

# A system for assisted living and home automation

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**Abstract** – Aim of this paper is the design and implementation of a system for assisted living and home automation. The apparatus is able to both monitor vital signs of persons with medical problems and automate the home management. Concerning the home automation, the system can manage lighting, actuate the opening of doors and windows, schedule appliances, manage electrical loads, thermo regulators and video surveillance sensors. Hardware of proposed system is based on low-cost ARM processors. Important features of implemented application program are the real-time management of data transmission between the different system components, in order to control main home devices and generate alarm signals in case of vital functions outside the fixed ranges. Automation, monitoring and remote assistance are joined together to create a home environment of high security and prevention, to offer the user a high sense of security since his health status is continuously monitored.

*Keywords* — Assisted living; home automation; vital sign monitoring; remote control; efficient load control.

## I. INTRODUCTION

Electronics represent today one of the leading sectors of the so-called third industrial revolution. Together with informatics and telecommunications these technologies are still under a joined continuous evolution summarized under the name of Information and Communication Technology (ICT). For a long time these areas progressed along separate paths, but now, thanks to advances in digital technologies, they cooperate towards the realization of a set of products and services that are fundamentally changing the way people work and live [1]. In recent years ICT produced significant advances in different fields such as consumer electronics, communication and industrial systems. New advances are also focusing on people's daily life and concern new domestic applications that make the dream of a home of the future where an intelligent environment is modelled around the user's needs less utopian.

An important aspect that must be considered is related to the aging of population: by 2050 the number of

European people over 65 will be 3 times what it was in 2003, and the number of over 80s will have multiplied by 5. In line with the effects of European aging society, the number of people requiring care is also increasing, even if the cost for hospitalizations and medical visits cannot be increased in the same way. Many patients with chronic or debilitating diseases do not need to remain in the hospital but, nonetheless, need constant monitoring of their vital signs to assist in early detection of dangerous situations.

Important ICT applications must be oriented towards new methods of healing and improving aged people's quality of life, and specifically towards monitoring vital signs at home [2]. Circulatory and respiratory issues, in particular, pose a risk for the elderly, because they can lead to potentially serious conditions.

It is often difficult for the elderly and people with disabilities affecting their mobility, to get to their doors in time to greet a guest. Besides, for aged people it is sometimes difficult remembering to turn off appliances in their homes. Through home automation, appliances can be set to automatically turn off after a certain period of time and doors can be remotely controlled [3]. These technologies are frequently referred to as assisted living [4].

Operating in this direction will make it possible to increase the life quality also in less advantaged population segments. People benefit of their home keeping their habits of life, their social relationships and their personal freedom.

Important aspects about home automation are the house conception, its internal organization, the adopted technological equipment and systems as well as the overall design criteria. These aspects must be suitable to support mutable needs, changing dynamically with the user preferences, aims and priorities.

Solutions currently present on the market allow a full control of dwelling, making it possible for example to manage the lighting system, actuate the opening of doors and windows, check the electrical loads, regulate thermal systems, manage the electronic surveillance video, diffuse sound and access to multimedia content [1, 3].

In this paper we propose the implementation of a system for assisted living that monitors vital signs of a

person. The proposed system helps patients to monitor themselves at home, with the main benefit of improving the sense of security, knowing that user's health status is continuously monitored. These activities are integrated into an innovative home automation system capable to automate and control most of devices and appliances.

Main design aspects have been identified and analysed. Additionally, results from lab tests are presented.

## II. THE PROPOSED SOLUTION

The new trends in assisted living and home automation are today contradicted by a small end-user demand. People are more easily inclined to consider these technologies as science fiction and the relative products as luxury solutions addressed only to a specific target user community.

Home automation mainly depends on integrating together sensors, controllers, and an application framework. Unfortunately, there is no a sufficient level of standardization to drive the products available on the market, especially as concerning network technologies. On the contrary there are several solutions, such as: ZigBee [5], Z-Wave [6], Universal Powerline Bus [7], and others [8], but none is fully suitable for creating a market. Consequently specific products can be hardly integrated together, producing cost increases.

The main dissuading factors to the diffusion of these technologies can be synthesized in the following items.

