

ECG Simulation using Fourier Series: From Personal Computers to Mobile Devices

Sami M. Halawani, Sarudin Kari

Faculty of Computing and Information Technology
King Abdulaziz University
Rabigh 21911, Kingdom of Saudi Arabia
dr.halawani@gmail.com, sarudin.kari@yahoo.com

Ibrahim AlBidewi, Ab Rahman Ahmad

Faculty of Computing and Information Technology
King Abdulaziz University
Jeddah 22254, Kingdom of Saudi Arabia
ialbidewi@kau.edu.sa, hayinsuh@yahoo.com

Abstract—An electrocardiogram (ECG) signal is a test to measure the electrical activities of the heart by applying electrical impulses. This paper proposed a remote ECG simulation to assisting vital signs in healthcare, namely ECG Simulation using *Fourier Series* approximation. A single period of an ECG signal that contains *P*, *Q*, *R*, *S*, *T* and *U* waves is in sinusoidal/triangular shapes, periodic and satisfies Dirichlet's conditions. *Periodic Fourier Series* also satisfies the condition and is expressed in terms of sine and cosine functions, thus *Fourier Series* is used to represent the ECG signal. All waves in the ECG signal are analyzed in choosing suitable representation of the shape. The combination of all waves which yields the ECG signal is calculated and programmed in *Microsoft Visual Basic 2008 (MSVB2008)*. The results obtained could be run remotely on mobile devices using *Microsoft Remote Desktop*. Further details of results might be improved by proper consultations from medical practitioners.

Keywords- ECG, Fourier Series, Microsoft Remote Desktop, Mobile Device, MSVB2008

I. INTRODUCTION

The heart is an internal organ that beats in rhythm to pump the blood through the body. The heart diseases have become more frequent and fatal to the population. Though having a heart disease, it does not mean a patient is unhealthy to perform other activities. Due to bulky monitoring equipment in size, however, a patient is tied to a bed or chair in order to monitor continuously and as a result the patient has limited mobility. Besides, it will cost more in monitoring every potential patient's heart without reducing the size and power consumption. By reducing the monitoring system size, this will provide better mobility that is necessary for many potential patients.

The *Electrocardiogram (ECG)* is widely used to monitor a patient's heart condition. It was put to clinical use in 1913 with Einthoven's invention [1] of the string galvanometer. Einthoven's recording (triangle) is known as the "three lead" ECG with measurements taken from three points on the body, as shown in Figure 1. The difference between potential readings from point 1 and point 2 is used to produce the ECG output. The point 3 connection is needed to establish a common ground for the body and the recording device. It is a non-invasive diagnostic tool to measure electrical signals of the heart. The study of these signals could help in determining abnormalities related to the heart's function. Figure 2 shows the ECG waves [2] which are labeled in order as *P* wave, *Q* wave, followed by the *QRS* complex *S* wave, *ST* segment, *T* wave and *U* wave. A point to be noted that is not every *QRS* complex contains a *Q* wave, an *R* wave, and an *S* wave. By convention, any combination of these waves can be referred to as a *QRS* complex.

There are new technologies developed for the diagnostic evaluation of patients with cardiovascular diseases [2], however, ECG retains its central role. It is the most important test for interpreting cardiac rhythms, conduction system abnormalities, and for detecting myocardial ischemia. The

ECG is of great value in evaluating other types of cardiac abnormalities such as valvular heart disease, cardiomyopathy, pericarditis, and hypertensive disease. It is also can be used to monitor drug treatment (antiarrhythmic therapy) and to detect metabolic disturbances.

EINTHOVEN'S TRIANGLE

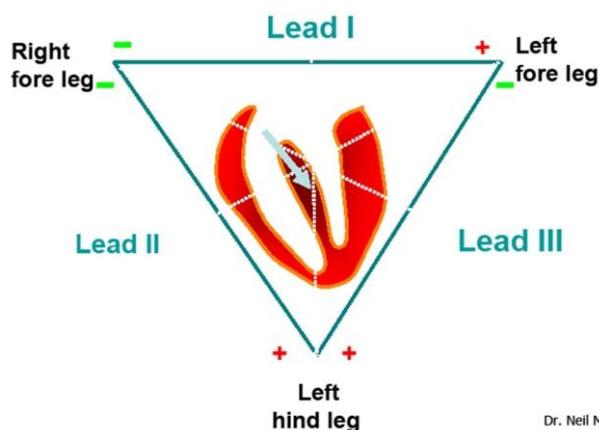


Figure 1. The Einthoven's "three lead" ECG.

The design and development of a new integrated device in [3] is for measuring heart rate using fingertip to improve estimating the heart rate. The proposed *Heart Rate Measuring (HRM)* device is economical and user friendly and uses optical technology to detect the flow of blood through index finger. Three phases involve to detect pulses on the fingertip are pulse detection, signal extraction, and pulse amplification. Qualitative and quantitative performance evaluations of the device on real signals have shown accuracy in heart rate estimation, even under intense of physical activity. The performance of HRM device is compared with ECG reports and manual pulse measurement of heartbeat of 90 human

subjects of different ages. The results showed that the error rate of the device is negligible.

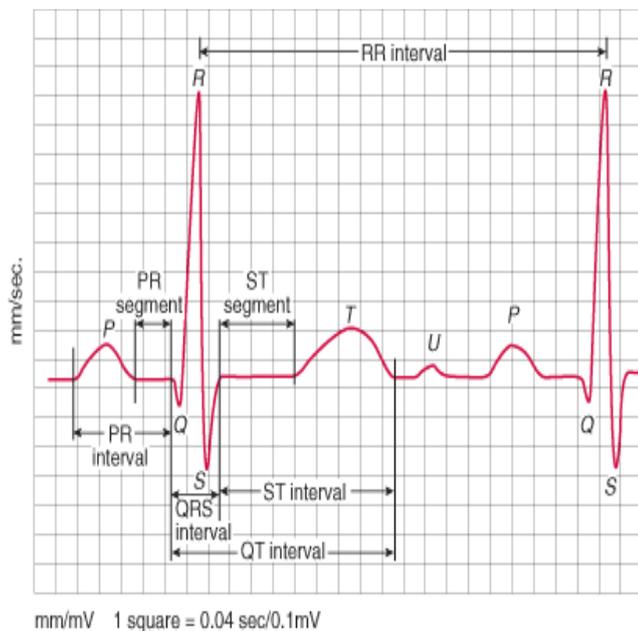


Figure 2. A sample of ECG waveform

A method [4] of heart beat modeling and ECG simulation is for constructing an electromechanical heart model. The cardiac excitation propagation was simulated by electrical heart model, and the resulted cardiac active forces were used to calculate the ventricular wall motion based on a mechanical heart model. Thus the source-field point relative position changes during cardiac systole and diastole can be obtained, and are employed to calculate body surface ECG based on the electrical heart-torso model. The results showed that compared with simulated ECG based on the static electrical heart model the simulated ECG based on beating heart model is more accordant with clinical recorded ECG.

