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Ambulatory Device to Predict Myocardial Infarction and the Likelihood of Ischemic Stroke

Anu.D.B[1], Nithya.K[2], Pavithra.S[3], Dr.Vijaya.K.S[4]

Final year students, Department of Biomedical Engineering, Sri Ramakrishna Engineering college, Vattamalaipalayam, Coimbatore, Tamilnadu, India[1,2&3]

Assistant professor (Sr. G) & Guide, Department of Biomedical Engineering, Sri Ramakrishna Engineering college, Vattamalaipalayam, Coimbatore, Tamilnadu, India[4]

Abstract – This paper identifies a robust approach in the development of an ambulatory device to predict myocardial infarction and the likelihood of ischemic stroke for modern healthcare in the aspect of preliminary diagnosis. This device best suits for low-cost and portable applications. The existing systems employed in the stroke diagnosis are only the imaging modalities which are very rigid, non portable and costly and hence, it is considered as a major drawback in ambulatory and emergency applications. The aim of this paper is to design a user friendly and portable device which uses the ECG (Electrocardiography) and PPG (Photoplethysmography).The PPG sensors are placed over the carotid (neck) region in the form of a neck pad and the radial artery (fingertip) to obtain the pulse wave. The obtained pulse wave in turn is processed to obtain the velocity profile of the artery thus as an indicator of arterial stiffness. Also, the blood pressure (BP) is calculated continuously from the PWV (Pulse Wave Velocity) which prevents the cerebrovascular accidents. The common ECG parameters those that cause myocardial infarction and that predict the likelihood of ischemic stroke are the arrhythmias, ST segment deviations, T–wave inversions and QT prolongations. The ambulatory device designed here is a portable unit interfaced along with the PC (Personal Computer) through the RS-232 serial port communication for the processing and analysis of the ECG and PPG signals using the MATLAB software.

Keywords: Myocardial Infarction, Ischemic Stroke, ECG (Electrocardiogram), PPG (Photoplethysmography), BP (Blood Pressure), PWV (Pulse Wave Velocity), MATLAB

I. INTRODUCTION

According to the World Health Organization (WHO), 17.3 Million people have died due to the Cardiovascular disease (CVD) of which myocardial infarction is the dominating disease at present[1].In addition to this, world's third highest morbidity rate is mainly due to stroke which is also given as the Cerebrovascular disease. Thus, the CVD's are the highest threatening factors of death. The morbidity rates due to stroke increases exponentially with the age. Brain has a major influence on the cardiac function. It has been known from the historical innovations that the cardiac abnormalities occur in context to the nervous dysfunction.

Patients with cerebrovascular disease are prone to electrocardiographic abnormalities. These changes of ECG with the intracranial events have been studied by innumerable scientists. Studies have shown that stroke victims may die unexpectedly of cardiac arrest, hypertension, and myocardial infarction. The major risk factor of stroke is due to the atherosclerotic deposition in the blood stream (arteries) thereby blocking the blood flow .This causes the impairment in organ function. The ischemic stroke can be detected by the imaging modalities which include MRI, CT, and Ultrasound methods. As a measure of reduction of the clinical costs, portability and continuous monitoring, a different modality is being implemented. A novel method using optical detection (photoplethysmography) is being developed to obtain the pulse wave velocity (PWV) at the carotid artery via a neck band and the radial artery via a fingertip probe. The pulse wave velocity is calculated from the pulse transition time. For the prevention of CVD's, the continuous monitoring pulse wave velocity and blood pressure is important. The

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range of blood pressure levels as classified by the WHO is given in the below table. 1.

The likelihood of stroke can be felt from the velocity profile of the common carotid artery (CCA) which branches out into the internal and external carotid artery. The velocity profile of the blood vessels may differ from subject to subject with respect to parameters like age, gender, body mass index, etc., The carotid arteries supply two-third of the blood to the brain, eyes, neck and the ear. The anatomy of the carotid artery distribution from the human heart is given in the below figure.1.

