A Proposition for Low Cost Preventive Cardiology for Rural Health Care System

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Abstract:

Recent studies indicate that cardiovascular disease is the leading cause of death for several million people annually. New habits, practices and lifestyles have introduced newer ailments that the public health care system of a country has not always been able to cope up with.

Of late, need for effective preventive cardiology has been advocated by several researchers[Pad'05]***. An important component of effective preventive cardiology is to collect, monitor and maintain health data of the target population*** [Low'01], [Gup'01], [NCMH'05], [Roy'03] ***over an extended period of time.***

In this paper, we propose a low cost methodology for collection, distribution and dissemination of information related to the cardio vascular system for rural population in a developing country.

The authors have developed a low cost version of a data collection equipment. Such a signal acquisition equipment, along with a few accessories may be sufficient for several tasks such as: a) collection of preliminary health data from house to house for a large population group, b) storing the data conveniently, c) basic analysis of data and diagnosis and d) transmission of data to the higher referral centre within a radius of 8-10 Kms even without the requirement of any conventional network connectivity. Sample waveforms for several biomedical signals have also been presented.

I. Introduction:

Cardiovascular disease is the leading cause of death worldwide, accounting for more than 16 million deaths annually [*WHO*]. The majority of these deaths are now seen in the developing countries and they occur earlier in life in developing regions than in developed countries. Different age groups are affected in the same pattern and the future predictions are worse for the young and middle-aged population. India is one of the fastest growing economies in the world. Rapid urbanization, introduction of new agricultural technologies and benefits of open trade is changing the economy of rural India. It is of concern that the fast changes have also created a perceptible degree of instability in the social and cultural life of the villages. Newer habits and practices are being identified as causes of ailments that the health care system of the country has not been able to keep pace with. It is noteworthy that our health system is primarily geared to cope with infectious diseases while the instances of chronic diseases, accidents and self-inflicted injuries are on the rise. For example, very little attention has been paid to adult deaths while the emphasis has been on reducing infant, child and maternal mortality rates.

It has been established by several research studies all over the world that major health gains can be made through the implementation of primary care interventions and basic public health measures targeting life style, diet and environment. Low cost strategies to improve detection and treatment rates are expected to fetch significant health benefits.

Information and communication technology (ICT) is playing a vital role in every sphere of modern life including education, health, administration and business. It can be used to create an essential health database of all people, which is the basic requirement for disease mapping of a region and draw appropriate plans. The emerging concept of e-health is about delivering viable health services using the tools of ICT to patients irrespective of their social status, place of stay and economic condition. Thus e-health is likely to promote healthy living and adoption of healthy life style. Preventive cardiology, when adequately supported by ICT, can take an important role in improving public health.

Burden of Coronary Heart Diseases in India

According to [Par'05], rural India has entered Phase I of the cardiac health disorder (CHD) pandemic that is presently a major concern in most of the developing south Asian countries. The implication is that if preventive measures are not introduced soon the situation may be well beyond control. WHO predictions hold that by 2020 AD cardiovascular diseases will claim the life of 2.6 million Indians, a significant percentage of which will be from villages and slums. In this context, it is important to note that Indians experience CVD deaths at least a decade earlier than their counterparts in developed countries i.e. at a mean age of 56.6 ±12 years in men and 61.8±10 years in women.

The Global Burden of Diseases (GBD) study reports an estimated mortality of 1.6 million from coronary heart diseases (CHD) in India [Gup'01]. Epidemiological studies have shown that the burden on rural health is 3-5%, a figure that cannot be ignored. The estimated cost incurred directly by the health sector for CHD is about Rs 100 billion while the indirect cost may accumulate up to another Rs 100 billion, totalling 0.8% of GDP. Apart from the adverse effects of such figures on the national economy, premature disabilities cause significant psychological and financial burden on the affected families the extent of which is difficult to calculate.

The three prime factors taken into consideration while monitoring health of a population are mortality rate, morbidity rate and life expectancy. A report from [NCMH'05] shows that population in rural India is growing more rapidly (birth rate: 26.4%) than in urban areas (birth rate: 19.8%) and that the death rate is also higher (8.7% compared to 6.0%).