The research [5] discussed the design and development of Digital Signal Controller based ECG simulator intended to use in testing, calibration and maintenance of ECG equipment, and to support biomedical engineering students' education. It generates all 12 healthy ECG derivation signals having a profile that varies with heart rate, amplitude, and different noise contamination in a manner which reflects true *in vivo* conditions. The heart rate can be set in the range from 30 to 120 beats per minute in four steps. The noise and power line interference effects can be set at the range of 0 to 20 dB in three steps. Since standard commercially available electronic components were used to construct the prototype simulator, the proposed design was also relatively inexpensive to produce.

The specialized measuring system [6] for ECG signal recording and introductory recognition is presented. The project aims at designing the complete PC-based Virtual Instrument as a "testing platform" for acquisition, processing, presenting, and distributing ECG data. A new design involving the latest technique in signal simulation was developed to create a controllable model of the ECG signal. The processing stage involving discrete wavelet transform is used to detect QRS complexes in the ECG signal, based on the time-

frequency analysis method. By using the controlled signal model and the real ones, the algorithm was shown to be advantageous in reducing ventilation artifacts and motion noise, resulting in good accuracy.

The study [7] emphasizes on an ECG simulator based on MATLAB Web Figure called WebECG, designed and implemented to facilitate the education on ECG signals. Advanced flexibility and good visualization capabilities including 3-dimension view, zoom and move on ECG graphics are provided by WebECG. The users are able to plot ECG signals with different parameters, to plot the ECGs of nine arrhythmia types. Furthermore, WebECG is capable to add three different noises to ECG and to plot and analyze long-term ECGs. These properties of the WebECG support efficient web-based education of ECG signals.

Healthcare is one of the most important social issues in the next few decades. As demographics shift and average life-span increases, a larger percentage of elderly will require medical care. Although the development of the traditional hospitals and health centers can alleviate these healthcare problems, the increasing users still cannot be effectively and efficiently served. The availability of pervasive computing technologies can provide more promising solutions to the personal healthcare in a low cost manner. As mobile devices are now getting more powerful, less power consumption and many added features, these can be optimized to build a complete ECG solution. It provides the option that could be easily connected to a personal computer or server for remote monitoring.

II. MATERIALS AND METHODS

A. The Heart Rate

The heart rate [8] is the speed of the heartbeat (the number of heartbeats per unit time) and typically expressed as beats per minute (*bpm*). The normal human heart rate ranges from 60–100 *bpm*. The heart rate can vary according to the body's physical needs, including the need to absorb oxygen and release carbon dioxide. Activities such as physical exercise, sleep, anxiety, stress, illness, ingesting, and drugs may provoke the changes in heartbeat. The interpretation is given in Table 1.

TABLE I. THE HEART RATE INTERPRETATION

The Heart Rate (BPM)	The heart rate classification		
	< 60 beats/min	60 – 100 beats/min	> 100 beats/min
Interpretation	Bradycardia	Normal	Tachycardia

In the context of adult, the resting heart rate [9,10] of under 60 *bpm* is called Bradycardia and it may drops below 50 *bpm*. It sometimes results in fatigue, weakness, dizziness, and at very low rates fainting. During sleep, a slow heartbeat with rates around 40–50 *bpm* is common and is considered normal. The absolute Bradycardia is a waking heart rate below 40 *bpm*. Tachycardia [11] is a heart rate that exceeds the normal range which is in general a resting heart rate over 100 *bpm*. Tachycardia can be caused by various factors that often are not malignant. Depending on the speed and type of rhythm, however, tachycardia can be dangerous. Tachycardia in pathology term is more correctly defined as tachyarrhythmia.

B. The ECG Wave

The ECG [2,12] as in Figure 2 is a graphical representation – time versus amplitude – of electrical vector projection of the electrical activity of the heart. It picks up electrical impulses generated by the polarization and depolarization of cardiac tissue and translates into a waveform. The waveform is then used to measure the rate and regularity of heartbeats. A normal ECG consists of several different waveforms that represent electrical events during each cardiac cycle in various parts of the heart. The event of each normal cardiac cycle is represented in sequence by the *P* wave, the *PR* interval, the *QRS* complex, the *ST* segment, the *T* wave, and sometimes the *U* wave.

The ECG waves [2] are recorded on special 1 mm² grid-like squares paper as shown in Figure 3. With the paper speed at typical 25 mm/sec, each 1 mm horizontal squares corresponds to 0.04 second. The thicker lines form larger squares that include five small squares and represent 0.20 sec intervals. A better define waveforms is attained when the paper speed is increased to 50 mm/sec where there are only six leads per sheet of paper.

