IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661, p- ISSN: 2278-8727Volume 16, Issue 2, Ver. VIII (Mar-Apr. 2014), PP 126-133
www.iosrjournals.org

A Smart and Wearable Cardiac Healthcare System with Monitoring of Sudden Fall for Elderly and Post-Operative Patients

Diptyajit Das[1], Arnab Pal[2], Souvik Tewary[3], Shreyosi Chakraborty[4], Sauvik Das Gupta[5]
(Department of Biomedical Engineering, Netaji Subhash Engineering College,WBUT, India[134])
(Department of Computer Science, Chandernagore Govt. College, India[2])
(School of Electrical and Computer Engineering, Oklahoma State University, Stillwater, OK, USA[5])

Abstract: *The dominance of chronic diseases, driven by an increasingly aging population with a new health paradigm that emphasizes early finding, early diagnosis and early treatment, is highly recommended. Especially, Cardiac disorders and sudden falls are the prominent reasons behind hospitalization of the elderly and post-operative patients. In the present work, we have designed and developed a GSM* **(***Global System for Mobile) based wearable smart system with 3-axis accelerometer and three lead ECG recording system. The whole system is wearable for all and can be used as a real-time monitoring, self-diagnosis, and remote-diagnosis tool as it will detect whenever there is an abnormal heart condition and a sudden fall situation. The entire data flow program and evaluation for the system has been done under NI LabVIEW platform. After detecting the health abnormalities the system sends alert notifications to the care giver and health professionals to take compulsory actions. This paper also deals with estimation of ECG parameters as they have significant clinical values in order to detect cardiac disorders. With this developed system, elderly or ill individuals especially senior citizens who live alone or have a disability could stay independently at their home.*
Keywords: *Wearable Electronics, Elderly Care, Post-Operative Patients, ECG, Fall Detection, LabVIEW, GSM.*

I. Introduction

In today's world with an expanding life expectancy with continuous rising cardiovascular disorders, it is almost impossible for people to be at home or become available for their near ones who might need them while they are suffering from any disease or physical disorder; especially in case of post-operative patients since they can develop complications once they get discharged from the hospital as cardiac problems may re-occur when they start doing routine work. Moreover, the elderly or people with disabilities want to remain in their homes when their health condition has been getting worse [1]. Hence, it is a prime requirement for the post-operative patients and elderly people to monitor their cardiac health frequently whether they are indoors or outdoors so that emergency treatment can be made possible. The average age of human population has increased and coronary heart diseases have been located in the first rows of death reasons as every year nearly 7.2 million people dies due to the heart diseases. Subsequently, monitoring of heart's electrical activities gained more importance [2,3].There are several smart home systems to support physical activities, technologies for detection of heart attack, fall prevention, and system to convey information to doctor or care giver. Thus telemedicine based system is widely considered to be a key research area for inevitable future.

Biomedical signal monitoring is an important tool used to understand physiological workings of the body and to diagnose potential problems, particularly, ECG signal which has valuable clinical information. An extensive range of human physiological conditions can be inferred from the PQRST parameters obtained from an ECG recording instrument. Three lead recording and monitoring of ECG is adequate for mobile devices and applications for purposes in other areas like-sport, telemedicine etc., where the emphasis is on determining heart rate and the most serious malfunction (Arrhythmia) of the heart. Most of the clinically useful information in the ECG is found in the intervals and amplitudes defined by its characteristics wave peak features and time durations. ECG signal not only can be used to evaluate heart rate, but also can be used to analyse Heart Rate Variability (HRV). In recent years, many companies have enabled development of wearable versions that collect and process ECG data [4, 5].

The fundamental idea of this paper is to develop a wearable healthcare smart system which can be used as a tool for self-diagnosis, real-time monitoring, and remote-diagnosis for chronic heart disease patients before sudden outbreaks with an intelligent and versatile home safety environment and respond promptly, so that it could be of help to the elderly and individuals with disability. Abnormal heart conditions including arrhythmia, palpitation, feeling dizziness or light-headed, fainting, ponding in chest, shortness of breath, chest discomfort with weakness and fatigue may come as a result of sudden fall in toilet or floor. Therefore detection of abnormal heart condition from remote place is definitely one of the most challenging tasks. To achieve that goal, we have implemented a wearable prototype system that can detect abnormal heart conditions of post-operative patients and elderly. After that, acquired information will be sent to doctor or care giver through mobile SMS and e-mail notification. The whole system is wearable for all which can acquire ECG (electrocardiogram) signal as well as body vibration signal from human body. If abnormality is found in either or any of previously mentioned signals, the system sends a text message alert to family member's mobile, nearby hospital and family doctor's cell phone using GSM module. In addition to it, an e-mail notification will be also sent by the same system to the care giver. As a result, early diagnosis and early treatment can be made possible for saving life of that patient.

