# CARDIOSCOPE SIMULATOR SYSTEM

**Zenon Chaczko and Hany Shehata**

ICT Group,
Faculty of Engineering, University of Technology, Sydney, Australia

zenon.chaczko@uts.edu.au, Hany.E.Shehata@eng.uts.edu.au

**ABSTRACT**
There is a need for effective, reliable and economic diagnostic technique to detect heart problems at an early stage. This paper presents an innovative approach to the ECG diagnostic modeling that considers a representation of the Inverse problem in multi-dimensional space. Assumptions are made regarding the shape and values for the electrical sources inside the human heart in order to estimate the body surface electrical potentials. An analytical set of expressions used in the proposed diagnostic model combined with the effect of associated source parameters is discussed, analysed and verified. The paper introduces an innovative Inverse problem method for determining the inner heart electrical activity parameters. Results can be then visualized given availability of a stream of body surface potential data. WSN technology is to be applied for collecting and processing diagnostic data.

Keywords: ECG diagnostic model, cardioscope, simulation model

## 1. INTRODUCTION

The ECG is considered to be one of the oldest (Einthoven 1908), and most reliable techniques for detection of heart abnormalities. Inevitably, it is one of very few techniques that can also be used for construction of predictive diagnostic models of the electrical activity of the heart. The reliability of ECG method depends on two important factors:

1. Quality and accuracy of statistical data that allows accumulation and correction of ECG shapes with types of diseases causing it. The ECG involves recording electrical signals measured from human body and reflecting electrical activities of the heart. Also, the method can be used to calculate characteristic parameters of the heart from captured electrical signals at the human body.
2. Cardiologists' experience and diagnostic skills in analysing heart problems using ECG technique. The training of cardiologist takes time. There are recorded cases (and undoubtedly, there will be such cases in the future) which impose critical situations, where a doctor's indecision is intolerable as only a decision taken fast can save patient's life.

For the reasons stated above, the research studies of the heart functions should extensively stress the need for modeling, analysis and diagnosis of the heart problems taking not only predominantly medical but also an engineering point of view. Two complementary techniques that use mathematical apparatus in construction of electric models contribute to formulation of ECG solution. The first technique allows building an abstract model representing the system and then examines the effect of the assumed parameters. This technique of computing ECG is also known as the forward problem. The second technique, which is based on the forward problem, is termed the inverse problem. It stars from available body surface potential data and ends up with recognizable electrical activities that can help in diagnosing heart problems. In the literature, both techniques are equally well covered. In our study, the emphasis is on the inverse problem. Since both problems are complementary, it is necessary to include some analysis of the forward problem. The introductory part will provide a brief description of the electric activity of the heart including the internal sequences of excitation and an overview of the system used to measure the ECG. The analytical stage is divided into three sections: (1) a calculation model for measuring body surface potentials, (2) collection of readings from the chest leads connectors (as originally postulated by Einthoven) and (3) the image reconstruction of the heart dipole vector that can be used to study the nature of ECG waves for diagnostic purposes.

This paper presents an innovative and simplified approach to the ECG diagnostic modeling that considers the representation of the Inverse problem in multi-dimensional space (in this study 2D only). Firstly, an analytical set of expressions for the proposed simplified model is elaborated on, and then the effect of source parameters is verified and analysed. Finally, a new approach to solve the inverse problem itself is presented. The process of Fourier series analysis helps to extract information about the source parameters embedded in the surface potential data. These parameters help to determine the electrical source width angle in a real time.

The main aim is to provide an improved model for the human body for ECG purpose. The model is used to estimate the body surface electrical potential. Assuming a certain shape and value for the electrical source inside the human heart we calculate the body surface potential. The research also aims to introduce a method for determining the inner heart electrical activity parameters and displaying them given a stream of body surface potential data. Current development involves design and deployment of WSN technology for collecting and processing potential data.

## 2. GENERAL ASPECT OF ECG (ELECTROCARDIOGRAPHY)

Active tissue during activity produces electric currents in the body. So, the heart acts as an electric generator when it beats. The electrical state of the heart varies during the cardiac cycle. This variation takes the form of a wave of electronegative on the outer surface of myocardial member (i.e. depolarisation). These electrical changes are similar to those in skeletal muscles and can be recorded by a sensitive galvanometer. ECG is a record of the electrical changes in the heart during any cardiac cycle. In animals recording is done by putting electrodes directly on the heart surface. In human, blood and tissue fluids are relatively good conductor of electric current. So, human ECG is recorded by putting two electrodes on the skin. The particular arrangement of the two electrodes is called a lead.

