A Body Movement Sensing System for Ambulatory Health Monitoring

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Abstract-Body movement is an important factor that must be considered while correlating the acquired physiological parameters and signals such as ECG with the patient's health status, particularly when the acquisition of the physiological data is performed during ambulatory conditions. Therefore, it is required that the body movement information should be available along with the ambulatory physiological parameters. We have designed a body movement sensing system with multiple 3-axis acceleration sensors that can measure the acceleration caused due to routine physical movement of the body. The acceleration sensor modules can be tightly attached to any limb or part of the body for measuring the movement. Since the size of the system is an important concern, we have designed it using a single Programmable System on Chip (PSoC). In this paper we present the PSoC based system for body movement sensing for ambulatory health monitoring purpose.

Key Words: Acceleration, accelerometer, cardiac monitoring, ECG, PSoC based systems, physical activity, wearable devices.

1. Introduction

ECG signals are widely employed as a non-invasive tool for cardiac monitoring. However, the quality of the ECG signal is severely affected by the physical movement of the patient. Hence it is necessary to sense the body movement during ambulatory or mobile cardiac monitoring for determining the quality of ECG signal and also to know the physiological effects of the physical activity [1-9]. In, [1-6], authors have proposed various methods for recognition and transition detection of body movement from the ECG signal itself. Based on recent research trends, in [7], a survey of ambulatory ECG monitoring has been presented and it is concluded from this study that physical activity related information is very useful for ambulatory ECG monitoring. In [8-9], authors have presented the systems that record acceleration signals along with ECG signals. Thus it is required to sense body movement for correlating it with the ECG signals while ambulatory health monitoring. We present a body movement sensing system for the same purpose in this paper. The presented body movement sensing system is very light-weight, small in size and hence suitable for wearable and mobile applications.

Usually, a movement sensing system has multiple accelerometer sensors attached to a central unit. This requires interfacing of several analog and digital integrated circuits. The integration of multiple-chips increases the cost and size of the design and results in a poor reliability which is a major concern in the health monitoring system. As a preferred option, PSoC (Programmable System on Chip) can be used for designing a dedicated health monitoring system. One such PSoC based system has been developed for temperature monitoring in [10] with a single temperature sensor interfaced with PSoC. Here we present a design of body movement sensing system with multiple acceleration sensors interfaced with a PSoC. Thus the proposed PSoC based system is a multi-channel system and it is configured in a different manner from the PSoC based temperature sensing system given in [10]. We have also made a provision by configuring a reserved ADC module in the PSoC to incorporate the acquisition of single-lead ECG signal. One can also used this reserved channel for any other physiological signal with appropriate sensors.

The organization of the paper is as follows. Details of hardware design, various modules like, accelerometer sensors, PSoC firmware and computer GUI are given in Section 2. Acquisition of the body movement data is explained and plots of the acquired data for a few body movement activities are presented for illustration in Section 3. Finally, we conclude the paper with discussion and future work in Section 4.

2. System hardware design

The proposed body movement sensing system consists of the following components:
1. Accelerometer sensors
2. Signal conditioning, ADC and Microprocessor (built-in PSoC)
3. LCD Display
4. Connectivity to a personal computer through UART (Universal Asynchronous Receiver Transmitter) / USB (Universal Serial Bus)
5. GUI for computer interface and data logging.

A schematic diagram and a picture of the PSoC system for body movement sensing are shown Fig. 1 and 2, respectively. Approximate dimensions of the system are 6x5 cm. The acceleration sensors are attached to the system externally through wires. Further details of various system modules are given in the subsequent subsections.

Figure 1 Schematic diagram of the PSoC system for sensing body movement.

Figure 2 Picture of the PSoC based system.

Accelerometer sensors

For measurement of acceleration, 3-axis accelerometer sensors are commercially available with many variants in terms of sensitivity and form of the output signal, e.g., analog or digital. A 3-axis accelerometer is a single chip that can measure the acceleration signals in three perpendicular directions called axis. We have used MMA7361L, 3-axis accelerometer manufacture by Freescale Semiconductors Inc [12]. MMA7361L can be configured for two different sensitivity values. We have configured it for the acceleration range of -1.5g to 1.5g. The sensor provides three analog channel output corresponding to 3-axis. A picture of an acceleration sensor module is shown in Fig. 3. The module dimensions are approximately 2x2 cms. This module should be tightly attached to limb or body-part.

Figure 3 A picture of the accelerometer-sensor.

