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Ubiquitous Healthcare Data Analysis and Monitoring Using Multiple Wireless Sensors for Elderly Person

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Abstract: Increasing life expectancy accompanied with decreasing dependency ratio in developed countries calls for new solutions to support independent living of the elderly. Ubiquitous computing technologies can be used to provide better solutions for healthcare of elderly person at home or hospital. Also, data fusion from multiple sensors shows itself the capability to have better monitoring of person. In this paper work, the healthcare parameters as like ECG and accelerometer are used to give a better treatment to the elderly person at home or hospital. Accumulated vital signs data through long-term monitoring is a valuable resource to assess personal health status and predict potential risk factors through the fusion monitoring of multiple sensors. The hardware allows data to be transmitted wirelessly from on-body sensors to a base station attached to server PC using IEEE802.15.4. If any abnormality occurs at server then the alarm condition sends to the doctor's personal digital assistant (PDA). The system provides an application for recording activities, events and potentially important medical symptoms. *Copyright © 2008 IFSA.*

Keywords: ECG, Accelerometer, QRS-Complex, P-wave, T-wave, Acceleration norm, Orientation angle, Ubiquitous healthcare

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1. Introduction

Reliable health monitoring requires the integration of research in the diverse fields of instrumentation, data acquisition storage, signal processing, approximate reasoning, feature extraction techniques and multi-sensor data fusion. Data fusion is the synergistic use of information from multiple resources in order to assist in the overall understanding of the condition of a system. It offers a more complete figure of the whole situation and more accurate evaluation of the condition based on the information from individual sensors.

Recent advances in sensor technology allow continuous, real-time ambulatory monitoring of multiple patient physiological signals including: ECG, body temperature, respiration, blood pressure, oxygen levels, and glucose levels [1], [2]. These systems are conveniently packaged as a single product and could be used to give a complete picture of the patient health. However they generate large amounts of patient data that must be intelligently analyzed and archived to be most useful. In previous studies, home telecare systems using non-continuous monitoring and telephone data transmission [3], [4] have already proven effective in the management of chronic diseases such as congestive heart failure and hypertension. Continuous monitoring would allow telecare systems to accommodate a larger number of pathologies including asymptomatic conditions like atrial fibrillation for which intermittent monitoring is not sufficient. Technology that would allow healthcare providers to deploy, configure, and manage such monitoring systems, would provide a tremendous service to the healthcare industry while at the same time improving the quality of life for thousands of patients.

Numerous heart diseases can be detected by means of analyzing electrocardiograms (ECG) and the changes in heart rate occur before, during, or following behaviour such as posture changes, walking and running. Therefore, it is often very important to record heart rate along with posture and behaviour, for continuously monitoring a patient’s cardiovascular regulatory system during their daily life activity. Falling is also one of the most significant causes of injury for elderly citizens or patients. By utilizing acceleration values corresponding to the user’s body motion, the system can also detect the fall of elderly person or patient.

Our system developed an robust platform for real-time fusion monitoring of multiple sensors for patients staying in their home or hospital and transmitting health data to doctors working at the hospital with extended ECG [5] and acceleration analysis [6], [7]. The changes in heart rate occur before, during, or following behaviour such as posture changes, walking and running. Therefore, it is often very important to record heart rate along with posture and behaviour, for continuously monitoring a patient’s cardiovascular regulatory system during their daily life activity. The ECG and accelerometer data are continuously recorded with a built-in automatic alarm detection system, for giving early alarm signals even if the patient is unconscious or unaware of cardiac arrhythmias [8]. Emphasis is placed on recent advances in wireless ECG system for cardiac event monitoring and behaviour monitoring such as walking, running with fall detection of patient [9]. An accelerometer data for supporting the ECG analysis gives some detail about the effects of motion while the person is in the motion or fall down.

Fig. 1 shows the system architecture of fusion monitoring of ECG and accelerometer sensors for ubiquitous healthcare system. The system also provides an application for recording activities, events and potentially important medical symptoms. The hardware allows data to be transmitted wirelessly from on-body sensor to the base system and then to PC/PDA. After receiving the serial data received from the base station node attached to server, ECG and accelerometer data are analyzed, which includes searching the QRS-complex, P-wave, T-wave and calculating the norm and orientation angle, in real time. Server/Client software programs were developed in C# based on .Net compiler for monitoring and analyzing the ECG and Accelerometer recordings.

For ECG analysis, QRS detection algorithm is based on the originally developed QRS detection algorithm by Pan-Tompkins [10] in assembly language for implementation on a Z80 microprocessor and later improved and ported to C by Hamilton and Tompkins [11]. This QRS detector uses a signal ECG channel and was originally designed to operate at 200 Hz. The advantages of this QRS detection algorithm are that it is efficient and easily modified for different sample rates. This algorithm is improved according to our software analysis requirement and is developed in C#.net language to comfort with P and T-wave detection and accelerometer analysis at server. If any abnormality occurs at server then the alarm condition sends to the doctor's PDA.

