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SMARTCARE: On the Design of an IoT Based Solution for Assisted Living

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***Abstract*—In the wake of the Covid-19 pandemic, Ambient Assisted Living (AAL) and Home Monitoring System (HMS) frameworks came into focus as an alternative to classic healthcare services for the ageing world population. Both overwhelmed healthcare systems and the susceptibility of older adults to develop severe complications are indicators that in the near future there will be a shift to a decentralized monitoring paradigm for chronic disease patients.**

This paper introduces the SMARTCARE system, a solution that integrates both AAL and HMS features in order to provide maximum flexibility in defining monitoring scenarios through the use of IoT devices. More, the system tackles the lack of uniformity that exists in standardization across the IoT field through the use of a modular architecture.

Keywords—assisted living; IoT; home monitoring.

I. Introduction

The 2019 UN World Population Ageing report [1] states that globally there were 703 million persons aged 65 or above,with a projected increase of 120% to 1.5 billion until 2050.Moreover, approximately 80% of older adults have at least one chronic disease, with 77% having at least two [2]. This poses a challenge for the current health care service, with it's hospital care oriented paradigm, as it will put pressure on one of the critical resources - the healthcare workers.

Also, the ongoing COVID-19 pandemic in Italy, having one of the most aged populations in Europe, it emerged that persons with cardiovascular diseases, diabetes or obesity are most vulnerable to severe forms of COVID-19 [3].All these facts are proof that in the near future the healthcare model is to shift to a decentralized approach by providing healthcare services at home in AAL (Ambient Assisted Living) and HMS (Home Monitoring System) frameworks. The Internet of Things (IoT) technology already provides solutions for assisted living [4]. However, the lack of standardization generates a lot of issues with impact on communication, scalability, security, interoperability [5] and the impossibility to build a customizable AAL system independent of hardware layer and users needs.

To address these issues, we propose a software platform,able to integrate IoT devices in order to automate the development process of customizable assisted living solutions for home autonomy. The SMARTCARE platform will allow the design and implementation of various monitoring and assistance scenarios by providing modules for integration and customisation of needed hardware and software modules. The SMARTCARE platform will allow an easy integration of monitoring solutions for both physiological parameters and the environment. Thus, SMARTCARE will be a generic solution for implementing a wide and varied range of monitoring scenarios targeting people with special needs or conditions.

II. State of the Art

In [6] the authors design a set of sensors with Wi-Fi communication aimed at AAL deployment and evaluate their performance with emphasis on power consumption. The authors perform an in-depth analysis of the energy consumption behavior in various use cases. Their study proves that power performance is suitable for practical exploitation and the designed sensors will be used within the framework of the "Activage" project (EU-Horizon 2020 LSP-IoT).

The authors of paper [7] present a complete monitoring architecture ranging from home sensors to cloud-based back-end services. The paper main focus is the evaluation of different data analysis methods that can lead to automatic detection of relevant trends and anomalies. A prototype system has been deployed in the framework of the NOAH AAL-JP and ACTIVAGE H2020 projects.

The NOAH project [8] has an architecture that exploits IoT technology for continuous monitoring purposes coupled with a cloud environment. Also, a toolkit has been implemented,featuring several strategies supporting behavioral analysis. Pilot systems have been deployed over a set of European sites.

The paper [9] performs a user-centered study of existing IoT-enabled systems tackling elderly monitoring and introduces a hierarchical model for elderly-centered monitoring:perception layer, Gateway layer and Cloud layer. The study focuses on five different sections: health monitoring, nutrition monitoring, safety monitoring, localization and navigation,social network.

The ACTIVAGE H2020 EU project [10] developed a smart-home IoT infrastructure for the support of independent living of the elderly through a combination of heterogeneous devices that provide both human behavior monitoring and measurement of vital signs. The data is sent to a cloud infrastructure that can run advanced data analytics to assist in decision making.