Table.1 Classification range of BP by the WHO

Category	Systolic BP	Diastolic BP
Optimal	<119	<79
Normal	120-129	80-84
High-Normal	130-139	85-89
Grade I Hypertension	140-159	90-99
Subgroup: Borderline	140-149	90-94
Grade II Hypertension	160-179	100-109
Grade II Hypertension	>180	>110
Isolated Systolic Hypertension	>140	<89
Subgroup: Borderline	140-149	<89

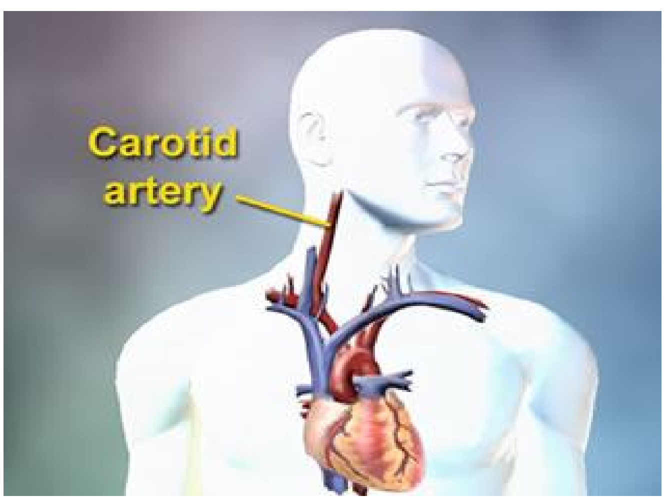

Fig.1 Anatomy of carotid artery distribution from the human heart

The variations in the ECG contribute not only to the abnormalities like arrhythmias and myocardial infarction but also affect the aortic blood flow. Myocardial infarction at times may lead to stroke. Thus, stroke occurs as a result of obstruction of blood vessel supplying blood to the brain. The carotid artery region is chosen in consideration to the accessibility of the artery even by palpating the neck. It is also stated that the pulses can be felt accurately at the carotid artery in the neck.

II. BLOCK DIAGRAM OF THE PROPOSED SYSTEM

The block diagram of the proposed system is shown in the below figure.2. The ambulatory device acquires the ECG and PPG from the subject and conditions the acquired signals using the amplifier and filter. The PPG is obtained from the fingertip by the fingertip probe and carotid artery (neck) by a neck band/pad as desired by the comfort of the subject. The analog conditioned signals are fed to the microcontroller. The analog signals are converted to digital signals by the Analog to Digital Convertor.

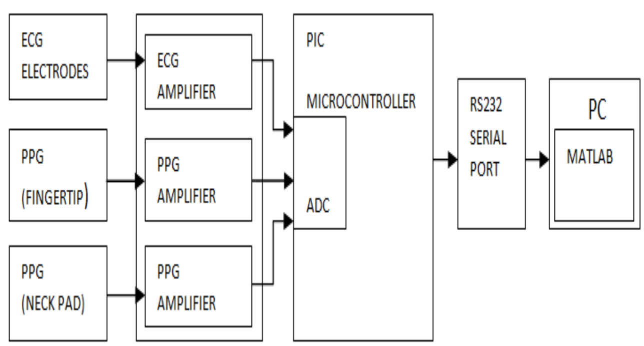

Fig.2 Block Diagram of Ambulatory Device to Predict Myocardial Infarction and Ischemic Stroke

The components used in this paper are classified into three sections: A) Design of ECG signal conditioning unit B) Design of PPG sensing and signal conditioning unit C)Interfacing the ECG and PPG units with the microcontroller D) Interfacing the data acquisition modules with PC through RS-232 serial port communication E) Processing the ECG and PPG signals using MATLAB Software.

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III. PROTOTYPING THE AMBULATORY DEVICE AND ITS DESIGN

A. *Design of ECG signal conditioning unit*

Before understanding the design of ECG signal conditioning unit, let us consider the principle and working of an electrocardiography unit used in a healthcare facility. The electrocardiogram is the measure of the variations in the cardiac potentials over time. The ECG can be recorded using the electrodes attached to the legs and wrists as per the standard 3 lead configuration (Lead 1, Lead 2 and Lead 3) by the Einthoven theoretical triangle. The representation of the Einthoven's triangle is shown in the below figure.3 and the physiology of the normal ECG wave is shown in the below figure .4.

The ECG signal conditioning unit is designed using the TL072 instrumentation amplifier. The TL072 is a high-speed JFET dual input output op-amp. The amplified ECG signals contain the line frequency, low frequency and high frequency components which are then filtered and fed to the Pulse Width Modulation (PWM) circuit to convert the analog signal to pulse format for isolation. The isolation is done by the optocoupler as a measure of protection.