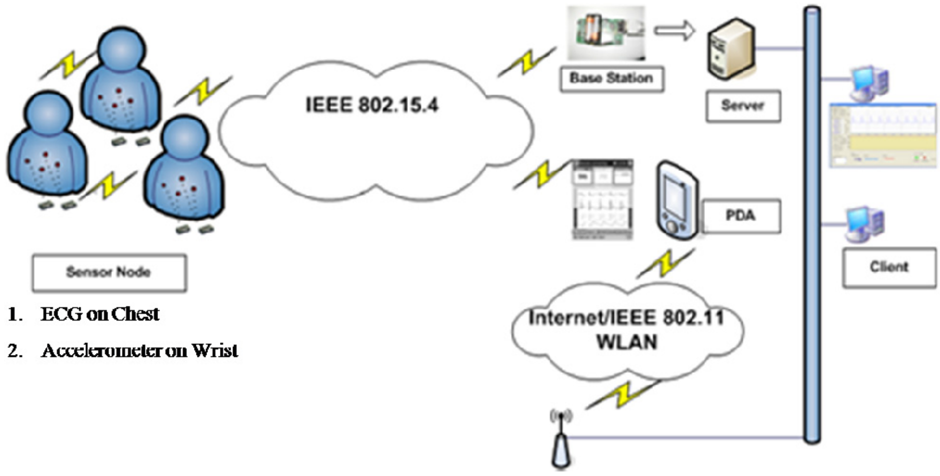


Fig. 1. System architecture for fusion monitoring of ECG and accelerometer sensors.

2. System Designing

Sensing technology plays an important role to assist an elderly person or patient. The concept of ubiquitous healthcare system placed unobtrusive sensors on patient's body to form a fusion data monitoring. An ECG and accelerometer sensors are attached to the human body and transmitting data to the base station. Heart rate, norm, orientation and other parameter of ECG are calculated with fall detection on server. After detection an abnormal ECG or fall of elderly person or patient then alarm condition sends to the doctor's PDA. Flow chart of ECG and accelerometer signal analysis is shown in Fig. 2.

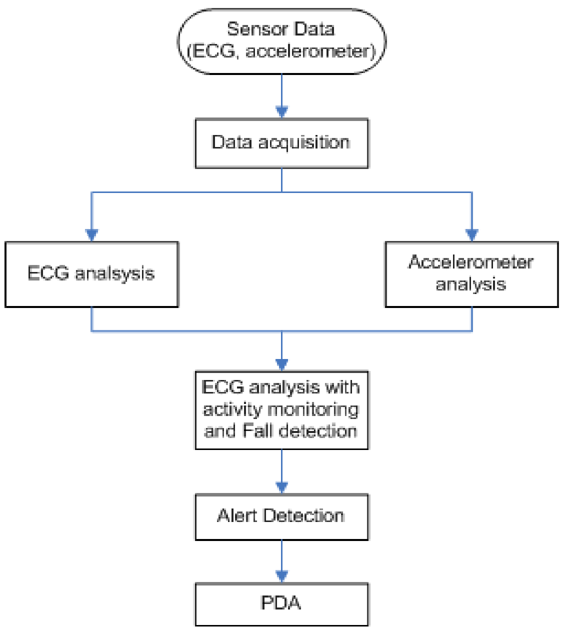


Fig. 2. Flow chart for ECG and accelerometer data monitoring and analysis.

2.1 QRS Detection

QRS detection is based on the analysis of slope, amplitude, and width of QRS complexes. It includes a series of filters and methods that perform low pass, high pass, derivative, squaring and integration procedures. Filtering reduces false detection caused by the various types of interference present in the ECG signal. This filtering permits the use of low thresholds, thereby increase the detection sensitivity. The algorithm adjusts the thresholds automatically and parameters periodically to adapt the changes in QRS morphology and heart rate. The flow chart for QRS-complex, P-wave and T-wave detection algorithm is shown in Fig. 3.