### 2.1. Body Surface Potential And The Lead Theory

The conventional electrocardiogram is a time base record of the potential differences developed in one or more leads (a lead is a combination of at least two electrodes). It started by recording the potential differences between the left arm, right and the left leg which was described by Einthoven early in the nineteenth century. These were originally called the limb leads I, II and III. Each of them refers to the potential difference between one of the three points and the electric mid-point of the other two points. Six additional pericardial chest leads were introduced by (Wolf Worth and Wood 1932), to provide more information about the electric activity of the heart. These are the potential difference between central terminals of Wilson (the average of the three points on the chest). These set of leads records the myocardial activity in the horizontal plane. It is important to note that an individual chest lead does not represent the electrical potential of a localised area of the underlying myocardium. But it represents all the electric events all over the heart as viewed from that particular lead site. However, owing to the proximity of the pericardial lead to the surface of the heart, potentials generated in the underlying portion of the heart muscle will dominate other relatively more remote portions.

### 2.2. Chest Leads

Six electrodes are placed at six different positions around the chest. These six leads are monitored from six progressively different positions and they are numbered V1 to V6 in successive steps. If leads V1 to V6 are assumed to be the spokes of wheels. The centre of the wheel is the (A-V) node. These six leads are cutting the plane of the body into top and bottom halves in horizontal plane. In these leads we show the complex QRS is mainly positive or negative.

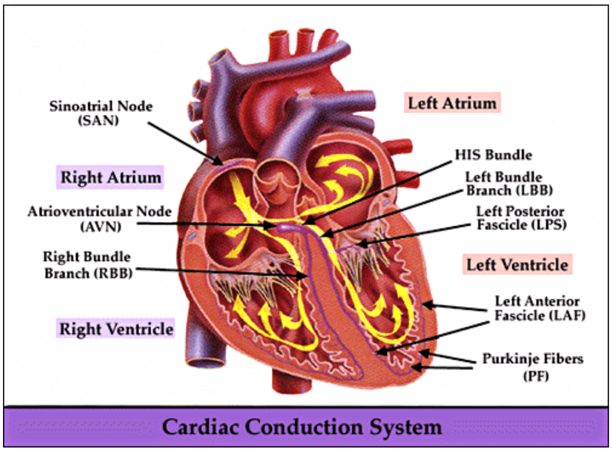


Figure 1: Cardiac conduction system.

## 3. RECONSTRUCTION OF THE HEART DIPOLE VECTOR

Until now, Einthoven's triangle has been widely accepted for clinical applications as a basic relationship between the bipolar electrocardiogram leads and the heart vector. It means that bipolar leads are simple projections of the cardiac vector. Although this concept is practically widely accepted, it includes the following assumptions:

1) The electric activity of the heart is represented at any instant by a single dipole.

2) The human body is regarded as an imaginary sphere within infinite conductor, with the cardiac dipole located at its centre and the electrodes located at equilateral triangle on the imaginary sphere.

3) The electric conductivity of the body is uniform (homogeneous) and independent of the direction of the cardiac vector (isotropic)

In 1964 Burger and Van Milaan, started with general of the lead potential V as follows:

$$V = \vec{C} \cdot \vec{P} = C_x P_x + C_y P_y + C_z P_z \qquad (1)$$

Where: $\vec{P}$ is the cardiac dipole vector and $C_x, C_y \;\&\; C_z$ are coefficients correspond to the site of measuring electrode on the body surface. The coefficients of the position vector were calculated for each point of interest on the body surface. For the designated medium and dipole position, each surface point has its space vector C which is constant. Therefore, according to the equation the potential V of that point can be obtained by projecting the time-varying cardiac vector P on the fixed vector C and then multiplying it by the magnitude of C. In this sense each point on the body surface corresponds to a vector C and the end of it (tip point) represents an imaginary surface known as the image surface. The connections between the point corresponding to the right arm (RA), the left arm (LA) and the left foot (LF) on the image surface from a non equilateral triangle in a plane somewhat oblique to the frontal plane. This triangle is known as the Burger triangle.

### 3.1. The Normal ECG

This consists of the three positive waves above the isoeletric line P-R and two negative waves below isoeletric line Q and S, where P is atrial in origin and Q R S T are ventricular. These waves were discovered by Einthoven in 1895.

1) P-wave represents spread of excitation wave in both atria i.e. depolarization of the atrial muscle. It is a small positive wave starts 0.02 sec before the mechanical response of atrium.

2) Q.R.S. represents spread of excitation wave in ventricles i.e. depolarization of ventricular muscle. It begins 0.02 sec before mechanical response of ventricular.

3) Q-wave (0.02s) is small negative wave representing spread of excitation wave in interventricular septum.