The whole algorithm is developed in NI LabVIEW software platform. It has its own intelligence to acquire and analyse the real time ECG & body vibration signals along with message handling system with a suitable external reset [6]. We have also used Biomedical Workbench to analyse and extract ECG parameters.

This paper is organized as follows: Section II introduces related works which are already carried out in the past. Hardware design and signal acquisition system of ECG, algorithms for ECG signal processing and features extraction, fall signal detection, text message handling and e-mail notification process are described in Section III. In Section IV, the experimental results with discussion are given. At last, Section V gives the conclusion.

II. Related Studies In Literature

The combination of textile and electronic industries has resulted in the advent of wearable systems or wearable sensors. The first wearable system was developed in 1955 to make prediction in roulette by Edward O. Thorp [7]. Later on several articles were published to describe wearable systems in real time processing of ECG signal with different studies. In [8], they propose a plug and play wearable system using Bluetooth as the wireless communication protocol. Different integrated technologies (RFID, GPS, GSM and GIS) that are proposed in [9], worked as a prevention system for elderly with dementia disorder. In [10], they developed a mobile patient monitoring system based on Wireless Local Area Network (WLAN) technology and current Personal Digital Assistant (PDA) technology. In another study in[11], a remote healthcare monitoring system is developed using a smart phone, wireless sensors, web servers and IP webcams that can care for the elderly and the chronically ill in their homes with care facilities. In [12], a wearable system is designed by placing sensors and the antenna in the textile materials to continuously monitor the children's ECG to decrease the risk in sudden baby death syndromes. The fall detection system with accelerometers and a processor developed in [13] is an intelligent sensor that is capable of analysing incoming data in real time and classifying motions event such as falls or other normal and abnormal events.

III. Design And Implementation Of System Hardware

A. Structure of ECG signal acquisition and pre-processing

In recent years, Electrocardiography (ECG) is the most commonly used diagnostic tool in cardiology. It contributes significantly to the diagnostic and management of patients with cardiac disorders. Especially, it is essential to the diagnosis of cardiac arrhythmias and the acute myocardial ischemic syndromes .That's why it is crucial to acquire accurate raw ECG signal caused by heart muscle, so that further signal processing can be performed with ease. The main desirable characteristics of the electrodes designed to pick up signals from biological objects is that they should not polarize. This means electrode potentials must not vary considerably even when current is passed through them[14].In our prototype, we have used three disposable Ag-AgCl button type surface electrodes to collect ECG signals attached to right arm, left arm and right leg. They are very light in weight. Snap-On type electrode cables were also used to transmit ECG signals to the amplifier.

Bio-electrical signals have very low amplitude. The Ag-AgCl electrodes convert ECG signal into equivalent electrical voltage. As the output voltage of the electrode is very small and insignificant, amplification is required before moving to the signal processing stage. We have designed a two stages cascade instrumentation amplifier using AD620 from Analog Devices. It is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 10000 [15].Conceptual architecture of the system for ECG signal acquisition and pre-processing is shown in Fig.1 (a).In our present work, we have set an overall gain of 1200, although for ECG signal processing 1000 gain is sufficient. The gain is calculated using the equation given below, where R_G is the Gain set resistor –

$$G = [(49.4k\Omega/R_G) + 1] \text{ --------------------- } (1)$$

We have used PCB mounted precision trimming potentiometers instead of a single resistor so that we can easily vary the values of R_G and can obtain suitable gain according to our need. The bio-medical amplifier simulation is done in NI Multisim.The appearance of an unwanted interference signal in the form of 60 or 50 Hz in the output signal is one of the major problems in electro-cardiographic recordings. ECG signals are often contaminated by this power line interference, which arise from power lines to the measurement systems despite amplifier design, shielding and proper grounding. To eliminate the interference and further motion artefacts in ECG signals, we have implemented 6V battery as power supply and filter circuit in our hardware which is set according to our understanding of the useful signal and interference.

