Knowledge on Heart Patients Through Stethoscopic Cardiac Murmur Identification for E-Healthcare

Lanka Udawatta, AM Harsha S Abeykoon, D Kasun Prasanga, SKLB Prasad, WARP Perera, KLN Perera
Department of Electrical Engineering
University of Moratuwa
Sri Lanka
e-mails: lanka@ieee.org; harsha@elect.mrt.ac.lk; prasanga@ieee.org; ee.prasad@gmail.com; rangamora06@gmail.com; noshanmrt@gmail.com

***Abstract*—Cardiac murmurs are the sounds produced by the abnormal passage of the blood flow inside the heart due to the diseased valves or tissues. Identifying the type of the murmur can diagnose the cardiac pathology related to that particular murmur. This paper describes a researched digital stethoscope that can be used as a stethoscope as well as a murmur identification device. To capture the heart beat, a chest piece of a traditional stethoscope is used with a condenser microphone attachment. Then the signal is amplified and filters out the noise and sent to the ARM processor. At the processing module, sampling is carried out and stores the sampled data if the data transmission is not being done. Then the sampled data is transmitted to a central location using radio frequency transmitter module to carry out the signal processing. If the user wishes, the signal processing can be done in the stethoscope itself since the ARM processor is in the stethoscope unit.**

I. Introduction

Auscultation is being used to diagnose many cardiac pathological conditions for a long time. When there are abnormalities present in the cardiac valves or problems in the tissues of the heart, cardiac pattern differs from the usual waveform and produces abnormal sounds in between called as murmurs. For an example, in the case of coronary artery disease (CAD), higher frequency components are visible in the heart sound spectrum [1].

Before other symptoms occur such as ECG abnormalities, abnormality present in the heart sound is the only diagnostic information [2]. However according to the records, considerable percentage of the fresh medical graduates is unable for proper diagnosis of cardio pathology by listening to the cardiac abnormality sounds [3]. Therefore some visual aids are also used to properly distinguish the abnormalities present. Electrocardiogram (ECG) is one such visual aid to measure the electrical activity of the heart. But the problem is that the timing between the electrical and mechanical activities in a particular cardiac cycle is not exactly constant for all the patients due to the difference of the pathological conditions [4], [5]. One such method to visualize the mechanical activity of the heart is the Phonocardiogram (PCG). PCG is a graph plotted for the sound of the heart beat is very important in diagnosing cardio vascular diseases [2].

As the Fig. 1 illustrates, inside the heart, there are four valves present, Tricuspid, Pulmonic, Mitral and Aortic.

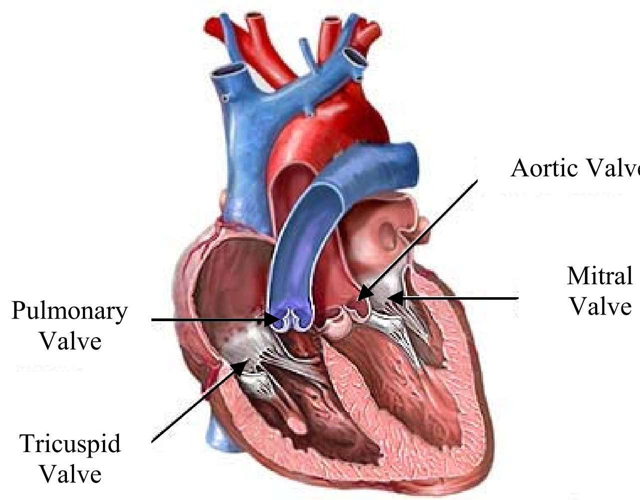

Figure 1. Valves of the heart

Heart sounds are produced when the blood is flowing with the operation of those four valves. The heart sounds are generally divided in to the first beat (S1) and the second beat (S2). The interval between the S1 and S2 referred as the Systole, which is the contraction phase of the heart and the interval between the S2 and S1 is referred as the diastole, which is the expansion phase of the heart [7]. S1 is the mitral valve with the tricuspid valve shut down and S2 is the aortic valve with the pulmonic valve shut down [8].

