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LARES: An AI-based teleassistance system for emergency home monitoring

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Abstract

The latest progresses in medicine are helping people live longer and better. An ageing population is a sign of a developed society with an advanced health care system. Improved life expectancy should be welcomed as a major achievement, but it should not cause a financial or social burden. In this scenario, it is critical to support older and handicap adults to continue living independently and retaining their current lifestyle. New technological advances in Wireless Sensors Networks (WSN) and Artificial Intelligence (AI) can facilitate this task.

In this direction we present LARES, an AI-based system that integrates a (i) WSN for receiving information of the environment and the dependent person, (ii) an autonomous robot able to take decisions based on the received information, and (iii) a Web-based system to provide telecare assistance. LARES has been tried in two dependent elderly home environments during several weeks, and the experiments show that is able to detect anomalies and generate alarms in abnormal situations.

Keywords: Autonomous control; Robotics; Elderly monitoring; Wireless Sensor Networks; Emergency detection

1. Introduction

An ageing population is a sign of an advanced technological society, with a developed health care system. However, ageing often reduces the people's mobility and their mental capabilities. Disability is a personal drama that affects families as well as the whole society. Behind each dependent person there is a human being with diminished capacities and a strong psychological impact, which is usually extended to the rest of the family. Under these circumstances, often the relatives must become caregivers and time is subtracted from their professional and personal lives. The cost of disability in social terms is huge and affects a large segment of the population, not to mention the economical stress that it causes.

In this context, a growing social problem in developed countries is to support and easy the life of elderly and handicap people. The consensus among professionals is to empower personal autonomy of the dependents, keeping their current lifestyle as much as possible instead of moving away to nursing homes. Solutions for this problem have been tackled through telemedicine and telecare systems. The first solution uses Information and Communication Technology (ICT) to provide clinical health care from the distance for health-care providers. Telecare systems combine electronic devices with ICT to assist and care

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for people (McLean, 2011). Our work focuses on the second one.

Common commercial telecare systems consist of a telephone network device associated to a necklace with an emergency button. The dependent person can press the emergency button at any moment, and automatically the device will communicate with a teleoperator in a call center. This communication is done through a powerful speaker and a microphone, and depending on the situation, the operator may deploy resources to deal the emergency.

Despite its success, classical telecare systems present a number of disadvantages. Perhaps the main one, at least in cases of dementia like Alzheimer, is to forget to wear it. The dependent person simply does not remember to wear it, reducing, if not eliminating, the effectiveness of the system. Quite often the users simply decide not to use the necklace for different reasons, for example, because they feel that the necklace marks them as dependents. The psychological rejection in telecare systems is one of their strongest limitations according to professionals and families. Finally, in other cases, the dependent person may press the button accidentally, without being aware of it. In this sense, we can affirm that classic telecare systems need the user cooperation in order to give them full support, being this the weak point of this type of systems.

In order to overcome the above problems, we need new ways of operating the system without the user's collaboration, relegating him to a purely passive role. In addition, the system should be easy to deploy and maintained by people with no (or very little) technical background. With those objectives in mind, we present an Artificial Intelligent (AI)-based solution called LARES, designed to operate without the collaboration of the dependent. It is based on three keystones: (i) a Wireless Sensor Network (WSN) to receive both environment data (e.g., temperature, presence, noise) and the dependent person status information (e.g., falls detection); (ii) a low-cost robot located at the dependent person's home that integrates an AI engine to detect emergency situations through the collected data; and (iii) a Web-based system to provide telecare assistance and telepresence by means of the robotic platform.

The paper is structured as follows. Section 2 presents the latest research in teleassistance systems. Section 3 describes the LARES architecture and its different components. Section 4 shows the experiments performed in two houses with dependent people. Finally, conclusions and future work are outlined.

2. Related work

The growing social need to address the dependency problem has led to an intense research activity, reaching in some cases, as in Japan, the status of National Strategy. However, the integration of certain technologies such as robots is not without controversy, especially if it is analyzed from a social and ethic perspective (Frennert & Östlund, 2014; Lin, Abney, & Bekey, 2011). In this regard, Smart Environments and Ambient Intelligence (AmI) are being perceived as two key enabling technologies to face the dependency problem through the careful placement of telecare systems. In fact, the WSNs are the technological advances which empower the deployment of this kind of systems. There are several projects whose goal is to create an AmI in an enclosed environment, we can mention Carelab (Ruyter & Pelgrim, 2007) developed by Philips, which is structured as one bedroom apartment that incorporates a WSN used to construct behavior patterns and identify activities; or the Independent Life Style Assistant (Haigh, Phelps, & Geib, 2002), which integrates a WSN and situation assessment.