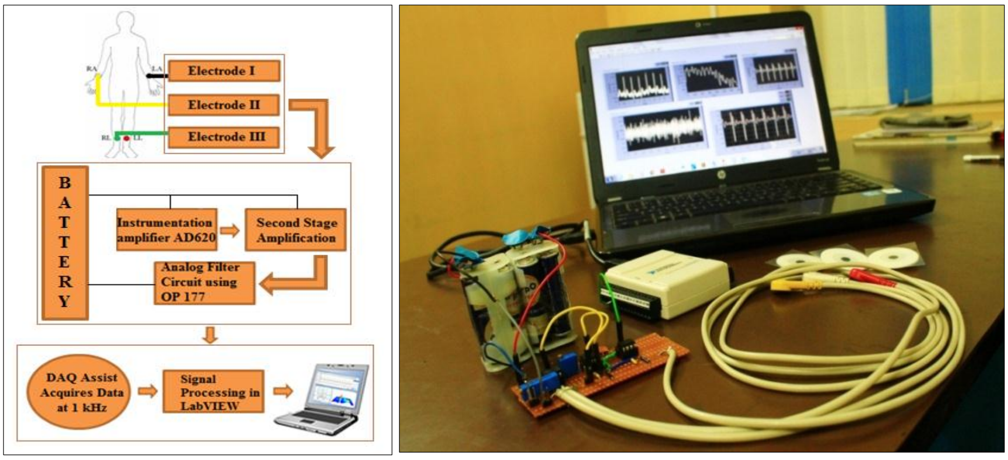


Figure 1: (a) Functional block of ECG system. (b) Experimental set up details for ECG system.

Most of the useful signal is between frequencies of 0.05 Hz and 100 Hz [16], hence the cut-off frequency of low pass filter is set accordingly. Both, passive and active filter can be used in this case. In our prototype, we made an analog active low pass filter to enhance the signal characteristics for diagnosis by using an Ultraprecision Operational AmplifierOP177 from Analog Devices with no internal gain. Then the amplified and filtered data is acquired by NI USB-6008 data acquisition device. It is an Analog to Digital Converter (ADC) DAQ manufactured by National Instruments. We have set the sampling frequency at 1 KHz. After proper digitization of pre-processed ECG signal, it is fed to USB port of computer under LabVIEW platform.

B. Computer analysis of ECG signal

While gathering and recording electrocardiogram, (ECG) signals may get mixed with various kinds of noises. So de-noising of ECG signals is a massive factor in terms of their parameters estimation. Several approaches are proposed in [17–19]. However, our selection of algorithm is motivated by Wavelet Transform (WT) which aligns with section III A. It is a competent technique of providing localization of a signal in both frequency and time domain. A wavelet transform is the representation of a function by wavelets. The wavelets are scaled and translated copies of a finite length or fast decaying oscillating waveform. Wavelet transforms have advantages over traditional Fourier transforms for representing functions that have discontinuities and sharp peaks for accurately deconstructing and reconstructing finite, non-periodic or non-stationary signals [20]. The shape of QRS complex is similar to Daubechies wavelet family and their energy spectrum is concentrated around low frequencies. Therefore we used Daubechies WT as it is more suited for ECG analysis. We have used wavelet transform approach with the help of Advance Signal Processing Toolkit (ASPT).The frequency range of baseline wandering in ECG signal is usually very low and generally below 0.5Hz. Usually it comes mainly due to patient respiration, which is similar to the frequency range of ST segments.

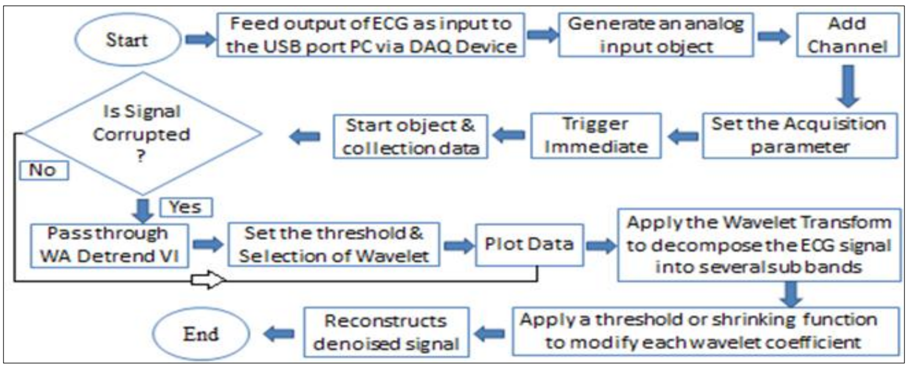


Figure 2: Flow chat showing baseline wandering and wide band noise removal of ECG signal.

In order to remove such low frequency trend from signal, we used WA Detrend virtual instrument provided by ASP toolkit. With the use of a high pass digital filter it is also possible to suppress it, although WA Detrend provides no latency as well as less distortion. After removing baseline wandering from ECG, signal is now more static compared to the original signal. Next, we used Wavelet Denoise Express Virtual instrument in order to remove high frequency noise which arises by muscle movements. Fig.2details the flow chart of baseline wandering removal and removal of wideband noise. After the elimination of all noises by WT approach resulting ECG is now ready for features extraction procedure.