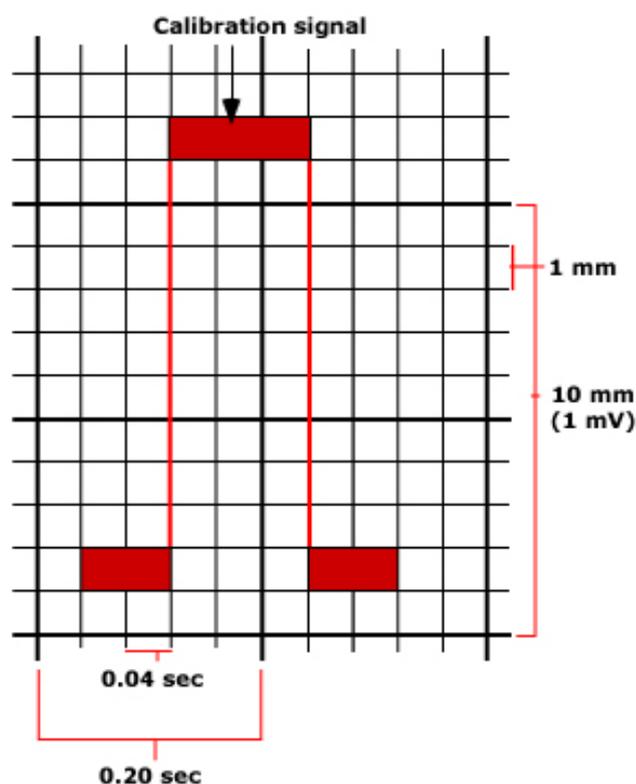


Figure 3. ECG grid lines and standardization

By this speed [2], each large and small square represents 0.10 sec and 0.02 sec respectively. In addition, the heart rate would be one-half of what is recorded at 25 mm/sec paper speed and all intervals are doubled the normal ECG. The ECG graph measures the height (amplitude) of a given wave with standard calibration as 10 mm (1mV). For others, double standard (2 mV) for small waves and for very large waves at half standard (0.5 mV).

The details of wave portions are given as follows:

- The ***P* wave** is the first positive deflection on the ECG and it represents atrial depolarization. The duration is generally less than 0.12 sec and the amplitude less than 0.25 mV. PR interval includes the *P* wave as well as the *PR* segment. It is measured from the beginning of the *P* wave to the first part of the *QRS* complex (*Q* wave or *R* wave). The length of the *PR* interval [2] changes with heart rate, but is normally 0.12 to 0.20 sec. The *PR* interval is shorter at faster heart rates (sinus tachycardia) which are due to sympathetic enhancement tone of atrio-ventricular nodal conduction. It is longer when the rate slows down as a consequence of slower AV nodal conduction resulting from withdrawal of the tones. The normal sinus *P* wave when present shows a morphology (smooth contour) and *PR* interval may suggest sinus, atrial, junctional or even retrograde from the ventricles. If *P* wave is absent then it might suggest a sinus arrest or atrial fibrillation.
- The ***QRS* complex** represents the time for ventricular depolarization and is the combination for three graphical deflections *Q*, *R*, and *S* waves seen on a typical ECG. These waves occur in rapid succession, reflect a single event and do not all appear in all leads, thus usually considered as one. A *Q* wave is a negative deflection after the *P* wave. An *R* wave follows as a positive deflection, and the *S* wave is a negative deflection after the *R* wave. An entirely negative *QRS* complex is called a *QS* wave. If the cardiac rhythm is regular, the interval between successive *QRS* complexes determined from the ECG grid can be used to determine heart rate. However, the entire *QRS* duration in adults which normally lasts for 0.06 to 0.12 seconds is not influenced by heart rate.
- The ***Q* wave** may be present or absent in a normal ECG. Small *Q* waves are often seen as a result of initial septal depolarization and are considered normal. The initial negative deflection represents the normal left-to-right depolarization of the inter-ventricular septum. For this reason, they are referred to as septal *Q* waves. Normal *Q* waves are defined as having deflection amplitude of 0.2 mV and duration at 0.04 sec. Pathologic *Q* waves occurs when the electrical signal passes through stunned myocardium and as such, they are usually markers of previous myocardial infarctions with subsequent fibrosis. It is defined as having a deflection more than normal amplitude (> 0.2 mV) and duration (> 0.04 sec) or more than 25% of *QRS* complex's depth. The *Q* waves are only significant if they are present and have larger amplitudes.
- The first positive deflection of the *QRS* complex is called the ***R* wave**. It represents the left ventricular myocardium since its mass is much greater than the right ventricle. The negative deflection following the *R* wave is the *S* wave which represents terminal depolarization of the high lateral wall. The *R* wave should progress in size across the pre-cordial leads. Normally the *R* wave is small. However, due to more left ventricular forces, the *R* wave amplitude grows to reach its greatest amplitude. The increase in *R* wave's amplitude while *S* wave becomes smaller in the pre-cordial chest leads is called *R* wave progression. Usually when the *R* wave is disturbed, there are also unusual reciprocal changes in the *S* wave.

- The **J point** is the point between the termination of the *QRS* complex and the beginning of the *ST* segment. It is easy to identify when the *ST* segment is horizontal and forms a sharp angle with the last part of the *QRS* complex. However, when the *ST* segment is inclined or the *QRS* complex is longer, they do not form a sharp angle and the location of the *J*-point is less clear. In these circumstances, there is no clear agreement on the precise location of the *J*-point. However, it can be defined as the first point of inflection of the upstroke of the *S* wave or the point at which the *ECG* trace becomes more horizontal than vertical.
- The **S wave** is the first negative deflection [13] of the *QRS* complex that occurs after the *R* wave. An *S* wave may not be present and its presence or absence does not have major clinical significance. The morphology of the *S* wave is examined to determine if ventricular tachycardia or supraventricular tachycardia with aberrancy is present. In some normal cases such as sinus tachycardia, the *J* point is depressed and the *ST* segment is rapidly positive within 0.08 seconds after the end of the *QRS* complex.
- The **T wave** is the positive deflection after the *QRS* complex and follows the *S* wave. It represents the period of ventricular repolarization. Since the rate of repolarization is slower than depolarization, this wave is wide with slow upward and rapid downward movements. This makes the *T* wave asymmetric and the amplitude varies [9]. The *T* wave is usually smooth up and down. The variations in the atrial *ST* segment and *T* wave may occur with other pathologies, such as atrial infarction or atrial tumor invasion. The *T* wave vector on the *ECG* [13] normally is in the same direction as the major deflection of the *QRS*. This means that the *QRS* and *T* wave axes are generally harmonious.
- The **QT interval** consists of the *QRS* complex, the *ST* segment and *T* wave. The *QT* interval [13] is primarily a measure of ventricular repolarization and used in most clinical situations. The increment in *QRS* complex duration may cause an increase in the *QT* interval but this does not reflect a change in ventricular repolarization. A widened *QRS* must be considered if a prolonged *QT* interval is being evaluated. The time for ventricular repolarization is dependent upon the heart rate; it is shorter at faster heart rates and longer when the rate is slower. Thus, the *QT* interval has to be corrected for heart rate based on Bazett's formula [13]. This is simple; however it is inaccurate at heart rate extremes and results in over-correcting at high rates and under-correcting at low ones. Other approaches to correct the *QT* interval yield the normal value for the $QT_c \leq 0.44$ sec for men and ≤ 0.46 sec for women.
- A **U wave** follows the *T* wave. The exact cause [13] is uncertain, though it has been suggested that it represents repolarization. The amplitude of the *U* wave is typically less than 0.2 mV and is clearly separated from the *T* wave such as in hypokalemia and bradycardia. The *U* wave may merge with the *T* wave when the *QT* interval is prolonged or may become very obvious when the *QT* interval is shortened (hypercalcemia).

