Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

10th International Conference
on Electrical Engineering
ICEENG 2016

Acquisition and Analysis of Electrocardiogram Waveforms with Diagnosis Transmission through Short Message Service Communication System

By

B. Yu Jeco*,** R. Doma* M. Morales* E. Tarroza* M. Villaflores*
A. dela Cruz* E. Guevara* R. Vicerra* M. Asilo*

Abstract:

In this study, we integrated the electrocardiogram waveform acquisition, analysis and diagnosis transmission into a single monitoring system. The electrocardiogram monitoring system is divided into 3 stages, namely the data acquisition stage, the decision making stage and the alerting system stage. We used a low-pass Butterworth filter in the data acquisition stage for removing the artifacts that introduce noise to the electrocardiogram waveform after the analog-to-digital conversion. In the decision-making stage, we implemented the zero crossing algorithm for measuring the different segments of the electrocardiogram waveform. And in the alerting system stage, the diagnosis was transmitted to a mobile phone capable of recognizing attention commands via short messaging system. In this study, the integration of the electrocardiogram waveforms acquisition, analysis and diagnosis transmission into a single monitoring system has been successfully implemented. This monitoring system has demonstrated the capability to measure and detect heart rate and heart rhythm respectively. In a bigger picture, an individual can implement this improvised monitoring system using a personal computer interfaced with a mobile phone.

Keywords:

Electrocardiogram monitoring, Electrocardiogram analysis, waveform acquisition, ECG

* Department of Electronics Engineering, University of Santo Tomas, Manila, PH
** Department of Electrical Engineering and Information Systems,
The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan

1. Introduction:

An electrocardiogram (ECG) test evaluates the electrical activity of human heart over a period of time. In this test, the strength, rate, and rhythm regularity of the heart are determined to detect abnormalities and disorders that can affect heart function even at an early stage of the heart disease [1, 2]. The ECG waveform, also known as the PQRST wave, is evaluated by segments, namely the P wave, QRS complex and T wave. These segments represent the condition of the electrical activities of the heart. Thus for ECG diagnosis, the interval, deflection, shape regularity, distinctive peaks and depressions of each of these segments are measured. [3, 4]

In measuring the PQRST wave segments, electrical disturbances called artifacts are inevitably introduced in measuring devices. To filter out these artifacts, the use of Recursive Least Square (RLS) and Least Mean Square (LMS) algorithms were reported by Raya and Sison [5]. In a study by Almeida, et al [6], ECG waveform acquisition and analysis has been integrated in a single system. However, the filtering techniques used in the data acquisition require modification to improve the removal of the artifacts. In addition, the alerting system which includes diagnosis transmission has been partially established in the previous work of Almeida, et al [6].

With the aforementioned problems, we implemented the electrocardiogram waveform acquisition, analysis and diagnosis transmission as a single monitoring system. To remove unwanted artifacts [7], we used a 60-Hz interference filter before [8] and then a low-pass Butterworth filter after the analog-to-digital conversion of the ECG waveform. For the testing of the monitoring system developed in this study, we used the ECG waveforms of the heart patients stored in the Massachusetts Institute of Technology - Beth Israel Hospital (MIT-BIH) database [9]. To improve the functionality of the alerting system, the short message service module program codes by Almeida, et al [6] has been modified.

The integration of the electrocardiogram waveform acquisition, analysis and diagnosis transmission into a single monitoring system has been successful. Using this monitoring system, the heart rate and the heart rhythm were successfully measured and detected respectively. This electrocardiogram monitoring system only requires a personal computer interfaced with a mobile phone to implement this improvised system. Thus, this system can be implemented in any household.

2. Materials and Methods:

A. Gathering of Samples

In this study, 6 test samples were used - 5 were from the MIT-BIH database and one was acquired from the human test subject. There were 5 types of ECG waveforms used, each with distinct diagnoses namely, the Normal Sinus Rhythm, Arrythmia, Atrial Fibrillation, Ventricular Tachyarryhmia and Congestive Heart Failure. These samples were selected according to the waveforms available from the MIT-BIH database. These waveforms were limited to signals with abnormalities in rhythms and missing waves. For the Normal Sinus Rhythm, an ECG test result was acquired from a clinical laboratory. This was used as a reference aside from that of the MIT-BIH database. The consent of the subject was obtained following the University ethics guideline on researches involving human. The tests for each sample were done for 10 repetitions to determine the accuracy of the system.

B. Overview of the Electrocardiogram Monitoring System

The block diagram of the ECG monitoring system is shown in Fig. (1). In the data acquisition stage, the electrodes attached to the test subject acquire an ECG waveform, or a previously acquired waveform stored in a text (.txt) file is fed directly to the Matlab program. The waveform acquired is then subjected to amplification via instrumentation amplifier and isolation amplifier. In the decision-making stage, the amplified analog signal is converted to digital signal. The waveform is filtered and analyzed based on the criteria set in the MatLab program which implements the zero-crossing algorithm. The final stage of the monitoring system is the alerting stage. Depending on the user's settings inputted to the Matlab user interface and upon program execution, the computer sends the three (3) parameters, namely the heart rate, rhythm and diagnosis of the ECG waveform together with the name and age of the test subject to a cellular phone capable of recognizing attention commands (AT) and receiving short message service (SMS).