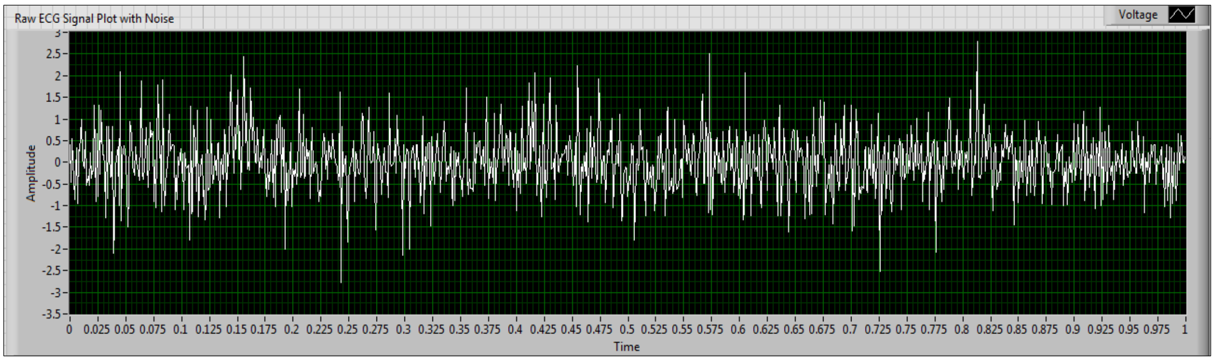


Figure 3: Snap shot of Raw ECG signal acquired from DAQ device.

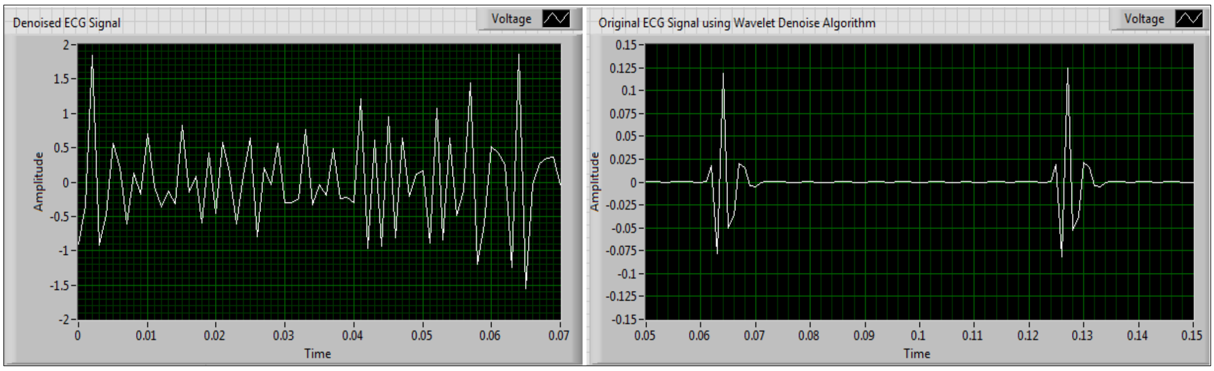


Figure 4: Snap shots of denoised ECG signal after using WA Detrend algorithm and Wavelet Denoise algorithm respectively.

C. ECG parameters extraction and their estimation

The task envisaged for signal processing is mainly the estimation of the clinically important parameters (features) including PR intervals, QRS intervals, QRS amplitudes and Heart rate variability (HRV) from the ECG constituents which, in turn, will enable ECG waveform interpretation. Here for features extraction, we have used biomedical toolkit in LabVIEW and biomedical workbench.

D. Detection of ECG peaks and calculation of their intervals

Detection of P, R, and T points by specifying proper width and threshold is an important and integral part of any sophisticated ECG processing system. We used multiresolution analysis for detection of peak and valley. With the help of a 8 level Daubechies(db06) wavelets, Multiresolution express virtual instrument completes the process. After that WA multiscale peak detection virtual instrument is used to detect P, R and T waves. Fig.5 (a) & (b) details the flow chart of P, R and T wave's detection as well as peak-valley detection. We have also recorded processed ECG data (for one minute each) from five different subjects and stored them into a TDMS file format. Later on we processed those TDMS files in ECG feature extractor toolkit provided by biomedical workbench to find out PR interval, QRS amplitudes, Heart rate and QT interval. Generally, normal heart rate of adults is 60-80 beats per minute while cardiac arrhythmia can be characterized by slower (bradycardia) or faster (tachycardia) as well as regular and irregular heartbeats. It may be caused due to variation of time of impulse conduction over the heart muscle or irregular generation of the cardiac impulse at the SA node or by both.