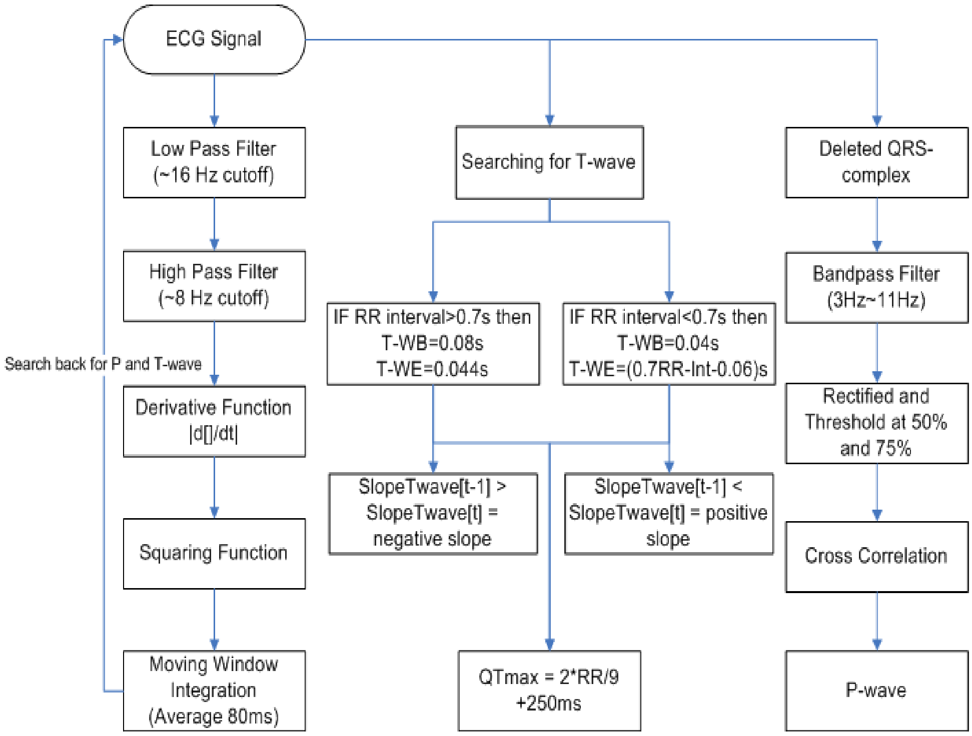


Fig. 3. P, QRS and T wave detection algorithm.

By using moving window integration process, we can calculate R-R intervals, width of QRS complex and heart rate variability. Heart rate is computed by measuring the length of the R-R interval, or a full period of the waveform. These parameters are used to detect abnormality in patients.

2.2 P-wave and T-wave Detection

P-wave and T-wave detection algorithm searches for the T-wave first, after a QRS-complex has been detected. The wave is expected within a specific time window. The start and end duration of window depends on the R-R interval:

If the R-R interval>0.7 second:

T-wave Window begin = 0.08 sec after QRS end.

T-wave window end = 0.004 second.

If R-R interval<0.7 second:

T wave window begin = 0.04 second.

T wave window end = (0.7R-R interval -0.06) sec.

Within this window, the minimum, maximum and order of the slope of the derived function are important for detecting the T-wave. Bi-phase T-wave can be identified in the same way. The change of slope, as well as the end of the T-wave, is detected based on thresholds. The slope must include positive and negative values and the slope magnitude needs to be at least 0.006 mV/s for a T-wave to be detected. The algorithm searches for this combination, until the beginning of a new QRS complex is detected. If SlopeTwave[t-1]> SlopeTwave[t] then the slope is negative and if SlopeTwave[t-1]<SlopeTwave[t] then the slope is positive. It will check for five consecutive slopes then can decide finally positive and negative slope. Where p is the number of slope encounter and SlopeTwave is the calculated slope during T-wave detection. Initially, the value set as t=1 and SlopeTwave[0]=0.

The detection rule for a P-wave is a positive slope followed by a negative slope. The magnitudes of both slopes have to be greater than 0.004 mV/s. The algorithm searches for this combination, until the beginning of a new QRS complex is detected. After detecting a QRS complex then it is deleted and replaced with the base-line. The base line is determined by analyzing a few samples preceding the QRS complex. The resulting signal is band pass filtered with -3 dB points at 3 Hz and 11 Hz and the search interval is defined as QTmax =2RR/9+250 ms, where RR is the interval between two successive QRS complexes. The signal is rectified and threshold at 50 % and 75 % of the maximum to obtain a three level signal. After taking a cross correlation of the result computed with three levels signal and from a representative set of P waves. The peak in the cross-correlation corresponds to the location in the original ECG. Estimated P-R interval should be less than 0.02 sec for normal ECG, which extends from the beginning of the P wave to the first deflection of the QRS complex.

2.3 Accelerometer Norm and Orientation Calculus

If X_i, Y_i and Z_i are the acceleration values at a particular instant of time then acceleration norm A_n is given as

$$A_n = \sqrt{(X_i^2+Y_i^2+Z_i^2)}$$

and the orientation is calculated using the dot product of the norm and the vertical axes

$$\cos\Theta = Z_i/A_n$$

The data collected at the base station attached to PC are the sample level values in the range [0, 4096] of the voltage signal from sensor unit. So for calculating the acceleration from these samples first voltage level is calculated and checks weather this voltage level is for positive acceleration or negative acceleration. The formula used for calculating using the exact acceleration values is given as

$$V.L. = \frac{[(VDD(mV)*Sample\ Level)/4096-500(mV)]}{200(mV)},$$

where 1500 mV is the reference voltage level of the accelerometer, above this level is positive acceleration and below is negative acceleration and 200 mV/g is the sensitivity of the accelerometer.