Murmurs can be broadly categorized in to two as systolic murmurs and diastolic murmurs based on their occurrence of the different region of the heart cycle [6], [7]. Systolic murmurs occur when the ventricles are contracting to pump the blood outside of the heart while the diastolic murmurs occur in the expansion of the heart [7]. All together there are many types of murmurs present independently as well as in combined. When there is only one murmur present it can be identified with a less effort. But when there are several murmurs present at once, distinguishing them is a difficult task. Cardiologists have to carry out an echo test to verify the exact type.

This research was carried out to develop an electronic stethoscope that can identify the type of the heart murmur. Although there are digital stethoscopes available on the market, but none of them are capable of doing the signal processing in the stethoscope itself. Having considered that, this stethoscope was designed to do the processing part inside the device. For that, an ARM processor having a sufficient digital signal processing power has been selected. Fig. 2 shows the architecture of the stethoscope.

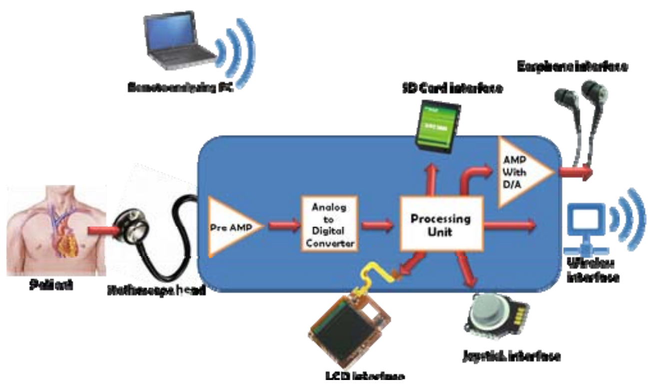

Figure 2. Architecture of the stethoscope

The patient's end of the stethoscope has been designed using the ordinary stethoscope head of an ordinary stethoscope. To capture the heart beat, a condenser microphone is used and it is attached to the stethoscope head nearby. Once the sound is captures it is sent to the processor to get the sample data and then it is transmitted to a central computer to process the data via a radio frequency wireless module.

II. Methodology

A. *Mechanical Design*

Mechanical design of the stethoscope includes the patient end of the stethoscope and the stethoscope enclosure unit.

1.) *Chest Piece Design*

To capture heart, various methods are available such as MEMS sensors [9]. For this research, a chest piece of an ordinary stethoscope has been used as the patient's end, so as to ensure a good capture of the sound.

To convert this sound to the digital signals a condenser microphone is used as it has a flat frequency response in a wide band of frequencies. As the heart sounds contain some higher order frequency components, this type of a microphone is selected to capture all the signals of different frequencies.

Microphone was connected as near as possible to the chest piece so as to reduce the attenuation of the sound inside the stethoscope. Flexible rubber tube was used to connect the microphone with the chest piece. The rubber tube was selected so that it fits well to both the stem of the chest piece and the condenser microphone. This is shown in Fig. 3.

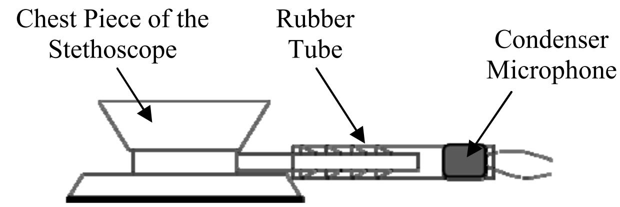

Figure 3. Condenser microphone assembly to the chest piece of the stethoscope

Condenser microphone was connected to a female socket of a 3.5mm stereo audio jack with a screen wire. To obtain a good finish to the assembly, all those components were placed in line and covered with a black coloured heat shrink to get a better look.

The complete assembly of the chest piece of the stethoscope is illustrated in Fig 4.

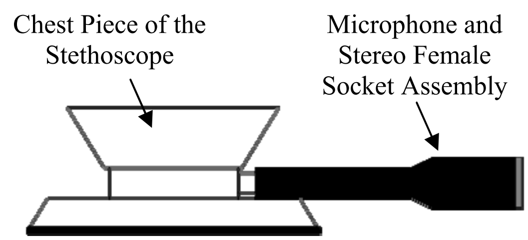

Figure 4. Completed assembly of the chest piece

This complete assembly of the chest piece and the main functioning unit of the stethoscope is connected through a screen wire cable having two stereo mail jacks in the both ends. Screen wire is selected for connecting the two ends to avoid the distortions caused by the interference problems from the outside. Easy detachment of the chest piece from the main controlling unit increases the flexibility of the product.