- Some home automation products are still luxury items.
- Actual systems use proprietary technologies and communication protocols that make the integration with products provided by a different manufacturer difficult.
- Proposed solutions generally present low customizability and scalability.
- Most manufactures have a reduced attention towards people with physical defects or advanced age.
- Most available measurement systems have reduced precision and accuracy.

To solve these problems, the proposed system has been designed adopting non-proprietary communication protocols. It ensures modularity from both hardware and software points of view. Regarding hardware, the different modules have been designed to be autonomous; in this way a problem occurring in one or more units shall not affect the correct working of the entire system. From the software side, a single implemented application can operate on different devices, by a suitable algorithm configuration. Each element can be dynamically linked to the system, based on its specific function, current overall configuration and user requests. Programs can run under different operating systems.

Special attention has been oriented towards the overall application program, mainly focused on real-time management of data communications between the

different system components. Transmitted data concern both device management and generation of alarms when vital functions exceed the optimal intervals.

Home automation devices execute the following main activities:

- turning on or off lights;
- manoeuvring shutters;
- releasing and rearming electrical loads;
- controlling the home temperature;
- creating scenario environments (pre-configured settings governing the behaviour of all the aspects of home surroundings including lights, climate control and other devices);
- controlling the alarm system;
- operating multimedia devices;
- accepting controls from smartphone application.

Vital parameters of one or more persons are continuously monitored by the system; these tasks are integrated with those related to home management, setting different monitoring frequencies and task priorities according to the specific criticalities.

### A. Hardware architecture

The whole system has been developed using high-performance boards based on two different Texas Instruments ARM microprocessors: the OMAP 4460 and SITARA. They have both reduced cost and high performances, especially related to low energy consumption. OMAP 4460 is a powerful system-on-chip that includes the perfect balance of power efficiency and high performance, based on the dual-core ARM® Cortex™-A9 MPCore and capable of speeds of more than 1 GHz per core, while the SITARA (AM3715) presents similar characteristics but with only one ARM Cortex-A8 core at 800 MHz. The operating system is an open source Linux.

The overall architecture of proposed system, shown in Fig. 1, is based on two different kinds of boards: one Primary Control Unit (PCU) and some Secondary Control Units (SCUs).

The PCU controls the entire house by means of different SCUs connected with an Ethernet link and receives data related to vital signs. This main system is located in the home area where the user spends the majority of time during the day (for example the living room). It is linked to a touchscreen that shows the user all kinds of information. The basic screen of PCU Graphical User Interface (GUI), reported in Fig. 2, shows some icons that, when clicked, present a specific area of the house.

One SCU operates and controls a specific application, such as the thermal system or the lights. The SCUs are located in the home area to be controlled (e.g. bedroom, kitchen, bathroom, etc.). From this device, the user can view on another touchscreen the information related to the area under the SCU control, such as energy consumption or alarm state. Fig. 2 shows a typical SCU

screenshot.