After calculating all parameter of ECG signal then can classify shape and beat of ECG. For example, in rest if the heart rate is greater then 100 then is called sinus tachycardia disease and if the heart rate is lees then 60 then it is called a sinus bradycardia disease. If the heart rate is in between 60 and 100 then it is a normal sinus rhythm. But it is not sure during moving activity of patient, which is shown in Fig. 4. The moving activities (walking and running) of patient is recorded in experiments up to acceleration norm value 3g (where $g = 9.8\ m/s^2$).

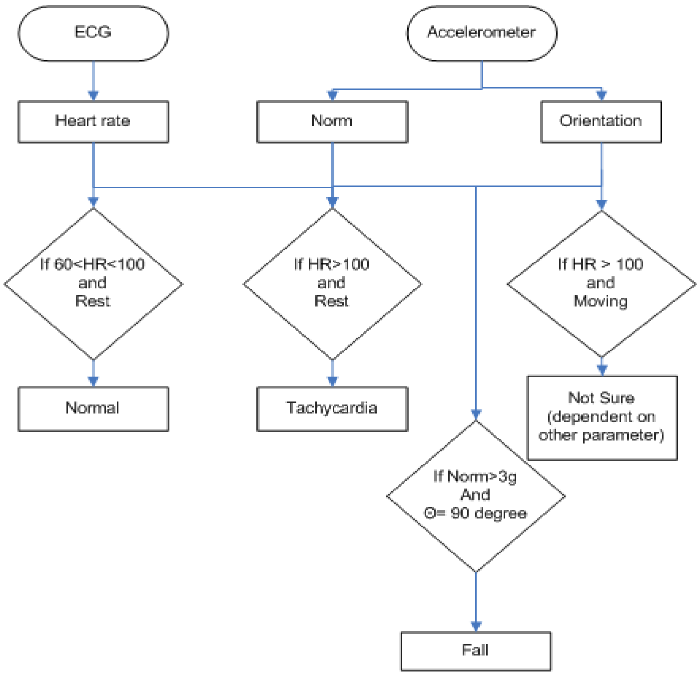


Fig. 4. ECG analysis with activity monitoring

Basically, the algorithm developed using acceleration sensor decides fall detection. When people fall, acceleration is rapidly changed, according to their changes algorithm can classify the status of patient. Fall can be detected by measuring large acceleration threshold and orientation horizontal with ground within a time interval. The functionality behind this method was to observe a significant changes in the user's orientation angles, look for a large acceleration within the same time interval, and when both are present, classify as a fall which is shown in Fig. 5. If the resultant value is greater than acceleration threshold value for continuously 15 seconds then analyze the orientation angle. If the orientation angle is horizontal with ground (90 degree) then classify as a fall. Wait for 15 seconds more if the orientation angle is not horizontal with ground but deviated towards ground. If there is no activity encounter in the orientation angle and resultant value then consider as a fall.

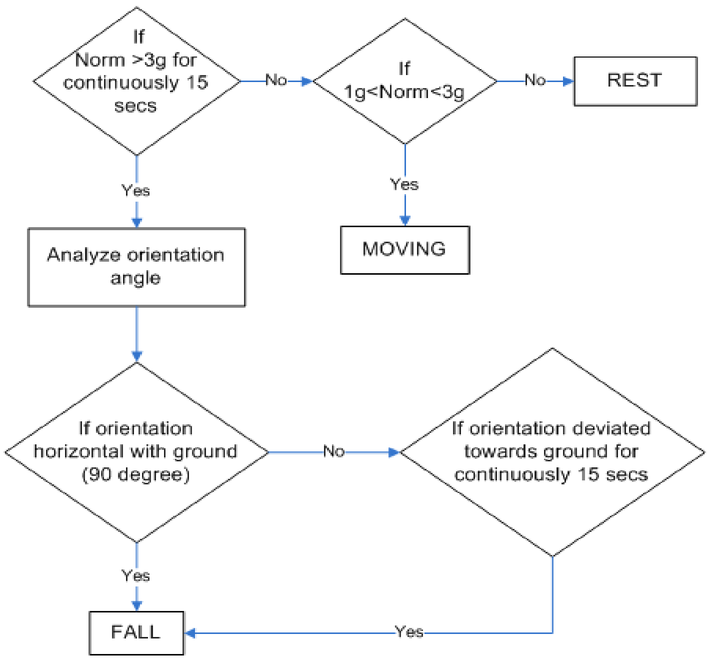


Fig. 5. Fall detection and activity monitoring algorithm.