The *ECG* values [14] can be tabulated as in Table 2.

TABLE II. THE *ECG* WAVES VALUES

Details	The waves / segment					
	<i>P</i>	<i>Q</i>	<i>QRS</i>	<i>S</i>	<i>T</i>	<i>U</i>
Amp (mV)	≤ 0.25	≥ 0.2	1.6	0.025	0.35	0.025
Dur (sec)	≤ 0.12	≥ 0.04	0.06–0.12	0.066	0.142	0.048
Interval	0.12–0.20	0.166	-	0.08	0.2	0.433

C. The Fourier Series and *ECG* waves representation

A periodic Fourier Series involve sine and cosine functions and is obtained by taking $f_1(x) = \cos x$ and $f_2(x) = \sin x$. A general Fourier Series for any integrable function $f(x)$ over an interval $[-L, L]$ is given by

$$f(x) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty} a_n \cos\left(\frac{n\pi x}{L}\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{n\pi x}{L}\right) \quad (1)$$

where

$$a_0 = \frac{1}{L} \int_{-L}^L f(x) dx \quad (2)$$

$$a_n = \frac{1}{L} \int_{-L}^L f(x) \cos\left(\frac{n\pi x}{L}\right) dx \quad (3)$$

$$b_n = \frac{1}{L} \int_{-L}^L f(x) \sin\left(\frac{n\pi x}{L}\right) dx \quad (4)$$

and $n = 1, 2, 3, \dots$

Generally, any periodic functions which satisfy Dirichlet's condition can be expressed as a series of scaled magnitudes in terms of sine and cosine frequencies which occur as a multiple of fundamental frequency. An *ECG* signal is periodic with its fundamental frequencies determined by the heartbeat and it satisfies Dirichlet's conditions where it has single value, a finite number of maxima/minima between finite intervals and finite number of discontinuities. It is also finite in a given interval and integrable. A single period of an *ECG* signal as shown in Figure 2 is a kind mixture of sinusoidal and triangular wave forms. *P*, *T* and *U* wave's portion are in sinusoidal form and these might be represented by sine or cosine functions. For *Q*, *QRS* segment and *S* waves, these portions could be represented in the form triangular wave. Once each of these portions is generated, these waves can be added to get the final *ECG* signal.

Let L , a and b are the *ECG* interval (heart rate), amplitude and duration for each portion of the wave. These approximations can be performed as follows:

- **The sinusoidal waves – P, T and U.** Figure 4 shows the representation for *P*, *T* and *U* portions in terms of a , b and L .

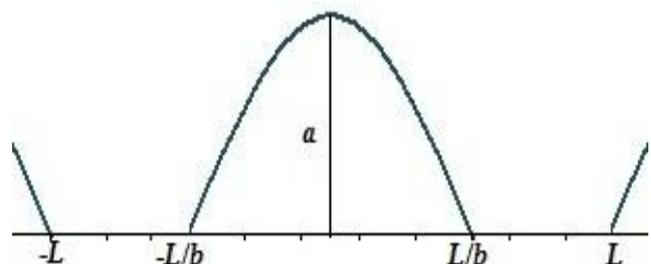


Figure 4. The sinusoidal waves – *P*, *T* and *U*.

The computations for the coefficients as in Eqn. 2 to Eqn. 4 are as follows. From Figure 2, the function is

$$f(x) = \cos\left(\frac{b\pi x}{2L}\right),$$

then using [15]

$$a_0 = \frac{1}{L} \int_{-L/b}^{L/b} \cos\left(\frac{b\pi x}{2L}\right) dx = \frac{4}{b\pi} \quad (5)$$

$$a_n = \frac{1}{L} \int_{-L/b}^{L/b} \cos\left(\frac{b\pi x}{2L}\right) \cos\left(\frac{n\pi x}{L}\right) dx$$

$$= \frac{4b}{(b-2n)(b+2n)\pi} \cos\left(\frac{n\pi}{b}\right) \quad (6)$$

$$b_n = 0, \text{ as this is an even function} \quad (7)$$

Hence

$$f(x) = \frac{2}{b\pi} + \sum_{n=1}^{\infty} \frac{4b}{(b-2n)(b+2n)\pi} \cos\left(\frac{n\pi}{b}\right) \cos\left(\frac{n\pi x}{L}\right),$$

$$n = 1, 2, 3, \dots \quad (8)$$

- **The triangular waveforms – Q, QRS segment and S:**
 The function $f(x)$ that can be derived from Figure 5 is as follows:

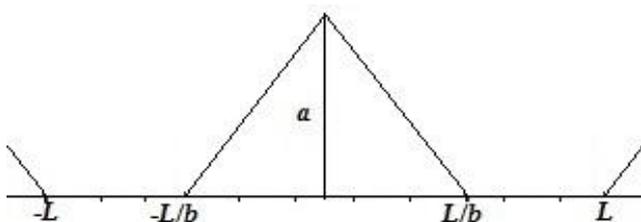


Figure 5. The triangular waveforms – Q, QRS segment and S.