Coronary artery disease and coronary risk factors have become prevalent among uneducated people and people belonging to lower socio economic classes. A rural-urban comparison shows that while the prevalence has increased 2.06% in the rural areas in the 1970s, the rise has gone up to 414% in the 1990s.

In this paper, we propose a low cost methodology for collection, distribution and dissemination of information related to the cardio vascular system for rural population in a developing country. Previous studies have reported that major incidents of CVD in rural population include different abnormalities that are manifested in ECG, ankle-brachial index, arterial compliance and insufficient hemoglobin in children and pregnant women. A non-invasive approach is advocated for preliminary assessment of CVD by collecting the following biomedical signals: a) 3-lead ECG, b) Phonocardiogram, c) Plethysmograph, d) blood pressure and e) pulse oximetry. As all the signals can be obtained in a non-invasive way, this approach offers several benefits such as the following:

a) low cost of diagnostic tests,
b) average time of data collection per subject is low,
c) no risk to the subject is involved,
d) easier to train and orient paramedical staff,

e) low capital investment necessary for integrating the new scheme with the existing public health system,
f) automated record keeping and
g) possibility of simultaneous acquisition of multiple signals.

The last attribute is of special significance in this context as it makes measurement of several important time intervals (such as the Q-R interval, pulse transit time and so forth) possible in a cardiac cycle.

II. Need of Preventive Cardiology for Rural India:

As mentioned earlier, the basic health problems of rural people in India is still associated with communicable diseases, parasitic infestations and deficiency disorders all of which are related to low literacy rate, poor living conditions and lack of balanced diet. However these have been the problems for ages now and the health sector is aware of the problems and ways to tackle them. Various national level Health Programs have been targeted at these problems time and again. As a result, our health infrastructure is fairly equipped to manage most of the situations. For example, immunization programs are conducted successfully, potable water has been provided to many villages and health awareness among the rural populace has been elevated with the help of media propaganda and rural health workers.

However, with higher per capita income, the rural people are adopting new life style, food habits and addictions thus inviting a possible endemic of the so-called life-style diseases. Very little attention has been paid to adult deaths caused directly or indirectly by these and other related factors. A major attention now needs to get focused on these so-called modern diseases that are fast emerging in our rural society. The particular health problem we have tried to focus in this paper is the emerging global pandemic of coronary artery diseases.

*Existing Rural Health Infrastructure***:**

Although Indian health infrastructure lacks sophisticated diagnostic and treatment facilities or health insurance scheme for the general population, there is an integrated network of rural health centers and subsidiary heath centers along with health workers strewn across the country. The health manpower figures available in 2005 show that there are 21974 doctors in the PHCs, 20086 male and 19773 female Health Assistants along with 60756 male and 138906 female health workers in rural India. This strong manpower and basic health infrastructure can be very effective in creating a health database for the residents of every village so that the cardiovascular risk factors can be monitored at regular intervals to identify the at-risk population who would require intervention of any kind. Different investigations show that on an average 89% of rural Indians have to travel about 8 Km to access basic medical treatment. If a data collection and analysis center (kiosk) can be set up for every 4-5 neighboring village over a radius of 6-8 kms it will be approachable and practicable in many respects.

In the following section we describe a data collection platform, which may be effective in collecting preliminary cardiovascular health information over a period of time. Multiple biomedical signals are to be collected following non-invasive measurements. A special feature of the system is that upto four cardiovascular signals can be measured and stored simultaneously. Simultaneous measurement of multiple signals pertaining to cardiovascular system is expected to help in parametric modeling of a section of arteries. The scheme also has a provision to transfer collected health data to a distant database using wireless techniques.