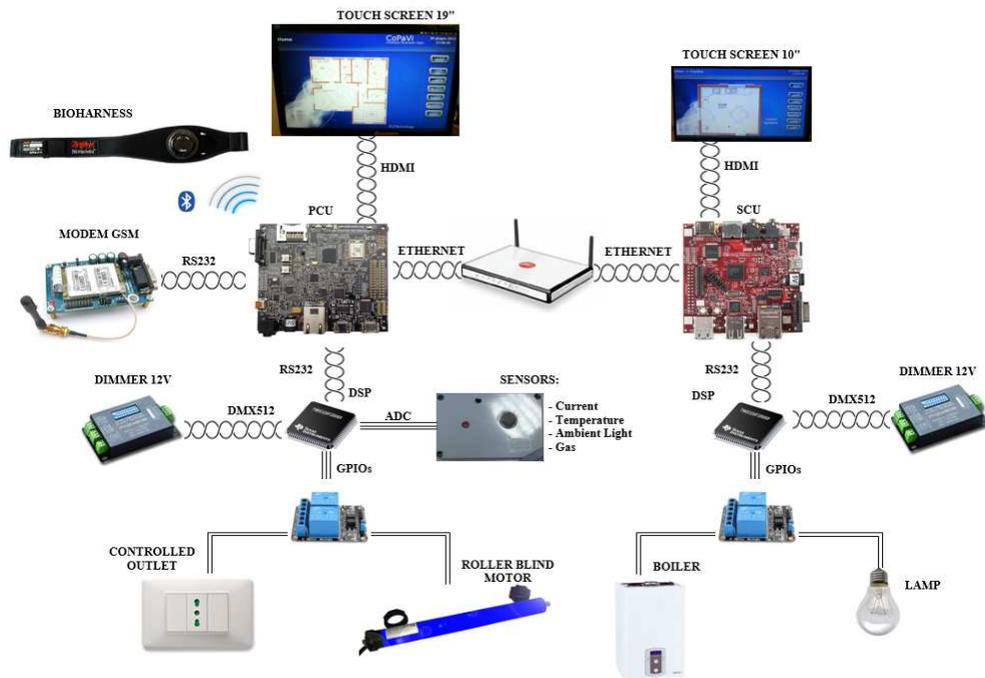


Fig. 1. Block diagram for the proposed system.

In the first prototype we implemented just one SCU, even if the entire projected system can work with more units. The implemented SCU manages the home electrical power system using the TMS320F28069, a C2000 Texas Instruments Digital Signal Controller (DSC). The DSC acquires signals related to current, temperature, ambient light and gas sensors using the internal A/D converter. It also controls a 12 V dimmer using a RS-232 link and the DMX512 (Digital MultipleX) protocol [9], and electric loads using GPIOs and solid state relays. The connection between SCU and DSC is based on a RS-232/485 link; also the connection between PCU and DSC is based on the same standard.

Concerning the physiological parameters, our choice went towards a continuous, non-invasive monitoring system, the based on a highly wearable chest strap that provides motion tolerant sensing capabilities (Bioharness in Fig.1). This system acquires, processes and transmits a number of physiological parameters with a Bluetooth radio interface:

1. 3-lead ECG, analysed in real time;
2. heart rate, analysed in real time;
3. respiratory rate;
4. body temperature;
5. status motion and posture, analysed in real time.

Signal compression and analysis are executed at the mobile application level to minimize transmitted data. When a certain limit is exceeded, the system generates alarms on the screen and contacts specific telephone numbers with a GSM modem (Fig.3). To avoid false alarms, the thresholds have been customized for each user according to medical suggestions.



Fig. 4. Temporal diagram of control algorithm on DSC TMS320F28069

#### B. Software architecture

The standardisation of communication stack ensures interoperability with other systems.

Both PCU and SCU user interfaces have been developed on JAVA, the cross-platform language par excellence, available for installation on Windows, Linux, and other operating systems. These boards are interfaced through TCP IP. Each node can perform client or server functions running a specific algorithm. In case of malfunction, the card can be excluded allowing an automatic network reconfiguration. To accomplish the required compatibility with other

communication standards, only non-proprietary protocols have been used, such as Bluetooth for monitoring vital parameters and DMX512.



Fig. 3. Particular of box with PCU and GSM-modem

Each board (PCU and SCU) has a database to store all data related to housing, state of electrical loads, sensor outputs, alarms related to vital signs.

The management and control of an electrical power system is a critical task, mainly because of the rapidity with which absorbed currents can vary. We implemented it mainly for this reason, to guarantee the easily SCU applicability to other tasks.

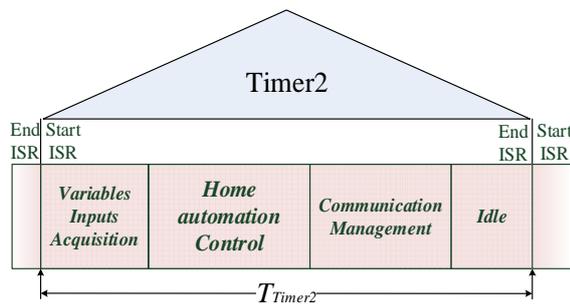


Fig. 4. Temporal diagram of DSC control algorithm

The algorithm implementation is based on the so-called Synchronous Programming, a technique that synchronizes the control algorithm with respect to the input (acquired variables) and output (I/O commands, PWM, communications) data. For this purpose, we adopted a Base Period, the time it takes to complete the overall processing cycle. During a base period the system acquires the inputs, executes the control algorithm and calculates the command outputs, which are updated at the end of the period. This procedure synchronizes all the operations at the beginning of each period.