$$\frac{f(x)-a}{x-0} = \frac{a-0}{0+L/b} \rightarrow f(x) = \frac{abx}{L} + a, -\frac{L}{b} < x < 0$$

and

$$\frac{f(x)-a}{x-0} = \frac{a-0}{0-L/b} \rightarrow f(x) = -\frac{abx}{L} + a, 0 < x < \frac{L}{b}$$

which can be written as

$$f(x) = \begin{cases} \frac{abx}{L} + a, & -\frac{L}{b} < x < 0 \\ -\frac{abx}{L} + a, & 0 < x < \frac{L}{b} \end{cases} \quad (9)$$

Now, using [15] and $f(x)$ in Eqn. 9

$$a_0 = \frac{1}{L} \int_{-L/b}^{L/b} f(x) dx$$

$$= \frac{1}{L} \int_{-L/b}^0 \left(\frac{abx}{L} + a\right) dx + \frac{1}{L} \int_0^{L/b} \left(-\frac{abx}{L} + a\right) dx \quad (10)$$

$$= \frac{a}{b}$$

$$a_n = \frac{1}{L} \int_{-L/b}^{L/b} f(x) dx$$

$$= \frac{1}{L} \int_{-L/b}^0 \left(\frac{abx}{L} + a\right) \cos\left(\frac{n\pi x}{L}\right) dx$$

$$+ \frac{1}{L} \int_0^{L/b} \left(-\frac{abx}{L} + a\right) \cos\left(\frac{n\pi x}{L}\right) dx \quad (11)$$

$$= \frac{2ab}{(n\pi)^2} \left[1 - \cos\left(\frac{n\pi}{b}\right)\right], n = 1, 2, 3, \dots$$

$$b_n = 0, \text{ as this is an even function} \quad (12)$$

Hence

$$f(x) = \frac{a}{2b} + \sum_{n=1}^{\infty} \frac{2ab}{(n\pi)^2} \left[1 - \cos\left(\frac{n\pi}{b}\right)\right] \cos\left(\frac{n\pi x}{L}\right),$$

$$n = 1, 2, 3, \dots \quad (13)$$

All portions depend on its amplitude, duration and interval as shown in Table 2. The QRS segment is calculated using Eqn. 13, however, due to some similarities the others could be grouped as follows.

P, T and U waves:

$$af(x) = a \left(\frac{2}{b\pi} + \sum_{n=1}^{\infty} \frac{4b}{(b-2n)(b+2n)\pi} \cos\left(\frac{n\pi}{b}\right) \cos\left(\frac{n\pi x}{L}\right) \right)$$

$$, n = 1, 2, 3, \dots \quad (14)$$

Q and S waves (negative gradient):

$$-f(x) = - \left[\frac{a}{2b} + \sum_{n=1}^{\infty} \frac{2ab}{(n\pi)^2} \left[1 - \cos\left(\frac{n\pi}{b}\right)\right] \cos\left(\frac{n\pi x}{L}\right) \right],$$

$$n = 1, 2, 3, \dots \quad (15)$$

The ECG wave is obtained by adding all values from Eqn. 13 to Eqn. 15.

D. The Flow diagrams

Figure 6 to Figure 8 are the ECG simulation flow diagrams to be used in the programming part. These diagrams involve the computation for all waves segments using Eqn. 13 to Eqn. 15.

E. Remote Desktop Connection

This paper is focused for accessing the ECG Simulation remotely using Remote Desktop Connection (RDC). RDC connects two computers, for example home PC and office PC or a computer and an android over a network or the Internet. With RDC, Windows can be run on another computer or an android. This feature is almost included with all editions of Windows 7 – Professional, Ultimate, or Enterprise editions. Once connected, the remote computer's desktop appears on these devices and all applications, files; programs and network resources are accessible remotely.

There are some nice mobile applications that allow the connection between a mobile device and a remote PC. Microsoft's Remote Desktop (MSRD) client for mobiles is one of them and besides free, it doesn't require an agent installation on a PC prior to use it. The overall architecture for the remote connection is as given in Figure 9 using MSRD.

The following steps are the connection setup for a remote PC and a mobile device.

The setup for remote PC

1. Create an account and a password for a remote desktop.
2. Click **Start**, then right click **Computer** and click **properties**.
3. Click **change Settings**, Figure 10 appears.
4. Click **Remote**, and choose the appropriate button to allow connection.
5. Click **Select Users**.
6. Click **Add** and the account name could be entered manually or click Advances to locate it.
7. Click **OK** to close all the pop-up windows and computer properties.

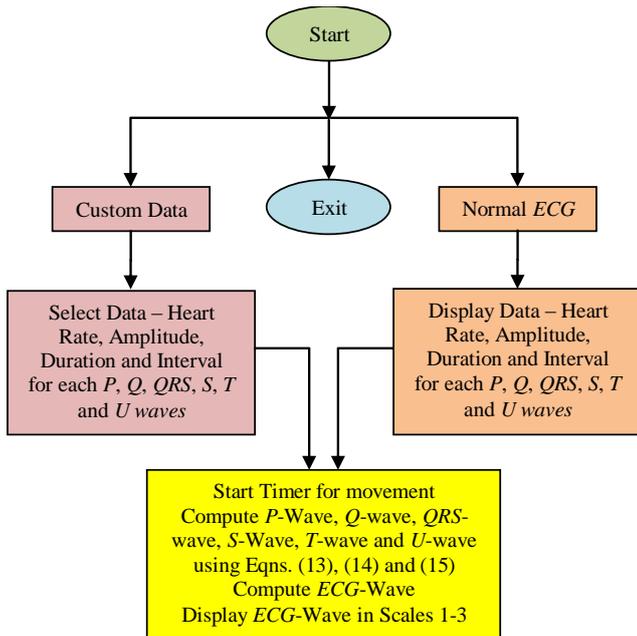


Figure 6. The ECG simulation flow diagram.