3. Experimental Results

Our experimental set-up obtains the ECG and accelerometer data from the sensors placed on real human body and MIT-BIH arrhythmia database [12]. Firstly data are transmitted from human body to base station and then to server for ECG and accelerometer analysis. According to server analysis, if there is any abnormality then sends alarm condition to doctor's PDA for further suggestion. The sequence flowchart of step results of QRS-detection is shown in Fig. 6 and their output in Fig.7. After detecting MWI then the software will measure R-R interval and QRS width with the calculation of heart rate. Searching for P-wave is done after deleting QRS complex from the ECG signal and replaced by a base-line and again band pass with 3Hz~11 Hz frequency. T-wave duration is calculated within the specified duration of window and point slope function. A Tri-axial accelerometer graph for analysis of activity behavior is shown in Fig. 8 which indicates red graph as an x axis, blue as a y-axis and green as a z-axis. Firstly up to 17 seconds it shows the patient is in rest position and then shows moving position of patient.

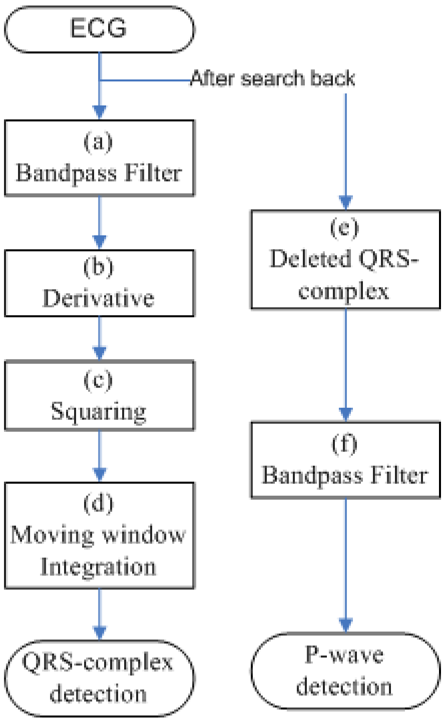
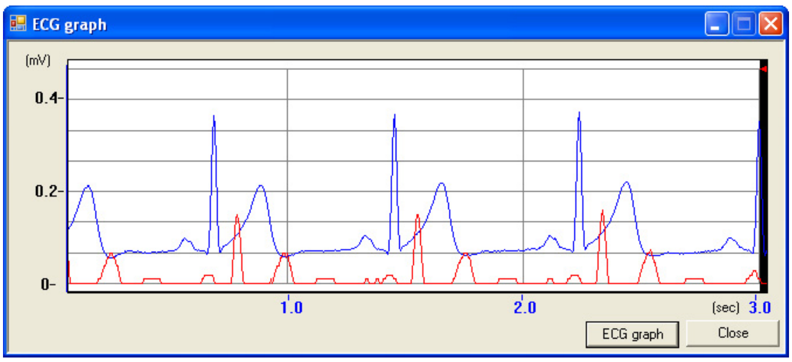
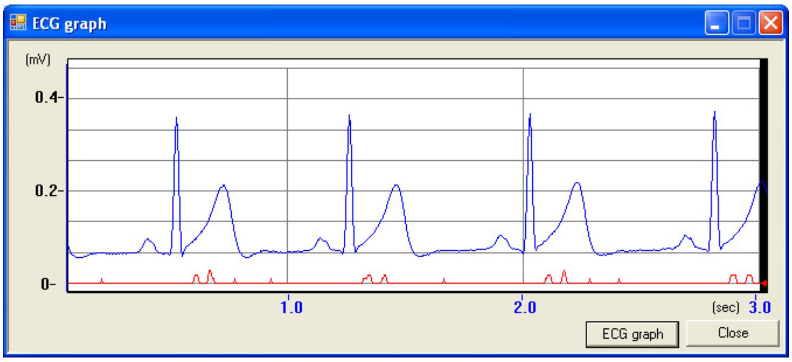


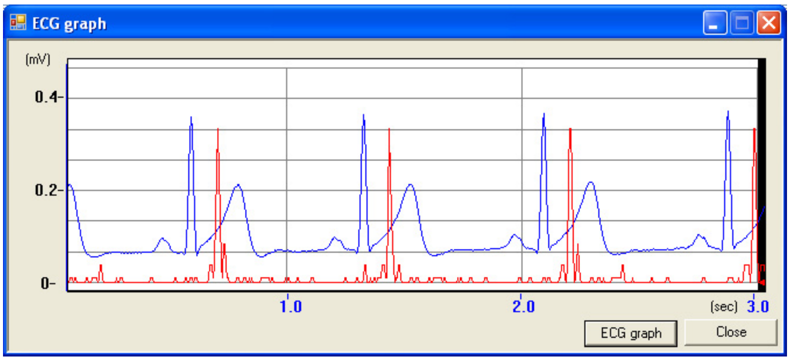
Fig. 6. Sequence flowchart of step result of Fig.7.