Despite of these technological advances, the dependency problem is not an easy problem to assess. It needs the complex perception of a wide range of risky situations from the environment and the dependent person. Some approaches focus on handling the dependency problem by exploiting techniques from the plan synthesis area and adapt it to perform plan recognition such as Autominder (Pollack et al., 2003). This approach makes decisions about whether and when it is most appropriate to issue reminders. Also, it models client's daily plans, tracks their execution by reasoning about the client's observable behavior, and makes decisions about whether and when it is most appropriate to issue reminders. Also, the Aware Home Project (Mynatt, Essa, & Rogers, 2000) addresses three key areas in the dependent care: recognizing and adverting crisis, assisting daily routines, and providing awareness of daily life and long-term trends. I-Living (Wang et al., 2006) and BelAmI (Anastasopoulos, Niebuhr, Bartelt, Koch, & Rausch, 2005) are systems which provide an architecture concerned to key aspects of smart environments and assisted living. Other approaches simply focus on the assessment in a single risky situation, e.g., the COACH system (Boger et al., 2005) has been designed to help people with dementia disease by modeling the guidance decision process as a Partially Observable Markov Decision Process (POMDP). It focuses on the behavioral monitoring of a hand-washing task performed by a vision system; or the Assisted Cognition Project (Kautz, Arnstein, Borriello, Etzioni, & Fox, 2002), which provides active assistance to Alzheimer's patients. The main contribution is the "activities compass" that helps reducing spatial disorientation both inside and outside the home, and an "adaptive prompter" that helps patients carry out multi-step everyday tasks.

Nevertheless, fall injuries are one of the most common problems in dependent people. A recent line of research which is being developed in the last decade is the detection of falls. There are several techniques for detecting them. On the one hand, we have *fall recognition* based on artificial vision. In this direction, we can mention the work of Fu, Culurciello, Lichtsteiner, and Delbruck (2008), that create an algorithm to be able to pick out different activities through the position, height and velocity of the person movement; or the proposal of Antonello, Carraro, Pierobon, and Menegatti (2017) in which a mobile robot equipped with a 3D depth sensor can detect people falling down. On the other hand, we can find dedicated devices, such as accelerometers (Noury et al., 2007) (usually placed on the trunk (Gibson, Amira, Ramzan, Casaseca-de-la higuera, & Pervez, 2016)), or more popular devices such as smart-phones (Albert, Kording, Herrmann, & Jayaraman, 2012) or smart-watches (Collado et al., 2016) for detecting the falls. Other authors (Pan, Yung, Liang, & Lai, 2007) present a homecare service for fall discovery using a body-worn tri-axial accelerometer and reporting such a discovery to an emergency center. This service is based on a neural network implemented in an intelligent fall detector to recognize the fall event, and then, request an emergency service to the telecare service center. As well, there are other projects focused on using sound as a data source to detect falls or activities in general (Collado, R-Moreno, Barrero, & Rodriguez, 2017; Zigel, Litvak, & Gannot, 2009).

Inside telecare services, there are some approaches such as GrandCare[1] and WellAWARE[2] systems whose goal is monitoring the dependent people status through several automatic procedures. However, these are invasive systems which do not guarantee people's privacy. This kind of systems use a wide variety of closed methods, so it is too complex to do a direct comparative among them. But, it is worth mentioning the GiraffPlus project,[3] funded by EU, that seeks the dependent person supervision using all kinds of sensors (Coradeschi et al., 2013). The greatest interest of this project lies on the Giraff robot. This robot allows virtual access to the dependent person (Frennert & Östlund, 2014), and thus s/he can get in contact to the caregivers in case an emergency occurs (Frennert, Forsberg, & Östlund, 2013). Nonetheless, it does not perform processing of sensor data to infer improper conduct and it does not perform any kind of inference on tasks or goals achieved.

Despite the huge variety of AmI developed to assess the dependency problem, there are no approaches taking into account the joint work of a web page service together with alarms setting from sensors located in the house and on the person as well as a robotic platform for in situ monitoring and situational awareness. The aim of this paper is to show our telecare platform and how the different modules interact to provide solutions to the more demanding telecare sector.

3. The LARES architecture

The objective of the LARES architecture is to provide an advanced and low-cost telecare solution able to operate with passive users, i.e., the dependent person is monitored without requiring to perform any action from his/her side. To achieve such objective, the system is decomposed into three components (see Fig. 1):

- WSN: an easy to deploy sensor network that gathers data of interest. Two different types of sensors have been implemented: environmental and biomedical. The environmental sensors measure home parameters such as temperature, humidity, light or motion. The biomedical sensor detects possible falls when the user wears it (Collado et al., 2016).
- Robotic platform: an autonomous robot that enables telepresence, allowing the caregivers to take a look around the house and, in case of necessity, to interact with the dependent person. The robot has the WSN master node that acquires data from the WSN and processes it within its control computer. An AI subsystem analyzes the data, triggering an alarm in case it detects an anomalous situation.
- Data infrastructure: an Internet of Things (IoT) service that stores the data provided by the robotic platform. This includes the LARES server with a customized web application that displays the data and provides the telepresence interface. It also handles the alarms to inform the caregivers. The caregiver interface is designed to be operated by a dedicate center with trained personnel that can control several houses.

These three components interact in the following way: the environmental and biomedical sensors send data periodically to the robot, which is in charge of analyzing the information and relaying it to the IoT platform. By analyzing the information we mean to evaluate the current information to infer if there is something anomalous. For instance, if we detect motion or lights on during the night. In the case of an anomalous situation, an alarm is triggered and the robot autonomously moves to the sensor location where the event was detected. The robotic platform can handle alarm triggering in real time (independently of the number of motes), meanwhile the communication of the event to the caregiver service requires up to a few seconds when using a cell network connection.

