Evaluation of Sensors' Precision in a Low Cost e-Health Monitoring System

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Abstract. In this paper, a low cost e-health platform is evaluated concerning the precision of the employed sensors. The sensors used by the developed e-health platform are not medically certified but are compared against medically certified ones. The developed platform exhibits enhanced key characteristics to cover a broad range of medical scenarios in a reliable and flexible way. A low-cost Sensor Controller capable of performing both simple medical tests and more advanced ones communicates with a Gateway and a tablet or smart phone providing instructions to the patient. The employed protocol used for the communication between the Sensor Controller and the Gateway, supports a variety of sensors with different sampling profiles. The platform exhibits high portability due to the power saving modes that have been employed. However, the sensors' accuracy is an important issue that is investigated in this paper in order to highlight the medical cases where the (low-cost) developed e-health platform can be used in a fairly reliable way. Such a platform would be especially useful for the enhancement of the quality of life of residents in distant or isolated rural areas. Moreover, it would be possible to use part of this platform for the continuous monitoring of livestock (e.g., excluding the tablet/phone).

Keywords: health monitor, sensors, accuracy, low power

1 Introduction

Experts can remotely monitor aging population using health care systems (Zhang et al, 2014). The results of the tests that are performed can be securely stored in a remote cloud or database. In (Gay and Leijdekkers, 2007), a monitoring system was proposed based on wireless sensors and smart phones to monitor high risk cardiac patients exploiting the usage of a real-time ECG. In (Chan et al. 2008) a similar monitoring architecture is proposed based on commercial sensors. In (Mukherjee et al. 2014) a perception layer is introduced, where Bluetooth, Zigbee and WiMAX protocols are used to connect the patient sensors to the monitoring infrastructure. The available sensor/communication technology for the implementation of wearable systems and patient monitoring is reviewed in (Patel et al., 2012). The importance of

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achieving both high precision and low-energy sensors is denoted. Cooking Hacks e-health kits are employed in an experimental Body Sensor Network (BSN) platform suggested in (Khelil et al. 2014).

A versatile framework for home monitoring of wireless sensor networks is presented in (Antonopoulos et al., 2015). It consists of an extendible wireless digital sensor network that transmits data to a Home Gateway (HG). The gathered data are forwarded to the Service Data Platform (SDP) which performs several tasks like database transactions, data processing and decision-making. No details are given in this framework for the connection of analog sensors. There also exist a number of expensive commercial platforms like e-Shimmer Health BSN (The Shimmer Platform, 2008), with proprietary (not open-source) components.

The current work is based on the platform initially presented by the authors of this paper in (Petrellis et al., 2015) and is based on the low-cost e-Health kit by Libelium-Cooking Hacks. A flexible communication protocol capable of supporting a variety of sensors' sampling profiles has been defined. Moreover, smart solutions for low power consumption have been employed for the development of a low cost flexible and portable e-health sensor platform.

The Libelium-Cooking Hacks e-health platform supports 9 sensors both digital and analog including: body temperature, airflow, galvanic skin sensor, patient position, measurement of the oxygen in the blood (SPO2), glucose meter, blood pressure, ECG and electromyogram (EMG). In this paper we focus on some of these analog sensors and evaluate their precision, comparing them with commercial, medically certified devices where necessary.

In Section 2 a brief overview of the developed e-health system and its key features is presented. The evaluation results of the sensors mentioned above and their measurements are given in Section 3.

2 System Description

The architecture of the developed heath monitoring system is shown in Fig. 1. The patient that is monitored by this e-health system reads instructions by a smart phone or a tablet through a user-friendly interface. The supported medical sensors are listed at the right of Fig. 1 and are connected to the developed Sensor Controller. The e-Health kit by Libelium-Cooking Hacks equipped with a Raspberry PI microcontroller board is used as the Sensor Controller. A Gateway coordinates the communication between the Sensor Controller and the Tablet as well as the communication with the cloud or remote database where the sensor values are forwarded. A supervisor doctor can view the measured values by visiting this cloud. Moreover, the instructions given by the supervisor doctor to the patient are also retrieved by the Gateway and downloaded to the Tablet and the Sensor Controller. All sensors are connected in a wired manner to the Sensor Controller that has to be carried by the monitored person. For this reason, the Sensor Controller should be characterized by increased portability. The Sensor Controller and the Tablet communicate with the Gateway in a wireless way.

