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Development of wearable hardware platform to measure the ECG and EMG with IMU to detect motion artifacts

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Abstract—Wearable biomedical devices make it possible to monitor physiological parameters of human beings where physical fitness is critical for their work. However, the motion artifacts corrupt the ambulatory measurements of electrophysiological parameters and it is necessary to detect and eliminate these motion artifacts. The long term measurement and analysis of health parameters require enormous data processing and storage resources on board. It is also challenging to perform sensor fusion of multiple devices and to manage multiple communication channels. This paper describes the development of a wearable hardware platform to measure electrocardiogram (ECG) and electromyogram (EMG) with an additional IMU sensor to detect the motion artifacts. Bringing all the sensors on single platform resolves the sensor fusion problems. The measurements are digitized and sent wirelessly through a bluetooth interface to a remote unit in real-time. Which is capable for the implementation of extensive processing and analysis algorithms to detect the motion artifacts and extract The features of ECG and EMG waveform structures.

Index Terms—ECG, EMG, IMU, Motion artifact.

I. INTRODUCTION

The human body has an enormous capacity to sense, control and maintain daily routine activities through the nervous system by using an electrochemical communication network spread out on a cellular level. Most of these electrochemical activities are usually measured from the skin surface using different types of noninvasive techniques [1]. The measurement of ECG and EMG signals from the human skin surface involves electrodes, leads, instrumentation amplifier hardware, analog to digital conversion, data communication interface hardware and preprocessors [2]. All these, the hardware, the environment and other electrical activities happening at the same time in the body and various body movements introduce noise and artifacts in the ECG and EMG signals – specifically when the test subject is in ambulatory state for long-term healthcare monitoring. These extra unwanted signal components makes it challenging for physiologists to make proper diagnosis for ECG and EMG [3-6]. There is a need to effectively detect and remove such unwanted contaminants from the original ECG and EMG signals [7]. In recent studies several efforts has been made to detect and remove the motion artifacts (MA) from ECG and EMG signals by using an additional motion sensor IMU [8-10].

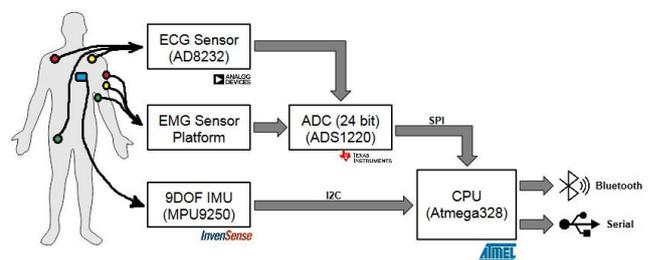


Fig. 1: Block diagram of combined hardware platform.

Most of the present devices available in the consumer market primarily focus on providing whole independent solution for each electrophysiological parameter by using separate processing unit, power source, memory and wireless interface. There are challenges in sensor data fusion of multiple devices connected through independent communication channels and powered by separate sources [11-12]. In this paper above technical challenges are answered by developing a body sensor network powered by single source, controlled by single processing unit and connected through one communication channel. The on-board simple processor is used to only collect and organize the data. A wireless interface is used to send the data in real-time to an advanced powerful processing unit for the implementation of complex algorithms which simplifies the wearable hardware electronics. Figure 1 shows the block diagram of the wearable hardware platform with the placement of electrodes and IMU position on the test subject. Section II of this paper introduces the development of hardware platform. Section III elaborates the measurement setup for data collection. The results of processing and analysis algorithms are presented in Section IV. Finally concluding remarks are given in Section V.

II. HARDWARE PLATFORM DEVELOPMENT

The hardware platform is developed by using a basic microcontroller ATmega328 by Atmel to collect, manipulate and send all the data from the ECG, EMG and IMU sensors. A multichip inertial sensor module MPU-9250 by Invensense

with nine degree of freedom (9DOF) is used for the detection of motion artifacts. A four channels sigma-delta analog to digital converter ADS1220 by Texas Instruments having resolution of 24-bit is deployed to digitize the ECG and EMG data [13]. An off-the-shelf bluetooth RN-42 modem by Sparkfun was used to establish a real-time communication environment between the CPU and other data-receiving units. A serial communication interface is developed to program, test and debug the hardware.