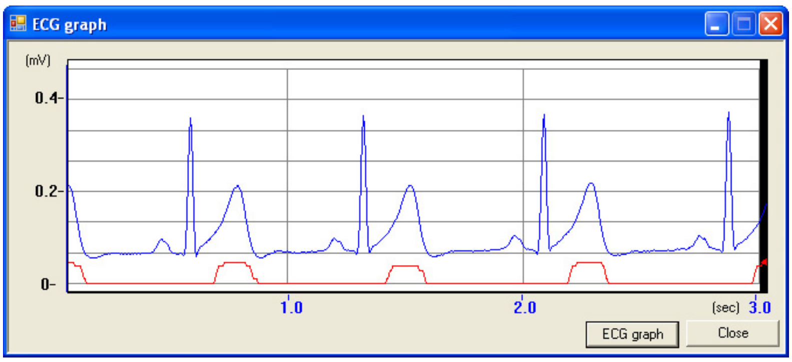
(a) Output of Bandpass filter with cutoff frequency 5Hz~11 Hz
can effectively suppresses the power-line interference, if present.



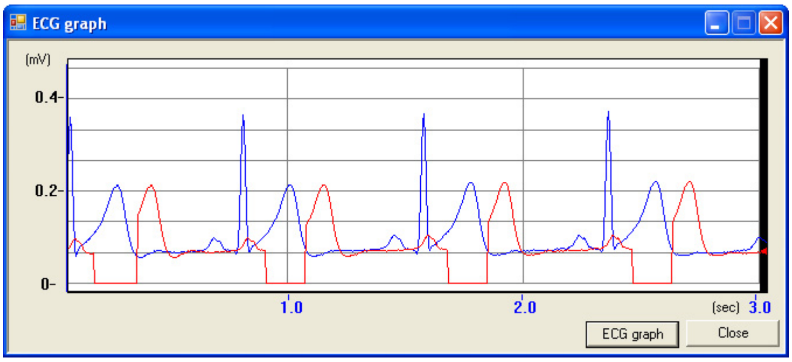
(b) Output of five point derivative function with ideal differential operator up to 30 Hz. It suppresses the low-frequency components of the P and T waves, and provides a large gain to the high-frequency components arising from the high slopes of the QRS complex.



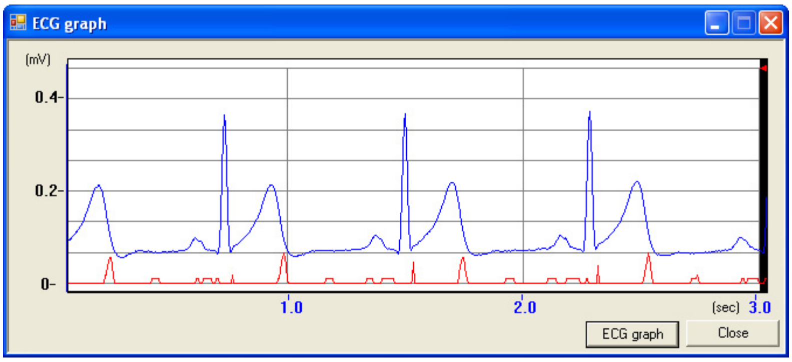
(c) Output of squaring function. It makes the result positive and emphasizes large differences resulting from QRS complexes; the small differences arising from P and T waves are suppressed. The high-frequency components in the signal related to the QRS complex are further enhanced.



(d) Output of Moving Window Integration. It performs smoothing of the output of a derivative-based operation will exhibit multiple peaks within the duration of a single QRS complex. The choice of window width of N=30 was found to be suitable for 200 Hz frequency.



(e) Output of deleted QRS-complex for detection of P-wave. After detecting a QRS complex then it is deleted and replaced with the base-line. The base line is determined by analyzing a few samples preceding the QRS complex.



(f) Output of the resulting signal of Fig.13 (e) is band pass filtered with -3dB points at 3Hz and 11Hz.

Fig. 7. Step results of ECG analysis.