III. Design and Description of Data Collection Platform Following a Non-invasive Approach:

In this section we briefly describe the major elements of our scheme. As shown in Fig.1, the system consists of a data acquisition unit (DACU) housing four transducer units and the necessary signal conditioning and amplification circuitry. These units consist of analog electronic circuits, such as low frequency amplifiers, active and passive filters and dc-offset circuits. The DACU also includes digitization circuitry and plug-and-play type USB interface so that the unit can directly communicate with a PDA (or a local computer). The handheld computer (PDA) is an important element in our scheme as it facilitates easy storage of data locally in a mass storage device and digital signal processing facilities. It also allows connectivity to a variety of wireless transceivers, such as a GPRS enabled cellphone or an IEEE802.11b/g compliant wireless access unit. If no wireless infrastructure is available in a remote location, proprietary wireless systems may be used. For example, a frequency-hopping based wireless transceiver from MaxStream has been successfully used by the authors through RS-232 interface. The remote database, noted in Fig.1, may be located in a primary health center (PHC) or in a health kiosk that can cover a population of 25,000 or more.

In the following, we describe the portions of the transducer and signal conditioning units as has been designed and tested by the authors.

ECG Amplifier

An ECG amplifier is a low-frequency differential bioelectric amplifier. The main challenges involved in ECG amplification are:

- DC electrode offset potential
- 50 Hz AC induced interference from power line.

The problem of DC electrode offset potential was mitigated using silver-silver chloride (Ag-AgCl) electrodes as it approximates a non-polarizable one.

Since the circuit is dc coupled and has a high gain (1000V/V), it only works when the electrode offset potentials are low (<10mV) to avoid instrumentation amplifier output saturation. Restoration of dc allows much larger offsets to be tolerated. To remove the motion artifacts, which can go upto ± 500mV, a dc restoration amplifier is used in a feedback arrangement. The feedback circuit is a low pass filter which responds only to dc signals below its cutoff frequency (0.05 Hz.). Seven Op-amps have been used to design the ECG amplifier.

Plethysmograph:

For photoplethysmographic measurements a reflective type sensor unit has been designed using TIL78 (IR LED) and TIL32 (Photodiode) with peak spectral response at 940 nm. The PPG waveform was recorded using both transmission and reflective modes. The sites of recording included the fingertip and the brachial artery near the elbow region.

The PPG circuit comprises a constant current source driving an infrared LED. The infrared (IR) detector comprises a photodiode and a current to voltage converter, detecting the transmitted or reflected light through the finger. The signal from the photodiode contains a large DC component or offset. Superimposed on this is an AC characteristic reflecting the pulsatile component of the circulation that we want to observe and record. This component can vary from 0.01% to 1% of the DC level. A DC restoration circuit is used to get rid of the unwanted DC, so that proper amplification of the AC signal was possible without saturating the amplifier circuit. Before amplification the signal was filtered using two stages of fourth order Butterworth Low pass filter of cutoff frequency 25Hz.

Multiple prototypes of both reflective and transmissive probes have been designed and tested in the lab.

Pulse-Oximeter:

Pulse Oximeter measures the oxygen saturation (SpO_2) of arterial blood and pulse rate by non-invasive technique. The ratio of Red and Infrared Signals after normalization is calculated and is related with arterial oxygen saturation.

The designed Probe for pulse oximeter (reflective type) consists of two narrow band GaAs LEDs as sources of light and two detectors. One is Red LED of *660* nm and the other one is Infrared LED of 940 nm. Separate matched photo detectors are used for detecting the two lights respectively. The ambient light interference is detected by switching the transmitting circuit off for both the red and IR modules separately. The detected signal consists of a cardiac synchronous AC signal from arterial blood superimposed on a DC level. The DC level depends on LED intensity, tissue absorption, path length and detector sensitivity. This signal has been passed through two stages of fourth order low pass Butterworth filter of cutoff frequency 25 Hz. Since for calculating SpO_2, both AC and DC amplitudes are important, they are separated at the initial stage and then appropriate gain is provided so that both AC and DC can be measured reliably.

Phonocardiogram:

The phonocardiograph is a contact or air coupled acoustic microphone held appropriately against the patient’s chest. We have used a condenser microphone (CZ034 from Ringford) that can record the heart sound directly from the chest with proper arrangement. Abnormal sound usually ranges between 4Hz and 2 KHz. A low pass fourth order Butterworth filter has been designed with a cut-off frequency of 2 KHz. To remove the DC baseline shift due to motion artifact DC restoration circuit has been used.