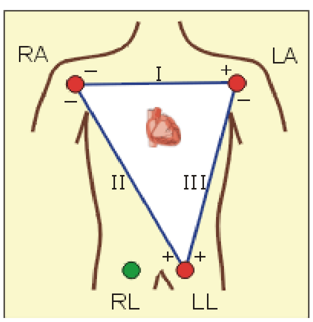

Fig.3 Einthoven triangle for Standard 3 Lead Configuration

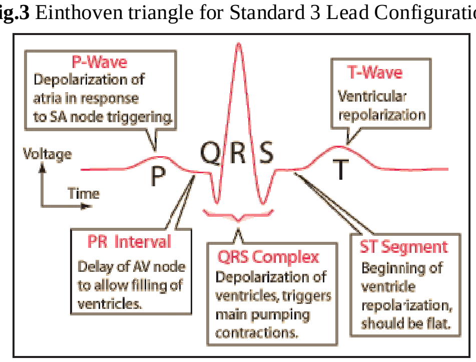

Fig.4 Physiology of the normal ECG wave

Then, the Pulse Width Demodulation circuit reconstructs the pulse signal to analog signal and the line frequencies are finally filtered by the notch filter using the TL074 JFET amplifier. Thus, this amplifier is a low cost design which gives an interference free original signal.

B. Design of PPG sensing and signal conditioning unit

The photoplethysmography reflects the blood movement in the vessel from the heart to the periphery in a wave-like motion as shown in the below figure .5.

The PPG is a non-invasive optical measurement technique which employs a light source and a detector. It uses the invisible infrared light as a source which is a low cost and convenient component of use.

The source and the detector can be placed using two methods which are the:

a) Reflectance PPG-The detector detects the reflect light from the tissue of interest. It is used to obtain the weak signals.

b) Transmission PPG-The emitter and the detector are placed on opposite sides.

In our system, the transmittance PPG is employed at the fingertip as show in the below figure.6 and the reflectance PPG is employed at the carotid region(neck) through a neck band or it can be design with an adhesive material so that it does not make the subject uncomfortable as shown in the below figure.7. The circuit description includes the removal of dc component using the coupling capacitor to the IR detector. The amplifier section is designed using the LM324 quad operational amplifier which has different stages of amplification.

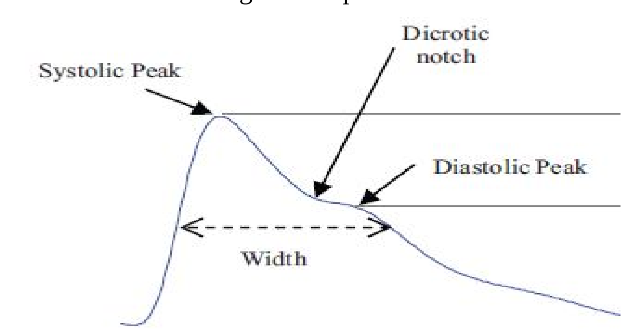

Fig.5 Normal PPG signal

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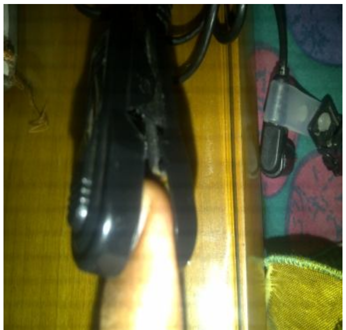

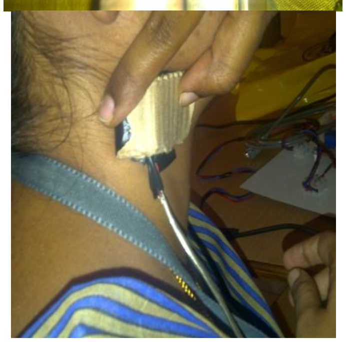

Fig.6 Transmittance PPG sensor **Fig.7** Reflectance PPG sensor

C. Interfacing the ECG and PPG signal conditioning units with the microcontroller

The ECG and PPG signal conditioning units are interfaced to the microcontroller thus enabling the acquisition of the analog signals.

PIC 16F8XX microcontrollers are RISC controllers with very small instruction set only of 35 instructions. PIC 16F887 is a 40-pin 8-bit CMOS FLASH microcontroller. It comes with three operating speeds with 4, 8 or 20 MHz clock input. It has two types of internal memories; one is program memory and another is data memory. Program memory is provided by 8K words of FLASH memory and a data memory has two sources.