2.) *Stethoscope unit enclosure*

The enclosure of the stethoscope was designed to cover all the electronic circuitry parts of the stethoscope. Since this instrument is used by the doctors who are not that much familiar with the electronic circuitry stuff, it was planned to expose only the essential parts of this stethoscope.

Enclosure covers the micro processor board, Batteries, Amplifier, Filter and the Wireless Module and exposes only the Liquid Cristal Display (LCD) to the outside. This design was carried out using the Solid Works and the design is as in the Fig. 5.

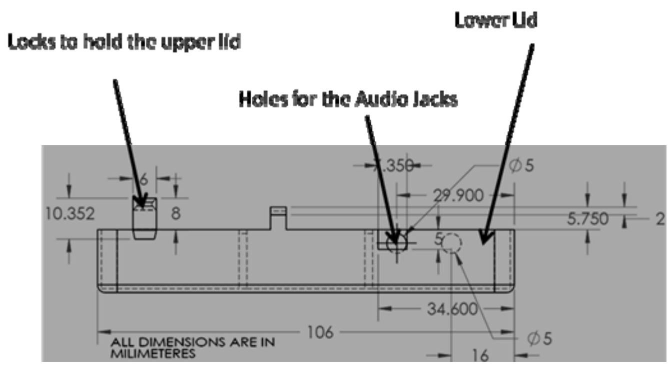

Figure 5. Stethoscope enclosure drawing

This has been designed in to two parts so as to make it easier to open and replace the batteries. The opening of the top most part reserves the space to the display unit of the device.

B. *Research Design*

This includes all the circuitry from capturing the heart sound to the data transmission to a remote computer.

1.) Amplifier Module

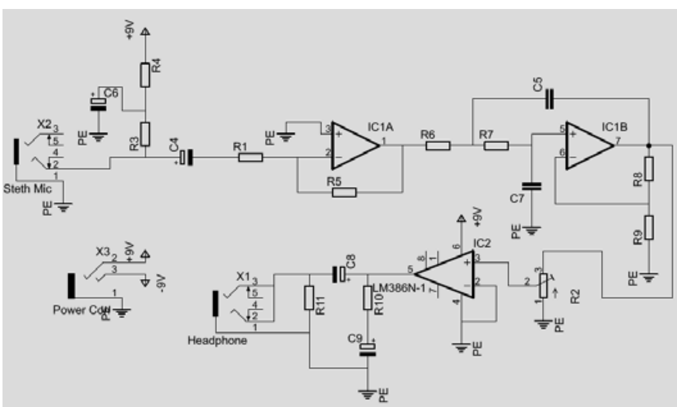

Figure 6. Amplifier module

Condenser microphone produces very weak electrical signals to the variation of the heart sound. Therefore it is essential to get a proper amplified signal that can be sampled. For this reason, an amplifier was designed with multiple operational amplifier modules. Fig. 6 illustrates the designed amplifier module for the stethoscope.

As the user of the stethoscope hear the sound using an earphone, it should be exactly the same as what is heard from an ordinary stethoscope apart from the amplification. In order to achieve this, capacitors are used here to do the filtering for the unwanted frequency components.

2.) Processor and Wireless Module

For this research, a high speed ARM processor of 72MHz has been used. The main reason for this selection is to carry out the signal processing part in the processor itself without a computer where necessary.

For the wireless transmission of data to a central location, a radio frequency wireless module has been used.

C. *Software Design*

1.) User Interface Design

In order for the ease of use of the stethoscope, a very friendly user interface has been designed to be operated at the central location. This interface has been designed using MATLAB. The interface is as in the Fig. 7.

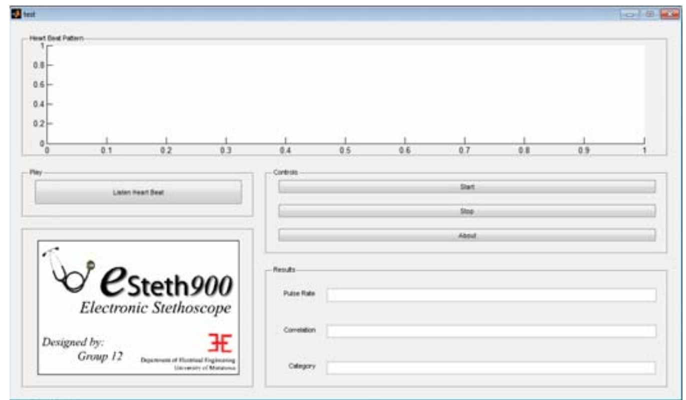

Figure 7. User Interface of the central location

When the software is running and if the stethoscope is located within the range of the wireless module, this interface can maintain the data connection between the stethoscope and the central location automatically until we stop it.

