Home and Physiological Remote Monitoring System for Elderlies and People with Chronic Diseases

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Abstract. This paper presents a modular system of wireless monitoring of physiological and ambient conditions based on Internet of Things (IoT). It is specially designed for elderly people and people with chronic diseases to promote their independent living. The system consists of a network of physiological and home ambient sensors developed under standard IoT protocols. These sensors are designed and manufactured at the laboratory with low-cost components. In addition, commercial sensors can be added according to the requirements of the patient. The system also provides a web based user interface for medical and family caregivers. It displays real time data and it includes an alarm system to report unsafe events via email. The caregiver can also see historical data with the possibility to compare all the parameters of a certain day and time. Furthermore, a home automation system was proposed to control home devices to improve home safety. The evaluation of the system was performed under a controlled environment at the laboratory in pilot tests before being tested in patients.

Keywords: Elderly · Assistance · Remote monitoring · Sensors · Internet of Things

1 Introduction

A recent survey of the World Health Organization (WHO) [1] reveals an increase in life expectation (estimating 400 million people over 60 years old in 2050), which is associated with longer treatment for chronic diseases. This situation leads to increasing health costs and a social problem for personal care and hospitalization. A new concept of home care and real time monitoring based on Internet of Things (IoT) would lead to a more efficient public health solution. It would increase the quality of attention and provide alternative ways for more humanitarian models of assisted alternative to institutionalization, promoting and improving the independence and quality of life.

The system presented consists of a technological implementation to remotely monitor home ambient and health parameters of the elderly and people with chronic

diseases. It consists of a network of sensors that continuously acquire ambient parameters (light, temperature, humidity, carbon monoxide leaks and motion) and health sensors to measure physiological parameters (body temperature and heart rate), a home automation system to preserve the parameters within a safe range, and a user interface that allows family members, doctors or caregivers to remotely monitor all the parameters, query historical data and receive alerts about dangerous events and system failures.

2   Materials and Methods

The system has the following main blocks: home and health modules networks, a central processing unit and a user interface (Fig. 1).
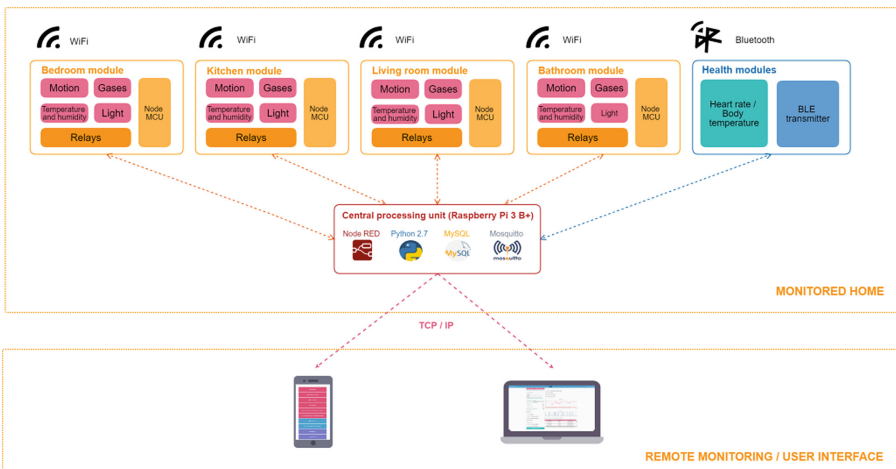

Fig. 1. Block diagram of the technological implementation.

2.1   Home Sensors Network

A module was designed for each room of the house in order to measure temperature, humidity, carbon monoxide leaks, light intensity and presence of somebody in the room and also to control home devices. The modules include the following components [2]:

Temperature and Humidity Sensor. The sensor selected is the DHT22 due to its low cost and small size. It measures humidity in a range between 0% and 100%, with an accuracy of 2%–5% and temperature in a range between −4 °C and 80 °C, with an accuracy of ±0.5 °C. For the data analysis, a temperature range between 18 °C and 24 °C, and humidity range between 40% and 50% were considered as safe thresholds. Higher levels of humidity could trigger respiratory diseases, asthma and allergies [3].

