A Raspberry Pi Based System for ECG Monitoring and Visualization

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***Abstract*—In this paper, a Raspberry Pi based system for electrocardiogram (ECG) monitoring and visualization is presented. A sensor by Olimex has been used to read the ECG while a Raspberry Pi 0 W, together with an ADC integrated circuit, have been employed to acquire the signal. By using the Wi-Fi connection, the signal is sent to a Raspberry Pi 3 that displays the ECG on a monitor. Thanks to the use of a 6th order Butterworth filter and of a 50 Hz notch filter the displayed signal is noiseless and the frequency of the ECG signal is easily extracted by using a peak detection algorithm.**

***Keywords*— Raspberry Pi system on chip, ECG monitor, Wi-Fi communication**

I. Introduction

Epidemiological data indicate the progressive increase of advanced chronic patients, often elderly, or of people confined, or semi-confined, in the home requiring ongoing care and assistance. The elderly patients (more than 65 year old), with chronic pathologies, for which the public assistance is activated are, in Italy, more than 500,000. Moreover, patients with debilitating end-stage chronic diseases (oncology or not), assisted at home by “Palliative Care Centers”, are in Italy more than 50,000. On the other hand, the indications of the "health decision makers" underline the need to prevent exacerbation of the diseases and to treat these patients at home. Otherwise, these patients would converge on hospital facilities, especially on critical areas (Emergency Services, Reanimations), with increased costs and with a deterioration of their quality of life.

For these patients, before hospital admission, it could be useful to carry out an ECG to be transmitted to the attending physician or to a treatment center. This could, in some cases, avoid hospitalization and extra-costs for health and/or insurance systems.

This paper will present a system for the acquisition and transmission of ECG data between people affected by chronic pathological diseases confined at home and suitable health care centers.

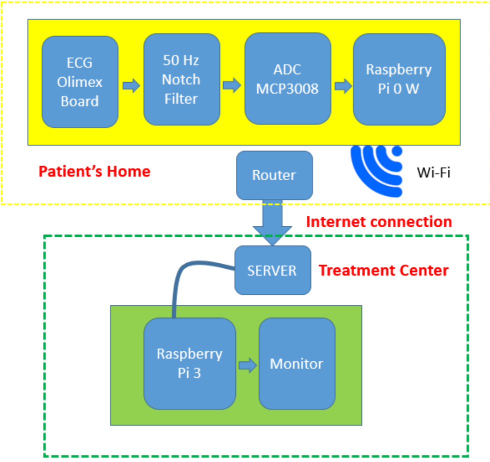

Fig. 1. Block scheme of the monitoring system.

II. System Description

The proposed monitoring apparatus is shown in Fig. 1. The system has been realized by combining an ECG board by Olimex [1] followed by a notch filter, an ADC, and a battery powered Raspberry Pi 0 W [2], linked to a visualization tool realized through a Raspberry Pi 3 [3] and a monitor. These two parts are connected to each other through the home communication network (Wi-Fi), the Internet connection and a support server where a MySQL database is loaded. This system makes possible to visualize the ECG of a patient in his home environment through a monitor located in the treatment center.

A. Control Units

The Raspberry Pi is a single-board computer developed and produced by the Raspberry Pi Foundation. The Raspberry Pi family is based on the system-on-a-chip (SoC) Broadcom which incorporates an ARM processor, a Video Core IV GPU, which supports graphic output resolutions via HDMI, 1080p60. The card does not provide integrated non-volatile memory unit, but it relies on SD cards thanks to an integrated MicroSD reader. Another common denominator of all the Raspberry Pi family cards is the presence of General Purpose input/output (GPIO) ports integrated directly on the board. These ports include power supply, logic signals, digital I/O, switches and physical communication buses including UART, I2C and SPI.

Fig. 2. Raspberry Pi 3.

Fig. 3. Raspberry Pi 0 W.

The power supply can be carried with a simple 5 V charger through the micro USB connector on the board or through one of the power contacts on the GPIOs. All family cards are compatible with operating systems based on the Linux kernel or Risc OS, Windows 10 IoT and even Android Nougat. Among the OS with Linux Kernel the most used is the Raspbian.