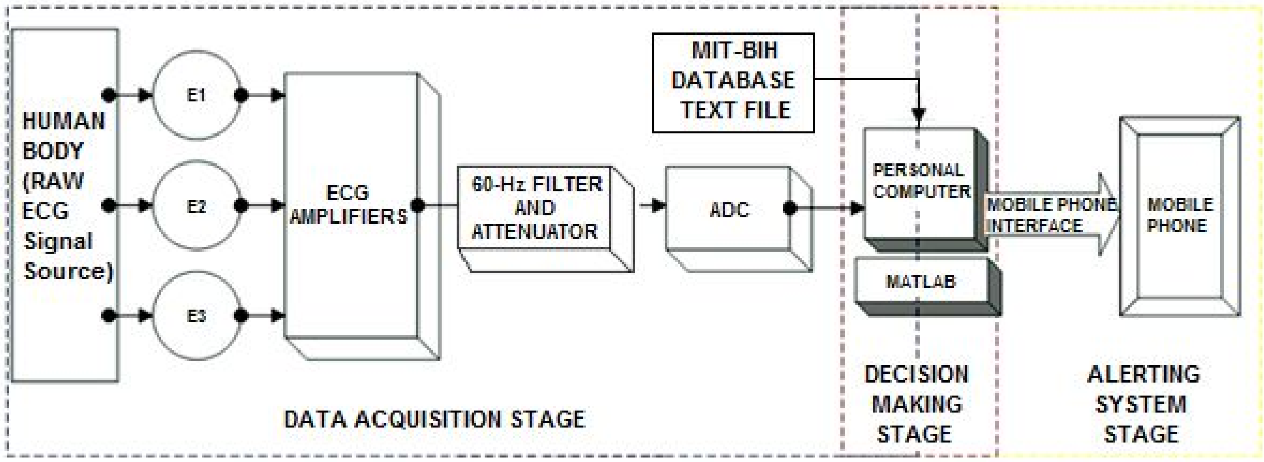


Figure (1): *Block diagram of the Electrocardiogram Monitoring System*

C. Data Acquisition Stage

The cardiac signal, typically 5 mV peak to peak, is an AC signal with a bandwidth of 0.05 Hz to 100 Hz. The basic heart frequency range is 0.50 – 3.0 Hz for a heart rate of 30 - 180 bpm. Although the highest frequency depends on the state of health, age, and gender of the test subject, the typical value is about 125 Hz [10]. Therefore, the ECG monitoring system must be capable of accepting signals within the mentioned frequency range.

The hardware used is shown in Fig. (2). The ECG electrodes are placed on the body in several pre- determined locations to provide information about heart conditions based on the 3-lead Einthoven triangle [11, 12]. Therefore the axis deviation was not evaluated [13]. The test subject must remove all metallic objects from his body and then be placed in a relaxed position. Personal information from the patient such as name and age, the time interval and the duration of the device usage will be encoded in the user interface developed in Matlab Graphical User Interface (GUI) as shown in Fig. (3).

The instrumentation amplifier has a built-in safety component, which is the AD202 isolation amplifier. This amplifier by e- Gizmo© was designed to have a high common mode rejection ratio (CMRR), thus it is capable of removing unwanted artifacts from a bioelectrical signal [14, 15]. The Isolation Amplifier and the Dual Operational Amplifier further enlarges the ECG waveform acquired. A DC offset value of 4.8 V is added to the output of the ECG waveform amplifier block in preparation for the analog-to-digital conversion. The analog-to-digital conversion of the ECG waveform acquired was implemented using the Z8 6412 Microcontroller. The attenuator is composed of a fixed 500 Ω resistor and a variable resistor connected in series to protect the microcontroller from over voltage.

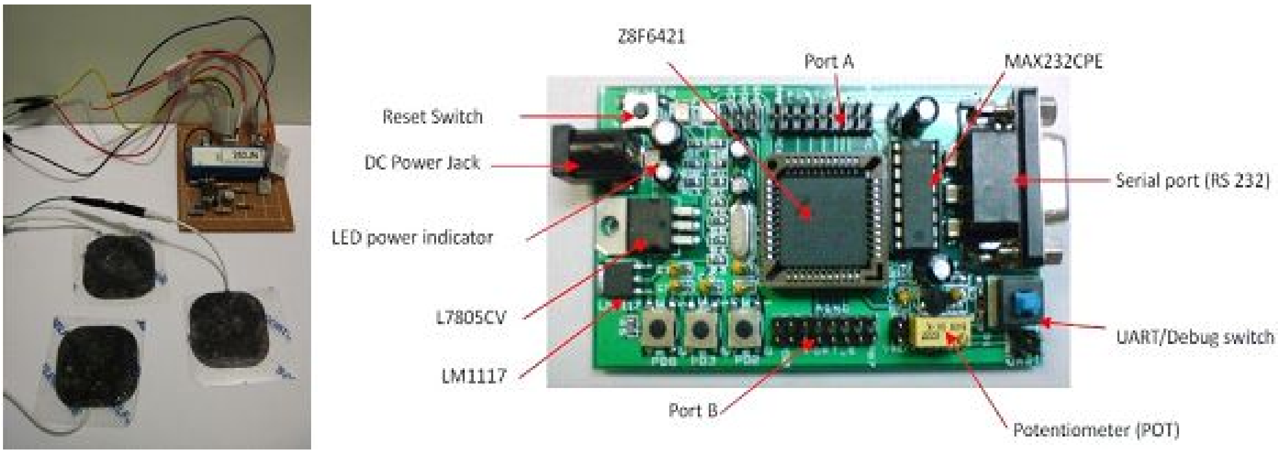


Figure (2): *Electrocardiogram amplifier and the 3 wired electrodes (left) and Z8 6412*

Microcontroller (right)

The data is filtered using first order low pass Butterworth filter with a cut off frequency of 120 Hz, to acquire a desirable ECG waveform. The digitized ECG waveform is received through HyperTerminal.