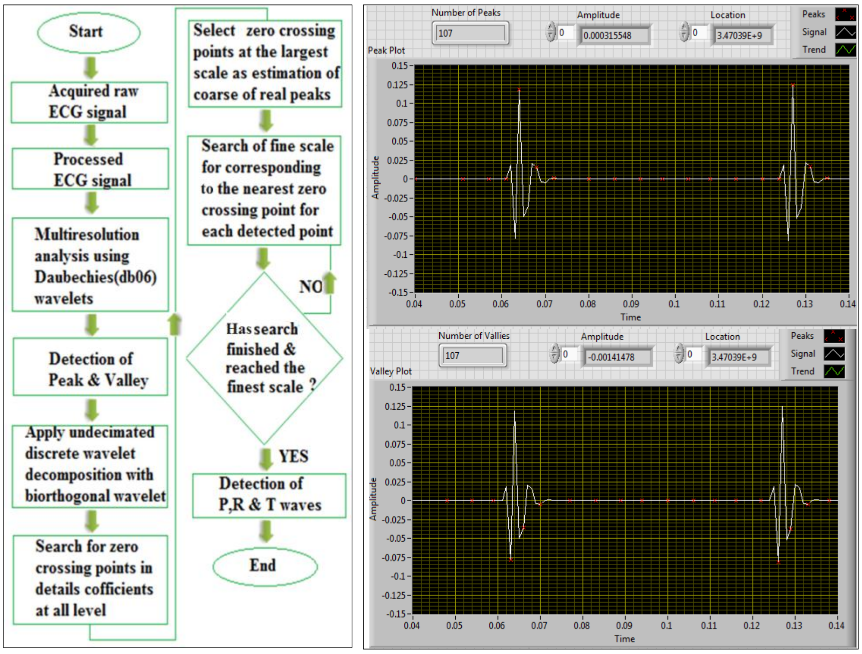


Figure 5: (a) Flow chart showing Multiresolution analysis and Detection of P, R & T waves.
(b) Snap shot of ECG Peaks and Valleys after using Multiresolution analysis.

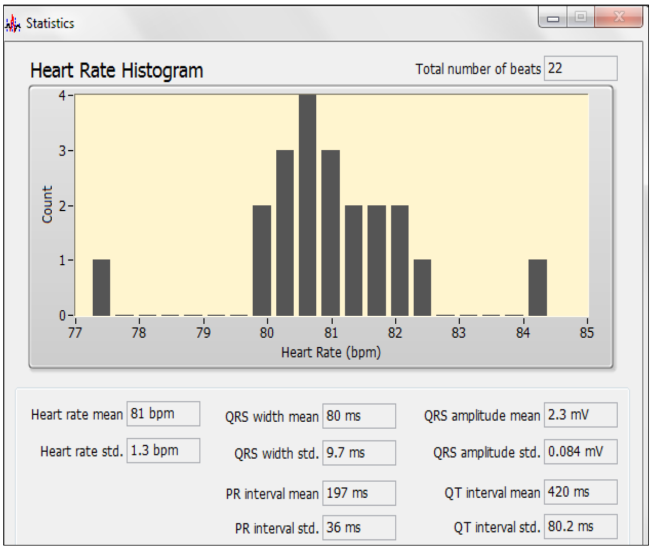


Figure 6: Heart Rate Histogram analysis in biomedical workbench.

E. Heart rate variability

Heart rate variability (HRV) is the natural rise and fall of beat-to-beat variations of heart rate in response to breathing, blood pressure, hormone levels and even emotions [21]. We have used biomedical toolkit in LabVIEW and heart rate variability analyzer provided by biomedical workbench to calculate HRV. We obtained the variety of the activities of sympathetic and parasympathetic nerves of five persons.

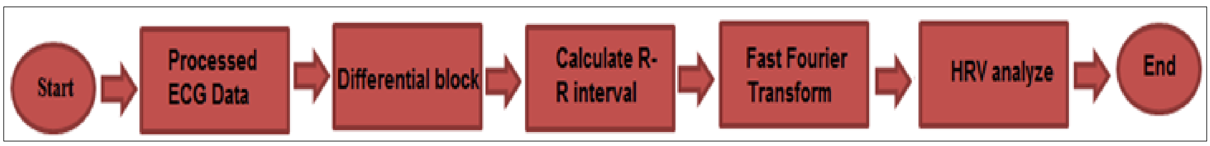


Figure 7: LabVIEW software flow chart for HRV analysis.