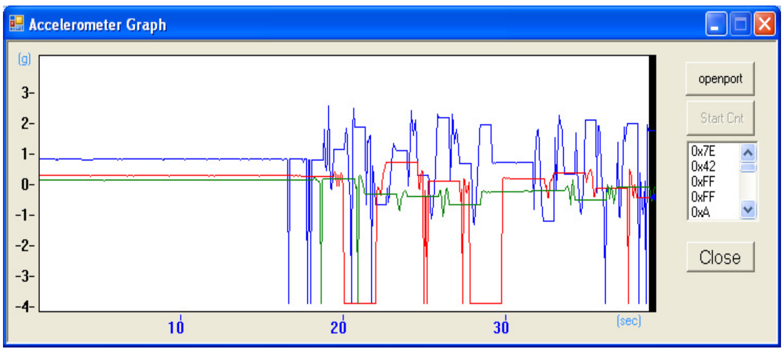


Fig. 8. Tri-axial accelerometer graphs: red graph as an x-axis, blue as a y-axis and green as a z-axis. Firstly upto17 seconds it shows the patient is in rest position and then shows moving position of patient.

Accelerometer data is received by sensor unit which consist of 3-axes accelerometer and data acquisition board (AD5893, 12 bit ADC-MUX) connected to MicaZ motes (Crossbow Technology Inc.). Normal ECG data is taken from real body of human being by using MIB510 data acquisition board attached to MicaZ mote. Abnormal ECG is taken by MIT-BIH arrhythmia database which was created in cooperation between the Massachusetts Institute of Technology and Beth Israel Hospital in order to develop and evaluate real-time ECG rhythm analysis.

The abnormal status of ECG analysis with possible disease of ventricle ectopy is shown in Fig. 9. Then the alarm condition sends to the doctor's PDA which is shown by red button in the interface. The fusion data monitoring using ECG and accelerometer sensors is shown in Fig. 10 with abnormal status of ECG due to tachycardia disease and running situation of patients. Combined analysis result of ECG and accelerometer data did not show the abnormality because of running situation of patient. During running situation of patient, the heart rate can be greater than 100 bpm in normal condition. Therefore, the alarm condition did not send to the doctor's PDA. The ECG interface with their parameter values shown in Fig. 11.

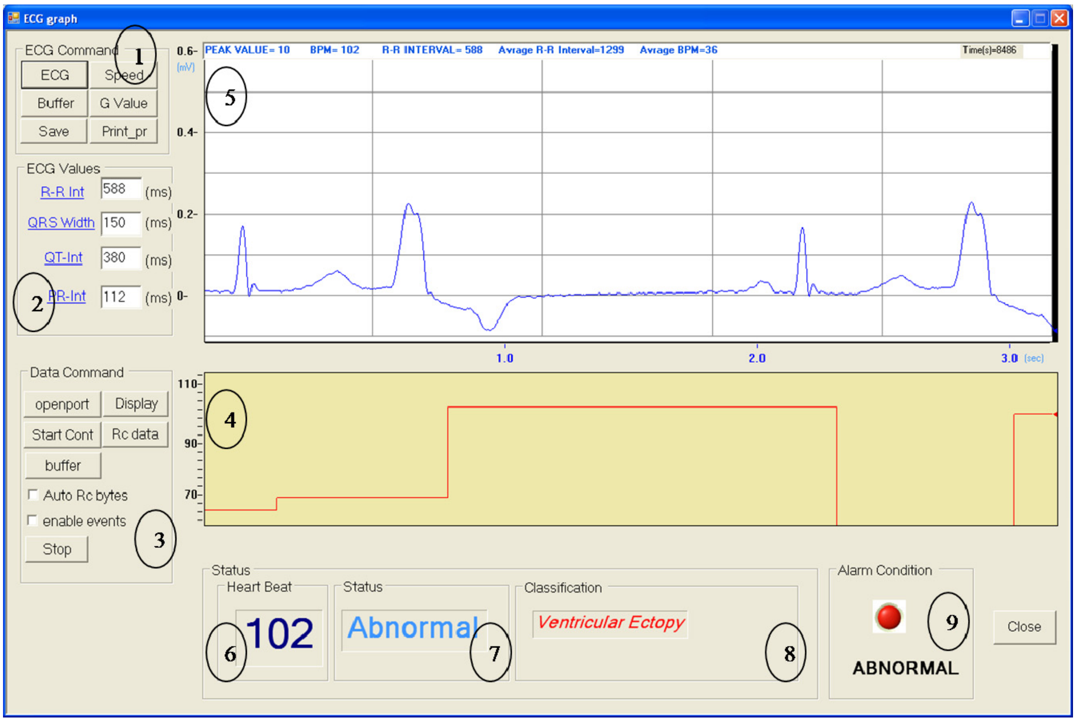


Fig. 9. An ECG interface with abnormal status and heart rate variability graph on server: R-R interval= 588 ms, QRS width = 150 ms, QT interval= 380 ms, PR interval= 112 ms and HR = 102. The data is taken by file no. 119 from MIT-BIH arrhythmia database.