Name

Age 0

Time Interval 0 min.

Duration 0 min.

e.g. +639123456789

Figure (3): *Graphical user interface developed in Matlab*

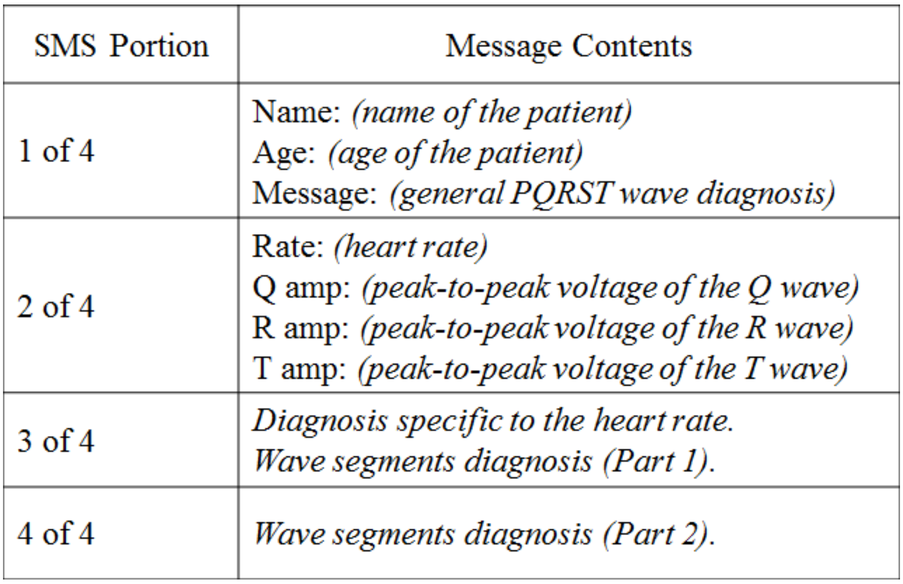
D. Decision Making Stage

Signal processing and analysis are done in MatLab. Zero crossing algorithm was used to resolve the interval from the consecutive points which are then computed simply by subtraction. The code captures three cycles of the signal. Therefore, a normal signal is expected to have twelve cross points. If the number of cross points is below or above the normal value, it is assumed to have a missing wave and/or an irregular rhythm. Additionally, array sorting is used to determine the amplitude of the waves. The signal analysis begins with sorting the acquired ECG waveform values in descending order. The sorted values are then stored in a new array. This is from which the maximum and the minimum amplitude values are obtained. After sorting the amplitude values, their corresponding time intervals are arranged from lowest to highest to ensure that the proper interval is aligned to the correct wave.

E. Alerting System Stage

The analysis results containing the diagnosis is transmitted via short message system using attention commands integrated to the Matlab program. Depending on the time interval and the duration of device usage set in the user interface, the mobile phone interfaced to the personal computer receives the measured ECG waveform parameters together with the patient’s name, age, and device’s diagnosis to the mobile phone of the attending cardiologist, physician or anyone concerned with the patient, as summarized in Table (1). To send the complete analysis, the entire diagnosis must be split into 4 messages since a single message by default in Nokia© N77 model used contains a maximum of 160 characters. The first message contains the name and age of the test subject and the overview of the ECG waveform diagnosis. The second message contains the heart rate, and the peak-to-peak voltages of the Q, R and T waves. The third message contains the heart rate diagnosis and the first part of the wave segments diagnosis. Lastly, the fourth message contains the second part of the wave segments diagnosis.

Table (1): *Summary of SMS Transmission of the Electrocardiogram waveform analysis acquired from the Electrocardiogram monitoring system.*



SMS Portion	Message Contents
1 of 4	Name: *(name of the patient)* Age: *(age of the patient)* Message: *(general PQRST wave diagnosis)*
2 of 4	Rate: *(heart rate)* Q amp: *(peak-to-peak voltage of the Q wave)* R amp: *(peak-to-peak voltage of the R wave)* T amp: *(peak-to-peak voltage of the T wave)*
3 of 4	*Diagnosis specific to the heart rate.* *Wave segments diagnosis (Part 1).*
4 of 4	*Wave segments diagnosis (Part 2).*

F. Electrocardiogram Waveform Diagnosis Criteria

The ECG waveform is composed of a P wave, a QRS complex and a T wave. Each segment represents a specific condition of the electrical activity of the heart. The P wave represents the atrial muscle activation and the T wave represents the period of recovery for the ventricles repolarization To determine their condition, their deflections are evaluated. The P-R interval is measured from the beginning of the P wave to the beginning of the QRS complex. QRS complex represents the spread of the electrical impulse through the ventricular muscle depolarization. The S-T segment represents repolarization [3, 4].

The zero cross points of the ECG waveform were used to determine the heart rate and the rhythm. The heart rate is calculated by taking the interval of the R-wave peaks, denoted as the RR interval and dividing this value by 60. The normal range for this parameter is 60- 100 bpm when the subject is at rest [16, 17]. Lastly, the heart rhythm is evaluated by the regularity of the PQRST wave for 3 cycles using subtraction of the zero cross points location along the time axis.

The normal ranges of the evaluated parameters are summarized in Table (2). These values were incorporated in the Matlab program for ECG waveform analysis.