B. Raspberry Pi 3

The Raspberry Pi 3 (see Fig. 2) is the latest updated version of the Pi and has a size of 65 mm x 54 mm. It uses a SOC Broadcom BCM2837, with an ARM Cortex-A53 1.2 GHz, 64-bit, quad-core processor and a video card with 1GB shared memory. The card has 4 USB ports, an Audio Jack output, an HDMI video output, 40 GPIO ports and an Ethernet port. It also has integrated wireless connections: Wi-Fi Wireless LAN 802.11n, Bluetooth 4.1. The average consumption of this card is around 800 mA (4.0 W).

C. Raspberry Pi 0 W

The Raspberry Pi 0 W model has dimensions of 65 mm × 30 mm (Fig. 3). It has 2 microUSB ports (data and power), the wireless connection 802.11n Wi-Fi and Bluetooth 4.1. The SoC is the Broadcom BCM2835, which includes a 32-bit 1GHz dual core processor and mounts 512MB of RAM memory (shared with the GPU). The GPU guarantees a video stream output 1080p60. The GPIO ports remain the same as the Pi 3 model. One of the advantages of the card, in addition to its integrability, is its reduced consumption, which is around 150mA (0.8W), which is a negligible consumption for a single-board PC with an operating system always running. However, the strength of the device is the price that is only 11 $. All this actually makes this board the smallest and least expensive single-board computer in the world.

In order to power the Raspberry Pi 0 W, the zero LiPo module, developed and sold by Adafruit, has been used. This module is connected to the Raspberry through the GPIOs and, thanks to a step-up converter present inside it, converts the 3 - 4.2 V of LiPo batteries to the 5 V power supply of the Pi 0 W. The same power supply can also be used to power the other active elements of the sensor.

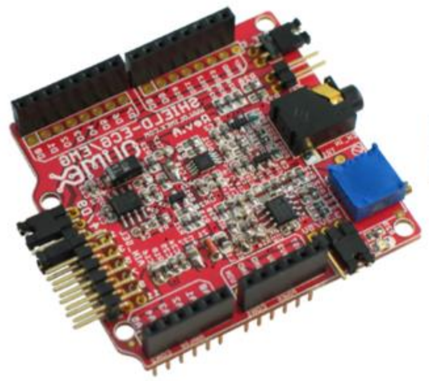

Fig. 4. ECG Olimex Board.

D. Olimex Board

The Olimex ECG is a shied designed by Olimex for Arduino boards (Fig. 4). The analog signal output of this card is a filtered and amplified ECG signal. On the board there are the comb headers for the external connections of the circuit: on one side all the digital input signals and on the other side all the analog output channels together with the power supply.

The Olimex shield was designed to work with an Arduino board. However, in this work the Raspberry Pi 0 W cards will be used. The reasons for this choice are that the Arduino libraries are not standard and are often written by the Arduino-community. Moreover, with Arduino it is not possible to create a visualization tool compatible with any screen on the market. Vice versa, the Raspberry environment allows creating a portable acquisition tool, integrated with the Olimex board, that transmit ECG data via wireless network thanks to the small size and connectivity on the Raspberry Pi 0 W. Moreover, Raspberry is easily programmable in any language (high or low level) and libraries and tools in Linux environment can be used. Finally, Raspberry Pi 3 allows creating a visualization tool that, thanks to its direct HDMI output and graphical interface of Linux, is able to display the ECG on any kind of monitor.

III. System Realization

A. Hardware design

Since the Raspberry Pi 0 W does not incorporate an Analog-to-Digital converter (ADC), an integrated device, the MCP3008, has been used as ADC [4]. The MCP3008 is a 10 bit converter (based on successive approximation) with 8 channels that interface, through SPI protocol, with the Raspberry Pi 0 W (see Fig. 5). This specific converter has been chosen because there are Raspberry Pi low-level libraries dedicated to the component and its resolution and speed specifications are suitable for this application, indeed the maximum sampling rate is 200ksps, 3 orders of magnitude higher than that needed to sample an ECG signal.

The Olimex ECG card incorporates a simple 3rd-order low-pass filter with a cutoff frequency of 40 Hz. Hence, it was decided to cascade a 50 Hz notch filter into the board. This was done as shown in Fig. 6. In practice, the notch is a double-T filter, with two buffer stages placed at its input and its output, so as not to load the output of the Olimex and the input of the cascaded ADC.

Both the converter and the filter were made on a breadboard to which two headers were added to allow connection from the Olimex board and to the Raspberry Pi 0 W, thus creating a sort of mini shield (see Fig. 7).