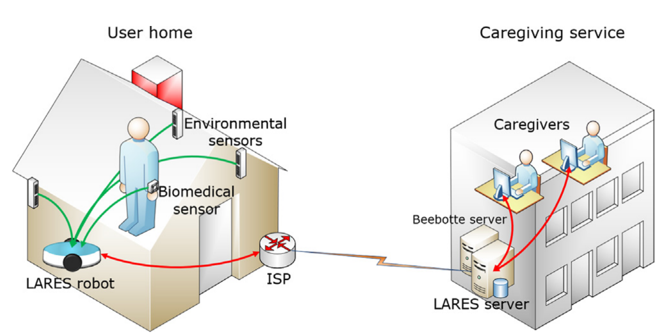
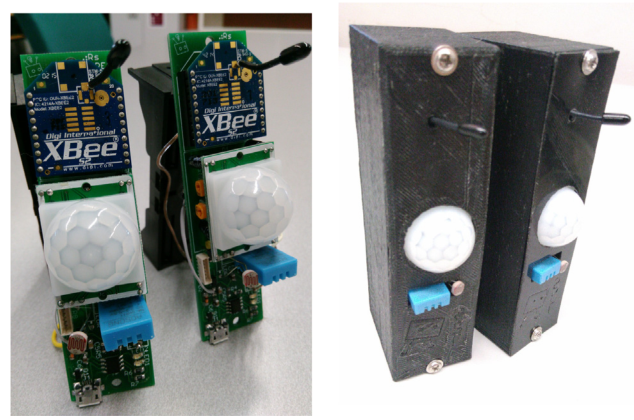


Fig. 1. LARES general architecture with a WSN that captures environmental and biomedical data, a robotic platform that centralizes data acquisition and a data infrastructure that provides storage, data processing and an interface to the caregivers.

[1] http://www.grandcare.com.
[2] http://www.wellawaresystems.com.
[3] http://www.giraffplus.eu/.

The caregiver can observe the environmental and biomedical information through the data infrastructure. The cameras and the microphone of the robot enable the caregiver to assess the situation of the dependent person (for example, by asking confirmation through a conversation), and if needed, to telecommand the robot to observe the house on its own. In this way, the caregiver can alert the emergency services while keeping in touch with the dependent person until the help arrives. When the emergency is under control, the caregiver can finish the session and the robot autonomously returns to the charging station. This acting sequence is depicted in Fig. 2, being the loop box executed continuously meanwhile the robot is at the charging dock and the alt boxes execution alternatives, i.e., an alarm is triggered and/or emergency services shall be deployed.



(a) Environmental mote electronics

(b) Environmental mote inside a printed case

Fig. 3. LARES environmental mote.

3.1. The Wireless Sensor Network

The WSN is a mesh network composed of multiple tiny motes placed in strategic locations. The goal of the WSN is to cover an area, typically a home, with tiny motes leveraging the collaborative effort of improving the situational awareness. In our case study, two classes of phenomena must be sensed: biological and environmental ones. Environmental data is gathered through a custom-designed WSN (see Fig. 3) with cost and energy saving (Vaquerizo-Hdez, Muñoz, R-Moreno, & Barrero, 2017) as the main design objectives. Biological data is captured through a mote placed in a bracelet on the wrist.

The WSN must cover the user's home and the user himself. To this end, each room in the house contains an environmental mote while the user wears a biomedical mote. On the one hand, the environmental mote measures the temperature, humidity, luminosity, presence and depending on some particular house features (for instance, if the kitchen has a butane stove) other kind of sensors can be included. On the other hand, the biomedical mote collects data from the accelerometer to detect possible falls using Machine Learning (Collado et al., 2016).

The WSN was carefully designed for quick, reliable and energy-efficient communication since we cannot trust a dependent person to maintain it. They often suffer pathologies that affect their capacity to perform simple tasks such as changing batteries. In this sense, the WSN must meet four requirements: (i) protection against data misappropriation; (ii) independence from the power grid; (iii) low-power consumption to boost its autonomy; (iv) communication coverage for medium to large houses.

In the last decades several standards for low-power wireless communications have been developed to cope with these requirements. One of them is the IEEE 802.15.4 standard published in 2003 for Wireless Personal Area Networks (WPAN) or the ISO/IEC 1800-7:2009 standard, both for the physical and data-link layer, MAC. In our

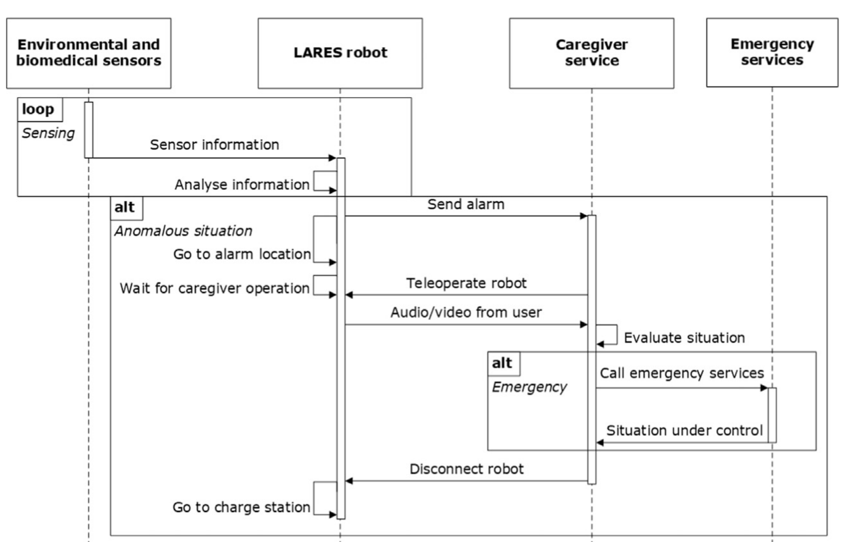


Fig. 2. High-level LARES acting procedure for emergencies.