The base period has been dimensioned in relation to the shorter time constant of quantities under monitoring, in this case the load currents detected by the current transducers. In the implementation we set the base period at 100 ms, a compromise that ensures a right current monitoring making possible to run the processing algorithm.

Referring to Fig. 4, during the time interval called Home Automation Control, the DSC acquires electrical power consumption and all the other quantities such as temperature and lighting state. Since electrical currents have a dynamic change faster than other measured parameters, they are acquired every 2 ms, with a frequency 10 times greater. Within this control all the I/O commands (light loads) in addition to DMX512 and RS-232 communications are also managed.

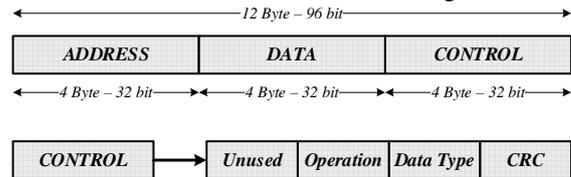


Fig. 5. Data protocol DSC-ARM board (TOP) and particular of control package (DOWN)

A serial communication protocol has been adopted to interface the measurement system with the ARM board (shown in Fig. 5). It uses request and response fields of fixed length and a CRC field to check for a correct transmission of communication packet. Fig. 5 (UP) shows the communication sequence between central unit and DSC. This sequence consists of three sections: Address, Data and Control. Address section contains the memory address of DSC on which to perform the operation specified in the Control field. Data section contains just the information to be transmitted received. Control section contains Operation, Data Type and CRC (see Fig. 5). Operation indicates a read (82 in ASCII) or write (87 in ASCII) command. Data Type indicates a 32 or 16 bits (32/16 in ASCII) variable to read/write. CRC is the Cyclic Redundancy Check calculated by both SCU and DSC to check transmission error.

### III. THE MONITORING OF VITAL SIGNS

As previously discussed, the wearable chest strap represents an innovative solution in the field of physiological monitoring. The belt communicates with the ARM board using a Bluetooth link with a point to point data transfer without addressing and adopting a simple request-response technique.

The unit responds to the prompt with one of the two main types of messages. If the request message turns out to be valid, the answer is in the form of an ACK with the requested data included; if determined to be invalid, the answer is in the form of a NACK message and no data is in the message. There is an exception to the rule in which messages "periodically" are transferred between units. In this case no responses are needed.

Fig.7 shows the basic format of a message:

- *STX* (Start of Text) denotes the beginning of the message (02 in ASCII).
- *Msg ID* identifies each message; a response message

uses the same Message ID of the request.

- **DLC** (Data Length Code) specifies the number (0 to 128) of bytes in the data field (payload) of message.
- **Data Payload** contains the actual data transmitted between local and remote units.
- **CRC** field (8 bits) is used to control the polynomial 0x8C (CRC-8).
- **ETX** (End of Text) indicates the end of message (ASCII 03). When sent by the transmitter, the receiver replies with **ACK/NACK**.
- **ACK/NACK** is present in the response message to acknowledge the message.

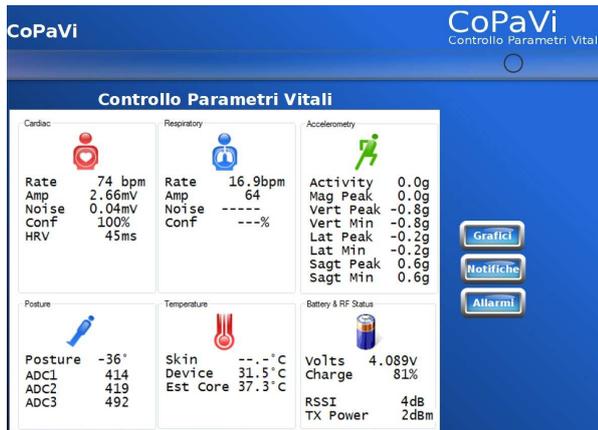


Fig. 6. GUI for vital signs

#### IV. EXPERIMENTAL TESTS

During the system design we carried out extensive use of simulation methods as well as experimental investigations. Design strategies have been oriented toward modular solutions to the advantage of simplicity and cost reduction. These activities have allowed developing the prototype and validate its performance through tests on individual components.

