MOBILE-BASED TELE-ECG FOR RURAL HEALTH CARE

Electronics Division
and
Bhagyashree Sarode
Senior Research Fellow. BRNS Project
and
P.N. Jangale
Medical Division
and
Alaka D. Deshpande
Medicine Department, Grant Medical College & J.J. Hospital, Mumbai

Telemedicine enables a physician or specialist at one site to deliver health care, diagnose patients, give intra-operative assistance, provide therapy or consult with another physician or paramedical personnel at a remote site. Though, there is no substitute for face-to-face consultation between a clinician and a patient, there are medical cases that can be managed more efficiently, by adopting telemedicine. The concept of Telemedicine was introduced more than 30 years ago through the use of telephone, facsimile machine and slow-scan images. In this approach, the biomedical signal from the patient is transmitted using landlines such as Public Switched Telephony Network (PSTN) or the Integrated Services Digital Network (ISDN). However, these telemedicine applications are limited to communication between fixed locations equipped with conventional handsets. Therefore, there is a trend to develop wireless telemedicine built around satellite communication\(^1,2\). It requires expensive equipment, dedicated links and skilled manpower. Similarly wireless Local Area Networks (LANs) and short-range Radio Frequency (RF) transceivers, as used in hospitals, can’t be used for timely ambulatory applications. To allow worldwide communication, therefore, mobile cellular network like Global System for Mobile (GSM) or better Third Generation network (3G) is needed\(^3\).

Through this, a patient from rural area can be provided with a regular routine check via a mobile phone, without commuting to a hospital. Similarly routine inspections and monitoring can be carried out, while the patient is at home, traveling or at work. This also decreases the load on resources of the hospital, which can now cater to more number of demanding patients.

Vast area with varied topography, more than a billion population, high population per physician (around 2000) and majority of the population (more than 70%) living in isolated villages, support and justify the need for Telemedicine in our country. Though Telemedicine benefits all branches of medicine and surgery, cardiology needs special attention due to its higher incidence rate as well as the risk associated with heart diseases. Many a times, delay in transporting the patient from a village to a nearest city may prove fatal.

In view of the above and the fact that mobile phones are becoming more and more affordable, the Electronics Division has developed a hand-held battery-operated Tele-ECG with mobile connectivity to an expert. The details of this development follow.
What is ECG

Electrocardiography (ECG) is the graphical record of electrical potentials generated by the heart muscle. The history of Electrocardiography folds back to 1889, when Willem Einthoven gave evidence for the first time, of electricity generated by heart in both humans and animals in 1889, during the 1st International Congress of Physiologists in Bale. He obtained the cardio-electrical signals from both the arms and the left leg, with the help of saline solution tubs wired to the input of a String Galvanometer as shown in Fig. 1. He named this signal as ELECTROCARDIOGRAM.

Electrocardiography got an impetus in 1934, with the invention of a special-purpose amplifier called differential amplifier by BNC Matthews. Interestingly, this invention originated from Life Sciences. Matthews modified the configuration of push-pull amplifier (originated in radio engineering as a means for increasing the output power) by carefully matching the tubes for equal amplification and assuring rejection of common mode signals. This development changed the face of electrocardiography; surface electrodes replaced saline tubs and differential amplifier and a strip chart recorder replaced the string galvanometer.

ECG is generally recorded in 12 different configurations by electrodes placed on the body surface, each configuration is called a ‘Lead’. These are named as I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, and V6, popularly known as Einthoven’s Leads. Lead I is the difference between signals appearing at left arm and right arm; Lead II is the difference between signals appearing on left leg and right arm; Lead III is the difference between signals appearing at left leg and left arm; aVR is the signal at right arm measured with respect to average of signals at left leg and left arm; aVL is signal at left arm measured with respect to average of signals at left leg and right arm; aVF is signal at left leg measured with respect to average of signals at left arm and right arm. Similarly Vi (i = 1 to 6) is measured as the signal appearing at ith chest position with respect to average of signals at right arm, left arm and left leg. This average signal is very close to zero and is often referred to as augmented ground or the reference. Leads I, II and III are also called standard leads or bipolar leads, whereas the other leads namely aVR, aVL, aVF and chest leads V1
to V6 are called unipolar leads. Generally any abnormality appearing in a particular lead is corroborated by one or more remaining leads. Fig. 2 shows the placement of electrodes and type of signal recorded in various leads.