***Table (2):** Summary of Electrocardiogram waveform diagnosis criteria*

Deflection	Normal Range	Interval	Normal Range	Amplitude	Normal Range
- P wave	Positive	- PR	0.12 to 0.20 sec	- P	2 to 3 mm
- T wave	Negative	- QRS	0.06 to 0.12 sec	- Q	Above 25% of R wave amplitude
Heart Rate	60 to 100 bpm	- QT	0.36 to 0.44 sec		
		- P	0.06 to 0.12 sec	- R	Within 5 mm
		- Q	up to 0.04 sec	- T	Within 0.5 mm

3. Discussion of Results:

A. Electrocardiogram Waveform Processing

The raw ECG waveform obtained from the electrodes is denoted as the green plot in Fig. (4). After the waveform has passed through the analog low-pass filter, the 60-Hz interference component of the waveform has been successfully removed. This waveform processing stage prior to the analog-to-digital conversion is shown as the blue plot in Fig. (4). After the analog-to-digital conversion, artifacts were introduced. The signal captured by Matlab was then filtered using a digital low pass Butterworth filter and viewed in time domain using the plot function. Although the waveform displays the QRS-complex, P- and T-waves were still found to be indistinguishable. Thus, the curve fitting and polynomial evaluation functions in MatLab called polyfit and polyval respectively were used. After this step, the graph displayed a clearer P-Q wave as shown by the red plot in Fig. (4). However, the waveform still did not show an entirely smooth signal, which resulted to more than 12 cross points in some test repetitions, making it difficult to determine the regularity of the signal.

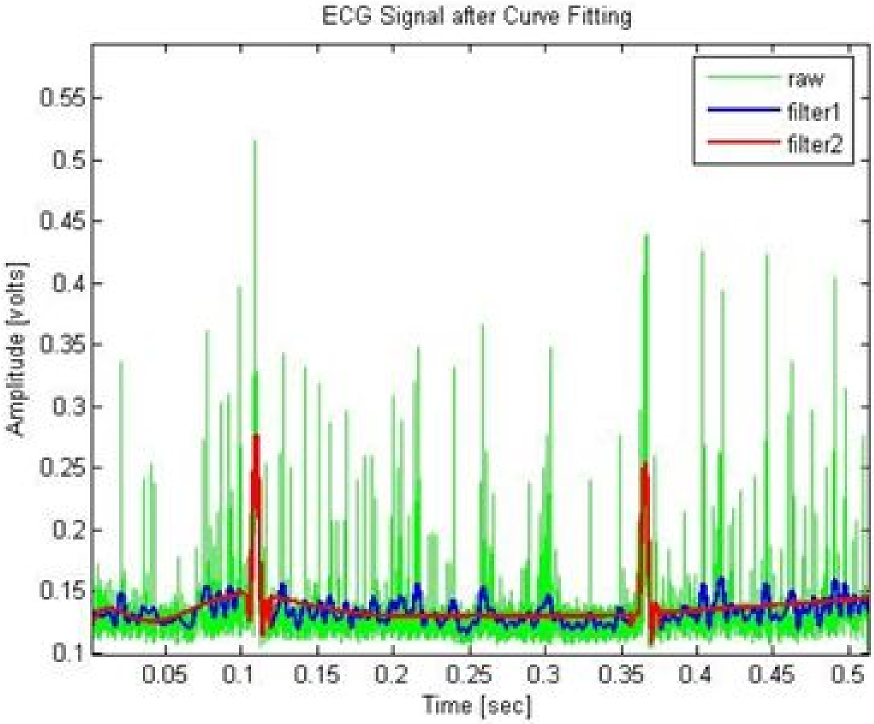
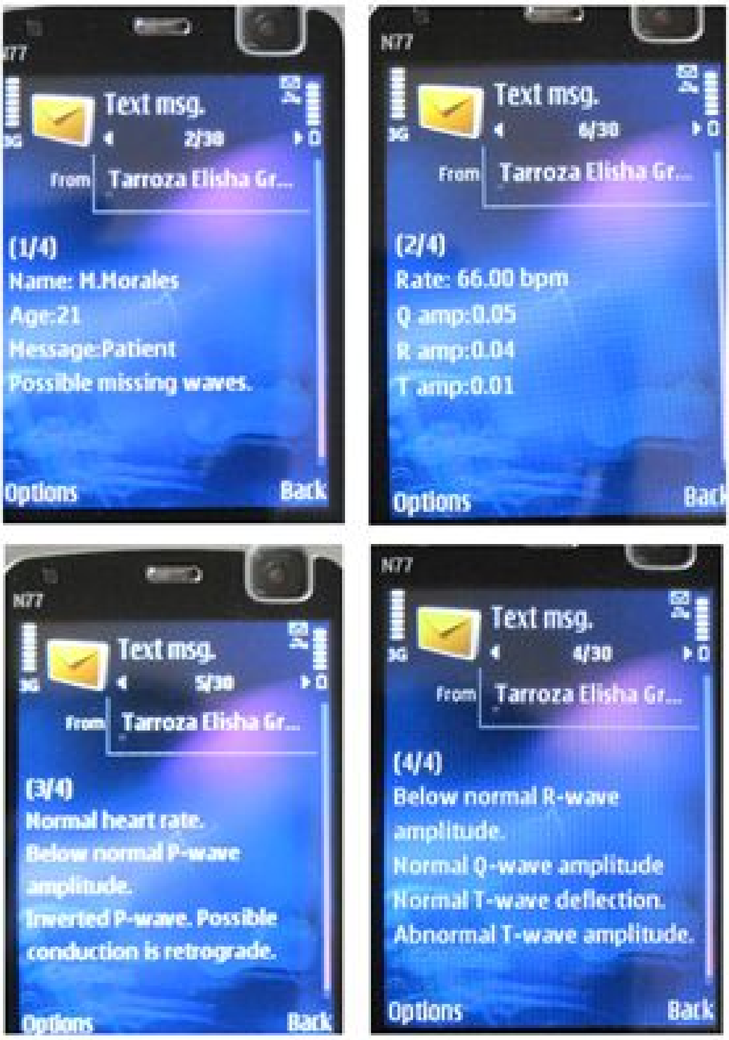