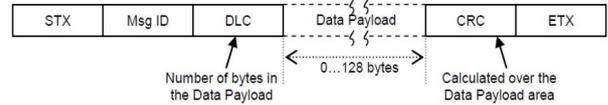
As part of the development phase, we performed some preliminary tests to the prototype in the laboratory, to verify its functionality. The first step was related to verify the correct functioning of each single board, device and piece of program. Successively we tested each subsystem to verify whether the integration between more devices posed malfunctions and/or problems. At the end we conducted a test with the overall system.

Specifically we conducted tests to analyze the:

1. alarms generated when vital parameters exceed programmed thresholds;
2. algorithm that sets each electrical load as primary (uninterruptible) or secondary;
3. intelligent load management algorithm that switches off appliances when the electricity consumption exceeds the available power;
4. careful management of consumption;

5. communications between the devices, including also conversions between free non-proprietary protocols and those adopted by devices available on the market.

**Request:**



**Response:**

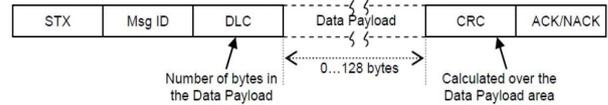


Fig. 7. Format message of Bluetooth communication

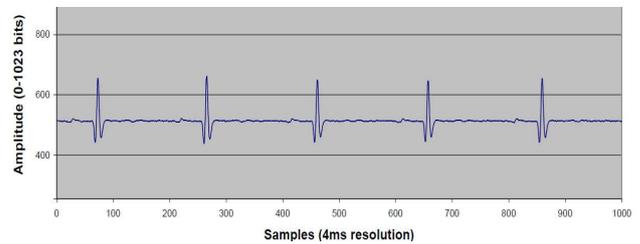


Fig. 8. Example of ECG waveform

During this phase we obtained satisfactory and encouraging results. Both PCU and SCU appear to operate correctly, interacting with all transducers and actuators as designed. Home automation and assisted living tasks have been executed without problems.

We planned to carry out successive long-term tests to monitor the system performance over a long period in an actual home application.

All baseline data collected can be used to create a profile for each individual, so it would be clear if at any time an individual was going beyond their normal thresholds due to stress, anxiety, fatigue, malnourishment, heat stress, hypothermia, hypoxia, or many other common problems that people were susceptible to.

#### V. CONCLUSIONS AND FUTURE DEVELOPMENT

The proposed system is able to carry out the home monitoring of vital signs of persons with medical problems and automate the home management.

The measurement of the heart rate and electrocardiogram (ECG) allows to control the heart's activity, in the case of rest or an effort. In the first case, through the analysis of values, it is possible to highlight diseases of coronary arteries, abnormal heart rhythms (hypertrophy) and the conduction of the electrical impulse. With the values of the ECG under stress it is possible on the other hand to obtain a dynamic path which can highlight latent heart disease,

as well as determine the limits of physical activity for patients with coronary heart failure.

The wearable belt integrates two piezoelectric transducers that convert the force into an electrical signal. The recorded signal is a sine wave whose rising edge corresponds to the inspiratory while the falling edge is expiratory (Fig.9).

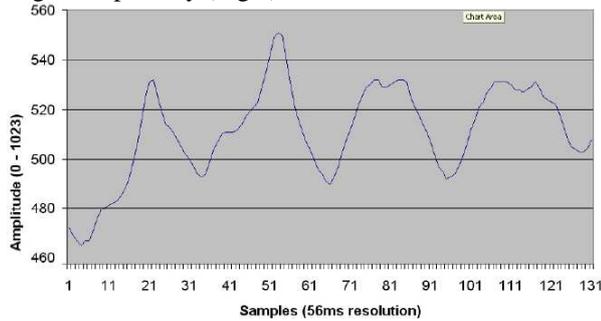


Fig. 9. Example of breathing waveform

The characteristics of vital signs measurement are shown in Tab. 1.