Various deflections in the waveform are labeled as P, Q, R, S and T points, as shown in Lead II ECG in Fig. 2. P represents the depolarization of right and left atria. Q, R and S as a complex represent onset of depolarization of right and left ventricles. T represents the repolarization of ventricles. Sometimes there are additional points on the waveform such as U-wave, early and late potentials etc. The segment following T wave, till the onset of the next cardiac cycle, is commonly referred to as iso-electric segment and is used as reference for measurement of amplitude of different waves. Though P and T waves are more or less similar in all the leads except aVR, the morphology of QRS varies significantly from lead to lead as evident from the figure.

Heart diseases are easily detected from the ECG. Some cardiac disorders like thickening of the ventricle, bundle branch block produce electrical axis deviation, which can be detected from bipolar leads. Decreased voltages in the ECG represent diminished muscle mass probably subsequent to series of old myocardial infarctions. Decreased voltage can also be caused by conditions surrounding the heart such as fluid in the pericardium, pleural effusion and pulmonary emphysema. Cardiac hypertrophy or dilation and purkinje system blocks can cause prolonged QRS complex. Highly distorted (bizarre) QRS complexes are noted in destruction of cardiac muscle in the ventricles with replacement by scar tissue and local blocks in the conduction of impulses by Purkinje system. Ischemia and myocardial infarction are associated with significant differences between the levels of ST segment and reference segment. An old recovered infarction is detected by the presence of significant Q wave in the bipolar leads.

Considering the large number of applications of ECG signal in the diagnosis of several diseases and its ability in monitoring critically sick patients, large variety of ECG machines are produced and marketed, by several national as well as international companies. The models have variation in respect of the number of channels, recording options and interpreting provision as follows.

Fig. 2: shows anatomical placement of the electrodes and the ECG signal recorded in various configurations. The difference signals I; II and III are recorded between left arm and right arm; left leg and right arm and left leg and left arm respectively as shown in the figure.
**Diagnostic ECG**

These are ECG machines having 1, 3 or 12 channels of input amplifiers for recording ECG. Twelve-channel machine records all the 12 leads simultaneously, whereas one-channel machine records all the 12 leads one by one and three-channel machine records 12 leads in 4 steps of three leads each. All these models have recording devices including thermal array recorder or an inkjet printer assisted by a micro-controller. Interpretation of ECG is normally available with imported machines, which is presently not available in indigenous ones.

Fig. 3 shows simplified block diagram of a one-channel ECG machine. The electrical potentials from the body are sensed with the help of metal electrodes labeled as RA, LA LL, V1, V2, V3, V4, V5 and V6. These signals are connected to pre-amplifier through amplifier protection and lead selector circuits, which configure these inputs into two differential outputs. The amplifier protection circuit is required to protect the amplifier IC from large voltages coming from the patient due to application of defibrillator or surgical diathermy. The calibration signal is also connected at the input of the pre-amplifier. The pre-amplifier output is used, to generate appropriate signal to be connected to the right leg of the subject, with the help of right leg drive circuit. This is specifically required to remove the mains interference in the output ECG signal. The pre-amplifier output is also connected to a base line restoration circuit in feedback loop. This helps to restore the base line quickly and nullify the change of DC potential at the electrode, when the lead is changed from the lead selector. The output of the pre-amplifier is connected to the isolation circuit as shown in the figure. The voltage supply to all the above blocks, on the left side of the dotted line in the

![Diagram](image-url)
figure, is powered from isolated power supply, which has no electrical continuity with the earthing of mains power supply. This insulation between the commons of these two power supplies gives full protection to the patient against any accidental electrical hazard and keeps the leakage current less than 50 uA, well below the limits provided by international safety standards (IEC 60601-1-1:2000).

The isolation circuit is powered from isolated power supply as well as conventional power supply to input and output segments in this block respectively. These segments have no electrical connection between them. The input signal is transferred to the output section either through high insulation transformer or optically. The output signal from isolation circuit is amplified further by the drive amplifier and finally connected to a recorder. These blocks are powered by the conventional power supply.

A micro-controller and a printer replace the recorder in the latest version equipment, as the use of personal computers and printers has become common. Also the computing power within micro-controller is made use of, in producing the machine-generated interpretation on the electrocardiogram.

More recent systems have 3 channels of pre-amplifiers and following circuits. In this case, the lead selector selects leads in four steps. In Step 1, Leads I, II and III are amplified. In Step 2, Leads aVR, aVL and aVF are amplified. Similarly V1, V2 & V3 and V4, V5 and V6 are amplified in steps 3 & 4 respectively. A compact print out of all the leads is made available on A4 size paper. The latest trend in electro-cardiography, is to record all the 12 leads simultaneously. In this case, the Lead selector circuit is replaced by simple Wilson’s network. Additional 11-channels of pre-amplifier and following circuit are incorporated. The outputs of 12 drive amplifiers are fed to ADC inputs of the micro-controller, which acquires and prints the ECG signal from all the 12 leads simultaneously.