case, we have chosen the IEEE 802.15.4 standard because is more suitable for periodic data gathering as suggested by Vilajosana, Tuset-Peiro, Vazquez-Gallego, Alonso-Zarate, and Alonso (2014). Also, we have chosen the ZigBee (or XBee) protocol for the application layer on a 2.4 GHz band since it implements an Advances Encryption Standard (AES) to allow protection against data misappropriation and it perfectly covers standard home sizes. Also, the ZigBee network could consist of a maximum of 65,535 distributed nodes in subnets of 255 nodes and 120 m of maximum distance of communication between two elements without obstacles, or 40 m indoor. These settings are wide enough for covering any medium-large house.

Each component in the WSN (robot and sensor motes) is linked to the other components with XBee, in particular they implement a module with XBee Series 2. The XBee module located in the robotic platform corresponds to the master of the network, and therefore it centralizes the WSN communications. The others XBee placed in environment and biomedical modules correspond to the sensor motes.

The Zigbee Application Support Sublayer (APS) describes three types of ZigBee Device Objects (ZDO) that coexist in the WSN: the coordinator, the end-device and the router. The coordinator is the object that forms the network and controls it. The end-device is a particular object that incorporates a mechanism to sleep and wake up the mote in order to reduce the energy consumption (i.e. the duty-cycling mechanism). The router allows raising the coverage of the network.

More in detail, on the one hand, the ZDO coordinator is in charge of starting up the network, it scans all channels, selects a channel with low or without activity and controls the joining and leaving of other motes in the channel. Therefore, the ZDO coordinator mote should always be powered on. On the other hand, the ZDO end-device is in charge of measuring phenomena.

To cope with the data gathering, each environmental and biomedical mote incorporates a ZDO end-device while the mote placed in the robotic platform incorporates a ZDO coordinator. In other words, the sensor motes incorporate a ZDO end-device while the master mote incorporates a ZDO coordinator. Hence, the end-device motes send to the coordinator mote the data gathered from time to time or when an event occurs. Nevertheless, the end-devices cannot route packages and therefore, ZDO routes are deployed in motes to improve the WSN coverage.

The end-devices incorporate a double duty-cycling mechanism (Vaquerizo-Hdez et al., 2017) that forces them to be in sleeping mode until new data have to be sent to the master device. The environmental modules send information when there is a change in the value of a measured variable, and the biomedical module forwards a notification when a fall is detected; in this way sensors save battery, allowing a longer operation without maintenance. Each device has a unique MAC address, which is mapped in advance to a house location to ease deployment, i.e., the person that deploys the system only needs to know that a certain device must be placed in a certain room.

Finally, the coordinator mote, located in the robotic platform, receives all this information produced by the end-device motes, being the end receiver of all the data transmissions. The coordinator sends the data to a RaspBerry Pi 3 to store it in an IoT platform (see Section 3.3). The benefits of this are double: on the one hand the robotic platform is usually placed on its base station, which provides energy. Then, energy consumption is not a concern most of the time. On the other hand the RaspBerry Pi 3 provides enough computational resources to process complex data.

3.2. The robotic platform

The brain of LARES is the autonomous robot deployed in each home. A key point is the adaptability and learning capabilities of the robot to handle anomalous events. Particularly, the robot is deployed with a set of standard rules to detect emergencies from the information provided by the WSN, but, by means of heuristics, the robot is able to adapt these rules to the dependent person habits. The initial set of rules that triggers an alarm are the following ones:

- For the temperature we have an admissible range between 15 °C and 35 °C. Values out of this range trigger an alarm.
- Similarly, the humidity must be between 15% and 60%.
- Moreover, an alarm is produced if there is an abrupt variation (higher than 20% between two consecutive values) of the temperature or humidity.
- The luminosity can also produce an alarm if a sensor detects more than 500 lux.
- Night time comprises the time between two user-defined hours; along the night, alarms are triggered due to motion detection or light detection (values higher than 65 lux).
- Finally, if the biomedical mote detects that the user is falling down, an alarm is generated.