Human activity recognition (HAR) assumes classifying the actions performed by the subject based on a number of observations and features. The current methods that address this problem rely on computer vision techniques: models based on hand crafted motion features - [11] improves dense trajectories for action recognition by correcting them using camera motion,[12] proposes a representation of each frame using a HOOF features which are independent of scale and direction of the moving person; depth information based models – [13] describes a method for HAR based on depth maps sequences. They generate Depth Motion Maps (DMM) using a projection of the depth maps onto the orthogonal planes and accumulating activities through entire video sequences; deep learning models- Wang et. al. improved the two-streams architecture [14], an output being temporal segment network (TSN).

III. THE SMARTCARE SYSTEM

A. Definitions

The SMARTCARE system is a solution for assisted living,which focuses on intelligent automation and monitoring of the patients' environment in order to enhance the life of elderly and/or suffering persons. There are several types of actors that are involved and interact in the proposed system.

Firstly, the **Administrator**'s role is to create and manage users and to establish permissions for accessing the different features of the system.

For each patient, there is a deployment of devices and hardware/software components in that patient's home. Each such project is managed by a user with the **Designer** role. This type of user can create a 2D/3D model of the home,position the various devices, and make the connections and workflows between the deployed sensors/actuators and various home electronics and devices.

The most important role is the **Patient**, whose activity around the house is monitored in order to detect different situations like the patient falling, becoming immobilized or just sleeping. Another aspect is monitoring the biophysical parameters, e.g. pulse, temperature, blood pressure, and other indicators that can potentially lead to a life threatening situation.

Each patient has to be supervised by a **Caretaker**, who has access to reports referring to alerts, the patient's activity and bio-physiological parameters, and who can configure and receive various notifications regarding the patient.

Lastly, the **Physicianis** the one that supervises one or more patients, has observation charts for each of them, and can communicate with the patient or with the assigned caretaker by means of the proposed system.

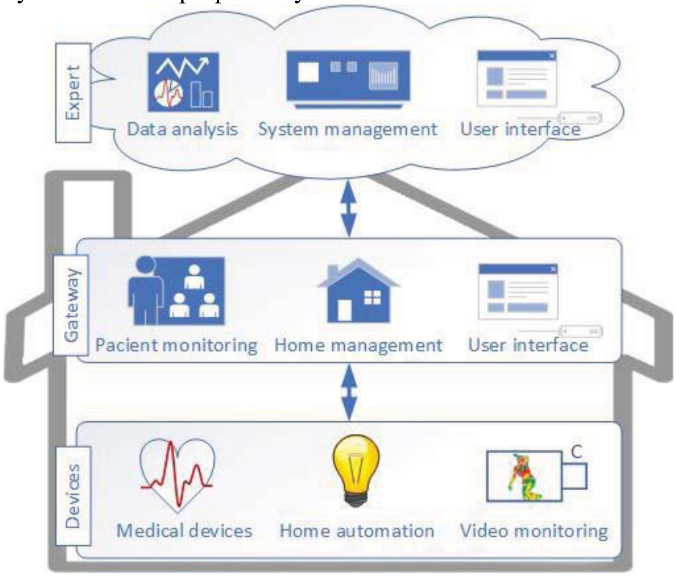

Fig. 1. Architecture overview of the SMARTCARE system

B. Architecture overview

The main goal of the SMARTCARE system is to improve the quality of life of elderly patients. This is achieved with the help of medical devices, various sensors and actuators, which are installed in the patient's home and which allow patient monitoring and home automation. Another element is a data processing unit, which gathers sensor data and provides an elaborate alert and notification system.

In terms of the proposed system architecture, there are three tiers, i.e. Devices, Gateway and Expert System, as presented in Fig. 1. The first two tiers are deployed in each patient's home, whereas the Expert System tier is a Cloud component that oversees all the gateways and takes smart decisions based on the acquired data.