4) R-wave (0.04s) is the largest wave. It represents the excitation of the apex of ventricular walls and the base of ventricles.

5) S-wave (0.02s) is a small negative wave representing retreat of excitation of the remaining part of the base ventricles.

6) T-wave (0.25 s) is a positive wave representing retreat of excitation wave from ventricular muscle i.e. repolarisation of ventricles.

### 3.2. Problem Formulation

The body surface potentials are directly related to the electric source within the heart. Therefore, any abnormality in the cardiac source and/or in the electrical properties of the body torso is totally reflected on the ECG pattern. Various studies focused on the relationship between cardiac sources and the body surface potential. With the use of mathematical and electrical models we have two complementary techniques. The first one is to assume a certain model representing the source, to try to calculate the body surface potential from this assumed source and to examine the effect of the assumed parameters on the computed ECG. This is called the forward problem. The second one is based on the forward problem. It starts from available body surface potential data and trying to estimate electrical sources in the heart and causes for having data in the forward problem. The forward solution is affected by several parameters such as body shape, heart shape, body size, heart size, blood conductivity, lunges size, shape and conductivity. So, because of the complexity of the problem, the modeling (simulation) should include some simplifications. This is done by eliminating the effects of some parameters, or giving less weight to others. While stressing on another parameters assuming that their effect is dominant. According to the type of simplification introduced, two main types of modeling were considered.

1. A homogeneous with realistic body and heart shapes which is a quantized form model.

2. Analytical inhomogeneous model using special geometrical shapes to approximate the human body and the heart shapes.

The simplification of the first type neglects the effect of inhomogeneity while the second type approximates the body and heart shapes. In this paper we are first considering a very simplified model represented in two dimensions. That offers an analytical expression for the proposed simplified model. It describes the surface potentials according to the new model. While in the second part we propose a different approach to solve the inverse problem. Solution for the inverse problem is not as a simple task for reasons such as:

1. Complex mathematical models need to be considered.

2. Simulation studies have not yet established acceptable parameters (numbers) for the model.

3. The solution of the problem does not offer unique results. The formulation of the problem itself has not yet reached a point where it could be solved on one to one basis.

For all these reasons alone we could confidently say that a break-through to the inverse problem does not exist until now. In this paper we try to propose an approach for a solution to the inverse problem. First, the model considered is a simple two dimensional concentric circular model with a homogeneous body. We used a trial and error technique to solve the inverse problem. That technique uses the body surface potential data to extract the required information about the source.

It is important to note that the difficulty of solving such a problem is obviously figured out if we knew that it is not a one to one problem. The proposed solution thus far has not been proven to be unique.

## 4. ANALYTICAL SOLUTION OF THE 2-D CONCENTRIC CYLINDERS MODEL

### 4.1. The Single Layer:

The source of all the electrical activities of the heart was first considered as a single dipole located at the heart centre as stated by Einthoven. The complicated surface distribution of the activation wave of the electric cardiac source could be simplified to have the following characteristics:

1. Discontinuity of the voltage with the value of its strength.
2. Continuity of normal current. The voltage at any point inside the heart was found to be given by V1 and outside the heart surface is V2

$$V_1(r,\theta)=\sum_{n=1}^{\infty}-\frac{M\theta_\circ \sin(\frac{n\theta_\circ}{2})}{4\pi(\frac{n\theta_\circ}{2})}(\frac{r}{r_\circ})^n \cos(n\theta)-\frac{M\theta_\circ}{2\pi} \quad (2)$$

$$V_2(r,\theta) = \sum_{n=1}^{\infty} - \frac{M\theta_\circ \sin(\frac{n\theta_\circ}{2})}{4\pi(\frac{n\theta_\circ}{2})} (\frac{r_\circ}{r})^n \cos(n\theta) \qquad (3)$$

### 4.2. Potential Distribution In The Radial Direction

The potential distribution suffers from attenuation with the increase of r. This attenuation increases gradually from heart surface .reaching its maximum value at the body surface. Figure2 shows the potential distribution across the human body from the heart surface to the body surface. It is plotted as calculated from the above formulas. We assumed b =0.4 and $\theta_\circ = 90^\circ$ (see 4.3)

### 4.3. Parameter Estimation By Using Fourier Series:

The main reason for choice of a two dimensional model is the form of the solution which could be carried out in a sinusoidal harmonics. The sinusoidal harmonics are very easy to handle.

Assuming that b (heart to body radius ratio) and $\theta_\circ$ (heart electrical wave width angle) are known, we solve the forward problem using the double layer model (similar to the single layer with assuming finite body radius r1)

.