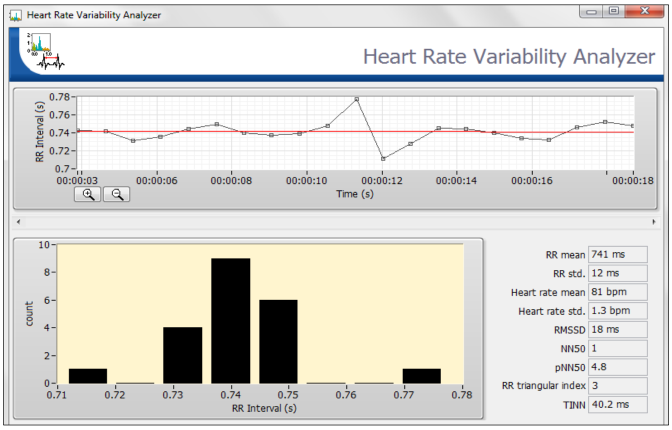


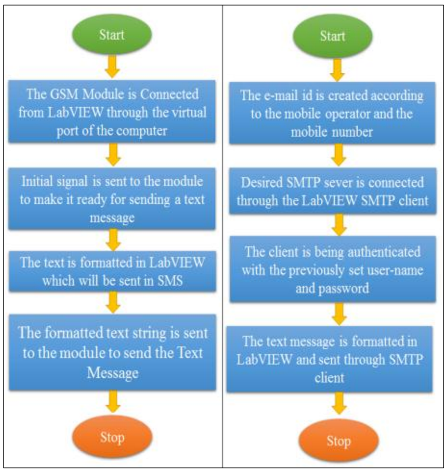
Figure 8: Snap shot of Heart Rate Variability (HRV) analysis of a patient in biomedical workbench.

F. Sudden fall signal acquisition and analysis from accelerometer

The fall detection system consists of a three axis low-g micro-machined accelerometer MMA 7631L which is a low power, low profile capacitive sensor with measurement up to ±1.5g/±6g featuring signal conditioning. This sensor is a 1-pole low pass filter, self-test, 0g-Detect which detects linear free-fall, and has g-Select which allows for the selection between 2 sensitivities from Freescale Semiconductor [22]. In our hardware we have left the g-select pin unconnected so that sensitivity of the sensor can be in 800 mV/g mode. When there is a sudden fall or vibration in the human body, the sensor is activated and the accelerometer will read the acceleration in 3 different axes (x-axis, y-axis and z-axis). In our project, we consider acceleration recording along the z-axis only as the measurement of acceleration in z-axis is quite enough to detect a sudden fall situation. Then the recorded analog signal is filtered and compared with a threshold. Finally, a fall is suspected if and only if the data acquired from the acceleration threshold exceeds a pre-defined threshold. However, the angular placement of this accelerometer should be vertical to the ground of a standstill human's wearable prototype.

G. Text message handling and E-mail notification process

After detecting sudden fall or abnormalities in ECG signal, the wearable device automatically sends a text message to the near ones of the elderly person to make the process of taking necessary actions to the latter more easier ensuring that the action will be more prompt than the other situations. We used a GSM Module to send the text message alert using the GSM technology. GSM module is connected to the USB Port of the computer using RS232. The module works in UART protocol. We used an UART to RS232 converter to connect it to the computer. Here, AT commands are applied to write a text message to a particular cell phone number. The device runs normally with its continuous signal acquisition process until both of the signals remain within its normal pre-defined values. When the ECG signal or the fall signal exceeds that pre-defined values (in terms of R-R intervals in case of ECG signal and in terms of voltage for fall signal), the GSM sends a text message. Fig. 9(a) depicts the process of sending a text message via GSM Module.



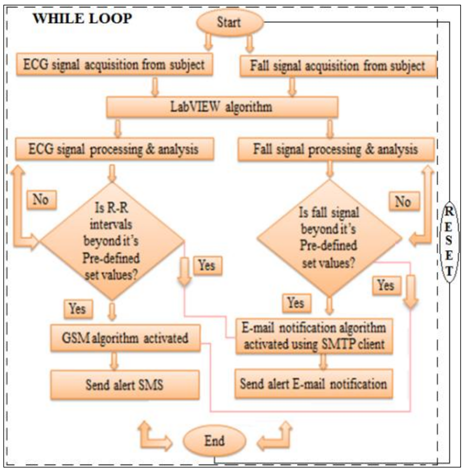


Figure 9: (a) A typical flow chart of sending SMS using GSM Module. (b) Flowchart for sending the e-mail.
Figure 10: Flow chart showing overall wearable system's SMS & e-mail sending procedure.