Digitization Unit:

The digitization unit consists of an Analog to Digital converter and a proper interfacing circuit that can communicate with another device like a PDA or a PC. The scheme for collecting the four signals at different sampling rates is shown in Fig.2. The reading sequence for different channels is shown in Fig.3, so that proper sampling frequency for different channels can be maintained.

IV. Results and Observations:

Fig.4 shows a typical Lead II ECG as obtained in the laboratory after transmission of the signal through wireless medium to a remote PC. The signal presented here is without any post processing and all the important segments like QRS complex, ST segment are clearly identifiable. Algorithms for determining heart rate and different timing intervals from the collected ECG signals have been developed and the results obtained are encouraging. We have collected ECG data for more than 50 subjects and in almost all the cases the data were interpretable and there were no problem with the developed hardware.

Pulse Wave Velocity (PWV) has been measured for different subjects from multiple PPG readings as well as from PPG ECG readings taken simultaneously. Table 1 shows PWV measurements done with multiple PPG readings taken from the hardware developed by the authors. The delay between two PPG readings have been measured and the average value is taken as Pulse Transit Time (PTT). By measuring the distance between the two sites of PPG recording (d), PWV was calculated as:

$$PWV = \frac{PTT}{d}$$

The Bramwell and Hill equation has been used to calculate arterial Distensibility (D) from PWV. ρ is the density of blood and is taken to be 1060Kg/m^3.

$$D = \frac{1}{\rho * (PWV)^2}$$

The results show that the PWV tends to increase with an increase in age. Along with it the arterial distensibility decreases with increasing age indicating that with age arteries become rigid and loose their elasticity.

Table 2 shows the PWV measurements using simultaneous reading of PPG and ECG. Fig. 5 is a snap shot of simultaneous reading of ECG and finger PPG.

Pulse oximeter measurements have been carried out in both time domain and frequency domain and results are shown in Table 3 and 4 respectively. A typical waveform collected using the designed hardware is shown in Fig. 6. A study on determination of SpO_2 by spectral analysis of collected data has also been carried out [Ana'06].

Fig.7 shows the phonocardiogram recording of a subject in the laboratory environment using the designed hardware. The first and second heart sounds are clearly visible in the collected data. We have also converted the collected data back to sound file and could hear the heart sounds with much clarity and flexibility.

A prototype of the signal conditioning and processing unit is shown in Fig.8. The size of the PCB can further be reduced using multi-layer PCB instead of single layer one.

V. Conclusions:

In this paper, a low cost methodology for collection, distribution and dissemination of cardio vascular signal for rural population has been proposed. A non-invasive approach has been followed as it may lead to several advantages. Design of a signal acquisition unit has been presented in detail and supplemented with sample waveforms as obtained in the laboratory using the prototype unit.