B. Software design

The programs for the acquisition and transmission of data from the Olimex board to the Raspberry Pi, and for displaying these data on a monitor were written using the C language. In particular, the Client-ECG code runs on the Pi 0 W and the Server-ECG code runs on the Pi 3. The two programs communicate according to a server-client structure, via the Wi-Fi network, using the TCP-IP protocol. The Linux library "Socket.h" was used to write the two codes.

The Client-ECG program has the function of acquiring, through the ADC MCP3008 and via SPI protocol, the analog signal of the ECG taken from the output of the Olimex board.

The Server-ECG program runs on the Raspberry Pi 3 and has the task of continuously listening to the data, processing them, when they are ready, and to plot them.

Since the electronic filter inside the Olimex board did not guarantee an appropriate noise rejection, the first processing done to the signal was its filtering through an algorithm that implements a 6th order Butterworth filter. To generate this filter a tool from the University of York [5] has been used. In particular, it was designed as a 6th order, low-pass Butterworth filter, with a cutoff frequency of 40Hz. The next implemented function is the detection of the “R” peak of the heart wave, the memorization of its amplitude and the evaluation of its temporal position. To graph ECG data the software gnu plot was used, sending plot commands and data directly from the real-time C program.

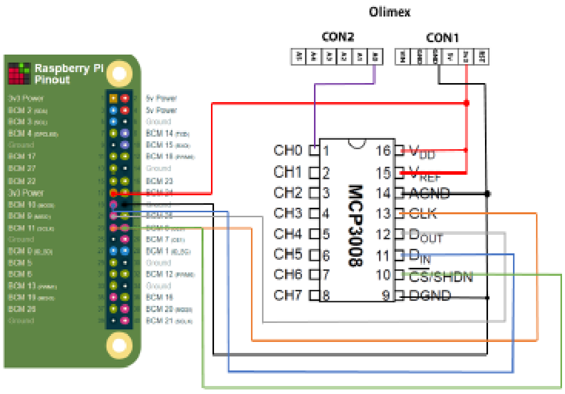

Fig. 5. SPI connection between the Raspberry Pi 0 W and the MCP3008.

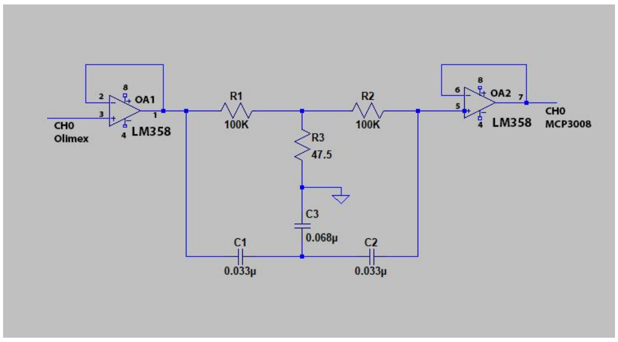

Fig. 6. Block scheme of the notch filter.

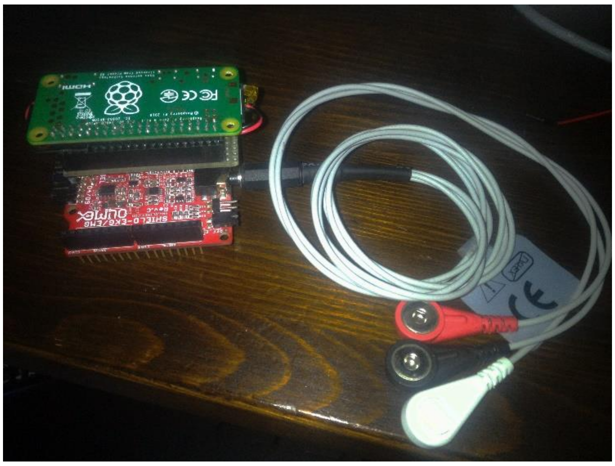

Fig. 7. Picture of the entire sensor board

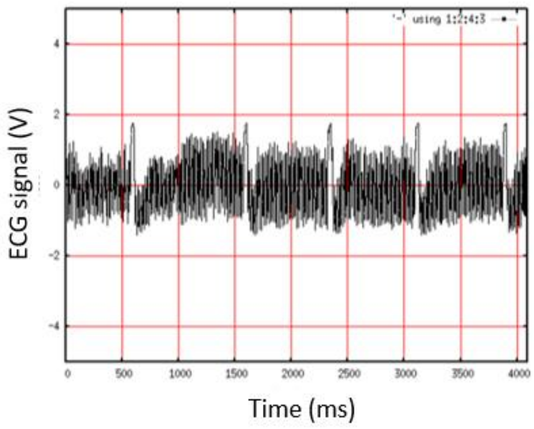

Fig. 8. Acquired ECG signal without any filter.