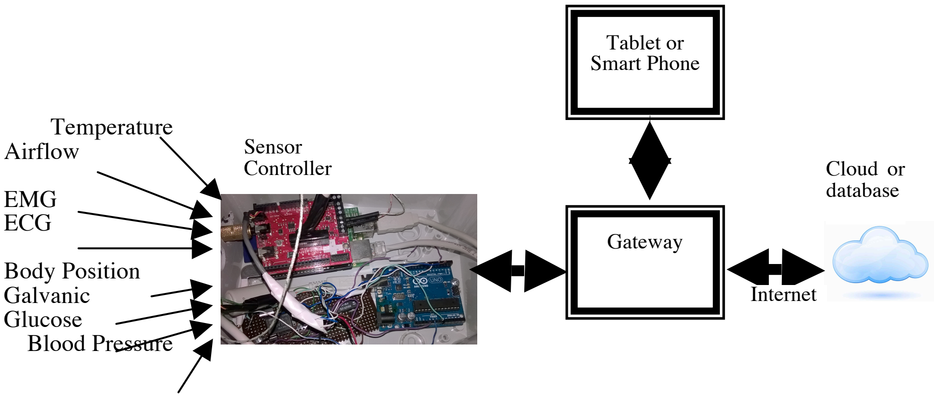
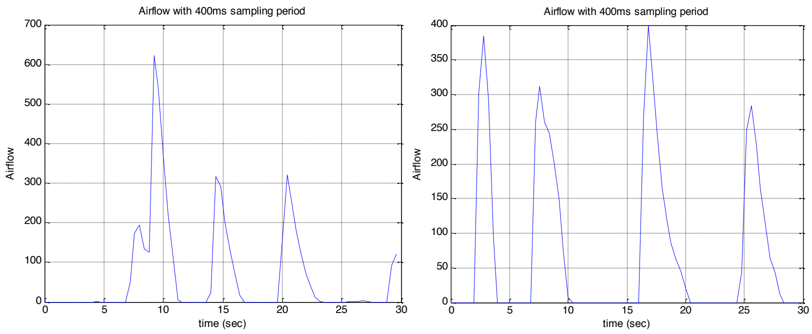


Fig. 1. The architecture of the health monitoring system

3 Experimental Results



(a) (b)

Fig. 2. Breathing patterns applied to the airflow sensor: a deep breath followed by two shallow ones (a) and two pairs of deep/shallow breaths (b).

In this section we focus on the behavior of 5 sensors of the Libelium Cooking Hacks e-Health kit with analog interface: the body temperature sensor, the breathing airflow, the body position sensor, the EMG and the ECG. Furthermore, we compare their behavior with commercial medically certified sensors where possible, like the temperature sensor and the ECG by Shimmer (The Shimmer Platform, 2008). Sensors like the breathing airflow and EMG are evaluated by applying breathing or muscle contraction patterns and see if they are represented well by the digitized electrical signals generated by the sensors. Of course only draft levels can be discriminated in this way but this is adequate for several applications.

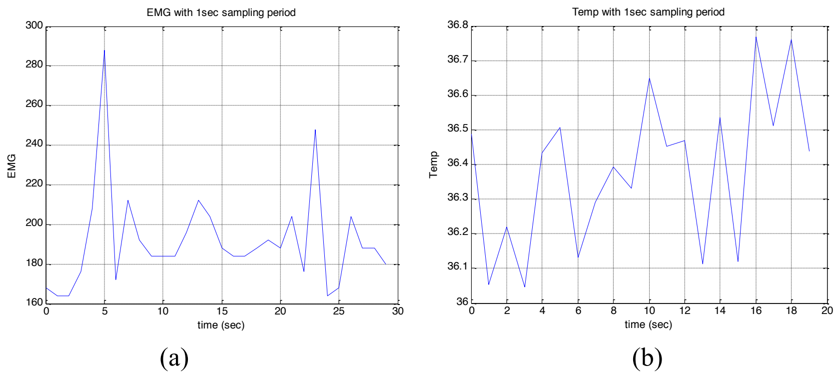


Fig. 3. EMG sensor output for two strong muscle contractions and three less strong muscle contractions in between (a). Temperature sensor output for a person that has a temperature of 36.5 ^{o}C (b).

The body position sensor has only 5 distinct values that show that the patient is in one of the following positions: a) standing or sitting, b) supine, c) prone, d) left and e) right. By testing several times this sensor, the experimental results showed that it produced 100% correct results.

The airflow sensor was tested by applying breathing patterns (e.g., deep breaths followed by shallow ones that have certain short durations). Such an example is shown in Fig. 2. As it can be seen, the sensor output can represent well the depth of a breath and its duration. It is not possible to measure more accurately the sensor output but it is feasible for the supervising doctor or an artificial intelligence software package to draw conclusions about the state of the patient by taking into account the shape of signals like the ones shown in Fig. 2. The sampling period for this sensor does not have to be shorter than a few hundreds of milliseconds.