During the nominal operation, the robot is on standby, i.e., the robot is at the charging station while the WSN provides data to the robot. When the rule engine triggers an alarm, the robot automatically starts the navigation camera and generates a path to the sensor location. The path is computed using a path planning algorithm (Muñoz & R-Moreno, 2012) based on a map of the house provided before deploying the system. The path planning is integrated with an AI planner that controls the robot behaviors (Muñoz, R-Moreno, & Barrero, 2016) in order to enable efficient task planning. This AI method is supported by an autonomous controller called MoBAr (Muñoz, R-Moreno, F-Barrero, & Ropero, 2018) that enables scouting

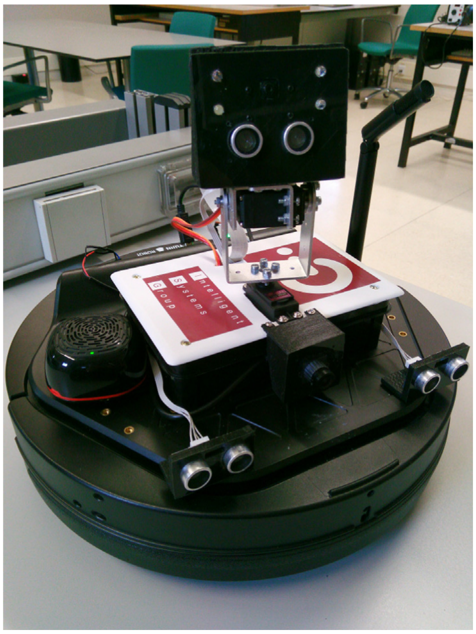


Fig. 4. LARES autonomous robotic platform. It is a customized version of a commercial TurtleBot II controlled with a Raspberry Pi 3.

and inspection operations (which are not currently exploited) for autonomous evaluation of the environment status. Particularly, the AI controller exploits the Planning Domain Definition Language (PDDL) McDermott (1998) to model the robot capabilities. In this regard, an alarm from the sensors implies the injection of a goal in the PDDL problem. The use of this PDDL planner also enables replanning during execution in order to overcome anomalous situations, e.g., dynamic obstacles that are not included in the initial map.

The objective of the AI planner is to provide a fast response to an alarm and to move the robot close to the location in which the event occurs. As well, this provides time in order to alert caregiver service. When a caregiver is available, the robot has reached (or is close to) the location where there is required human inspection. Then, the caregiver takes control of the robot, activating the high resolution camera mounted on a Pan-Tilt unit to enable pointing, and the microphone and speakers to provide a bi-directional communication channel between the dependent and the caregiver. As soon as the caregiver finishes the communication, the robot generates the path to the charging station and returns to the idle state.

Our current robotic platform is a modified TurtleBot II[4] endorsed with a Raspberry Pi 3 micro computer, a microphone, a speaker, four sonar and two cameras (a wide angle and a HD camera). Fig. 4 depicts the robot with its components. As well, the battery enclosed enables up to four hours of continuous operation. The TurtleBot provides a differential driver locomotion system, stairs detection and a front bumper for collisions.

The robot control is based on ROS[5] which provides the robot hardware drivers and several convenient robotic libraries. The integration of customized sensors and actuators with ROS is straightforward thanks to its normalized data model. The data streaming from the sensors to the web platform is implemented in the robot as an independent service from ROS. As well, the micro computer implements the path planning algorithm, the autonomous behaviors of the robot and the AI techniques to analyze the WSN data.

To provide video streaming the robot exploits the User space Video4 Linux collection (UV4L)[6] project. The video and the audio data collected by the robot are sent to the LARES server whereas the audio from the caregiver is reproduced by the robot speaker. The telepresence service is built on ROS to control the robot, while the user interface is an easy-to-use web page hosted in the LARES server.

3.3. Data infrastructure

The LARES data infrastructure is an implementation of an IoT storage solution coupled with a server to enable data display and telepresence. On the one hand, it uses Beebotte,[7] a commercial IoT service, to properly store the high amount of data produced by the environmental and biomedical motes. On the other hand, the LARES server exploits the data stored in Beebotte, providing the caregivers an integrated interface to also visualize in real-time the WSN measures with its historical logs and alarms.

Moreover, the web platform enables the telepresence, providing (i) the control of the robot using a joystick or four buttons on the web application (forwards, backwards, turn to the left or to the right); (ii) displaying video in real-time and (iii) allowing caregivers to talk to the patient anywhere in the house. In conjunction with the video, the web incorporates the house's map for the purpose of illustrating the robot's path.

The information generated in the user's home is sent first to the robot using the ZigBee protocol. Then, the robot relays it to the Beebotte and the LARES servers using the Internet connection of the house (if any) or a mobile network using an integrated 4G modem. The audio/video of the house, for security and privacy reasons, is directly transmitted from the robot to the LARES server. Then, to simplify the caregivers work, the LARES server obtains the historical data from the Beebotte server and provides all the information directly to the caregivers, i.e., the current state of the home and the dependent person, the historical data by means of charts and the audio/video in real-time. Fig. 5 summarizes the data flow among all the components of LARES.

[4] http://www.turtlebot.com

[5] http://www.ros.org/

[6] www.linux-projects.org/uv4l

[7] http://www.beebotte.com.

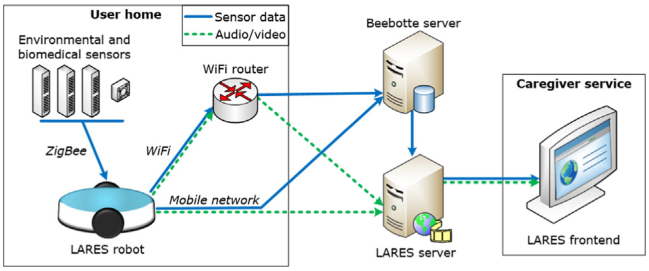


Fig. 5. LARES data infrastructure. The communication between the robot and the server may be done through a regular home Internet connection or with a 3G adapter in case such connections are not available.

