Integrated system for remotely monitoring critical physiological parameters

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Abstract. Monitoring several human parameters (temperature, heart rate, blood pressure etc.) is an essential task in health care in hospitals as well as in home care. This paper presents the design and implementation of an integrated, embedded system that includes an electrocardiograph of nine leads and two channels, a digital thermometer for measuring the body temperature and a power supply. The system provides networking capabilities (wired or wireless) and is accessible by means of a web interface that allows the user to select the leads, as well as to review the values of heart rate (beats per minute) and body temperature. Furthermore, there is the option of saving all the data in a Micro SD memory card or in a Google Spreadsheet.

The necessary analog circuits for signal conditioning (amplification and filtering) were manufactured on printed circuit boards (PCB). The system was built around Arduino Yun, which is a platform that contains a microcontroller and a microprocessor running a special LINUX distribution. Furthermore, the Arduino Yun provides the necessary network connectivity capabilities by means of the integrated Wi-Fi and Ethernet interfaces. The web interface was developed using HTML pages with JavaScript support.

The system was tested on simulated data as well as real data, providing satisfactory accuracy regarding the measurement of the heart rate (±3 bpm error) and the temperature (±0.3°C error).

1. Introduction

Monitoring of vital signs (heart rate, respiratory rate, blood pressure and body temperature) allows assessing the general physical condition of a person, provides indications to possible diseases, and helps evaluating the progress toward recovery. The monitoring is accomplished by means of specialized devices, known as medical monitors, which consist of sensors, processing units and display components [1], [2]. Furthermore, medical monitors can be supported by communication links that enable displaying or recording the results through the local network of the hospital.

This paper presents the design and implementation of a custom made portable monitoring device that includes an electrocardiograph of nine leads and two channels, a digital thermometer for measuring the body temperature and a power supply. The system integrates networking capabilities and is accessible remotely allowing the user to select leads, as well as to review the values of heart rate and body temperature.

There are similar projects that implement vital signals monitoring devices, supporting wireless transmission [3], [4]. Comparing to these projects, the proposed implementation provides...
improvements with respect to storing and transmitting the data. More specifically, the server and monitor are in the same device and multiple storing methods are supported. Furthermore, it is provided the capability to select ECG leads remotely.

2. Materials and Methods

The architecture of the proposed device is shown in figure 1. There is a battery regulated voltage supply of ±5V, minimizing the possibility of electric shock and making the device completely portable and functional for at least 5 days. The voltage supply is protected, by two diodes, from improper battery installation and there is a red LED that is activated by the microcontroller in case of low battery and the indication in case of battery replacement need.

Figure 1. Architecture of the proposed device.

The digital thermometer is designed to operate in the range of 25°C to 43°C and is implemented by means of a thermistor and a Wheatstone bridge. The output of the Wheatstone bridge is amplified by an instrumentation amplifier and then is filtered by a second order low-pass (LP) Butterworth filter, with cutoff frequency at 20Hz, in order to clean the signal from high-frequency noise.

The thermometer was calibrated by means of an Hg analog thermometer immersed in a tank of deionized water. A special device was used to maintain the temperature of the water to a specific value, selected by the user. The voltage output of the digital thermometer was measured for specific reference values in the range of interest. The equation, through the graph voltage – temperature, is used by the microcontroller to convert the measuring voltage into temperature.

The electrocardiograph supports the acquisition of ECG signals from bipolar or unipolar leads. The bipolar leads are connected to a multiplexer (MUX) with eight inputs and two outputs, whereas the unipolar leads are connected to a MUX with eight inputs and one output. The multiplexers are controlled by the microcontroller. An instrumentation amplifier follows the MUX and amplifies the differential signal between the two leads for the bipolar case or difference signal between each selected unipolar lead and the Wilson lead. The amplified signals are filtered by a second order high-pass (HP) Butterworth filter with cutoff frequency at 0.5Hz to eliminate the dc component. A fourth order low-pass Butterworth filter comes next with a cutoff frequency at 40Hz to eliminate the high-frequency noise. The line noise of 50Hz is rejected by a special band reject (BR) filter. The final step
is to amplify the filtered signal and to add a dc component to create strictly positive signal values for the microcontroller [5].