In the same way, the EMG sensor was evaluated by applying muscle contractions of different strength as shown in Fig. 3a. The EMG sensor output represents well the contractions applied and its sampling period can be as high as 1 second. Of course, if micro-contractions are useful to be captured a smaller sampling period has to be adopted. More than one EMG sensor can be connected at various muscles on the body of a handicapped person in order to distinguish several combinations of EMG sensor signal levels. Each one of these combinations can be used to apply a different control to prosthetic limbs with high accuracy. The Libelium Cooking Hacks e-Health kit offers only one EMG channel and can be used for simple experiments only. It is easy however to either use multiple e-Health kits or develop a new Sensor Controller board that uses multiple copies of the EMG interface circuit of the e-Health kit still with very low cost (compared with the usually expensive medically certified ones) and, as aforementioned, with reliable results.

The temperature sensor output is displayed in Fig. 3b. The displayed signal was retrieved after performing the best possible calibration based on the instructions of the manufacturer. A 1 sec sampling period is adequate and no faster sampling is necessary for most applications. The temperature of the same patient was measured at the same time by a commercial temperature sensor and was found 36.5 ^{o}C. As can be shown by Fig. 3b the individual measurements fluctuate between 36.1 and 36.8

degrees Celsius and this fluctuation might seem high for a valid measurement. However, the first 10 seconds can be assumed to be a transient period before the sensor temperature is stabilized and gets equal to the temperature of the patient body. Furthermore, if 10 samples of a moving window are averaged, the estimated patient temperature would be 36.48 ^{o}C, i.e., almost equal to the temperature measured by the commercial sensor.

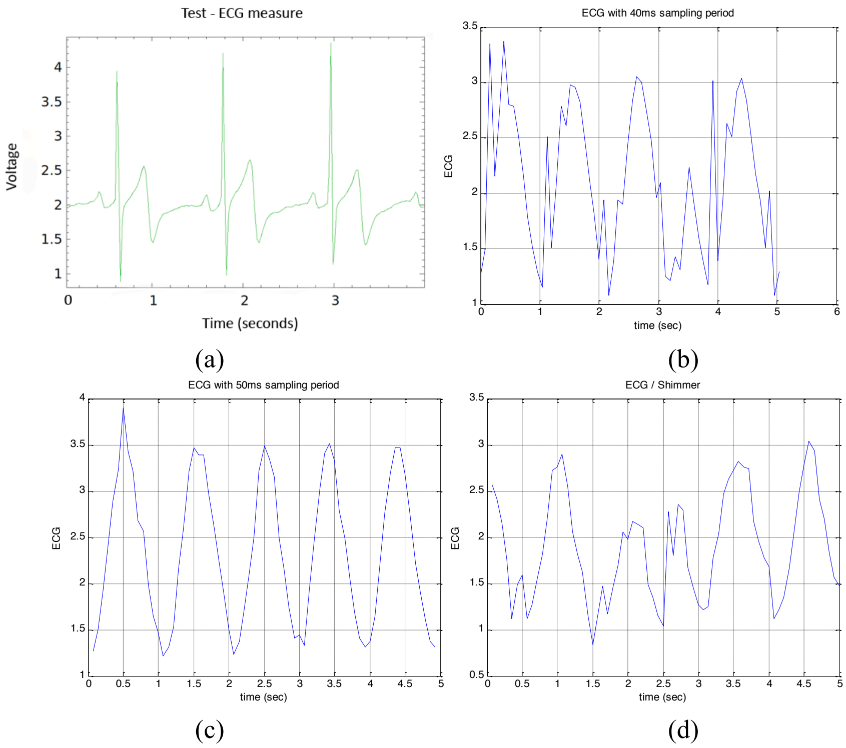


Fig. 4. Reference Cooking Hacks e-Health ECG sensor output (a), real ECG output using a sampling period of 40ms (b), 50ms (c) and Shimmer ECG output (d).

The single channel ECG sensor offered by the e-Health kit was compared to the corresponding sensor offered by Shimmer. The ECG sensor output should have the form shown in Fig. 4a. The best ECG output retrieved experimentally was the one shown in Fig. 4b using 40ms sampling period and no averaging. Even in this case it is difficult to match the peaks shown in Fig. 4a. The ECG shape gets much worse if a slightly different sampling period is used as shown in Fig. 4c. However it should be noted that the output of even medically certified ECG sensors may not be better as shown in Fig. 4d.

7 Conclusions

A low-cost platform for remote heath monitoring of patients was used in order to evaluate how precise measurements can be taken and which sensors are appropriate for specific applications. Several sensors including temperature, breathing airflow, body position, etc, that are not medically certified can be used even in professional applications for monitoring the habits of individuals or every day activity. Some of the low cost sensors like the electromyogram can also be used in more complicated and ambitious applications (e.g. for the control of prosthetic limbs). However, sensors like the electrocardiogram did not prove to be accurate and stable enough and should be used only for experimentation purposes.

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