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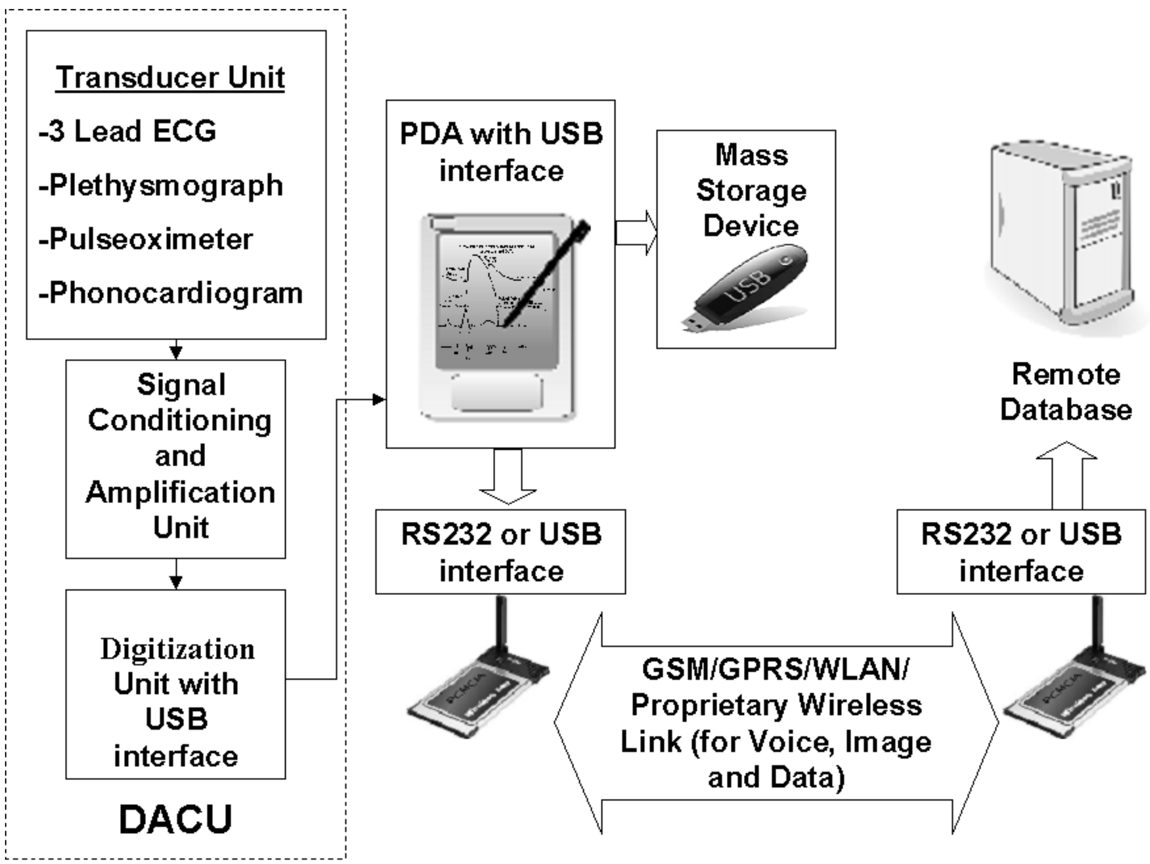


Fig. 1 Block schematic diagram of the wireless tele-monitoring system including the signal acquisition unit (DACU)