Analog and digital modules on PSoC

The output signals from the accelerometer sensor modules as discussed in the previous subsection are input to the signal conditioning block. The signal conditioning block processes the analog signals by providing the required amplification and pre-filtering before analog to digital conversion (ADC). The signal conditioning is built in PSoC and configured very easily through PSoC designer software tool. Thus PSoC allows configuration of analog hardware along with digital conversion and processing. We have used PSoC CY8C29466
manufactured by Cypress Semiconductor Inc [11]. Since each accelerometer sensor module has three channels, the PSoC is also configured in three channels when a single acceleration module is connected. For multi-sensor system we have configured the PSoC for appropriate number of channels in similar modular manner. The ADCs are configured for 12-bit resolution and sampling rate of 75Hz. The data in digital form from the ADCs are then transmitted through UART which then converted to USB standard output through a UART to USB converter manufactured by FTDI. The data output of the USB can be received on a personal computer. We have developed a GUI (Graphical User Interface) for this purpose which can operate on Windows (TM Microsoft Corp.) platform. The GUI is prepared using LABVIEW (TM National Instruments). The acceleration values are also displayed on a 16x2 LCD interfaced with PSoC. PSoC is programmed for performing these tasks of displaying and transmission. The details of the firmware of PSoC and computer GUI are given in the next subsection in the paper.

Firmware of PSoC and computer GUI

The PSoC is programmed with M8C controller instructions through a PSoC designer software tool from Cypress Semiconductors. The required digital and analog system blocks and components like PGA (Programmable Gain Amplifier), ADC, UART and LCD are initially configured. After the configuration of the system blocks, the configured system blocks in the PSoC are turned on through API (Application Programming Interface). The rest of the programming instructions are executed in a loop for continuously checking the arrival of the data from ADC using data ready signals from ADC through API. When the data are ready they are read from ADC output channels and transmitted through UART and also displayed on the LCD interfaced to the PSoC.

The data transmitted through a serial UART interface is converted into USB standard for connectivity to a personal computer. A GUI developed in LabView displays the received data in real time from various channels of sensors through USB and logs it in appropriate manner so that each of the sensor channels can be separated for monitoring and processing purposes.

3. Body movement data acquisition

The main objective of the system is to acquire the body movement data. Here we show the plots of the data acquired by the PSoC through the acceleration sensors during various different types of body movement activities. For example in Fig. 4, there are 3-axis acceleration signals plotted during standing still position of a person wearing the sensor at back of the waist. The signal values in the plots are nearly a constant as expected for a stand still condition. The differences among the levels of the 3-axis signals are attributed to the static gravitational acceleration. The sensor axis nearly aligned with the gravitational axis exhibits the highest acceleration level due to gravity.

Figure 4 3-axis acceleration signals acquired during standing still position. The sensor attached on back of waist.

Next, we have acquired data to represent movement of any limb. In Fig. 5, 3-axis acceleration signals are shown for repetitive movement of a hand in azimuth plane. These acceleration signals are acquired from the sensor tightly attached on the wrist. We can observe that there is a cycle in acceleration signals corresponding to each repetition of the movement and nearly four repetition of same type of hand movement are performed here.

Figure 5 3-axis acceleration signals for repetitive movements of hand in azimuth plane. The sensor attached to wrist position on the hand.

Similarly, in Fig. 6, the acceleration signals from a sensor attached to the wrist are plotted which are acquired during repetitive up-down movements of the hand. Here also the cyclic nature of the acceleration signal is visible because of repetitive actions of hand.
Finally, we performed the experiments for several other physical activities like walking, running, climbing stairs etc. that may occur in routine life and found that these activities can easily be sensed from the acceleration signal measurements from different parts of the body, like hands, legs, waist, chest, shoulders, and head etc.

4. Discussion and future scopes

We have presented a system for sensing acceleration caused due to body movement. The system is able to capture the body movements that are performed in routine life. Moreover, it is based on a single programmable chip that can be configured for analog and digital processing of the signals and transmission of the acquired data in real time. The acceleration sensor module can be attached separately on any part of the body for sensing the movement of that body-part. Various routine physical activities can be characterized and recognized from the acquired acceleration signal using the presented system. Though the body movement can easily be recognized with several acceleration sensors tightly attached to the body, it is cumbersome for a person to wear so many sensors. Therefore, it is preferred to attach fewer sensors at selected body parts that represent the body movements distinctly.

5. References