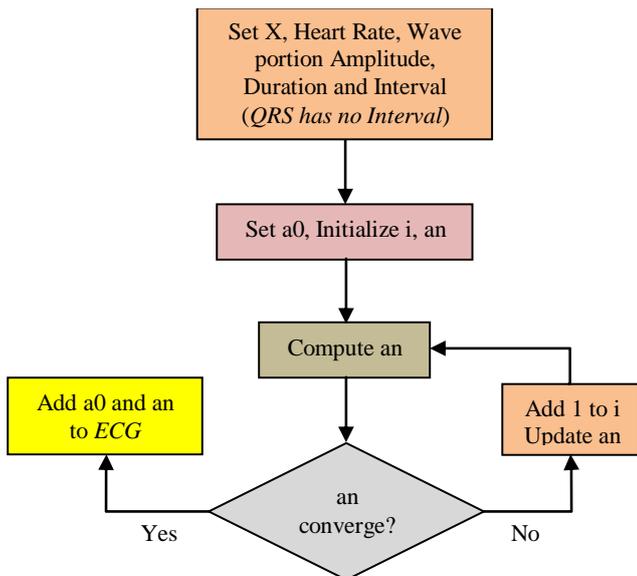


Figure 7. The flow diagram for wave portion computation.

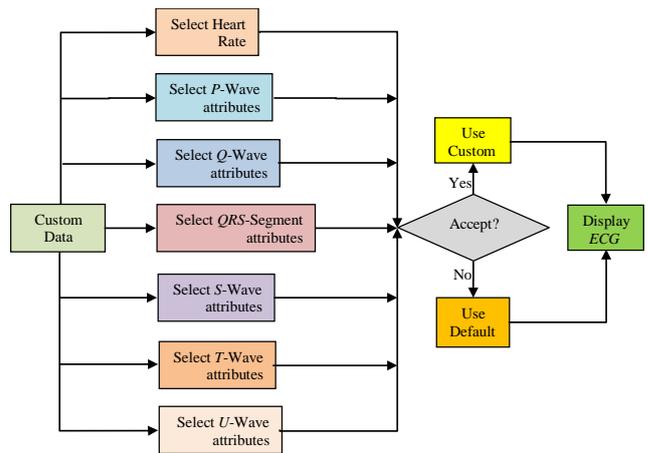


Figure 8. The flow diagram for selecting custom data.

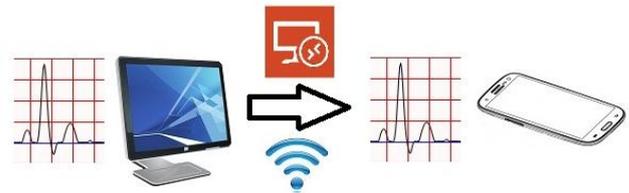


Figure 9. The Architecture of ECG Simulation Remote Desktop Connection.

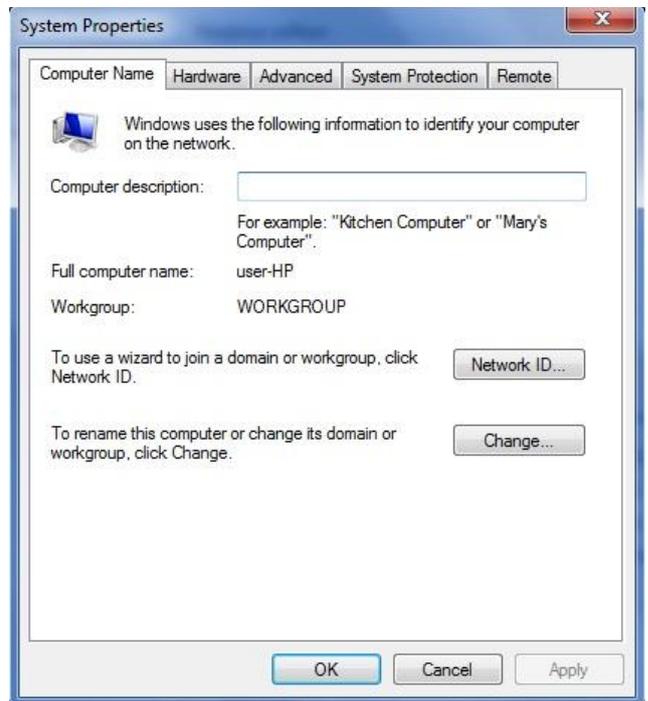


Figure 10. System Properties.

The setup mobile device connection

1. Download the Remote Desktop Client (RDC) from the mobile application.
2. On the Connection Center screen, tap **Remote Desktops**, Figure 11 appears.

3. Tap the add (+) icon, Figure 12 appears.
4. Enter Connection name. ECG Simulation.
5. Enter PC name: it is the IP address.
6. Enter Credentials: The user name: *MyECG* and password used for the remote *PC*.

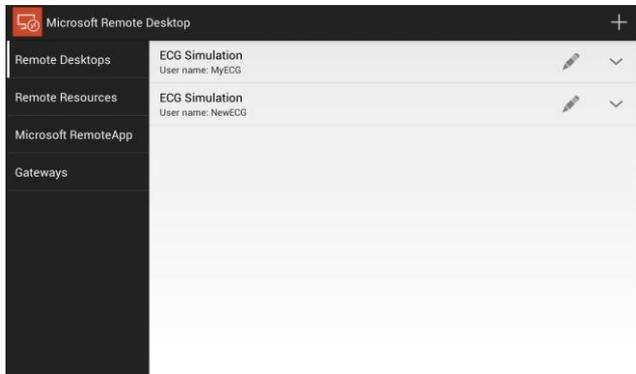


Figure 11. Microsoft Remote Desktop.

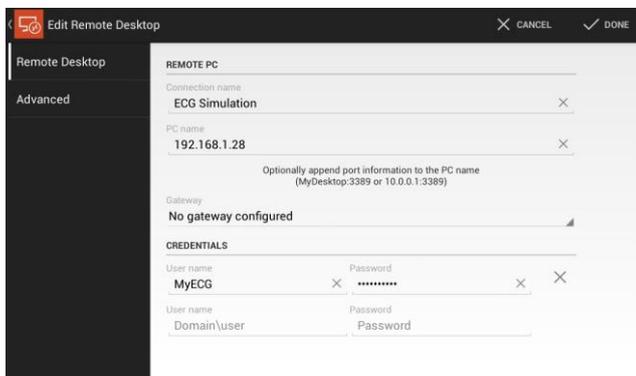


Figure 12. Information required for RDC.