This can display the patient ID, pulse rate, wave form of the heart beat and any identified abnormality of the heart if exists.

2.) Signal Processing

This is one of the major parts of the project. Signal processing is carried out to obtain the user outputs from the interface [10]. Major outputs from the signal processing are,

1. Pulse rate
2. Heart sound correlation and pattern matching
3. Categorization

2.1) Obtaining the pulse rate

In general, the acoustic heart waveform contains distinguishable peaks which may either correspond to systole of the heart or the diastole of the heart. When the number of samples between the two major peaks is obtained, pulse rate is calculated as follows (1).

$$\text{Pulse Rate} = \frac{F_s}{\text{No of Samples}} \times 60 \qquad (1)$$

Where F_s is the sampling frequency

2.2) Heart sound correlation and pattern matching

This is done using the Fast Fourier Transform and the Auto Correlation. After getting the sampled data from the stethoscope device, the ASCII data is first written to a text file. Then the ASCII data is carefully separated and the data is extracted

Then the data is undergone to the FFT and obtain the magnitude of the each data. After that the received data is correlated with the existing waveform data which have also been undergone to FFT and taken the magnitude.

Auto correlation algorithm is used to identify the type of the cardiac murmur. The auto correlation algorithm that was used is listed in the following equations.

$$SSxx = \sum (x_i - x)^2$$
$$= \sum x^2 - 2\bar{x}\sum x + \sum \bar{x}^2$$
$$= \sum x^2 - 2n\bar{x}^2 + n\bar{x}^2 \qquad (2)$$

Auto correlation function can be represented as in (3)

$$SSyy = \sum (y_i - \bar{y})^2$$
$$= \sum y^2 - 2\bar{y}\sum y + \sum \bar{y}^2$$
$$= \sum y^2 - 2n\bar{y}^2 + n\bar{y}^2$$
$$= \sum \bar{y}^2 - n\bar{y}^2 \qquad (3)$$

Similarly,

$$SSxy = \sum (x_i - \bar{x})(y_i - \bar{y})$$
$$= \sum x_i y_i - \bar{x} y_i - x_i \bar{y} + \bar{x}\bar{y}$$
$$= \sum xy - n\overline{xy} - n\overline{xy} + n\bar{x}\bar{y}$$
$$= \sum xy - n\overline{xy} \qquad (4)$$

$$ss_{xx} = N\ var(X) \qquad (5)$$

$$ss_{yy} = N\ var(y) \qquad (6)$$
$$ss_{xy} = N\ var(X, Y) \qquad (7)$$

Equation (8) gives the correlation coefficient.

$$r^2 = \frac{ss^2_{xy}}{ss_{xx}\ ss_{yy}}$$
(8)

Note that the other symbols used here have their usual meanings.

Having two FFT data subjected to the auto correlation, a correlation coefficient is obtained. This coefficient is in between 0 and 1. When the two signals are matching exactly, the correlation coefficient is 1. The coefficient deviates from 1 as the signal being considered get differs from the reference waveform.

Having obtained correlation coefficient of the particular heart sound with all the reference waveforms, the reference waveform having the maximum correlation coefficient is taken as the predicted waveform and thereby the relevant murmur.

Fig. 8 is a plotted waveform of a heart of normal person and is obtained from the user interface.