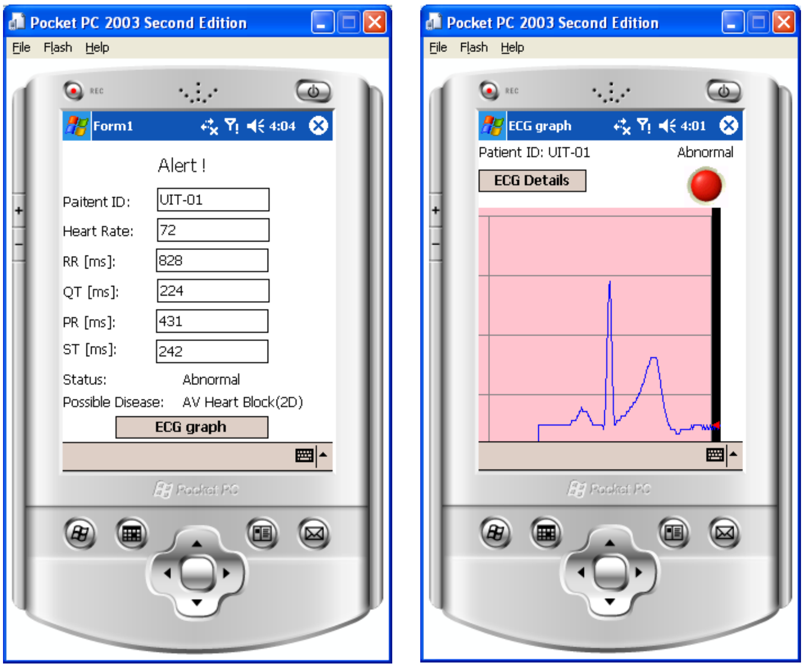
Table 1. Description of block numbers indicating in Fig. 9.

Block Number	Description
1.	ECG commands: to check the buffer, to increase or decrease the speed of ECG graph
2.	For various parameter of ECG which is detected after analyzing an ECG
3.	Serial communication command: to adjust an port number for communication
4.	Heart Rate Variability Graph
5.	ECG graph
6.	Heart Rate after calculated by algorithm applied on ECG
7.	ECG status: Normal or Abnormal
8.	Disease Status: Possible detected disease
9.	Alarm condition: if normal then OFF and if abnormal then ON and send necessary information to the Doctor's PDA

Fig. 10. An ECG and Accelerometer interface with abnormal status on Server: R-R interval= 408 ms, QRS width = 68 ms, QT interval= 406 ms, PR interval = 112 ms, Resultant = 1.276345, Angle (degree) = 12.47328 and HR = 147. ECG data is taken by MIT-BIH arrhythmia database and accelerometer data is received by sensor node attached to the human body.

Table 2. Description of block numbers indicating in Fig. 10.

Block Number	Description
1.	Tri-axial accelerometer graphs: Channel0 (x-axis)- Bule, Channel1 (y-axis) - Red, Channel2 (z-axis) - Green
2.	ECG graph
3.	Serial data receiving at server in packet format
4.	Serial data receiving at server
5.	ECG parameter values
6.	Accelerometer parameter values
7.	Heart Rate
8.	Possible detected disease and status of patient for moving or rest or fall condition
9.	Alarm condition: if normal then OFF and if abnormal then ON and send necessary information to the Doctor's PDA
10.	ECG and Accelerometer commands



(a) (b)

Fig. 11. An ECG and their status on PDA.

4. Conclusions

Growing demand on services oriented to elderly people makes development of improved system to help them to live longer in their home after increasing their quality of life. The prototype system presented in this paper represents an important step beyond the actual state of art in services to the elderly people. In deed, the services offer ECG measurement, activity monitoring and automatic fall detection in their home to the elderly person. According to that, a prototype of fusion health monitoring with ECG and accelerometer sensors was developed for the advanced ubiquitous healthcare of elderly person using wireless sensor network technologies.

This system acts as a continuous event recorder, which can be used to follow up elderly person at home. An ECG analysis and activity monitoring with fall detection of elderly patient is done on server. It can make correct diagnosis even under situations where the patient is unconscious and has the ability to carry out daily activity. This paper particularly focused on detection of arrhythmia disease, norm calculation, orientation calculation and fall detection to monitor an elderly person at home. The use of an affordable device for monitoring activities, analyzing ECG signals and fall detection of patient at home can provide informative details to the doctors using PDA/PC. After analyzing ECG and accelerometer data on server then the abnormal condition sends to the doctor's PDA. Thus, doctor can receive necessary information in the form of either value of ECG and accelerometer parameter or graph for patient diagnosis. The goal was to provide a capability for real time analysis of ECG signal with activity monitoring at server. After detecting an abnormality then notify to the doctor's PDA.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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