III. RESULTS AND DISCUSSION

A. The Source codes

Figure 13 to Figure 18 are part of the source codes in *MSVB2008* developed for *ECG Simulation* based on Eqns. 13 to 15 and the flow diagrams in Figure 6 to Figure 8. Figure 14 and Figure 15 adapted from [16] produced an *ECG-like* cycle and movement.

```
Private Sub Compute_SetPath_Plot(ByVal d As Double)
    Dim xval, hght As Single
    If MyDot IsNot Nothing Then
        MyDot.Dispose()
        MyDot = Nothing
    End If
    MyDot = New Bitmap(Me.ClientSize.Width, Me.ClientSize.Height)
    hght = Me.ClientSize.Height
    Dim gPath As New GraphicsPath()
    Dim pts As New List(Of PointF)()
    xval = 0.45
    For x As Integer = -3000 To 3000
        ecg = 0.0
        FTUwave(xval, AFwav, DPwav, IPwav, HRate)
        QSwave(xval, AQwav, DQwav, IQwav, HRate)
        QRS_Segment(xval, AQRswav, DQRSwav, HRate)
        QSwave(xval, ASwav, DSwav, -ISwav, HRate)
        FTUwave(xval, ATwav, DTwav, -(TIwav + 0.045), HRate)
        FTUwave(xval, AUwav, DUwav, -TUwav, HRate)
        pts.Add(New PointF(MyScale * x + d, CSng(ecg * MyScale * hght / 9 + 1)))
        xval += 0.01
    Next
    gPath.AddLines(pts.ToArray())
    PlotECG(MyDot, gPath)
    gPath.Dispose()
End Sub
```

Figure 13. Compute *ECG Simulation*.

```
Private Sub PlotECG(ByVal bmp As Bitmap, ByVal gPath As GraphicsPath)
    Using gECG As Graphics = Graphics.FromImage(bmp)
        gECG.Transform = New Matrix(1, 0, 0, -1, bmp.Width / 2, bmp.Height / 2)
        Dim i As Integer = 0
        While i < bmp.Width / 2
            gECG.DrawLine(Pens.Red, New Point(i, -bmp.Height / 2), New Point(i, bmp.Height / 2))
            i += magnifier
        End While
        i = 0
        While i < bmp.Height / 2
            gECG.DrawLine(Pens.Red, New Point(-bmp.Width / 2, i), New Point(bmp.Width / 2, i))
            i += magnifier
        End While
        i = magnifier
        While i > -bmp.Width / 2
            gECG.DrawLine(Pens.Red, New Point(i, -bmp.Height / 2), New Point(i, bmp.Height / 2))
            i -= magnifier
        End While
        i = magnifier
        While i > -bmp.Height / 2
            gECG.DrawLine(Pens.Red, New Point(-bmp.Width / 2, i), New Point(bmp.Width / 2, i))
            i -= magnifier
        End While
        gECG.DrawLine(Pens.Blue, New Point(0, -bmp.Height / 2), New Point(0, bmp.Height / 2))
        gECG.DrawLine(Pens.Blue, New Point(-bmp.Width / 2, 0), New Point(bmp.Width / 2, 0))
        gECG.SmoothingMode = SmoothingMode.AntiAlias
        gECG.DrawPath(Pens.Black, gPath)
    End Using
End Sub
```

Figure 14. Plot *ECG Simulation*.

```
Private Sub btnStart_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
    Me.DoubleBuffered = True
    Me.tmrECG.Start()
    MyScale = Int(Rnd() * 3) + 1
    btnStart.Text = Str(Trim(MyScale)) + "X"
    gbXintro.Visible = False
    gbXECGData.Visible = True
    ShowECGValues()
End Sub

Private Sub tmrECG_Tick(ByVal sender As System.Object, ByVal e As System.EventArgs)
    Me.tmrECG.Stop()
    MyDelay -= 5
    Compute_SetPath_Plot(MyDelay)
    Me.Invalidate()
    Me.tmrECG.Start()
End Sub
```

Figure 15. *ECG Simulation* movement.

```
Private Sub FTUwave(ByVal x As Single, ByVal WavAmp As Single, ByVal WavDur As Single)
    Dim i, a0, anOld, anNew, diff, coeff As Single
    a = WavAmp
    b = 2 * HRate / WavDur
    x = x + WavInt
    a0 = 2 / (b * pi)
    anOld = 0.0
    i = 1
    Do
        coeff = 4 * b * Math.Cos(i * pi / b) / ((b - 2 * i) * (b + 2 * i) * pi)
        anNew = anOld + coeff * Math.Cos(i * pi * x / HRate)
        diff = Math.Abs(anNew - anOld)
        anOld = anNew
        i += 1
    Loop Until (diff <= DigAcc)
    ecg += a * (a0 + anNew)
End Sub
```

Figure 16. *P, T and U* waves.

```
Private Sub QRS_Segment(ByVal x As Single, ByVal AQRswav As Single, ByVal DQRSwav As Single)
    Dim i, a0, anOld, anR, diff, coeff As Single
    a = AQRswav
    b = 2 * HRate / DQRSwav
    a0 = 0.5 * a / b
    anOld = 0.0
    i = 1
    Do
        coeff = 2 * a * b * (1 - Math.Cos(i * pi / b)) / (i * pi) ^ 2
        anR = anOld + coeff * Math.Cos(i * pi * x / HRate)
        diff = Math.Abs(anR - anOld)
        anOld = anR
        i += 1
    Loop Until (diff <= DigAcc)
    ecg += a0 + anR
End Sub
```

Figure 17. *Q and S* waves.

```
Private Sub QRS_Segment(ByVal x As Single, ByVal AQRswav As Single, ByVal DQRSwav As Single)
    Dim i, a0, anOld, anR, diff, coeff As Single
    a = AQRswav
    b = 2 * HRate / DQRSwav
    a0 = 0.5 * a / b
    anOld = 0.0
    i = 1
    Do
        coeff = 2 * a * b * (1 - Math.Cos(i * pi / b)) / (i * pi) ^ 2
        anR = anOld + coeff * Math.Cos(i * pi * x / HRate)
        diff = Math.Abs(anR - anOld)
        anOld = anR
        i += 1
    Loop Until (diff <= DigAcc)
    ecg += a0 + anR
End Sub
```

Figure 18. *QRS* segment.