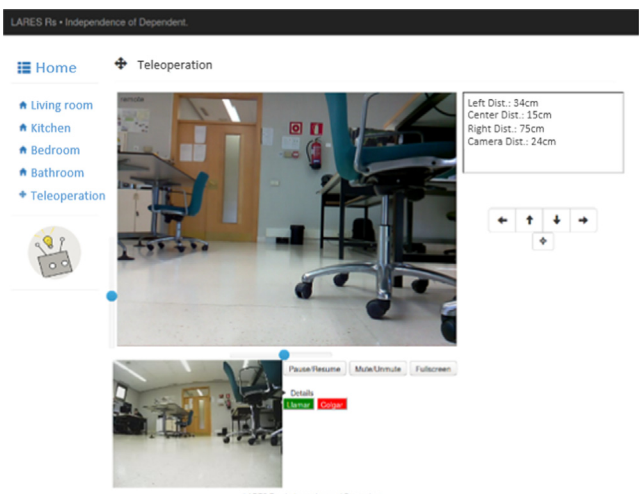


Fig. 6. LARES web application with robot teleoperation enabled. The screen shows the two cameras (wide-angle and regular lents), operation buttons (those with arrows) and sonar rangers measurements in the top-right.

In regard to the video display, there are two displays on the web that allow caregivers to watch the environment and the dependent person, as can be seen in Fig. 6. One of the display shows a wide-angle lens while the other one is the high resolution camera. The image of the wide-angle camera is gathered in the robotic platform, then it is sent to a ffmpeg server and finally it is shown on the LARES web site. On the contrary, the image of the high resolution camera is sent to a UV4L server which already incorporates a streaming application to show the image on the web.

Fig. 6 illustrates the interface that the caregiver has when teleoperating the robotic platform. The HD cam (mounted on the robot pan-tilt) can be moved through the joystick or the two scroll bars. Initial tests showed that distance estimation to the obstacles by means of visual inspection of the cameras is troublesome, increasing the number of collisions. Sonar range measurements help to avoid this problem, providing essential information to the teleoperator to effectively command the robot. The web interface shows the distance between the camera with the regular lens and the obstacles, the distance between the front of the robot and the obstacles and the distance between two angles of ±45° and the obstacles. For instance, in the Fig. 6 the caregiver receives information about an obstacle 34 cm from the robot's left hand side, an obstacle 15 cm from the robot's front side, an obstacle 75 cm from the robot's right hand side and an obstacle 24 cm from the pan-tilt mounted camera.

Also, the web interface enables the video call incorporating three buttons: Pause/Resume, Mute/Unmute and Fullscreen. The Pause/Resume button enables and disable the audio-visual channel. The Mute/Unmute button enables and disables the audio channel. The Fullscreen button enables a large scale visualization. All this process enables a customized care for the purpose of meeting the user needs and to efficiently mobilize the resources when needed.

4. Experimental results

The proper operation of a telecare system does not only depend on a flawless technology, but also on psychological aspects of human-machine interaction, which play a major role. The potential problems arising from the relationship between a dependent person, specially if affected by any kind of dementia such as Alzheimer, are very difficult to predict, so experimentation in real world is necessary.

We conducted a preliminary experiment to have a first feedback about how LARES is able to integrate into dependents' lives. In this experiment LARES was deployed in two houses providing telecare service to two seniors dependent with different profiles and needs.

- Case study 1: 75 years-old man with supervision needs that is living alone. He likes technology and usually uses computers. He suffers a disease that affects his motor system, making him highly vulnerable to falls. The disease also affects his cognitive and communication skills. He lives in a small flat (80 m^2) with optic fiber Internet access. A domestic helper visits him twice per week and other visits are scarce.
- Case study 2: 86 years old woman living with a professional caregiver. She does not like technology and has never used computers or cell phones. She suffers Alzheimer's disease in phase VI (out of VII phases) and requires continuous supervision and help. She lives in a big house ($250m^2$) with three floors and no Internet access. There is always a caregiver in the house and visits are common.

The current deployment of LARES consists of the components described in the previous sections: (i) the robot shown in Fig. 4; (ii) three sensor modules such as the ones depicted in Fig. 3; (iii) a bracelet and (iv) the web platform for caregivers. The deployment time in both case studies was constrained by practical considerations of hardware availability, families permissions and timetables of the people involved in the experiment.