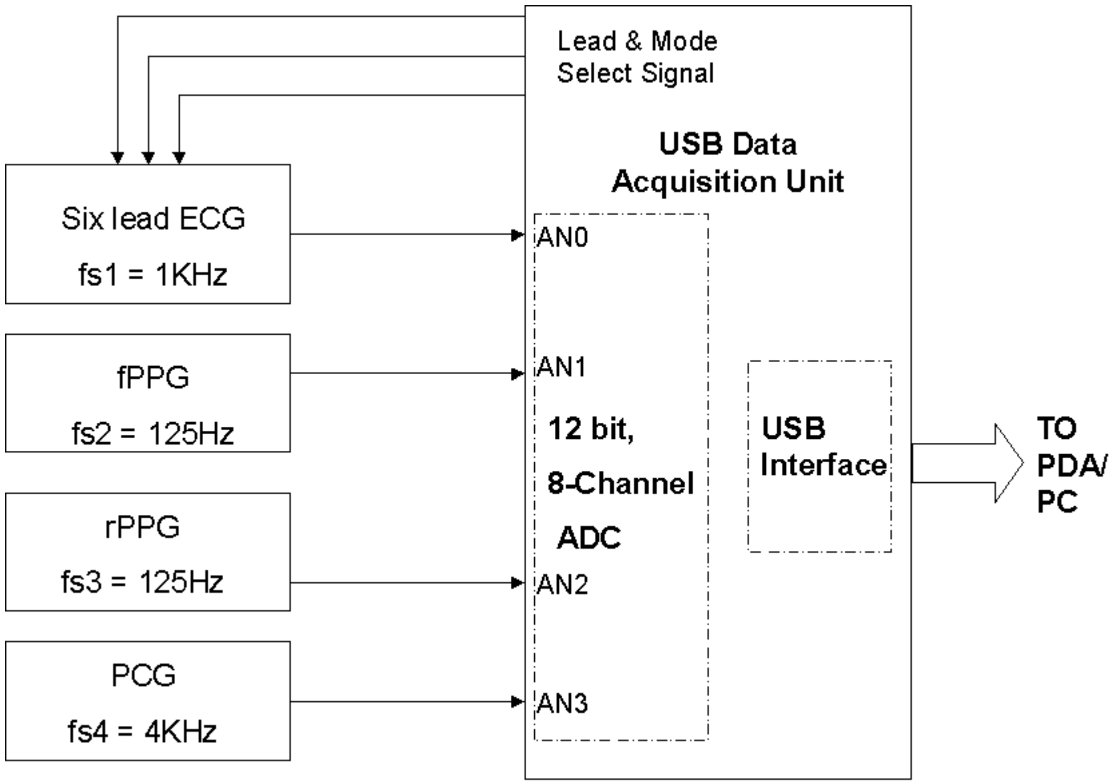
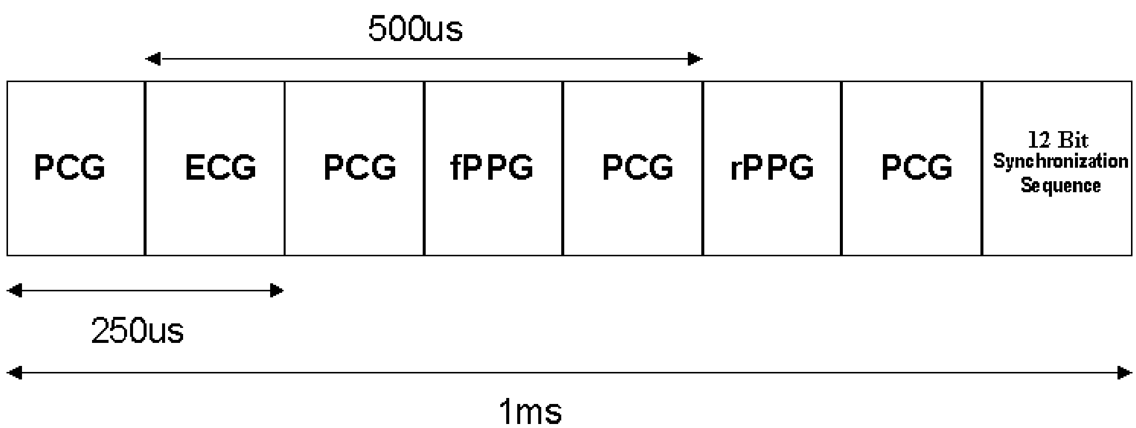


Fig 2. Block diagram of Multi-Signal Acquisition unit



PCG: One sample of phonocardiogram; ECG: One sample of ECG

fPPG: One sample of finger plethysmograph; rPPG: One sample of brachial plethysmograph;

Fig. 3. Multiplexing format for different signals.