D. Serial Port Communication

In communications, RS-232 is a standard for serial binary data interconnection between a DTE (Data Terminal Equipment) and a DCE (Data Circuit –terminating Equipment) which is common in computer ports. The serial port communication establishes the bit by bit data transfer. The acquired signals being digitally converted by the analog to digital converter in the microcontroller is in the form of TTL logic.MAX 232 IC is being used for TTL to RS 232 conversion. Serial data is recorded on the USB port of the PC with the help of USB to Serial Converter which is read by MATLAB software for plotting and analyzing the data in real time.

E. *Signal Processing in MATLAB Software*

The serial data is plotted in a real time in MATLAB by creating a serial data object and the processing of the signals is then carried. The signal processing module consists of several subdivisions which includes the following:

a. ECG signal processing
b. PPG signals processing
   (Finger PPG and neck PPG)
c. Decision making based on the measured values and the normal

A .ECG Signal Processing

The first step after the acquisition of the signals from the serial port is to preprocess the signals for efficient feature extraction. The preliminary preprocessing measure is to eliminate the baseline wander and the noise components using filter. The features of prime importance include the QRS-complex, S-T segment, T wave and Q-T interval. In this paper, Wavelet Transform has been proposed to analyze the biomedical signals which are non-stationary. The Wavelet Transform has been proposed since it aids in the conversion of time domain signals into frequency domain. It is of a highly known factor that a signal should be converted from time domain to frequency domain to get the complete information of it.

The Savitzky-Golay filter along with the Daubechies wavelet transform performs a smoothing operation over the noisier signal. This type of filter is much better than the FIR filters as it filters the higher frequency content of desired portion in a signal. Then, the Daubechies wavelet function is selected in order to denoise the signal. The Daubechies wavelet function has a wide number of constants from 1 to n. Here, the Db4 is chosen due to excellent results for feature extraction. Then, the Wavelets decomposition of the ECG samples is performed up to 4 levels.

All the features are recognized with respect to the QRS-complex. The R-peak being the tallest in the ECG signal is first determined. The method used to find the QRS-complex is based on J. Pan and J. Tompkins algorithm. The other features were detected with respect to the deviations from the isoelectric line. The S-T segment and T wave are measured with respect to the J point which

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is normally at the end of the QRS complex. The Q-T interval is calculated between the onset of the Q wave and the T wave. The prolongation of the QT interval results in an alarming sign to the onset of cerebrovascular disease and other cardiac complications. The normal values of the ECG values are tabulated in the table shown below in the table .2.

Finally, the ischemic episodes are recognized with a minimum duration of the signal being 30seconds.For this, a sliding window technique is used which moves with one beat in a window. The ischemic window is detected if the 30seconds window contains 75% of ischemic beats. The ischemic episode is identified with presence of at least two or more number of consecutive ischemic windows as a measure to improve accuracy.

Table.2 Normal and Abnormal Range or ECG and the associated abnormalities

Features	Normal value	Abnormality results in :
Heart Rate	60-120 BPM	Arrhythmias and Fibrillation thereby increasing the risk of heart attack and stroke.
S-T Segment	0.08mV approx(Should not be > or < 1mm from the isoelectric line)	Myocardial Infarction, Cardiac arrest, Decreased Cerebral Oxygenation
T wave	Twice the P wave ,should be upright i.e., positive amplitude(Should not 0 mV or inverted from the isoelectric line)	Ischemic Condition
Q-T interval	<=0.44 seconds(Should not be above 0.44 seconds)	Electrolyte abnormalities, Myocardial Infarction and Cerebrovascular Injury.

Table.3 Characteristics of right common carotid artery in 40 healthy men

Parameters	Mean+/- SD
Arterial wall thickness (mm)	1.32+/-0.32
Maximum change of arterial radius (mm)	0.19+/- 0.07
Pulse wave velocity (m/s)	5.00+/-1.13

B. *PPG Signal Processing*

The plethysmograph signals are acquired from the serial port and preprocessed for noise removal. Then, the PWTT or PTT (pulse transition time) which is the time taken for the blood to reach from the heart to the periphery through the blood vessels. The PTT is the time interval measured from the R-peak of the ECG and the peak of the PPG wave.

The PTT is new parameter which can indicate the change in BP (blood pressure).The pulse transition time is indirectly proportional to the pulse wave velocity (PWV) and BP. The pulse wave velocity is measured in meters per second which is derived from the PTT as per the formula given below:

$$PWV=K/PTT \text{ (m/s)}$$

Where K=Distance between the proximal to the distal position of sensor placement.

