple interaction (**b**) Interaction with telepresence robot (**c**) Replanning case.

8. Conclusions and Future Work

In this paper, an architecture developed by combining a robot with a network of sensors and actuators that integrate different components for the care of the elderly is described. The three outstanding components of the system are sensor network, hardware, and software. With respect to the sensor network, the essential characteristics for the implementation of different equipment and robots have been discussed. In the area related to hardware, different robots used up to now have been described: a telepresence robot, an interactive pyramid, and a biometric bracelet. Finally, the developed architecture has been proposed and current system modules for planning, acquisition, and control have been explained.

From the preliminary results, it can be seen that users positively perceive the proposed system. The interaction is natural and easy to understand for them. Concerning the example explained in the article, the telepresence robot was appropriately assessed in terms of personal call services and social behavior.

In future work, the system can be extended to more realistic environments and other features that have not been detailed in the article can be validated. In terms of performance, it is expected to be able to carry out long-term evaluations with an approach aimed at improving user–robot interaction through adaptation and learning.

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Abbreviations

The following abbreviations are used in this manuscript:

IoT	Internet of Things
RFID	Radio-frequency identification
WiFi	Wireless Fidelity
MQTT	Message Queuing Telemetry Transport

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