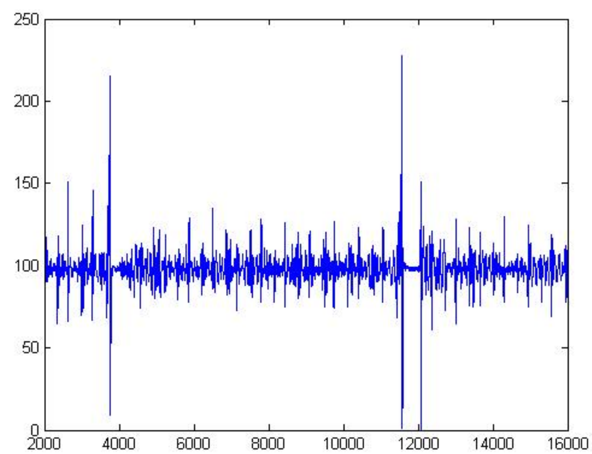

Figure 8. Waveform of a normal person

It has been confirmed even from the auto correlation algorithm implemented on the software that this is a waveform is of a normal heart.

III. OPERATING MODES

This stethoscope can be operated in two methods.

1. As a normal stethoscope with sound amplification

This stethoscope can be used as a usual stethoscope with the sound amplification capability. As the design has an amplifier and a noise filter built in to the device, it can be used as a usual stethoscope without any problem. Since there is a gain controller in the amplifier, user can control the sound output accordingly. This is very much helpful when we inspect the patients having more fat. Because the heart sound that comes out of the skin is very less in fat patients, we can put more gain to amplify the sound such that it is audible enough to the user.

2. As a diagnosing device

This stethoscope has the capability of signal processing inside of both the PC and the stethoscopic device itself. Since the processing unit inside the device has a significant processing power of 72MHz signal processing task can be achieved.

This stethoscope it mainly focused on identifying the type of the murmur. The heart sound captured by the microphone attachment is sampled in the signal processing device and it is then transmitted to the PC via a radio frequency (RF) module. With the aid of the software developed with the stethoscope device, the wavelet transform is carried out in the PC and the murmurs are identified.

IV. RESULTS

Using the computer software that was developed, audio sampling can also be done with the software. Following figures are the wave forms correspond to different cardiac murmurs of the heart. The heart sounds are sampled at 8 kHz.

Fig. 9 shows the graph of a normal heart.

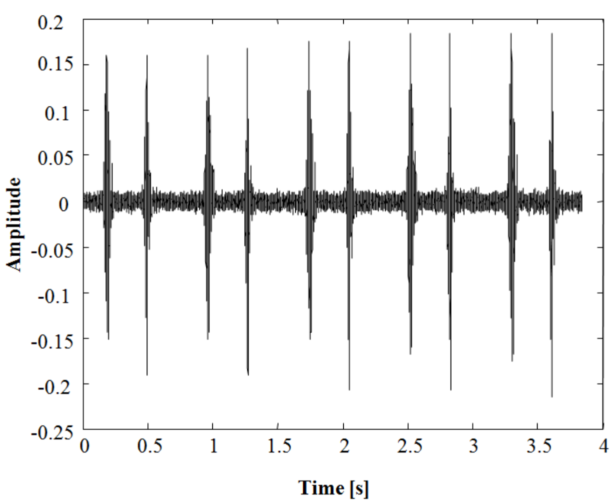

Figure 9. Wave pattern of a normal heart sound

In a normal heart, the sound is very clear and there are no any abnormal wave components in between the two major peaks which correspond to the systole and the diastole. It is clearly scene from the wave pattern that the interval between two major peaks is different. That is, the long interval corresponds to the diastole of the heart and the short period corresponds to the systole of the heart. In the above figure, the left most peak is the S1 beat and the next peak is the S2 beat and it continues along.

Early systolic murmur is the murmur occurs in the systole of the heart. It begins with the S1 and ends before the S2, i.e. in the middle of the systole. This is caused by the defects with the pulmonary hypertension.

Fig. 10 shows the wave Form of an Early Systolic Murmur. It is clearly seen from the wave pattern that there is some kind of abnormality is present after the S1 and the middle of the S1-S2 period.