1) Device tier: There are various types of devices that are employed by the SMARTCARE system and those devices fall into two main categories: medical devices and devices for home automation and monitoring. The medical devices allow monitoring the patient's vital parameters, e.g. pulse, temperature, blood pressure, oxygen level, blood sugar level. On the other hand, home automation devices can monitor room temperature, humidity, heating and lightning, they can detect gas, smoke and movement, they can allow video and audio monitoring, and they can control sockets, light bulbs and home electronics. An important issue is that devices use certain protocols for communicating with a processing system. The connectivity with a device can be performed via

WiFi,serial, or vendor specific protocols (e.g. Z-Wave, ZigBee). This problem is solved by the Gateway tier.

2) Gateway tier: This tier's role is to communicate and interface with different types of devices, environmental sensors and actuators. A device abstraction layer allows the Gateway to easily communicate with devices regardless of their particularities. Another element is the graphical user interface,which facilitates the configuration of the system. It features a 2D/3D home model with the devices and their positioning,and various rules for enabling triggers, notifications and alerts,based on the data received from the medical and home monitoring devices. Another important feature is the image and video processing component, which helps monitor the patient's activities and detects critical situations (e.g., if a patient fell or is immobilised). From a technical point of view,the gateway is a physical processing unit that can handle some real-time processing, while more computing intensive tasks,which include smart monitoring over a longer period of time,are performed by the Expert System.

3) Expert System tier: All the gateways are managed by the Expert System tier, which enables smart information processing by gathering data from the gateways, processing that data and by defining monitoring and alerting rules. An advantage of the Expert System is that it can correlate the data received from gateways to change the rules for other gateways. It can also detect behavioral patterns in patients and predict critical afflictions. Caretakers and medics can easily use the Expert System's user interface to monitor and receive notifications regarding a patients health.

C. Device tier design

When it comes to AAL or HMS solutions, the main deterrent for large scale deployment is the installation and hardware cost.

Deployment scenarios that include wired sensors and actuators yield extra costs due to the infrastructure needed (e.g. Modbus over RS485 implies a daisy-chain infrastructure based on a twisted pair cable and common ground) and also due to the particularities of the environment (e.g. retrofitting an older home with devices connected to the same communication bus).

Wireless devices pose specific challenges as they suffer from attenuation and multi-path fading meaning specialised hardware as amplifiers or repeaters may be needed in some cases. Also, even if the majority of wireless devices are battery powered, the ones that are critical for the backbone of the topology are mains powered and may pose extra restrictions regarding placement and network coverage.

Last but not least, the dependence most AAL and HMS systems have on specific hardware (i.e. fixed number of hardware interfaces and communication protocols) has an impact on the range of devices that can be used for deployment. With each technological iteration, manufacturers will integrate new features (i.e. updated hardware, new communication standards) in their devices thus having limited or no backward compatibility to an existing system.

The SMARTCARE system tackles these challenges by implementing a flexible device layer with the main objective of supporting heterogeneous deployments with a broad range of sensors and actuators.