Figure (4): *Resulting Electrocardiogram signal before 60-Hz interference removal (green), before analog-to-digital conversion (blue) and after the artifact filtering (red)*

B. Contents of the Short Message System

Fig. (5) shows the short message system texts received by the mobile phone interfaced to the personal computer. The output has displayed the waveform evaluation. While it is possible to provide a specific diagnosis (i.e. normal sinus rhythm, arrhythmia, and the like) it should be noted that the specific diagnosis was intentionally omitted since only licensed doctors are authorized to provide this. However, the acquired parameters are helpful for the licensed doctors to arrive at a correct diagnosis. With this result, it can be inferred that the integration of the ECG waveform acquisition, analysis and diagnosis transmission has been implemented successfully.



(1/4)
Name: M.Morales
Age:21
Message:Patient
Possible missing waves.

(2/4)
Rate: 66.00 bpm
Q amp:0.05
R amp:0.04
T amp:0.01

(3/4)
Normal heart rate.
Below normal P-wave amplitude.
Inverted P-wave. Possible conduction is retrograde.

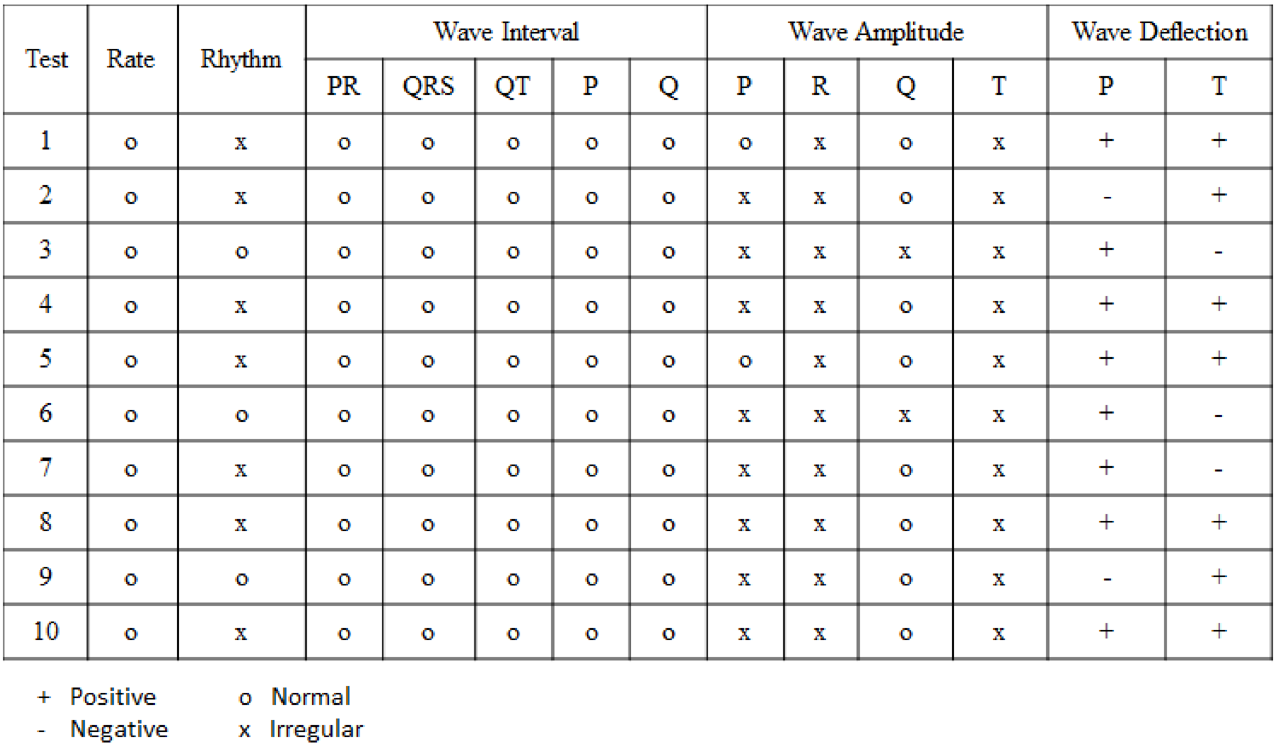
(4/4)
Below normal R-wave amplitude.
Normal Q-wave amplitude
Normal T-wave deflection.
Abnormal T-wave amplitude.

Figure (5): *SMS Transmission of the Electrocardiogram waveform of human test subject analysis acquired from the Electrocardiogram monitoring system.*

C. Waveform Diagnosis

Using the developed ECG monitoring system, the results obtained from the human test subject whose clinical laboratory diagnosis is Normal Sinus Rhythm are summarized in Table (3) and is further elaborated after this table.