However, we can also send the text message through the Short Message Service Center (SMSC). The mobile operators in the countries like USA support this service. In that case, we can send the text message by sending an e-mail to the desired number. Thus, the physical weight of the GSM Module can be eliminated from the wearable device. Fig.9 (b) describes the process for sending text message through e-mail. Here, all we need to have is an Internet connection to send a text message. Thus the wearable system becomes lighter in weight and much simpler, but unfortunately, the Mobile Operators in the countries like India do not provide the freely accessible Short Message Service Center (SMSC). So in that case we have to use the GSM Module. Whole wearable system's text message and e-mail sending algorithm is given in Fig.10.

The Bio-Medical workbench provided by National Instruments provide an option to send the detailed ECG report directly to the doctor's e-mail address from the patient's computer. We used that facility in our project. The process for sending an e-mail is same like the flowchart shown in the Fig.9 (b). As an extra feature we added the report file as an attachment to the e-mail.

IV. Results & Discussion

Different parts of designed prototype are shown inFig.11 (a). The final product shown in Fig.11 (b) is compacted after numerous experiments, verification and modification of algorithm. The entire system is developed and studied with volunteers and found working satisfactorily. However the system calibration is needed for reliable use as normal value of ECG and vibration signal varies from one person to another. The system's outcome also is depended on pre-defined set values for both ECG and fall signal. Typical normal and abnormal values with their parameters are given in Table-I and Table-II respectively. Moreover, the accelerometer should be fitted properly (perpendicularly with respect to body) as sensor position is vital to obtain accurate voltage along z-axis. This system can be utilized for remote medical systems to assist the elderly patients, or for physicians to diagnose diseases of the cardiac system and sudden fall situation. The future scope of work is miniaturisation of the system to have portability by adding an embedded FPGA system. Then it can be used as a more effective tool for giving care to elderly and post-operative patients. If it is possible to integrate advanced communication technologies such as Wi-Fi into our system then we will be able to feed live processed ECG and fall signals to long distances.

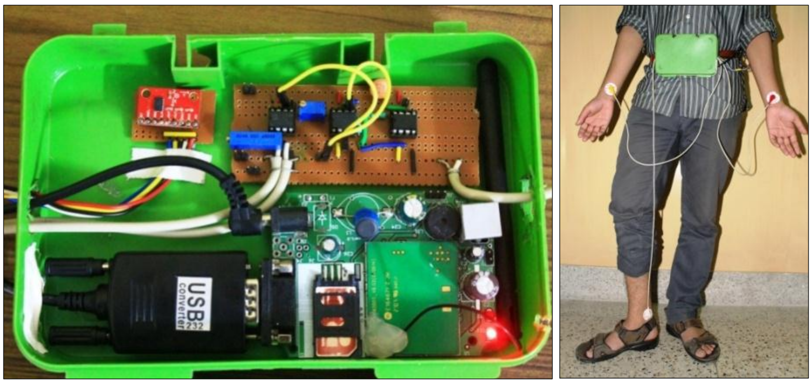


Figure 11: (a) Different parts of wearable prototype(b) Proposed Wearable Hardware prototype

Table-I: Normal set values with SMS & E-mail status

Parameters	Normal Pre-defined set values	SMS alert & E-mail notification Status	Signal Processing & analysis process
R-R Intervals of ECG signal	0.6 to 1.2s	Off	Continuous
Sudden fall signal (Accelerometer output)	Up to 800mv	Off	Continuous

Table-II: Abnormal values with SMS & E-mail status

Parameters	Abnormal values	SMS alert & E-mail notification Status	Signal Processing & analysis process
R-R Intervals of ECG signal	Less than 0.6s or greater than 1.2s	On	Stopped until alert sending procedure is completed
Sudden fall signal (Accelerometer output)	Greater than 800mv	On	Stopped until alert sending procedure is completed

V. Conclusion

The main goal of this study is to design and implement a low cost wearable healthcare smart system that can detect inevitably whenever there is an abnormality in ECG signal as well as sudden fall of elderly and post-operative patients that can alert respective care giver. The primary goal has been accomplished as the prototype is built and tested successfully. The advantages of this implementation are: portability, low cost, scalability, immediate analyse of ECG and sudden fall signals, momentarily display the result in the computer, applicable to each family. Therefore, it is easy to say that wearable technologies can play a key role in identifying transient activity-related features to potentially predict near-term risks of cardiovascular events or deaths as considerable number of cardiovascular disease patients die suddenly without prior symptoms.

References

[1]. S. Lanspery and J. Hyde, "Introduction: Staying put", In Lanspery S, and Hyde J Staying put: Adapting the places instead of the People, Amityville, NY: Baywood Publishing, **(1997)**, pp. 1-22.