Light Sensor. The BH1750 sensor acquires light through a photodiode capable of sensing visible and infrared light, with a response very similar to a human eye.

Measurements between 0 and 5 lx indicate a low light level and so the person cannot see properly. Measurements above these values, depending on the time of the day, mean that the room has a proper natural or artificial light level. These data can be used in the analysis of sleep hours and routines.

Motion Sensor. The SR-501 pyroelectric passive infrared (PIR) sensor was selected for motion detection and consequently the presence detection of the person in a certain room. In order to detect presence even when the person is not moving, some adjustments had to be made by software.

Carbon Monoxide Sensor. The MQ-9 sensor acquires digital and analog values of carbon monoxide concentration in a range between 10 and 1000 parts per million (ppm). For exposures between 1 and 70 ppm, the person does not have symptoms during prolonged exposures [4]. In any case, the threshold considered is 30 ppm to determine if there is a leak and so it is possible to stop it in time.

Information Management. The data has to be centralized and sent wirelessly to the system's central computer. For this purpose, the NodeMcu V1 development board was selected. This board has a microchip ESP266 integrated. It allows Wi-Fi connectivity and the use of sensors interconnection protocols like MQTT, suitable for IoT systems.

Automatic Control System. A 4-channel solid-state relay module, Arduino Pic Arm, was selected to control actuators and consequently the home devices. It has the advantage of being faster than conventional relays and of having greater durability because it does not have mechanical parts, it is not noisy, there is no risk of generating sparks, it generates less electrical noise and it is more immune to humidity and vibrations.

2.2   Wearable Sensors Network

A Wireless Body Area Network (WBAN) of wearable, lightweight and low consumption sensors was designed for getting real time information about the user's health status. The designed architecture allows the expansion of the network, making it possible to design or include other sensors. In this work, the modules used are:

Body Temperature Module. It consists of the LMT70 sensor from Texas Instruments®, which is small sized and has a precision of 0.05 °C in the range between 20 °C and 42 °C, and a CC2650 microcontroller also from Texas Instruments® with Bluetooth Low Energy (BLE) connection capability [5].

Heart Rate Module. It is based on the Pulse Sensor heart rate sensor specially designed for Arduino. For the implementation of the BLE protocol, the Adafruit Feather 32u4 Bluefruit LE module was chosen to acquire the data and to transmit it wirelessly.

2.3   Central Processing Unit

A Raspberry Pi 3 B+ with Raspbian operating system was used as a central computer to centralize and process data from home and health modules. It was selected due to its

low cost, versatility and storage capacity. It also has built-in Wi-Fi and support for the BLE protocol to communicate with the modules. It is configured as an Access Point, so instead of connecting to the Internet via Wi-Fi, it can generate its own Wi-Fi network. Furthermore, a Node Red architecture was implemented to interconnect the modules through the corresponding protocols, control dataflows, manage the data storage and develop the user interface

2.4   Data Communication

The MQTT protocol is implemented to establish communication between home sensors and the central computer by a star topology network. Multiple clients are able to send and receive data through publications and subscriptions to a broker which is the central node of the protocol. For the communication between wearable sensors and the central computer, the protocol implemented is BLE to satisfy IoT and wearable sensors requirements.

2.5   Validation Tests

The system has been tested for each module and for the complete system, under three requirements:

1. Preservation of data packets sent via Wi-Fi and BLE.
2. Remote monitoring through different networks using mobile phones and computers with Internet access.
3. Correct reception of alarms by simulating critical parameters for each sensor and inducing disconnections to check if the alarms are received satisfactorily.