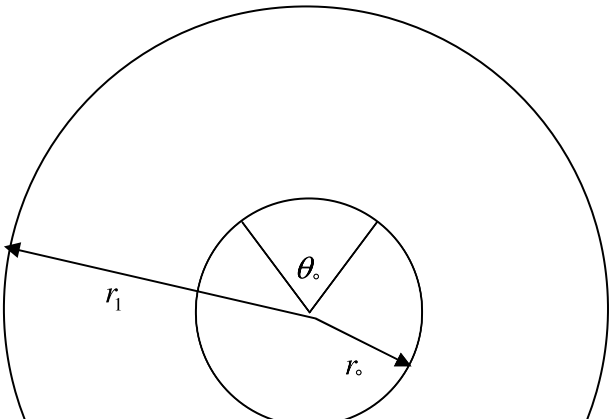


Figure 2: 2-D Model of The human body and heart

However, b is not known and hence solving the inverse problem reduces to finding a method to estimate b and $\theta_\circ$. Using two terms of Fourier series expansion of $V_2(r_1,\theta)$ and an initial estimation value for b, we used a trial and error method to calculate b and $\theta_\circ$ (to be discussed next section). We have plotted a number of curves to clarify the range that should be used for estimating the value for b. For b=0.7 the trial and error method is to be repeated for different values of harmonic numbers (n). The error in estimation of $\theta_\circ$ is calculated. The presented table summarizes the final results. From these results it can be concluded that the actual values of b and $\theta_\circ$ are nearly reached after five iterations of the loop.

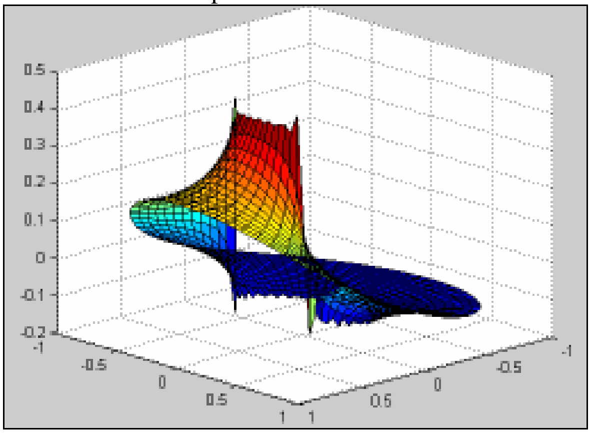

Figure 3: Potential distribution from the heart surface to the body surface.

## 5. EXPERIMENT RESULTS

### 5.1. Angular Variation Of Radius Ratio b

We have examined the effect of giving ***b*** a value other than its actual value in the solution of the inverse problem. We have also compared the actual figures at $b = b_{actual}$ and the estimated figures at $b \neq b_{actual}$ The comparison gives interesting results which can help to clarify that choosing a guess value for ***b*** that is larger than $b_{actual}$ is closer to the correct solution than choosing a value of ***b*** smaller than $b_{actual}$ (e.g. we can always start by assuming a value for ***b***=0.7) The trial and error method is repeated for different values of harmonic numbers *(n)*. Each time using the same value for ***b*** we calculated the error in estimation of $\theta_\circ$ for each value of n. We also repeated the above for different values of $(b,\theta_\circ)_{actual}$. The table shown summarizes the results.

Table1: Computations the radius ratio b.

| Actual | | No. of loops | | | | | Error in result | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| b | $\theta_\circ$ | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| 0.3 | 60 | 2 | 18 | 3 | 3 | 1 | X | 0 | 1 | 1 | 1 |
| | 90 | 18 | 3 | 1 | 1 | 18 | X | 1 | 0 | 0 | X |
| | 120 | 18 | 1 | 1 | 3 | 1 | 0 | 0 | 0 | 0 | X |
| | 150 | 2 | 3 | 18 | 3 | 18 | 0 | 0 | X | X | X |
| 0.4 | 60 | 1 | 18 | 3 | 2 | 1 | X | 0 | 1 | 1 | 1 |
| | 90 | 18 | 2 | 1 | 1 | 18 | X | 1 | 0 | 0 | X |
| | 120 | 18 | 1 | 1 | 3 | 1 | 0 | 1 | 0 | X | X |
| | 150 | 18 | 3 | 18 | 1 | 18 | 0 | 0 | X | X | X |
| 0.5 | 60 | 2 | 6 | 2 | 2 | 1 | X | 0 | 1 | 1 | 1 |
| | 90 | 18 | 2 | 1 | 1 | 18 | X | 1 | 0 | 0 | X |
| | 120 | 4 | 1 | 1 | 3 | 1 | X | 1 | 0 | X | X |
| | 150 | 18 | 3 | 18 | 1 | 12 | 0 | 0 | X | X | X |
| 0.6 | 60 | 2 | 18 | 2 | 2 | 1 | X | 0 | 1 | 1 | 1 |
| | 90 | 18 | 2 | 1 | 1 | 18 | X | 1 | 0 | 0 | X |
| | 120 | 18 | 1 | 1 | 2 | 1 | X | 1 | 0 | X | X |
| | 150 | 2 | 3 | 18 | 1 | 18 | 0 | 0 | X | X | X |