The PWV determines the arterial stiffness factor and the blood pressure. The PWV decreases with the increase in PTT thus indicating the increase in arterial stiffness and pulse pressure. The pulse at the carotid artery is extracted to obtain the velocity profile of the carotid artery supplying the head region. The higher the arterial stiffness, the higher is the possibility of vascular diseases. The arterial stiffness may be due to aging, atherosclerosis or by the formation of blood clot in the blood vessel. The arterial stiffness at the carotid artery results in impaired blood flow to the head region including the brain. This impairment when associated with the myocardial infarction may result in ischemic stroke. The characteristics of the right common carotid artery in 40 healthy men is tabulated as shown in the below table .3.

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IV. EXECUTION FLOW OF THE PROPOSED SYSTEM

The execution flow of the proposed system to predict the ischemic and stroke episodes is shown in the below figure.8.The below given figure has two conditions for decision making namely condition 1 and condition 2.

1. Condition 1 is TRUE if "ISCHEMIC EPISODE" alone is present. (ST-T deviation; T wave inversion; QT prolongation)
2. Condition 2 is TRUE if "BP is elevated" or "PWV is abnormal" or "ISCHEMIC EPISODE with elevated BP".

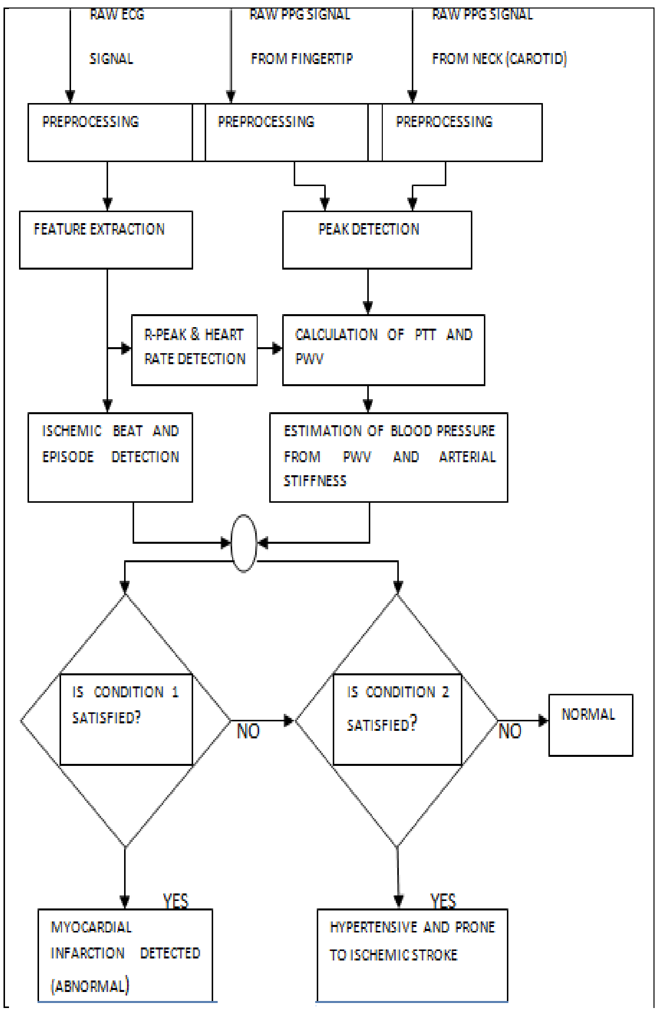

Fig.8 Execution Flow of the Proposed System

V. RESULTS AND ANALYSIS

The proposed system is primarily validated from 5 random ECG records from the European ST-T database and from a real time patient data. The PPG signals from radial and carotid artery are also preprocessed and pulse transition time is calculated. The blood pressure of the subject is monitored continuously and a mobile phone alert system is developed.