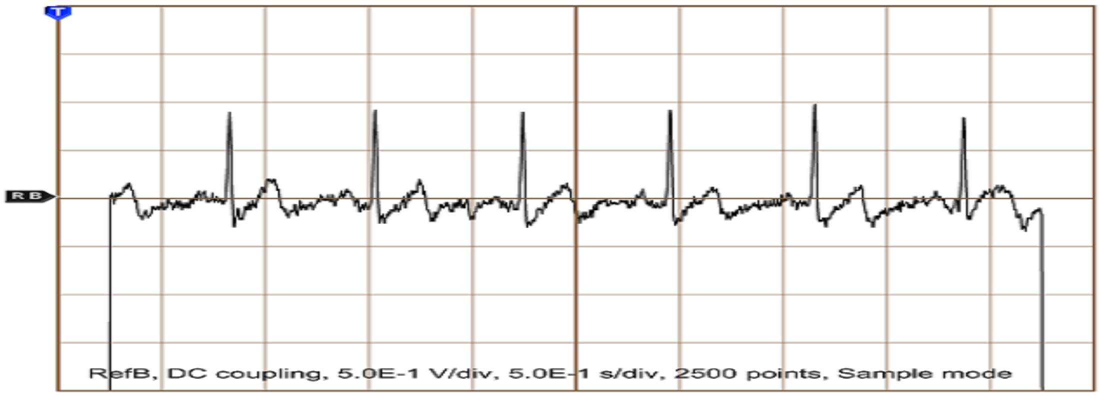


Fig. 4. Lead II ECG signal Collected using our ECG amplifier

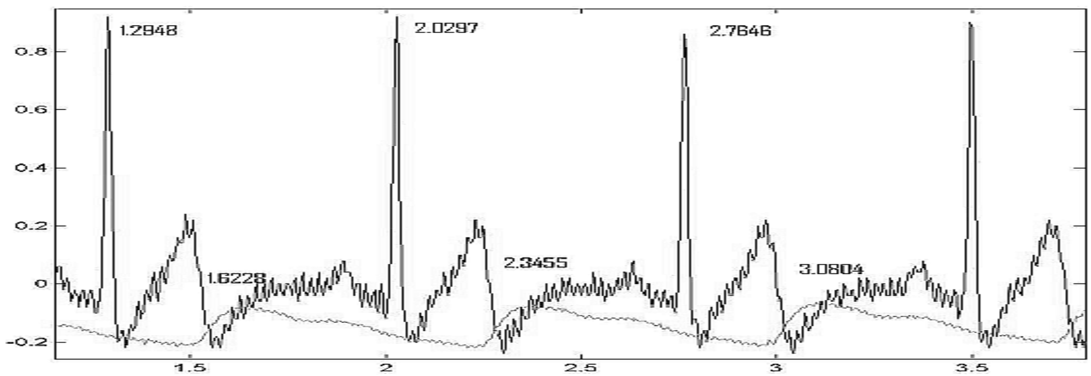
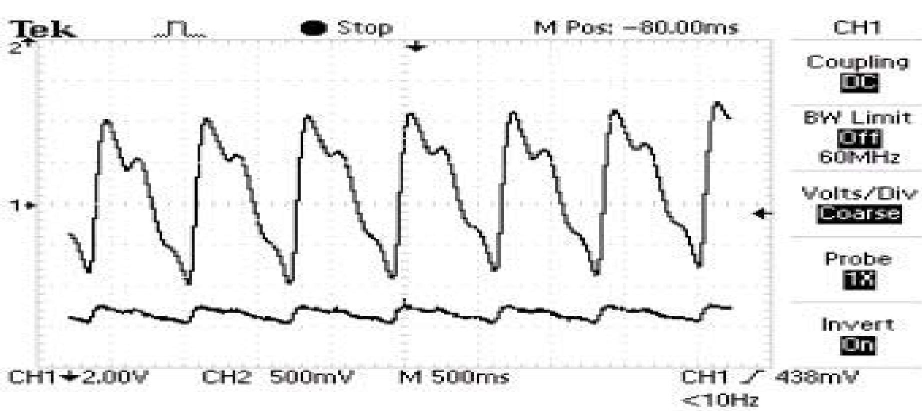


Fig. 5. ECG and PPG signals recorded simultaneously for determination of PTT



Waveforms of AC and DC components of a young healthy subject of 25 years using the IR module [Time Scale 500ms/Div]