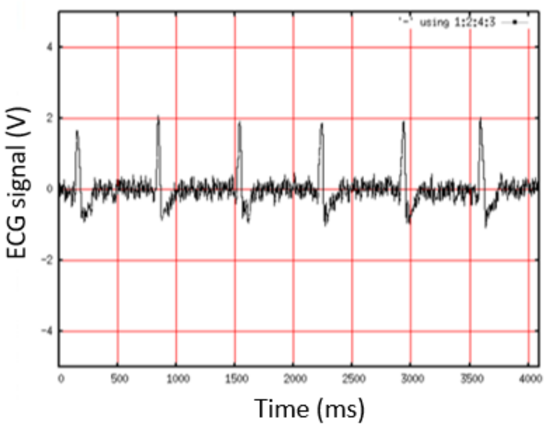

Fig. 9. Acquired ECG signal with the insertion of the Butterworth filter.

IV. Results

First, the ECG of a subject has been recorded without the insertion of filters. All measurements were performed using clamp electrodes with gel because they are comfortable and allow fast measurements. Normal disposable electrodes were also used with no significant differences. The obtained results are reported in Fig. 8. The figure shows a strong noise, that almost completely masks the ECG signal. Then, the ECG has been recorded adding the 6th order Butterworth filter. In this case, (see Fig. 9) the noise contribution is reduced. Finally, the notch filter has been added and the visualized signal appears to be almost noiseless (see Fig. 10). In this last case, in addition to the QRS complex, the P wave and the T wave are clearly visible. The Server program running on the Pi 3 performs peak detection (red dots on the figure) and calculates beats per minute. Finally, the signal is sent to a monitor and displayed together with the beats per minute (see Fig. 11).

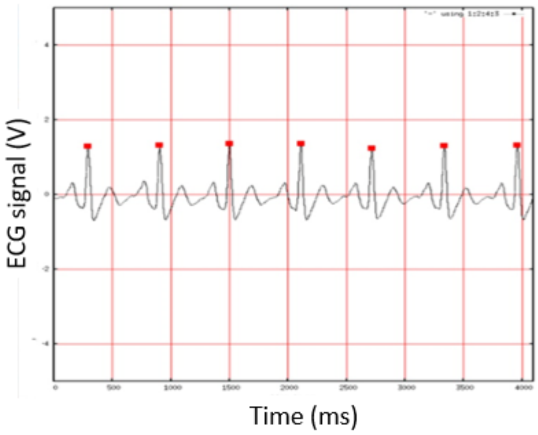

Fig. 10. Acquired ECG signal with the Butterworth and the notch filter.

Fig. 11. ECG signal displayed on a monitor.

V. Conclusions

In this paper a Raspberry Pi based system, for electrocardiogram (ECG) monitoring and visualization, has been presented. A sensor by Olimex has been used to read the ECG while a Raspberry Pi 0 W, together with an ADC integrated circuit, have been employed to acquire the signal. By using the Wi-Fi connection, the signal is sent to a Raspberry Pi 3 that displays the ECG on a monitor. Thanks to the use of a 6th order Butterworth filter and of a 50 Hz notch filter the displayed signal is noiseless and the frequency of the ECG signal is easily extracted by using a peak detection algorithm.

The proposed system allows the visualization of the ECG signal time behavior and of its frequency on a monitor that can be located in a proper treatment center. In this manner, a physician can evaluate the health status of the patient without hospital recovery. It is worth to note that the same system can also host other sensors to monitor for example temperature, pressure, oxygen concentration in the arterial blood, but also a web cam to provide the physician with a picture as general as possible about the patient's condition.

REFERENCES

[1] https://www.olimex.com/Products/Duino/Shields/SHIELD-EKG-EMG/

[2] https://www.raspberrypi.org/products/raspberry-pi-zero-w/

[3] https://www.raspberrypi.org/products/raspberry-pi-3-model-b/

[4] MCP3004/3008 data sheet

[5] http://www-users.cs.york.ac.uk/~fisher/mkfilter/trad.html