[2]. World Health Organisation (WHO), "The Atlas of Heart Disease and Stroke", 2002: http://www.who.int/cardiovascular_diseases/resources/atlas/en/index.html (Acessed: 28/02/2011)

[3]. V. Aslantas, R. Kurban, "CepBilgisayarı (PDA) TabanlıTasınabilirKablosuzElektrokardiyogram zlemeve Alarm Sistemi", ELECO2006 Electrical, Electronic and Computer Engineering Symposium, pp. 288-292, 2006.

[4]. U. Patel, C. Babbs, A computer based automated telephonic system to monitor patient progress in home setting, Journal of Medical Systems, vol. 16(2), 1992, 101-112.

[5]. G. Coyle, L. Boydell, L. Brown, Home telecare for the elderly, Journal of Telemedicine and. Telecare, vol. 1, 1995, 183-185.

[6]. National Instruments, http://www.ni.com/gettingstarted/setuphardware/dataacquisition/accelerometers.htm

[7]. E.O. Thorp, "The Invention of the First Wearable Computer", Second International Symposium on Wearable Computers, 1998, pp:4-8

[8]. Jianchu Yao, Schmitz R., Rarren S., "A wearable point-of-care system for home use that incorporates plug-and-play and wireless standards," IEEE Transactions on Information Technology in Biomedicine, vol 9, issue 3, Sept. 2005, pp 363-371 (2005)

[9]. Chin-Chih Lin, Ming-Jang Chiu, Chun-Chieh Hsiao, Ren-Guey&Yuh-Show Tsai,"A Wireless Healthcare Service System for Elderly with Dementia, TITB-00146-2005.R,@2006 IEEE

[10]. Yuan-Hsiang Lin, I-Chen Jan, Patrick Chow-in Ko, Yen-Yu Chen, Jau-Min Wong, and Gwo-jen Jan, "A wireless PDA-based physiological monitoring system for patient transport," IEEE Transaction on Information Technology in Biomedicine, vol 9, issue 4, Dec. 2004, pp 439-447 (2004)

[11]. P. Leijdekkers, V. Gay and E. Lawrence, "Smart Homecare System for Health Tele-monitoring", First International Conference on the Digital Society, ICDS '07, **(2007)**, pp. 3.

[12]. J. Coosemans, B. Hermans, R. Puers, "Integrating wireless ECG monitoring in textiles", Sensors and Actuators A: Physical, Vol. 130-131, pp. 48–53, 2006.

[13]. T. R. Hansen, J. M. Eklund, J. Sprinkle, R. Bajesy and S. Sastry, "Using Smart Sensor and a Camera Phone to Detect and Verify the Fall of The Elderly Person", European Medicine, Biology and Engineering Conference, **(2005)**.

[14]. Khandpur , " Handbook of Biomedical Instrumentation " TMH edition, New Delhi

[15]. Low Cost Low Power Instrumentation Amplifier, data sheet, Analog devices inc., www.analog.com static importedfiles data sheets AD620 .pdf

[16]. Richard Szeliski,Computer Vision algorithms and applications, (2010)

[17]. Y. H. Hu, W. J. Tompkins, J. L. Urrusti, V. X. Afonso, "Applications of artificial neural networks for ECG signal detection and classification," Journal of Electrocardiology, vol. 26, Suppl., pp. 66 – 73, 1993.

[18]. W. T. Cheng, K. L. Chan, "Classification of electrocardiogram using hidden Markov models," in Proceedings of the 20th AnnualInternational Conference of the IEEE Engineering in Medicine andBiology Society, 1998, vol. 1, pp. 143 – 146.

[19]. H.-Y. Zhou, K.-M. Hou, "Embedded Real-Time QRS Detection Algorithm for Pervasive Cardiac Care System," in 9th InternationalConference on Signal Processing, ICSP 2008, Leipzig, Germany, 2008, pp. 2150 – 2153.

[20]. ChannappaBhyri*, Kalpana.V, S.T.Hamde, and L.M.Waghmare, "Estimation of ECG features using LabVIEW", TECHNIA – International Journal of Computing Science and Communication Technologies, VOL. 2, NO. 1, July 2009. (ISSN 0974-3375)

[21]. Sumana Chatterjee, Subhrangsu Aditya, D. N. Tibarewala, "A Comparative Study between Females of Pre-Pubertal and Reproductive age groups to explore how HPG-Axis affects the Autonomic Control over Cardiac Activity",Indian Journal of Biomechanics: Special Issue (NCBM 7-8 March 2009).

[22]. https://www.sparkfun.com/datasheets/Components/General/MMA7361L.pdf