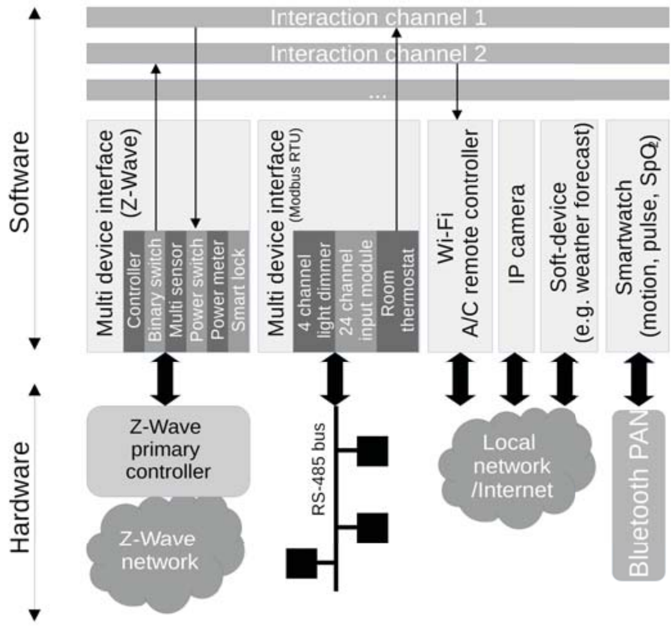

Fig. 2. Sample configuration for the device layer

1) Real-time interaction: The software components of the Gateway are to be run on standardised x64 hardware platforms. This approach allows the integrator to choose the most suitable hardware configuration (e.g. number and type of USB and network interfaces, RAM memory capacity, etc.) in order to leverage the costs with respect to the real-time constraints.

2) Modular interfaces: The IoT revolution has brought a plethora of smart sensing and monitoring devices, with current trends in the field trying to standardize or unify the current heterogeneous solutions. The software components of the Gateway that interface the connected devices are to be implemented independently with standardized Service Access Points for interaction with the upper layers of the system. This approach enables the integration of current and future devices,the only limitation being the availability of the API or interface specifications.

3) Configurable interaction modes: For each I/O resource available on a device, the integrator is to be able to set individual access methods - one shot, pooling, event based- in order to accommodate a broad range of interfaces. This allows the creation of a fine tuned real-time system without wasting resources. For example, let's consider a multi-sensor device (e.g. Aeotec MultiSensor 6 with Z-Wave interface)with temperature, motion, light, humidity, vibration and UV sensors. As the motion sensor monitors individual events, the suited access method is event based. The rest of the sensors must be pooled with different rates suited for the dynamics of the measured physical quantity.

4) Low-level coordination: In order to reduce the load on the upper layers of the system, the Device Layer is to integrate communication channels for basic interaction between the connected devices (i.e. hardwired scenarios related usually related to home management). The channels will be configured via simple scripts and will enable the implementation of causal interactions (e.g. triggering of a magnetic door switch integrated in ZigBee network will turn on the A/C unit via a IR remote controller accessible via Wi-FI).

Fig. 2 presents the architecture in a sample configuration that interfaces a Z-Wave wireless network, a Modbus RTURS-485 network, a couple of independent devices that use standard network medium and a Bluetooth smartwatch. All devices/networks are connected via standard ports (i.e. USB,WiFi, Ethernet and Bluetooth adapters) and are controlled via the modular interfaces. Depending on the interaction model with the hardware devices, the modular interfaces are implemented for (i) a single device (i.e. direct interaction via a standardized API) or (ii) multiple device connected to self-organizing networks (e.g ZigBee) or multiple slave devices connected to the same communication bus (e.g. I2C). Two sample low-level coordination channels are also present and through the use of hard-coded logic, raw sensor data can be used to trigger events across the system - for channel 1 if the temperature read from a wired Modbus room thermostat crosses a threshold, a window actuator is turned on via a Z-Wave power switch; for channel 2 a one-shot binary switch(e.g. magnetic door sensor, motion sensor) is used to turn on the air conditioning for a limited period of time.

IV. Conclusions and expected results

Currently, the development cost represents the main draw-back that slows down dramatically the commercial adoption of IoT based solutions for AAL of persons with special monitoring needs. The final price paid is significantly influenced by the complexity of the design and development of these systems,as well as the requirement for highly specialized human re-sources. Another important factor is the absence of automation tools for the design, development and deployment processes. SMARTCARE represents a framework that goes beyond the state of the art in the field of AAL systems and provides the required automation features that ca help lower the final cost and speed up the development of personalized monitoring solutions for a large range of scenarios. The framework is based on international standards for communication between heterogeneous devices. This approach allows the integration ofa wide range of third-party devices available in the healthcare area, facilitates the data transfer between SMARTCARE and proprietary systems and allows plug&play interoperability.

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