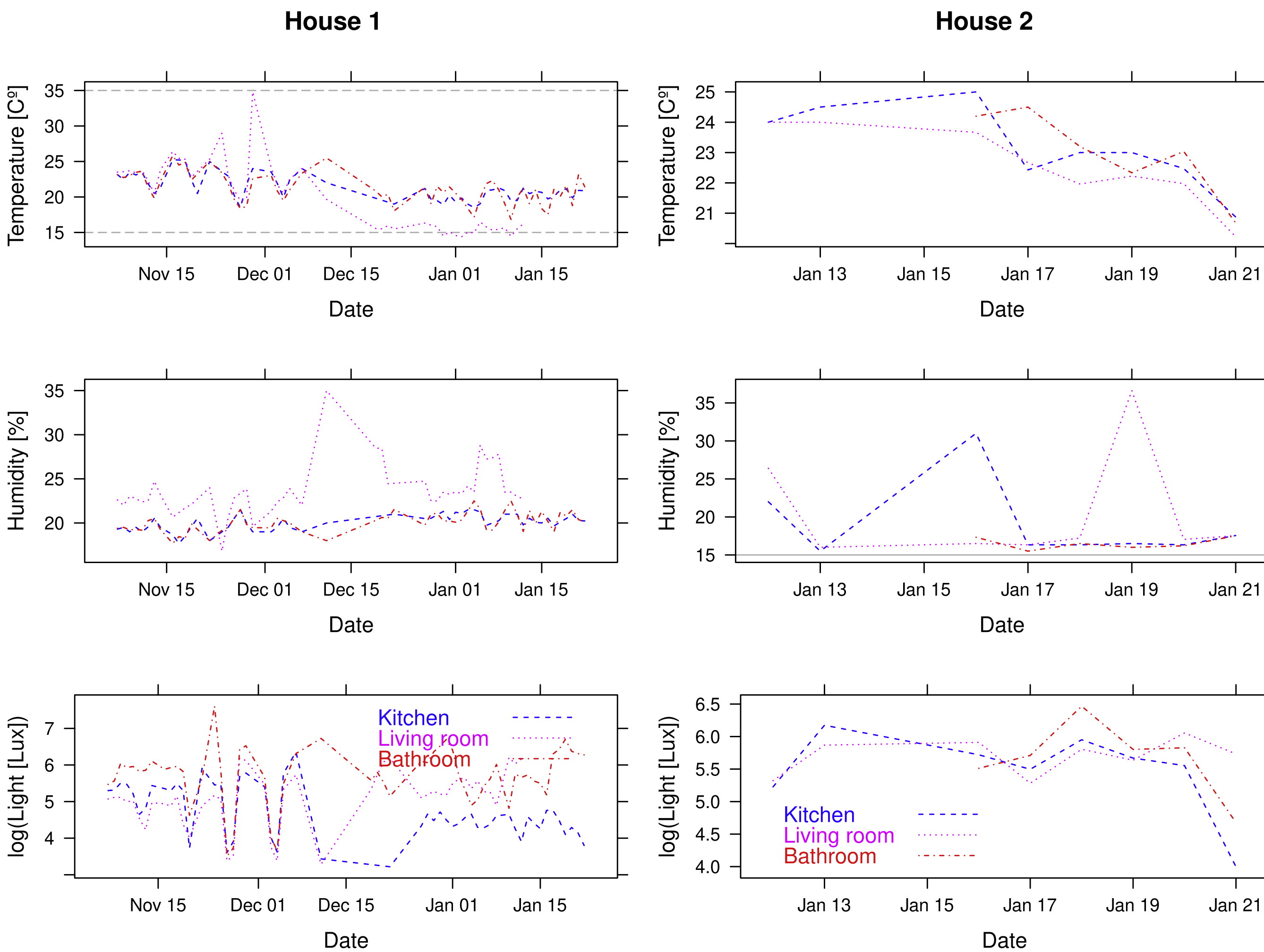


Fig. 7. Time-series with the WSN measurements in the two case studies under consideration. In both cases the WSN covers three rooms: The kitchen, the living room and the bedroom. The alarm thresholds are depicted with gray dashed lines.

Fig. 7 shows the measures given by the environmental motes in the WSN. Three variables (temperature, humidity and luminosity) were monitored in three locations (kitchen, living room and bedroom) for a period of time dependent on the study case. The thresholds to trigger an alarm are also depicted in Fig. 7 as gray lines.

Case study 2 in Fig. 7 shows an example of hot plug of a mote in the WSN. It can be seen that initially only two motes were operative (located in kitchen and living room), the mote located in the bedroom was placed in the middle of the time series. This feature is important to assure that maintenance can be done in the motes with little impact in the whole WSN.

Along this time the temperature alarm was triggered once on December 1st. The family discovered that the heater was not turned off. The experience showed that environmental motes provide interesting information for the house maintenance than for dependent assistance, however, under certain circumstances it may provide interesting information for the caregiver.

The most valuable data in our experiment were given by the motion detection. Fig. 8 shows data acquitted by the motion sensor in the environmental motes. In both study cases LARES detected motion in the early morning several times in a small period of time. When the dependent in case study 2 was asked about this issue, she answered that the lights on LARES motes kept her awake during the night. This problem was easily solved. On the contrary, the information provided by LARES in case study 1 suggested a systematic insomnia problem confirmed by the family after inquires. The caregivers shared that with the doctor, who decided to change the user's medication.