To obtain the desired flexibility and modularity, a key design specification for this system, we proposed and implemented a new home automation system. This is mainly because using an already available system for the monitoring of vital signs would have been economically and work-wise more expensive.

The best field application of the proposed system is for the dehospitalization: it allows diseased people to be under control as if they were in hospital but at the same time they can enjoy the freedom and the comfort of home. In this case the energy monitoring is not very important even if the simultaneous use of both tasks is still convenient.

Measure	Sampling frequency	Accuracy	Min	Max
HR	1 kHz	$\pm 1$ bpm	0	240
BR	25 Hz	$\pm 1$ bpm	0	120
Temperature	1 Hz	$\pm 2$ °C	10	60
Acceleration	100 Hz	$\pm 0.10$ g	-16	+16
Posture	1 Hz	$\pm 1$ degree	-180	+180

Tab. 1. Vital signs measurements

The developed system allows for many possible future developments, that can be planned to improve the system by increasing the number of SCUs and applying them to control different home appliances or devices. Another possible work can be planned to adapt the system to other fields.

With regards to the first case: during the development we noted that the indoor user localization through Wi-Fi can be of great utility, so we are working towards adding this feature to the prototype. We are also studying new algorithms to make home more serviceable for an assisted people.

Another aspect is the extension of analyzable physiological parameters. This is because some devices allow the automatic blood sampling and test at home [10, 11, 12], making an immediate mini analysis possible through sending data directly to a control structure. In this way it's possible to eliminate infinite queuing in hospitals for a simple analysis or simple health control. The user has to go to a medicine structure only in case of necessity of instrumental analyzes, very useful for example for people with physical problems.

## REFERENCES

- [1] Horizon 2020. Work Programme 2014 – 2015. (European Commission Decision C (2013)8631 of 10 December 2013).
- [2] N. T. Artinian, J. K. Harden, M. W. Kronenberg, J. S. Vander Wal, E. Daher, Q. Stephens and R. I. Bazzi, "Pilot study of a Web-based compliance monitoring device for patients with congestive heart failure". *Heart Lung* 32, pp. 226-233, (2003). DOI:10.1016/S0147-9563(03)00026-8.
- [3] A. Nicholl, M. Perry, "Smart Home Systems and the Code for Sustainable Homes". IHS - BRE Press; 1 edition (20 Nov 2009), ISBN-13: 978-1848061125.
- [4] "A GUIDE FOR ASSISTED LIVING. Towards LifeHome 21". Royal Institute of British Architects, 2011, ISBN 9781859464236.
- [5] <http://www.zigbee.org/Standards/ZigBeeHomeAutomation/Overview.aspx>.
- [6] <http://www.smarthus.info/support/download/zwave/Z-Wave%20Protocol%20Overview.pdf>.
- [7] K. Dostert, F.Verlag, *Powerline Communications*. Prentice Hall PTR, 2001, ISBN-13: 978-0130293428.
- [8] Home Automation Systems and Technology Choices. <http://www.automatedhome.co.uk/home-automation-technology-choices>.
- [9] ANSI E1.27-1-2006, Entertainment Technology - Standard for Portable Control Cables for Use with USITT DMX512/1990 and E1.11 (DMX512-A) Products.
- [10] V. Oncescu, M. Mancuso, D. Erickson, "Cholesterol testing on a smartphone", *Lab Chip*, Issue 4, 2014,14, 759-763, 28 Nov 2013, DOI: 10.1039/C3LC51194D.
- [11] M. Takai, et. al., "Colorimetric microchip assay using our own whole blood collected by a painless needle for home medical care", *Analyst*, Issue 21, 2013,138, 6469-6476, 23 Aug 2013, DOI: 10.1039/C3AN00881A.
- [12] CardioChek PA, Technology and Operating Principle. [http://www.quickmedical.com/Polymer/cardiochek\\_pa\\_tech.html](http://www.quickmedical.com/Polymer/cardiochek_pa_tech.html).