### 5.2. Real readings of body potential versus time

Figure 4 depicts the real body surface data versus time. The normal ECG wave can be recognized along one horizontal axis while the body potential distribution is shown along the other horizontal axis as measured from the six chest leads.

From the obtained results we can conclude that the actual values of $(b, \theta_\circ)$ are nearly reached after five times of the loop when we take n = 2 or n=3.

## 6. CONCLUSION

In this paper we have presented a solution of the inverse problem applicable for ECG diagnostics. It is possible fuse the electrical wave data with real time audio and/or video stream that is to be fed to a monitoring and/or recording device. Further development on the basis of the above study can be progressed by be the deployment of WSN (Wireless Sensor Network) technology that can collect the body surface potential from random and continuous readings. This technology can provide a rich source of analytical information.

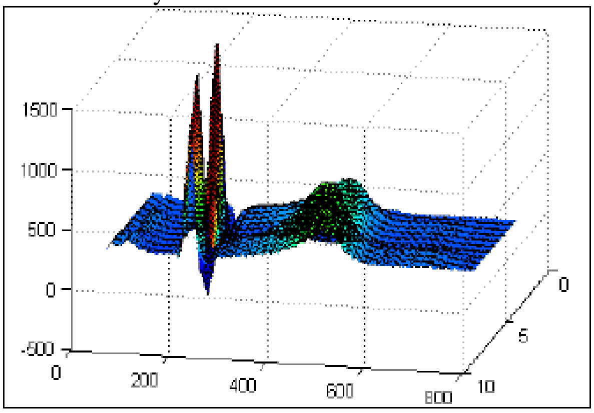

Figure 4: The wave of potentials across a body in time.

## REFERENCES


Einthoven, W., Fahr, G., Waart, A., 1950. *On the direction and manifest size of the variations of potential in the human heart and on the influence of the position of the heart on the form of the electrocardiogram Arch. Physiol*150: 275.

Gulrajani, R. M. , Savard, P. , Roberge, F. A., 1988. *The inverse problem in electrocardiography: Solution in terms of equivalent sources.* CRC *Crit. Rev. Biomed. Eng*16: 171-214

Gulrajani, R. M. , 1989. *The inverse problem of electrocardiography. In Comprehensive Electrocardiology*. *Theory and Practice in Health and Disease*1:237-88.

Burger, H. E., Milaan, J. B., 1948. *Heart Vector and Leads*, *Brit. Heart* 10:229.

Jenkins, D, 1996. *ECG time line - History of the electrocardiogram*, Available from: http://www.ecglibrary.com.ecghist.html [May 2008].

McSharry, P. E., Clifford, G.D., Tarassenko, L., Smith, L., 2003. *A dynamical model for generating synthetic electrocardiogram signals. IEEE Transactions on Biomedical Engineering*. 50:289-294.

Medvegy M., Duray, G., Pintér, A., Préda, I. 2002. *Body Surface Potential Mapping: Historical Background, Present Possibilities, Diagnostic Challenges, In Annals of Noninvasive Electrocardiology*, 7:139.

Throne, R. D., Olson, L.G., 2000. *Fusion of body surface potential and body surface Laplacian signals for electrocardiographic imaging Biomedical Engineering. IEEE Transactions* 47:252-462.

Wolferth, C. C, , Wood, F. C., 1932. *The electrocardiographic diagnosis of coronary occlusion by the use of chest leads. Am J Med Sci* 183:30-35


## AUTHORS BIOGRAPHY

### Zenon Chaczko

Senior lecturer in University of Technology Sydney. He has many publications and lectures in ICT and software Engineering. He is the research supervisor of many Master of Engineering students. He is teaching ICT in post graduate level. **Zenon** also is the supervisor of many under graduate capstone project.

### Hany Shehata

BSc in Telecommunication Engineering from Alexandria University Egypt. Master of Engineering Studies in Software and Information Systems Engineering from University of Technology Sydney UTS. **Hany** is a research student in UTS and he has several years of experience in the ICT industry. He has some efforts in the bio engineering research with strengths in mathematics and modeling.