Table (3): *Electrocardiogram results acquired from the test subject.*



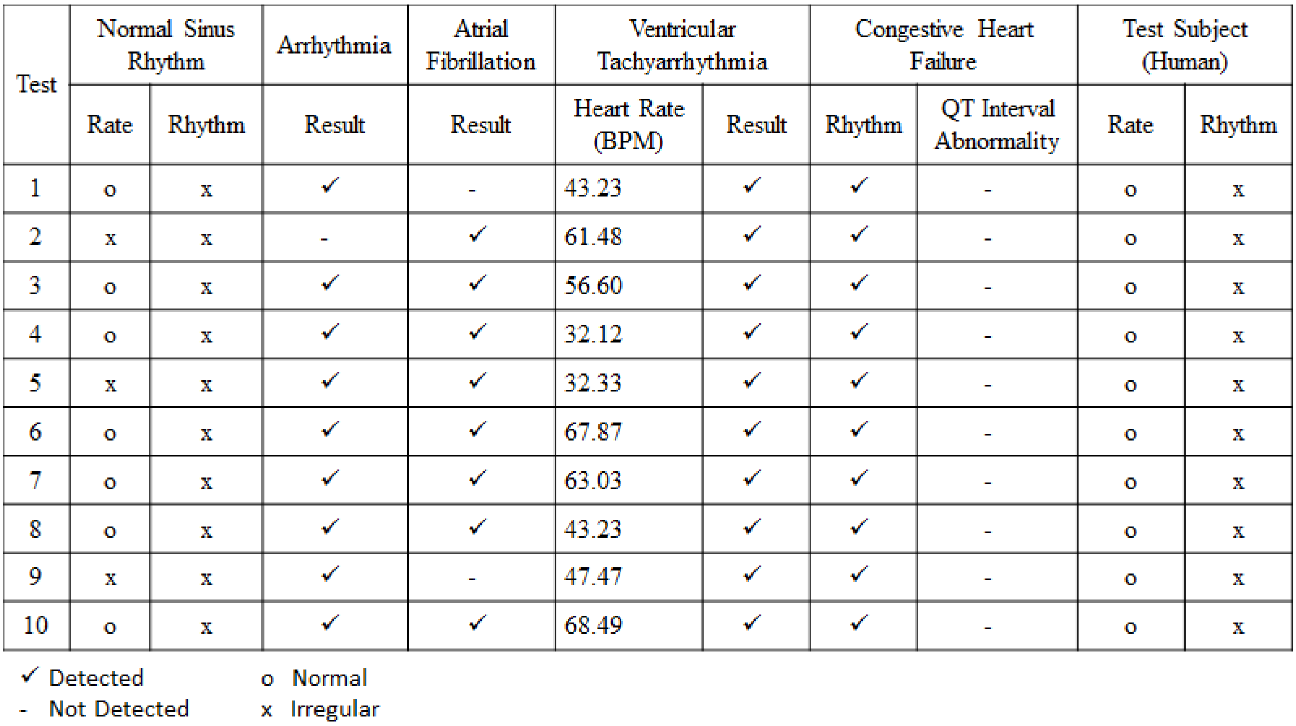
Test	Rate	Rhythm	Wave Interval					Wave Amplitude				Wave Deflection	
			PR	QRS	QT	P	Q	P	R	Q	T	P	T
1	o	x	o	o	o	o	o	o	x	o	x	+	+
2	o	x	o	o	o	o	o	x	x	o	x	-	+
3	o	o	o	o	o	o	o	x	x	x	x	+	-
4	o	x	o	o	o	o	o	x	x	o	x	+	+
5	o	x	o	o	o	o	o	o	x	o	x	+	+
6	o	o	o	o	o	o	o	x	x	x	x	+	-
7	o	x	o	o	o	o	o	x	x	o	x	+	-
8	o	x	o	o	o	o	o	x	x	o	x	+	+
9	o	o	o	o	o	o	o	x	x	o	x	-	+
10	o	x	o	o	o	o	o	x	x	o	x	+	+

+	Positive	o	Normal
-	Negative	x	Irregular

The heart rates measured consistently fall under normal range. On the other hand, the heart rhythm detection yielded 30% accuracy. This can be expected due to more than 12 zero cross points detected in some test repetitions. While all of the measured wave intervals obtained fall under the normal range, giving 100% detection, it should be noted that there is a high possibility that the intervals did not correspond to the correct wave segments. This is also attributed to the excessive number of zero cross points detected for some of the test repetitions. For the wave segments amplitudes, 20% for the P-waves, 0% for the R-waves, 80% for the Q-waves, and 0% for the T-waves were detected normal by the algorithm. For the deflections, the P- and T-wave deflections gave 80% and 70% detection respectively. These below 100% accuracies can be explained by the mixing of artifacts not filtered by the low-pass Butterworth filter with the original ECG waveform.

The results acquired from the ECG monitoring system using the 6 test samples for 10 repetitions are summarized in Table (4). Further discussion of these results follows after the table.