The single-lead ECG hardware platform consists of three wet electrodes to collect electric activity from the body, filters and amplifiers to improve signal quality, and an analog to digital converter (ADC) to digitize the analog signal for further processing and data storage. Figure 1 depicts the deployment position of three wet electrodes on the human body where the LA (left-arm) yellow electrode is the positive terminal, the RA (right arm) red electrode is the negative terminal and the RL (right leg) green electrode is a drive terminal. For the detection of the ECG signal, the filtering and amplification of the initial radio frequency interference (RFI), an off-the-shelf integrated circuit AD8232 by Analog Devices was selected to develop the wearable ECG acquisition platform.

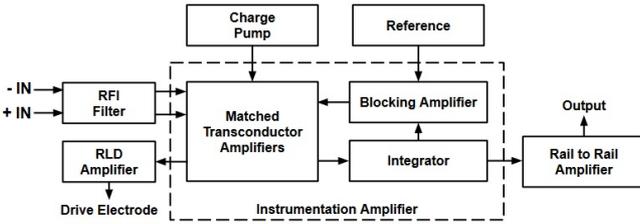


Fig. 2: Block diagram of ECG instrumentation amplifier [14].

The instrumentation amplifier as depicted in Figure 2 consists of two well matched transconductance amplifiers, a dc blocking amplifier (HPA) and an op amp integrator. The voltage at the input of transconductance amplifier generates the error current which is integrated by an op amp integrator to produce the output voltage. A rail-to-rail general operational amplifier is used at the output of the instrumentation amplifier to achieve addition gain and perform low-pass filtering [14]. The output signal of the transconductance amplifier is applied to the the right leg drive (RLD) amplifier which is configured as an integrator to give a loop gain at frequencies of 50Hz and 60Hz for common-mode line rejection. The output of the RLD amplifier goes to the right leg RL electrode on the test subject with the maximum 10uA current flow. This current contracts common-mode voltage variations to improve the common-mode rejection ratio.

The EMG hardware platform is built by using the precision instrumentation amplifier AD8221 by Analog Devices to measure the EMG signal from two differential electrode about 2cm apart on the biceps muscle and one ground electrode away from the muscle on a bony location as depicted in Figure 1. Figure 3 shows the block diagram of EMG hardware platform.

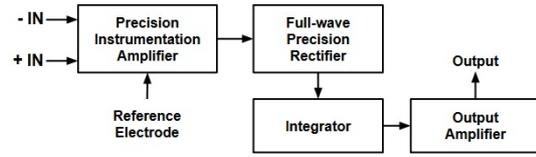


Fig. 3: Block diagram of EMG hardware platform.

The differential action potential signal from the biceps muscle is fed to the differential input of the precision instrumentation amplifier. It is based on the classic three op amp topology where two constant current biased transistors are used to produce error current at input stage. The error current is fed to precision current feedback amplifiers on second stage. Finally the third op amp receives the amplified differential signal and signal from reference electrode at the inputs [15]. The measured EMG signal is rectified using a full-wave precision rectifier, integrated for high-frequency noise filtering and amplified by an operational amplifier. Four general purpose JFET operational amplifiers TL084 by STMicroelectronics are used for full-wave rectification, integration and amplification.

III. MEASUREMENT SETUP

The combined hardware platform is tied on the chest of the test subject to record ECG and EMG data as depicted in Figure 4.

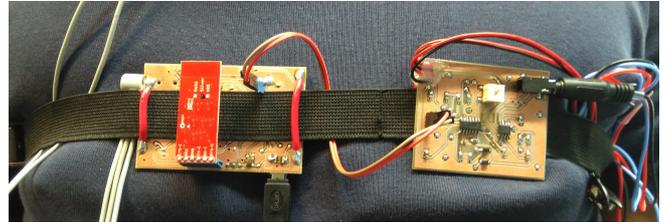


Fig. 4: Wearable hardware platform tied to the chest of the test subject.

The ECG and IMU data is processed for following events:

- ECG recording while laying still.
- ECG recording while sitting still.
- ECG and IMU data recording while sitting and breathing heavily.
- ECG and IMU data recording during transition from sitting position to standing position and vice versa.
- ECG and IMU data recording while walking with normal speed.

The EMG for the biceps muscle is focused for this study and the events related to the left-arm biceps muscle movement are planned. The following events are planned and executed for EMG data:

- EMG and IMU recording while folding arm on elbow pivot with empty hands.