The processed ECG signal and detected result is shown in the below figure.9.Also, the obtained carotid plethysmograph waveform is shown in the below figure.10.The performance of the system is measured in terms of sensitivity (S) and positive predictive accuracy (PPA).The sensitivity in this system refers to the ability to detect the ischemic episodes while the predictive positive accuracy renders the estimation likelihood that a detected episode is truly Ischemic.

$$S (\%) = [TP/ (TP + FN)] X 100$$

Where

TP = Truly Positive (correctly detected event)

FP = False Negative (erroneously detected event)

FN = False Negative (erroneously missed event)

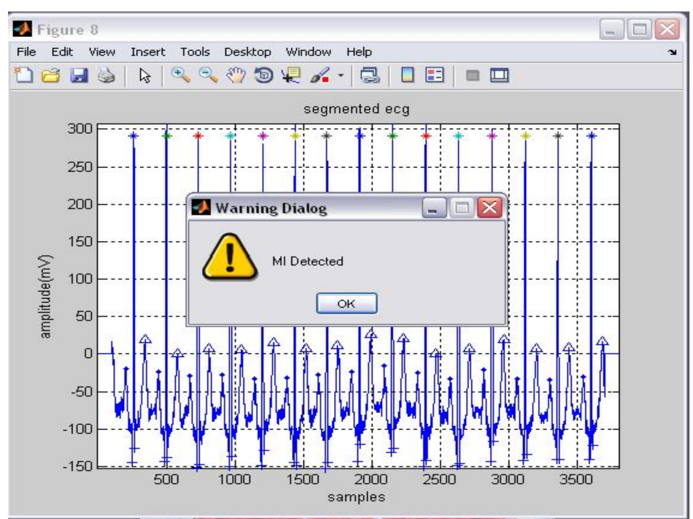

Fig.9 Myocardial infarction detection through processed ECG signal

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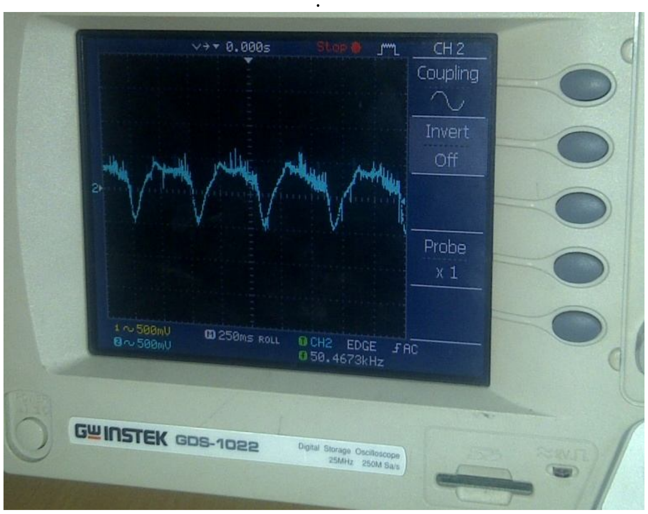

Fig.10 Obtained Carotid artery PPG Signal at the neck

Over the analysis of the system performance, the average sensitivity 93.33%.The inferred results of the proposed system for N trials are tabulated as shown in the below table.4.

Table.4 Accuracy of the proposed system for N trials

	Ischemic ECG Episodes	**Elevated PWV and BP Episodes**	**Both Elevated PWV and Ischemic Episodes**
Subject 1 (N=5)	5	0	0
Subject 2 (N=5)	0	5	0
Subject 3 (N=5)	0	1	4

Where the
Subject 1=Database with deviated ECG signals
Subject 2=Database with Abnormal PPG signals (PWV)
Subject 3=Database with deviated ECG and PPG signals

VI. FUTURE SCOPE

The prototype of the ambulatory device can be further enhanced by detecting all the cardiac diseases and parameters. Also, the prototype can be enhanced for the stroke analysis. Further, this prototype can be designed as a portable hand held device wherein the data analysis is performed by a smart phone in order to interpret the results.

This facility in future may help the care takers, nurses and medical practitioners in providing a preliminary first aid at ambulatory situations.

The clinical history can be maintained for the individual subject which can be an add-on feature of the android application. The signal analysis can be extended in such a modality suitable for remote applications.

VII. CONCLUSION

The presentation of this paper deals with design and development of a low cost, highly feasible device to predict myocardial infarction and stroke. The implementation of this prototype is executed through the design of a customized ECG and PPG signal acquisition units. With the help of this unit, the above mentioned conditions like cardiac arrest, myocardial infarction, hypertension, cerebrovascular accident and other disorders may be diagnosed.

This unit might be used to predict and control the progression of the above disorders. It is evident from the current study that the prediction of stroke and cerebrovascular accidents can be done from the existing commonly monitored physiological signals such as ECG and PPG. The data obtained from this unit helps the cardiologist and other health experts to study and analyze the reason behind the cause for the cardiac and cerebrovascular disorders.

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