ECG Monitors

For monitoring applications, some of the stringent specifications of ECG amplifiers are relaxed. For instance, the lower 3 dB point can be relaxed to 0.5 Hz in place of 0.05 Hz and the upper 3 dB to 70 Hz in place of 200 Hz. This range is considered adequate for monitoring the status of the patient during surgery and in Intensive Care Units. In this application, the ECG is continuously acquired from the subject in one or more leads and displayed in real time on the CRT Monitor. Alarm facility is provided for undue deviation in the heart rate or change in the status of arrhythmia. Also a 24-hour display is provided to the clinician, who can see on the patient’s status, at a glance.

Ambulatory ECG (Holter ECG)

This application has different requirements than the diagnostic ECG or ECG monitor. In the first place, it has to be battery-operated and ultra-miniaturized as it is to be carried by the patient on his body for 24 hours, while he is performing his daily routine. The unit is supposed to acquire ECG signal from five leads (I, II, III, V2 & V5) and store them in memory. There is also a provision to highlight part of ECG, as and when the patient feels discomfort. At the end of 24 hours, the patient reports to his doctor, who downloads all the data onto his workstation for further analysis. This kind of recording has two main advantages:

1) Detection of angina pain in Ischemic Heart Disease (IHD) patients, which is normally missed in resting ECG and
2) Documentation of the type and severity of arrhythmias in patients with coronary artery disease, who have already suffered myocardial infarction in the past.

Tele-ECG

The concept of Tele-ECG was introduced more than
30 years ago, through the use of telephone lines. However, this application is limited to communication between fixed locations equipped with conventional handsets. The latest trend is to develop wireless telemedicine built around satellite communication\(^1\,^2\), which requires expensive equipment, dedicated links and skilled manpower. Similarly wireless Local Area Networks (LANs) and short-range Radio Frequency (RF) transceivers, as used in hospitals, can’t be utilized for rural applications. Therefore, for worldwide communication and rural health care, mobile cellular network like Global System for Mobile or better a Third Generation network is needed\(^3\).

**Mobile-Based Tele-ECG Developed at BARC**

Tele-ECG system developed at the Electronics Division, BARC, comprises a hand-held ECG (HECG) unit which is connected via bluetooth to a mobile. The HECG acquires and processes the ECG signal of the patient in all the 12 leads in serial order and transmits the same with the help of a mobile tele-processor. At the operator’s end, we have the cellular phone (GPRS activated) or a laptop / desktop. The acquisition unit can be activated, operated and controlled by either of them. All the functions, like changing of lead, viewing of acquired signal, storing of data, transmission of data, saving of a person’s file, etc., can be performed from the mobile / laptop at the operator’s end. Every patient’s data file is stored as a bit map file (bmp/png) in the HECG unit as well as on the mobile / laptop. There is provision for generating automatic unconfirmed report of the patient on the mobile / laptop. If necessary, the operator can send the ECG file of the patient to an expert through GPRS network and seek his opinion for further management.

Fig. 4 shows the details of the HECG unit. The ECG signal from the patient is sensed with the help of surface electrodes labeled as RA, LA, LL, V1, V2, V3, V4, V5 and V6. The right leg is connected to the reference of HECG unit. These signals are connected to input protection circuits and buffers. This is particularly required to protect the sensitive amplifier from the transients coming from the ambience. The buffered signals are passed through a Wilson’s network for deriving differential signals for various leads, which are connected to two 12:1 multiplexers. The output of the multiplexer is controlled through the microcontroller, to output appropriate signals for different leads as follows:

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\(^1\)\(^2\)\(^3\)
The outputs from the multiplexers are fed as input to a differential amplifier followed with a band-pass filter. The gain is fixed as 1000 for first 6 leads and 500 for the later ones. The output of the filter is connected to ADC input of the micro-controller (based on ARM 7 micro-processor). Micro-controller also sends an output signal to multiplexers for selecting a particular lead. An SD-card is also interfaced to micro-controller for providing large storage capacity to the HECG unit. Also a blue tooth controller is interfaced to the micro-controller for transceiving the data, commands etc. from the cellular phone. The final specifications of the Bio-unit are as follows and meet the safety standards as prescribed by IEC 60601-1-1:2000.