Table (4): *Summary of results acquired from the Electrocardiogram monitoring system.*



Test	Normal Sinus Rhythm		Arrhythmia	Atrial Fibrillation	Ventricular Tachyarrhythmia		Congestive Heart Failure		Test Subject (Human)	
	Rate	Rhythm	Result	Result	Heart Rate (BPM)	Result	Rhythm	QT Interval Abnormality	Rate	Rhythm
1	o	x	✓	-	43.23	✓	✓	-	o	x
2	x	x	-	✓	61.48	✓	✓	-	o	x
3	o	x	✓	✓	56.60	✓	✓	-	o	x
4	o	x	✓	✓	32.12	✓	✓	-	o	x
5	x	x	✓	✓	32.33	✓	✓	-	o	x
6	o	x	✓	✓	67.87	✓	✓	-	o	x
7	o	x	✓	✓	63.03	✓	✓	-	o	x
8	o	x	✓	✓	43.23	✓	✓	-	o	x
9	x	x	✓	-	47.47	✓	✓	-	o	x
10	o	x	✓	✓	68.49	✓	✓	-	o	x

✓ Detected
- Not Detected

o Normal
x Irregular

The normal sinus rhythm is characterized as having a normal heart rate and rhythm. Using the MIT-BIH waveform with normal sinus rhythm as input, the resulting waveform is shown in Fig. (6). Here, it is shown that the ECG waveform deviates from the 0V reference axis. Since the signal acquired was distorted, the amplitudes of the waves cannot be determined. Though the offset voltage applied to the signal is 4.8V, subtracting this from the acquired amplitudes gives incorrect values. Therefore, only the rate and rhythm were analyzed. For the heart rate, 7 out of 10 test repetitions resulted to correct analysis. The source of the detection inaccuracy can be attributed to the observation that the rhythm detected is always irregular due to the unsatisfied number of zero cross points required to correctly diagnose the regularity of the waveform.

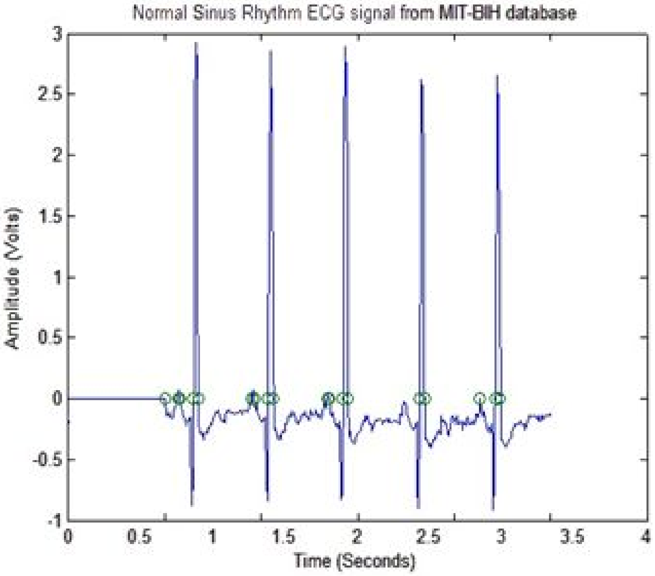


Figure (6): *Processed Normal Sinus Rhythm Electrocardiogram waveform from MIT-BIH database showing zero cross points (green circles).*

The ECG waveform from the clinical laboratory has visible axis deviations and the QRS complex was not always evident, although the ECG waveform was completely noise-free and smooth. From the laboratory result strip (not shown in this paper to protect the privacy of the test subject), the ECG waveform deviates from its reference axis and requires further normalization. On the other hand, the ECG waveform obtained by the developed system after several signal processing showed clear RR intervals with minimal axis deviation. However, this waveform is observed to be more susceptible to external artifacts. Therefore, these waveforms cannot be compared using a direct approach. However, it is still noteworthy that the two systems gave similar interpretations and final diagnosis, as summarized in Table (5).

Table (5): *Comparison of Electrocardiogram results from two different acquisition systems.*

Method	Diagnosis
ECG Laboratory Test	Normal Heart Rate
Low-Cost ECG System	Normal Heart Rate

Arrhythmia can be detected by evaluating the regularity of the heart rhythm. The signal from MIT-BIH database has observable missing waves, and this is the basis of the program to conclude an irregularity in the rhythm. For this heart problem, 9 out of 10 test repetitions resulted to correct analysis.

A missing P-wave suggests Atrial Fibrillation. Additionally, this abnormality can be categorized under arrhythmia, with the heart rate used as an additional parameter for its detection. For this heart problem, 8 out of 10 test repetitions resulted to correct analysis.

Ventricular tachyarrhythmia is described as having fast heart rate, typically above 100 bpm for adults. Heart rate and heart rhythm are used as parameters for detecting this. The averaged RR interval of the sample signal from the database is 1.072 seconds, which gives a 55.98 bpm average heart rate. The average heart rate obtained from the results was 51.58 bpm, which gives a 7.92% error and for all test repetitions, the irregularity is detected.

Although Congestive Heart Failure cannot be determined by a direct approach as applied in the aforementioned heart diseases, it can be determined by detecting symptoms such as abnormal cardiac rhythms and prolonged QT-intervals. Like in Normal Sinus Rhythm, QT interval cannot be analyzed correctly because the intervals depend on the zero cross points of the waves. As shown in Fig. (7), the waves are indistinguishable and the zero cross points needed for determining the QT interval were not detected. While zero cross points detected cannot be fully relied on due to excessive cross points acquired, it is conclusive that there is an irregularity since there is a missing waveform in the acquired signal.

Failed test repetitions which had lowered the accuracy for detecting Normal Sinus Rhythm, Arrythmia, Atrial Fibrillation, Ventricular Tachyarryhmia and Congestive Heart Failure can be attributed to the low complexity of the zero-crossing algorithm since it only uses subtraction for conditional statements selection coded in the Matlab program. Therefore the system will require an additional measuring algorithm.