The three analog signals (temperature, bipolar leads and unipolar leads) are converted to digital, by a 10 bit Analog to Digital Converter embedded in the development board Arduino Yún. The Arduino Yún contains a microcontroller ATmega 32u4 running at 16MHz and a microprocessor Atheros AR9331 running at 400MHz accompanied by a LINUX distribution. Furthermore, the Arduino Yún provides wired (Ethernet) and wireless (Wi-Fi) capabilities, as well as a Micro-SD card slot [6].

The microcontroller was programmed in C++. In order to calculate the heart rate from the bipolar leads, a sample of 3 seconds is taken to establish thresholds in order to identify the R wave which in turn signals a full heart cycle. The temperature is calculated using the equation from the thermistor calibration every 15 seconds. Furthermore, the microprocessor acts as a web server allowing the real time monitoring of the heart rate and temperature by means of web pages with embedded JavaScript code. The web pages also allow the selection of leads. Finally, the device supports the storing of acquired measurements in a micro-SD card, 2GB capacity, or in a Google spreadsheet.

3. Results and Discussion

Figure 2 presents the external and the internal view of the device.

![Figure 2.](image)

**Figure 2.** (a) The outside view of the device. (b) The inside view without the jumper connectors.

An ECG simulator was used to determine the accuracy of calculating the beats per minute (BMP) under various conditions (no noise, line noise, tremor, random noise and baseline wander) (Table 1).

| Real BPM | No noise | Line 50Hz | Tremor | Random | BL.Wander* |
|----------|----------|-----------|--------|--------|------------|
| 30       | 30       | 30        | 30     | 30     | 30         |
| 50       | 50       | 50        | 50     | 50     | 50         |
| 75       | 75       | 75        | 75     | 75     | 75         |
| 100      | 100      | 102       | 99     | 100    | 99         |
| 130      | 128      | 131       | 130    | 130    | 131        |
| 150      | 149      | 150       | 151    | 151    | 149        |
| 200      | 202      | 199       | 197    | 197    | 202        |

*Base Line Wander: A low-frequency noise that can be in the frequency bandwidth of interest.
The calculation of the heart rate allows an error of ±1 bpm, according to many protocol tests [7] or a maximum of ±2 bpm according to many manufacturers [8]. In our case, a maximum error of ±3 bpm was observed.

The digital and the Hg thermometer have an accuracy of ±0.1°C. According to many manufacturers, an error of 0.1°C is often permitted, but also errors up to 0.3°C can be acceptable [9]. The percentage of those errors is often depending on the type of using medical thermistor (YSI 400, YSI 700) and the accuracy of reference thermometer. In our case, the difference between reference and calculated values has a maximum error of 0.3°C (Table 2).

**Table 2.** Measurements of testing temperatures in pairs.

| Hg Thermometer (Reference Values) | Temperature Readings | Commercial Digital Thermometer (Reference Values) | Temperature Readings |
|----------------------------------|----------------------|-------------------------------------------------|----------------------|
| 26.7                             | 26.6                 | 36.8                                            | 36.6                 |
| 32.7                             | 32.9                 | 36.6                                            | 36.9                 |
| 37.0                             | 37.2                 | 36.8                                            | 36.6                 |
| 41.4                             | 41.3                 | 36.4                                            | 36.7                 |

4. Conclusion

In this paper a custom made portable device that measures a subset of vital signs was presented and can be used to home care and in hospitalization. The device provides fairly accurate results regarding the measurement of heart rate, under various noise conditions, and temperature readings for a cost of 160€ to 180€. The device could be made in smaller form factor using SMD technology and could be enriched by incorporating measurements of respiratory rate, blood pressure and oximetry. Also the Arduino Yún could be programmed to act as a web server providing worldwide access through the web pages.

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