B. The Outputs

The remote PC must be accessible by a mobile device via WiFi and MSRDL. Having clicked MSRDL application in the mobile device, the first two screenshots in the device from the remote PC appeared as shown in Figure 19 and Figure 20.

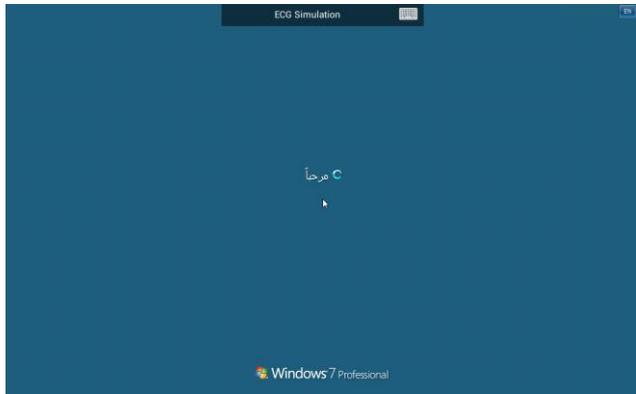


Figure 19. Welcome to Windows 7.

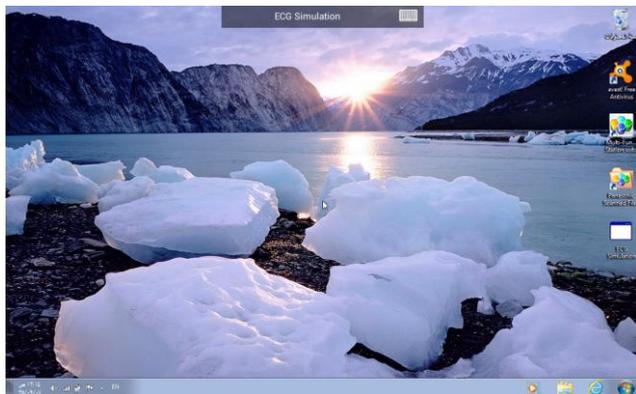


Figure 20. From remote desktop.

Upon executing ECG simulation application on the mobile device, a simple menu is shown as in Figure 21. The button "Show" displays the ECG movement (Figure 22) in scales 1 to 3 either by default or customized data. For more results, users can input values (Figure 23) derived from Table 2. Figure 24 and Figure 25 displays the respective ECG for the heart rate below 60–Bradycardia and above 100–Tachycardia.

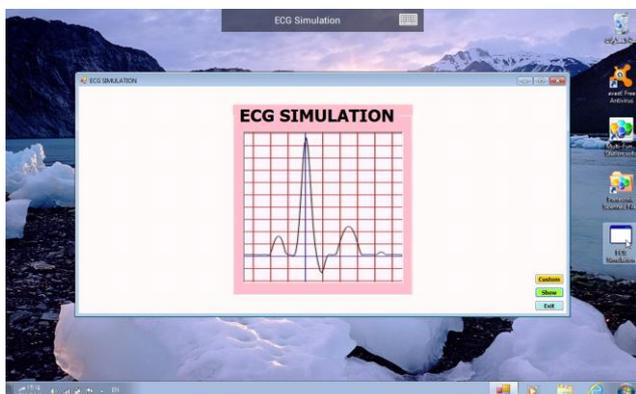


Figure 21. Introduction to ECG Simulation.



Figure 22. ECG signal – defaults with scale 2.

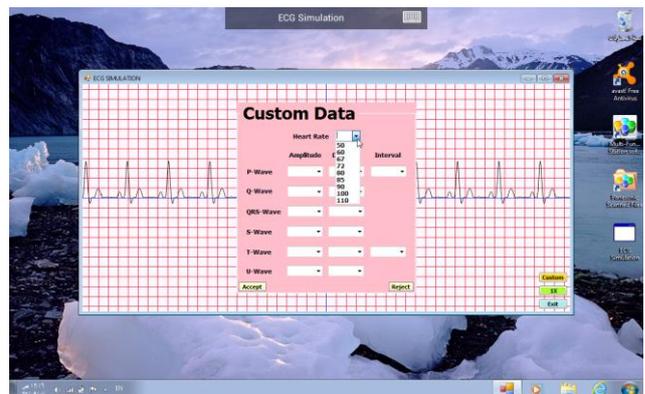


Figure 23. The user input.

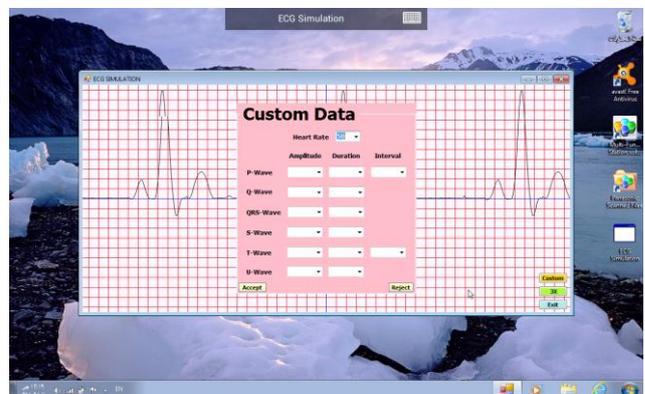


Figure 24. The heart rate < 60– Bradycardia,.



Figure 25. The heart rate > 100–Tachycardia,.

IV. CONCLUSIONS AND RECOMMENDATIONS

ECG Simulation is a kind of interactive simulation (an *ECG*-like movement) that enables anyone to observe the effect on the *ECG* pattern by selecting the preset values on the system. It may serve as an aide in basic aspects of *ECG* for any patient prior to seeking medical treatments. As it can be accessed remotely and in the presence of mobile devices, this can become a good companion for users.

The results have shown the outcomes for different heart rate and other values in the waves' portion; however, other hypotheses might be derived and included upon receiving some clear input from medical practitioners. As a research tool, this might also be useful to test any hypothesis they may have regarding the manifestation of cardiac malfunctioning in the *ECG* wave forms. This *ECG* Simulation only provides a simulation and some brief explanations. Further enhancement can be undertaken depending on the needs in the future.

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