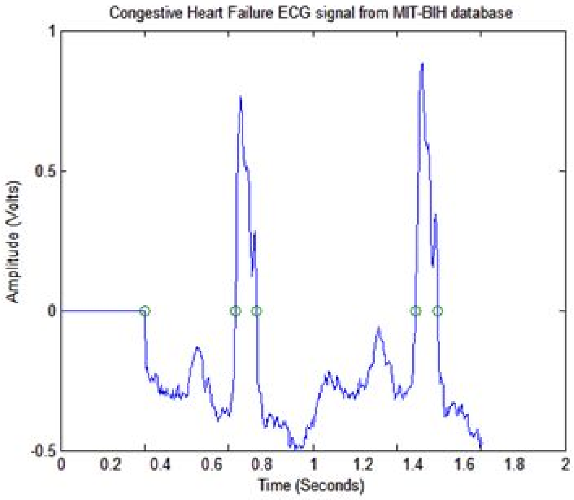


Figure (7): *Electrocardiogram waveform diagnosed with Congestive Heart Failure acquired using the monitoring system.*

4. Conclusions and Recommendations:

The integration of the ECG waveform acquisition, analysis and diagnosis transmission via short message system into a single monitoring system has been implemented successfully. However, in using the developed ECG monitoring system samples cannot be taken real-time, which means that the developed system requires recording of ECG signal prior to diagnosis processing and notification. Therefore, automating the data acquisition can be a possible future work.

The ECG waveforms processed by the developed ECG monitoring system were recognized as Normal Sinus Rhythm, Arrythmia, Atrial Fibrillation, Ventricular Tachyarryhmia or Congestive Heart Failure. However for some test repetitions, the zero crossing algorithm was unable to accurately determine the duration of the waves. Thus, the distortion of the ECG waveform makes the analysis using zero crossings unreliable. With this, it is recommended to make use of additional algorithms such as the curve tracing algorithm to improve the analysis. Furthermore, additional filtering and corrections of heavily distorted P and T signals can be implemented in a future work to reduce the mismatch between the time interval and the wave segment amplitudes.

Since ECG waveforms are extremely low-amplitude, low-frequency signals, they are very susceptible to motion artifacts. Therefore, sensitivity of the monitoring device must be improved so that a precise DC offset value can be obtained.

The modified program worked. However, since one diagnosis required sending four separate text messages, it is recommended to use Protocol Data Unit (PDU) mode of the mobile phone for it to be able to send the entire diagnosis details in a single message.

Acknowledgment:

We would like to express our sincerest gratitude to R.A. Acierto, A. Bautista, A. Larroder, Z.G. Orosco and J.M. Rocamora for manuscript proofreading and suggestions. One of the authors would like to acknowledge the research funding support from the University of Tokyo and the Ajinomoto Scholarship Foundation.

References:

[1] Kumar, A. "ECG-simplified." LifeHugger. (2010).

[2] Turnipseed, Samuel D., et al. "Electrocardiogram differentiation of benign early repolarization versus acute myocardial infarction by emergency physicians and cardiologists." Academic emergency medicine 13.9 (2006): 961-966.

[3] Aehlert, Barbara J. “ECGs made easy.” Elsevier Health Sciences, 2015.

[4] Stedman, Thomas Lathrop, ed. The American heritage Stedman's medical dictionary. Houghton Mifflin, 2004.

[5] Raya, Mary Anne D., and Luis G. Sison. "Adaptive noise cancelling of motion artifact in stress ECG signals using accelerometer." Engineering in Medicine and Biology, 2002. 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society EMBS/BMES Conference, 2002. Proceedings of the Second Joint. Vol. 2. IEEE, 2002.

[6] Almeida, M. S., et al. “Acquisition, Analysis and Monitoring of Electrocardiogram Waveforms.” unpublished.

[7] Chang, Kang-Ming. "Arrhythmia ECG noise reduction by ensemble empirical mode decomposition." Sensors 10.6 (2010): 6063-6080.

[8] Kumar, Yatindra, and Gorav Kumar Malik. "Performance analysis of different filters for power line interface reduction in ECG signal." International Journal of Computer Applications 3.7 (2010): 1-6.

[9] Mark, R., and G. Moody. "MIT-BIH arrhythmia database directory." Cambridge: Massachusetts Institute of Technology (1988).

[10] Vahed, Anwar. "3-Lead Wireless ECG." Available online: http://www.open-ecg-project.org/tiki-index.php?page=3-Lead+Wireless+ECG (2005).

[11] Goldberger, Emanuel. "The validity of the Einthoven triangle hypothesis." American Heart Journal 29.3 (1945): 369-377.

[12] Barill, T. "An ECG Primer." Nursecom Educational Technologies. (2003).

[13] “ECG interpretation: An incredibly easy pocket guide.” Lippincott Williams & Wilkins, 2005.

[14] eGizmo Technical Blog. “Project: Bio Amplifier. http://e-gizmo.blogspot.jp/search?q=ad202. Posted 20 March 2013.

[15] Almazan, S. P., et al. "Monolithic CMOS Current-Mode Instrumentation Amplifiers for ECG Signals." 13th International Conference on Biomedical Engineering. Springer Berlin Heidelberg, 2009.

[16] Bronzino, Joseph D. Biomedical engineering handbook. Vol. 2. CRC press, 1999.

[17] Provaznik, Ivo. Adaptive systems in ECG processing. Diss. Ph. D Dissertation, Technical University of Brno, Czechoslovakia, 1995.