An anecdotal fact in relation with case study 2 may illustrate the importance of psychological considerations. Because of Alzheimer's disease, the user begun to think that people appearing in television were real, and were going to come out to hurt her. These ideas generated her high anxiety as well as to her family. After several days expressing those ideas, the caregiver told her that a LARES environmental mote was a device designed to avoid people

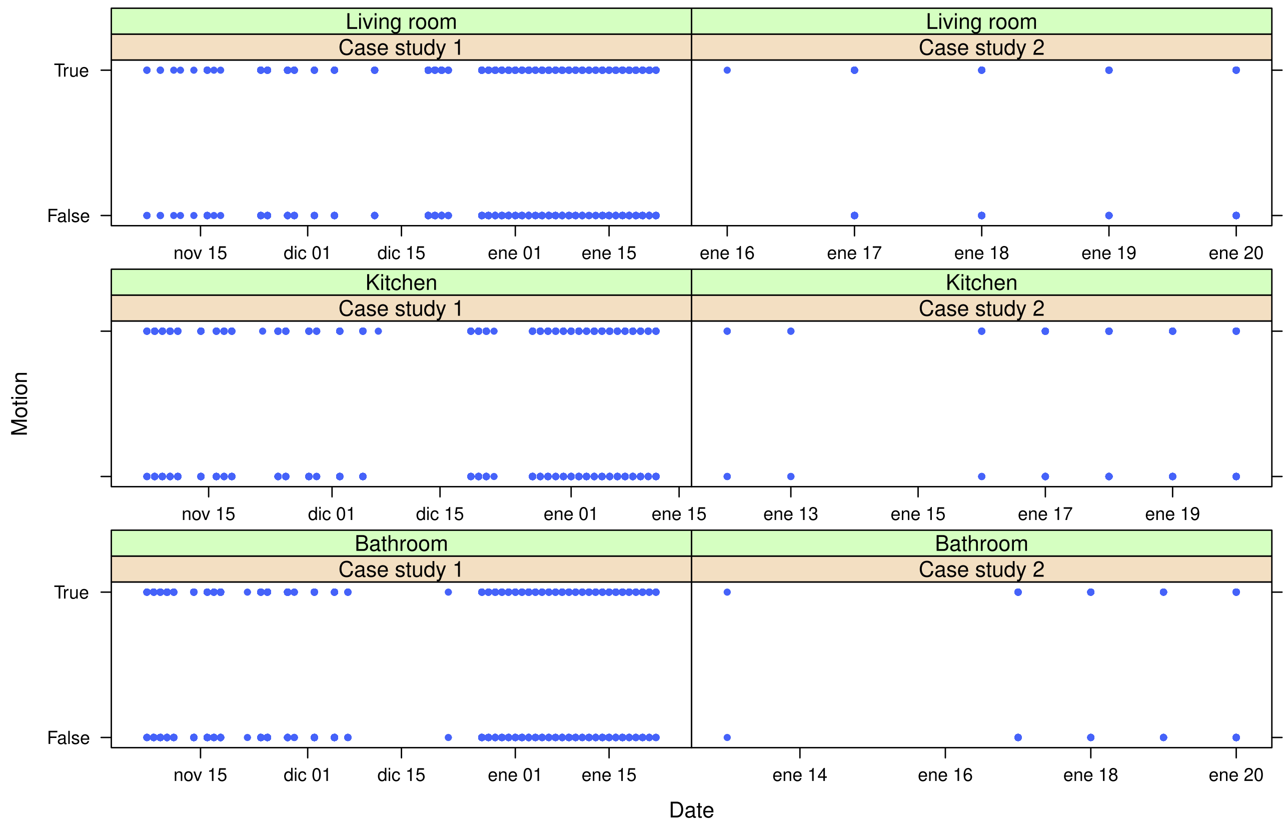


Fig. 8. Motion detection in the case studies. True implies that a sensor detects movement in the room.

coming out the television. Those words served to reassure the senior and no longer express the same concern.

The most serious episode in the experiment happened when the dependent in case study 1 woke up and tried to get up, but he was unable because of a sudden vertigo and general weakness. He could not move from the bed and finally phoned to the emergency service. An ambulance was sent to attend the emergency, and transported the person to the hospital. Despite LARES was deployed and operating, it was unable to detect the severity of the event; it only triggered the night motion alarm. In part LARES lacked the required heuristics to detect that event with the given sensors (several motion detectors activated at the same time in the night). That is easy to solve just by updating the heuristics, which was one of the objectives of this experiment. A similar situation was found in case study 2, where the presence of the professional caregiver and regular visits required the revision of LARES heuristics related to motion detection. The experience in these two case studies shows the limitations of sensing and the complexity of the problem at hand.

5. Conclusions and future work

Nowadays, aging is the most important factor driving the disability of the citizens in developed countries. According to *The 2015 Ageing Report* of the EU, the number of people aged 80 years old (or over) is rising from 5% to 12% becoming as numerous as the young population in 2060. Although medical advances have highly improved life expectancy in the last decades, elders mobility and mental capabilities cannot be guaranteed to remain intact.

In this context, it is important that elders and handicaps continue living independently and retaining their current lifestyle, instead of moving to nursing or family homes. To try to help both dependent people and families, technological solutions that allow activities monitoring without privacy violations are required.

In this paper we have presented the advanced telecare system called LARES. It consists of (i) a WSN to receive both environment data by means of sensors motes, and the person health status by means of a biomedical mote set on a bracelet; (ii) a robot that incorporates an AI engine to detect emergency situations at the dependent person's home through the collected data; and (iii) a Web-based system to provide telecare assistance. These elements enables fast response to caregivers meanwhile the user's privacy is kept intact at all times.

In the next future we want to extent the biomedical mote to detect unusual glucose levels and vital sign values for better monitoring the dependent person's health status. We also want to include in the alarm detection Fuzzy Logic and Machine Learning techniques.

Conflict of interest

The authors declared that there is no conflict of interest.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.cogsys.2019.03.019.

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