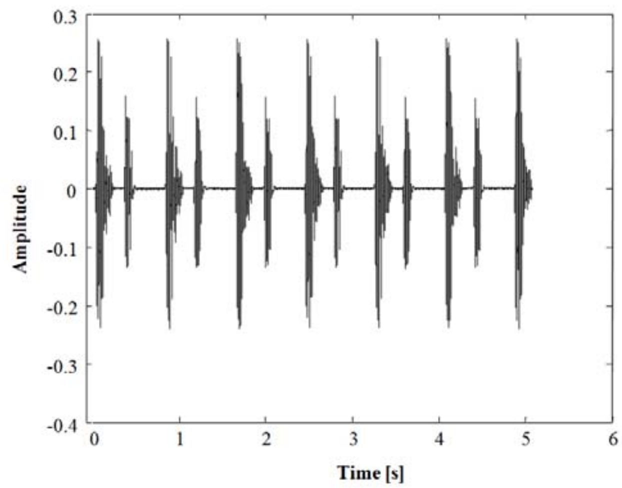

Figure 10. Waveform of an early systolic murmur

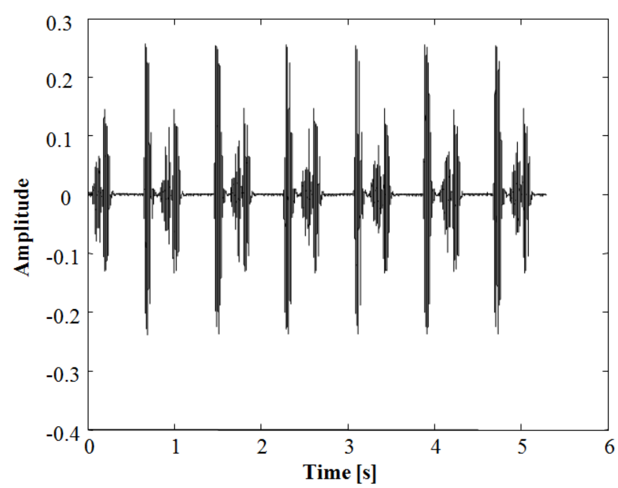

Figure 11. Waveform of a late systolic murmur

Late systolic murmur occur mainly due to the mitral valve prolapsed. This is occurring in between the middle of the S1-S2 period and the S2 beat.

Abnormality between the S1 and S2 can be seen in the wave pattern obtained for the Late Systolic Murmur in Fig. 11.

Waveform obtained from a patient having the Pulmonary Valve Stenosis is shown in Fig. 12. This murmur occurs when the blood flow from the right ventricle is blocked. This blocking takes place at the pulmonary valve that separates the pulmonary artery and the heart.

This mainly occurs when a fetus is being developed in the uterus. Still the cause for this problem is unknown but it is said that the problems in genetics resulted in this.

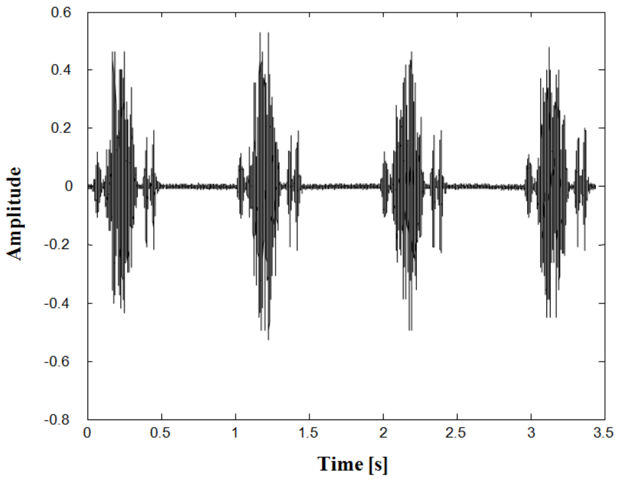

Figure 12. Waveform of a pulmonary valve stenosis

V. Conclusion

This research was carried out to develop an electronic stethoscopic system that can be used as an ordinary stethoscope as well as a device that can diagnose heart murmurs. Wave patterns have been obtained for different patients having different types of murmurs with the aid of the computer software that was developed.

Using this stethoscope amplified noise filtered heart sound can be heard through the earphone. Data sampling can be done in real time while the heart sound is heard. Because there is a gain controller in the amplifier, user can control the gain accordingly to inspect both fatty and non fatty patients.

Pulse rate can be obtained and the type of the murmur can also be identified using this stethoscope. They are displayed in the PC software as well as in the LCD display of the device. Also the data can be transmitted to the PC via a RF module for further analysis and diagnose of diseases. In addition to that, sampled data can be stored in the SD card using the SD card interface in the stethoscopic device for later analysis and playback.

Furthermore, this research can be carried out to diagnose the complex situations where more than one murmurs are present. Also the better signal processing algorithms can be tested in order to obtain results of higher accuracy.

Acknowledgment

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