Fig. 6. Sample of a pulse oximeter reading as obtained

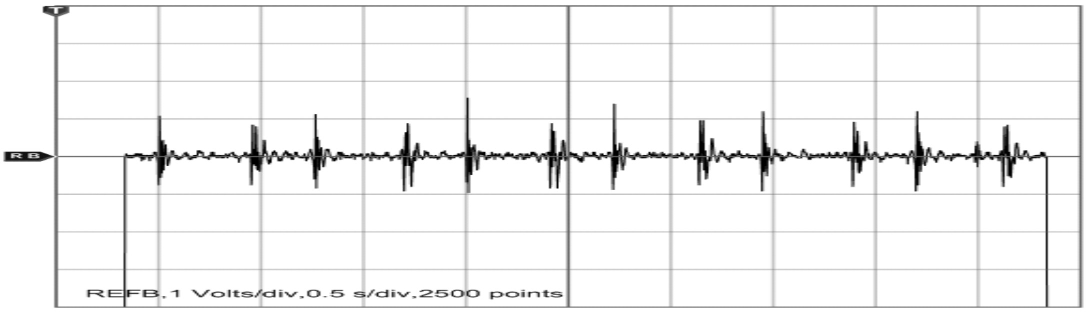


Fig. 7. PCG recording of a 45 year old subject using our PCG Amplifier.

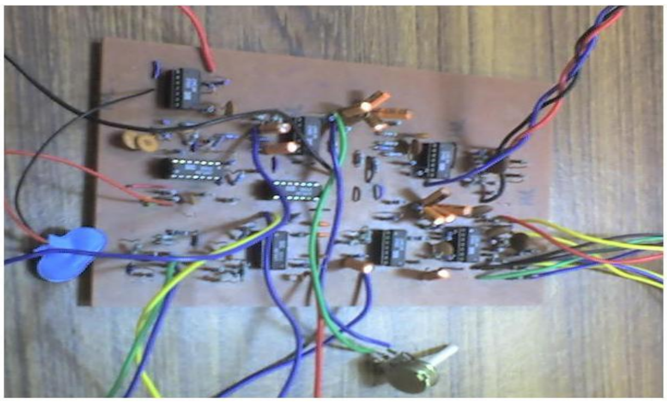


Fig. 8. A prototype of the signal conditioning and processing unit

Table 1. PWV measurements using multiple PPG readings

Subject number	Age	PTT (milli secs)	d (cm)	PWV (ms^{-1})	D (ms^2Kg^{-1})
1	22	52	42	8.07	1.45×10^{-5}
2	22	58	44	7.6	1.63×10^{-5}
3	24	53.5	35	6.54	2.2×10^{-5}
4	27	58.6	42	7.15	1.84×10^{-5}
5	41	46.5	42	9.032	1.15×10^{-5}
6	50	32.5	35	9.3	1.09×10^{-5}

Table 2. PWV measurements using ECG-PPG readings

Subject Number	Age	T2 (s)	T1 (s)	PTT (s)	d (cm)	PWV ms^{-1}
1	27	202	150	52	42	8.1
2	42	228	170	58	40	7

Table 3. SpO_2 measurement in time domain [Ana'06]

Red Signal				Infra Red Signal				R/IR= $(AC/DC)_{Red}$/ $(AC/DC)_{IR}$	SpO_2(%)= 110-25x(R/IR)
AC (p-p) (mV)	DC+ Ambient (V)	Ambient (V)	DC (V)	AC (p-p) (V)	DC+ Ambient (V)	Ambient (V)	DC (V)		
360	2.8	2.15	0.65	3.5	3.7	0.80	2.9	0.46	98.5
280	2.8	2.25	0.55	3.4	3.8	0.78	3.02	0.452	98.7
240	2.85	2.4	0.45	4.0	4.2	0.8	3.4	0.45	98.75
280	3.0	2.4	0.6	3.0	4.4	0.9	3.5	0.54	96.5
320	2.85	2.25	0.6	2.8	4.0	0.8	3.2	0.6	95
200	2.9	2.35	0.55	2.0	3.2	0.78	2.42	0.44	99
240	2.25	1.10	1.15	1.4	4.7	0.68	4.02	0.60	95

Table 4. SpO_2 measurement in frequency domain [Ana'06]

Red Signal		Infra Red Signal			R/IR	SpO_2 %	Mismatch with time domain measurement
AC Value (in dB)	DC (in dB)	AC value (in dB)	Cardiac Freq.(Hz)	DC (in dB)			
-121.3	0	-114.8	1.465	0	0.47	98.25	0.76 %
-128.7	0	-124.4	1.465	0	0.61	94.75	0.26 %