<table>
<thead>
<tr>
<th>Lead</th>
<th>O/P of MUX-1</th>
<th>O/P of MUX-2</th>
</tr>
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<tr>
<td>I</td>
<td>LA</td>
<td>RA</td>
</tr>
<tr>
<td>II</td>
<td>LL</td>
<td>RA</td>
</tr>
<tr>
<td>III</td>
<td>LL</td>
<td>LA</td>
</tr>
<tr>
<td>aVR</td>
<td>RA</td>
<td>(LL+LA)/2</td>
</tr>
<tr>
<td>aVL</td>
<td>LA</td>
<td>(LL+RA)/2</td>
</tr>
<tr>
<td>aVF</td>
<td>LL</td>
<td>(LA+RA)/2</td>
</tr>
<tr>
<td>V1</td>
<td>V1</td>
<td>(LA+RA+LL)/3</td>
</tr>
<tr>
<td>V2</td>
<td>V2</td>
<td>(LA+RA+LL)/3</td>
</tr>
<tr>
<td>V3</td>
<td>V3</td>
<td>(LA+RA+LL)/3</td>
</tr>
<tr>
<td>V4</td>
<td>V4</td>
<td>(LA+RA+LL)/3</td>
</tr>
<tr>
<td>V5</td>
<td>V5</td>
<td>(LA+RA+LL)/3</td>
</tr>
<tr>
<td>V6</td>
<td>V6</td>
<td>(LA+RA+LL)/3</td>
</tr>
</tbody>
</table>

The application software on the mobile, first detects the Bluetooth device (Bio-unit) using the Service Discovery Protocol (SDP). Once the device is detected, the application prompts for the subject’s name and starts receiving the CAL signal. This is developed using Java (J2ME). The commands are issued using the key pad ‘1’ for change of lead (lead number is increased by one by the embedded system software and switches back to calibration mode when lead 12 is being acquired). The data received is saved in a buffer (1000 samples per lead, acquired for two and a half seconds). The application software in the mobile gives the facility for converting data into a PNG file and transfer the same via MMS (Multimedia Message Service) to any mobile of choice or it can also be emailed.

An application, which will lead to a diagnosis of the ECG data received, is under development. The application uses an algorithm developed by IIT Roorkee for detection of QRS complex. The information derived from the QRS complex will be used, to provide a machine-generated unconfirmed diagnosis. At present, this facility is being developed as a desktop / laptop based application.

Fig. 5 shows the flowchart of the embedded software, which is developed in ‘C’. The system, on start, initializes the peripherals. The main application is an indefinite loop, which is entered into, after initialization of the timer. The timer handler is invoked every 2.5 millisecond. The handler also reads ADC data and transfers it via the bluetooth port. Also, it looks for commands via the bluetooth port, which may come from a mobile phone or laptop / desktop. The commands will correspond to change of lead (next lead) or start / stop. This will be executed as part of the handler. The initial data is acquired in Calibration mode. This signal also indicates the battery charge level and has been used to flag off battery low condition.

The outputs from the multiplexers are fed as input to a differential amplifier followed with a band-pass filter. The gain is fixed as 1000 for first 6 leads and 500 for the later ones. The output of the filter is connected to ADC input of the micro-controller (based on ARM 7 micro-processor). Micro-controller also sends an output signal to multiplexers for selecting a particular lead. An SD-card is also interfaced to micro-controller for providing large storage capacity to the HECG unit. Also a blue tooth controller is interfaced to the micro-controller for transceiving the data, commands etc. from the cellular phone. The final specifications of the Bio-unit are as follows and meet the safety standards as prescribed by IEC 60601-1-1:2000.

<table>
<thead>
<tr>
<th>Input Impedance</th>
<th>&gt; 10 Mega Ohms</th>
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<tr>
<td>Gain</td>
<td>1000/500 (selectable)</td>
</tr>
<tr>
<td>Frequency Response</td>
<td>0.05 Hz to 150 Hz (3dB)</td>
</tr>
<tr>
<td>Common Mode</td>
<td>&gt; 80dB</td>
</tr>
<tr>
<td>Rejection Ratio</td>
<td></td>
</tr>
<tr>
<td>Patient Isolation</td>
<td>&gt; 10 Mega ohms</td>
</tr>
</tbody>
</table>
rechargeable battery and connecting leads. The box dimensions are less than 4.5 x 3.5 square inches and can be called handheld in true sense. The ECG acquired from a subject in Lead II and displayed in the mobile at the operator’s end, is shown in Fig. 6 (b). The ECG received at the expert’s mobile is shown in Fig. 6 (c). As can be seen there is no significant loss of information from Fig. 6 (b) to Fig. 6 (c). This Tele-ECG system has been tested in the laboratory on volunteers and is ready to be sent for field trials.

Fig. 5: Shows the operative scheme of the embedded software in the Tele-ECG unit and mobile application.
The Tele-ECG system, reported here, is of considerable importance for developing countries, where more than 70% of the population inhabits rural areas and has meager access to medical facilities. This large section can now be provided state-of-the-art medical care with such Tele-systems.

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References