3   Results

3.1   Modules Design, Manufacture and Validation

To acquire and transmit both ambient and physiological measurements, ad hoc circuit boards with the components and sensors previously mentioned were designed. Four home sensors modules (bedroom, kitchen, bathroom and living room) were implemented for a first validation and test in preliminary trials, installed in a testing room. The entire system was tested for 72 h, limiting the results herein presented to the events produced in this time interval.

Furthermore, two different health modules were designed, both with different BLE transmitters and sensors (body temperature and heart rate). In a future line of research the objective is to develop modules able to measure more health parameters and to add other commercial wearable sensors. It was verified that the BLE protocol is the most suitable for this application, as was reported in the literature. Since it has low energy consumption, it can be powered by small batteries and thus keep a small size. The battery used is a 3 V 600 mAh CR2450, tested under the continuous functioning of each module for 3 consecutive days. The replacement is easy for users or caregivers, fulfilling one of the design requirements.

The requirements mentioned in Sect. 2.5 were tested under a controlled environment. All modules acquired data during 72 h in the laboratory accessing to the Internet by the local network. During this test, the correct reception of data packets was confirmed every ten seconds for the ambient sensors and every 30 s for the wearable sensors. In order to test the remote monitoring, the system was accessed through five different external networks using mobile phones and computers with Internet access. With the corresponding user ID and password, all users could access the system to interact with it. Moreover, with the purpose of checking the correct reception of the alarms and the system response, parameter values outside the safety thresholds and disconnections were forced. Regarding the disconnection test, ten seconds after the event occurred, the corresponding mailing alert was sent and a pop up message was shown in the interface. This test was done 20 times in all modules. Sensors were proved with experimental values above and beyond the pre set thresholds to verify the reception of the set alarms.

The system uses standard communication protocols that ensure accuracy in data management between devices and provide more scalability with commercial devices.

The implementation of Wi-Fi and BLE as wireless protocols is supported by international standards.

3.2   User Interface

A web interface was developed so that the caregiver can supervise the data collected by the sensors. A user ID and password are required for security. The caregiver can monitor in real time the measurements from all the sensors (data is updated every ten seconds from the ambient sensors and every thirty seconds from the health sensors).

They can check in which room the person is and control home devices when necessary if having the proper permissions. The web interface also has an alarm system that sends alerts via email when the patient is in a dangerous situation.

Moreover, it is possible to query historical data of a specific day and time range and visualize graphs with the measurements and their respective safe thresholds (Table 1). These thresholds can be personalized according to the specific health requirements of the person. In addition, relevant data is displayed: average, maximum and minimum of measurement values, frequency of entries into a room and maximum time the person remains in the same room (Fig. 2). The results of these queries can also be sent to the user's email address.

Table 1. Default parameters and their respective thresholds used in the monitoring system. All of them can be changed for specific requirements.

Ambient parameter	Threshold
Ambient temperature	18 °C–24 °C (acceptable range)
Humidity	40%–50% (acceptable range)
Light level	>5 lx to see properly
Carbon Monoxide	<30 ppm
Presence in the bathroom	<1 h
Presence in the bedroom	<0 h between 08 pm and 10 am
Health parameter	Threshold
Heart rate	50 BPM–110 BPM (acceptable range)
Body temperature	<37.8 °C

Fig. 2. Rooms historical data.

4 Discussion and Conclusions

The system developed, considering both the electronic modules and the web based user interface, fulfills the main objectives of this project: to support health care and independent living of elderly people and people with chronic diseases and to allow medical and family caregivers to monitor remotely their health status and home safety to ensure their well-being. Regarding the current public health situation, especially in developing countries, this system provides a possible solution to decentralize hospitalization in health centers.

When compared to other existing commercial systems, the main advantage of the proposed system is the possibility to integrate ambient and wearable sensors in a single platform at a low cost (less than 1000 USD).

Preliminary validation tests of the system were carried out, but validation test have to be carried out in uncontrolled environments in a future work. It is necessary to evaluate the interaction of patients and caregivers with the system, and also the response to unexpected fails not induced yet.

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