- EMG and IMU recording while folding arm on elbow pivot by carrying weight in hand.
- EMG and IMU recording while stretched arm at 90 degree with subject body and holding weight in hand.

IV. MEASUREMENT RESULTS

At remote processing unit the data is preprocessed to remove the dc components and nonlinear trends from the ECG and EMG signals using detrending techniques. The mean of the whole recorded data set is calculated and then removed from each of the data points, hence removing the dc offset from the actual signal. Figure 5 shows the breathing movement artifacts recorded in ECG signal in 60 seconds time span.

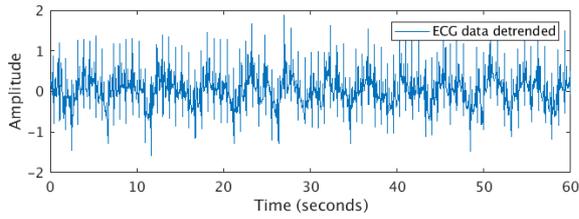


Fig. 5: Breathing motion artifact in ECG signal.

ECG data is processed during transition from sitting position to standing and vice versa. Similar trend is observed during the walking event. These repetitive and almost symmetric movements introduced motion artifacts into the ECG recording. The IMU detected the movements in all 9-axis during sit-stand event which can be used to remove the artifacts more effectively. Figure 6 depicts the ECG recording and the motion artifacts detected by the 3-axis of the accelerometer.

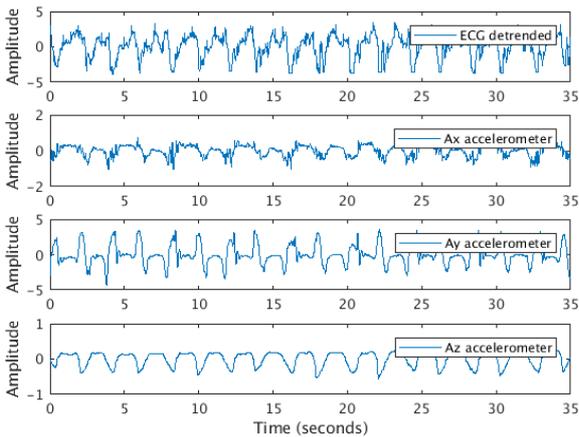


Fig. 6: ECG and accelerometer recording during sit-stand movement.

The signal is then filtered by using Savitzky-Golay filter to smooth the digital data and improve the signal-to-noise ratio. The data smoothing is based on local least-squares

polynomial approximation by forming low pass filtering which is equivalent to discrete convolution with a fixed impulse response [16]. The `sgolayfilt` function of *MATLAB*[®] R2017b version 9.3 is used to filter the ECG data by using the built-in function. Figure 7 shows a 5 second plot of raw ECG data and ECG data through S-G filter for the event – ECG recording while laying still.

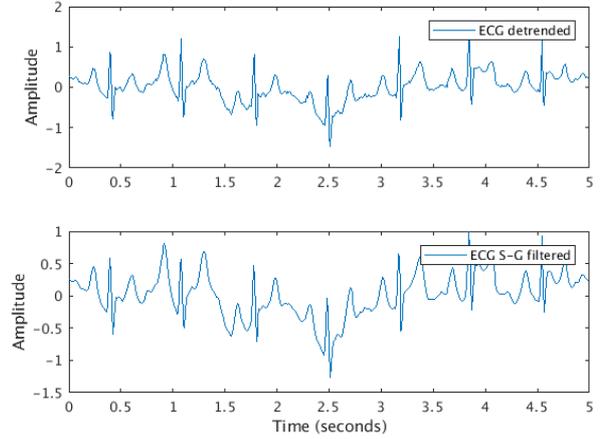


Fig. 7: ECG data filtered using an S-G smoothing filter for event – ECG recording while laying still.

The low-frequency components of the breathing motion artifact and chest muscle action potential artifacts are still part of the ECG signal. A fast Fourier transform is applied and lower frequency components were removed. Figure 8 shows a 35-second plot of the S-G filtered ECG signal and a plot of the signal with breathing artifact removed for the event ECG recording while sitting still. The same procedure was performed for all the events of ECG recording to remove motion artifacts and chest muscle action potential artifacts.

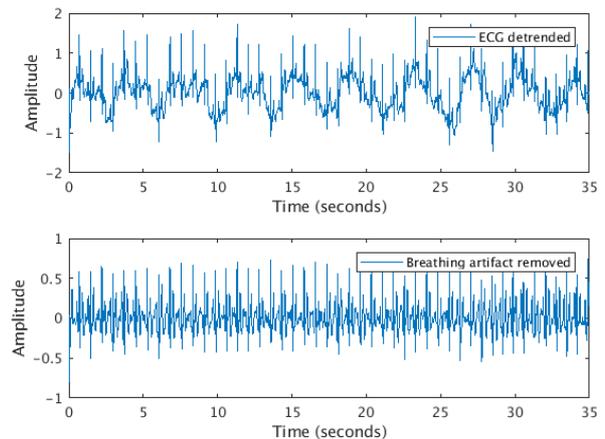


Fig. 8: Breathing artifact identification and removal for the event – ECG recording while sitting still.

The QRS peak is the highest action potential running through ventricles to squeeze the blood out of the ventricle and repeats once in single heart beat. A moving window algorithm with a window size, half of an approximated single ECG cycle, was used to detect the highest peak in the window. The minimum distance between two peaks helped to optimize the window size. A second pass through the optimized sliding window was implemented to find the QRS peaks. Figure 9 shows a 30-second plot of the ECG signal with QRS peaks detected for the event laying still.

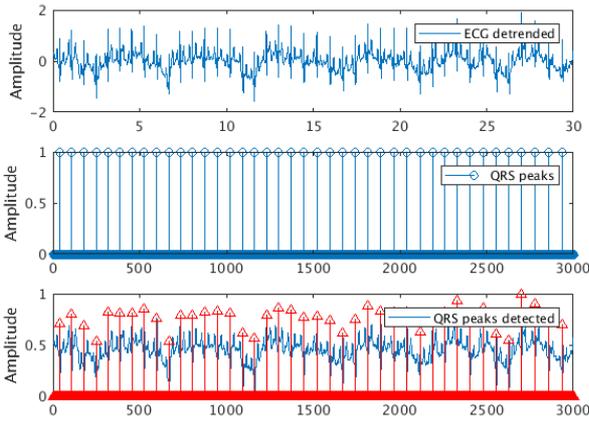


Fig. 9: Laying still ECG signal processed to detect QRS peaks.

The EMG data is recorded with the IMU tied on the chest of the test subject while repetitively lifting a weight of 5Kg for 60-seconds. The motion artifacts were detected by 3-axis of accelerometer and 3-axis of gyroscope. The EMG signal is filtered for high frequency noise components and smoothed by using the S-G filter. Figure 10 shows a 30-second plot of the S-G filtered EMG with the 3-axis of the gyroscope.

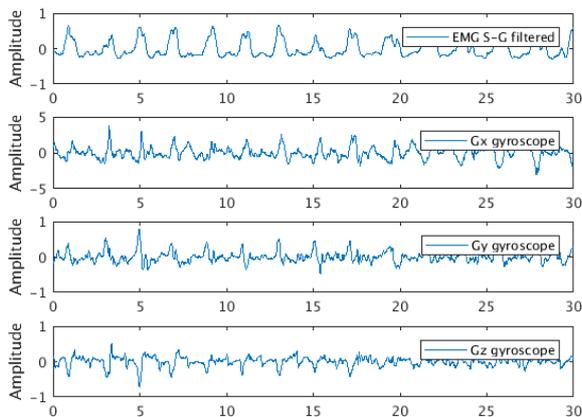


Fig. 10: The EMG signal with 3-axis gyroscope for elbow bending with weight.

V. CONCLUSION

In this paper the technical challenges of body sensor network are addressed by developing the hardware platform using single processing unit, power source and real-time wireless communication channel for all sensors. Furthermore the hardware setup is tested to measure the daily routine events and the data analysis algorithms are performed on the remote processing unit in real-time. It is presented that the developed platform successfully detected the motion artifacts during all the events and the necessary features of ECG and EMG waveforms are very well extracted by using various processing techniques. The work is a contribution towards the development of integrated wearable biomedical electronics for long-term ambulatory biomedical parameters monitoring. The wireless interface brings feasibility to perform smart processing on remote units in a real-time environment for the improvement of digital healthcare.

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