DESIGN AND DEVELOPMENT OF A LOW COST PERSONAL COMPUTER BASED ECG MONITOR

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ABSTRACT: ECG equipment is vital for diagnosis of cardiac problems. However, such equipment come from the rich Western countries at a huge cost in both procurement and maintenance, and therefore cannot offer services to a large population in the Third World countries. The only solution is to design and develop such equipment in individual countries by developing local expertise. With three decades of experience, the Dhaka University group has taken a step towards developing prototypes of ECG equipment for dissemination to the healthcare service providers. This paper presents the detailed design of an PC based ECG equipment where optimized choice of components and of the design have been made keeping the cost and maintenance in view, but not sacrificing the quality, and incorporating necessary safety features to protect the patient from known hazards. Both the hardware and the software have been developed locally and are detailed in this paper. Outputs obtained from human subjects are shown which are of reasonable good quality, and have been verified using standard ECG equipment. The PC based ECG system will allow digital post processing of signals for improved diagnosis through software. Besides, this can also become part of a nationwide telemedicine system.

Keywords: Low Cost ECG, PC based ECG, Low cost healthcare

1. INTRODUCTION

ECG stands for Electrocardiogram- electrical picture of the heart. The electrical activity of heart muscles in the form of depolarization and repolarisation of muscle fibres is the basis of the contraction of heart muscles which is responsible for the vital function of pumping blood around the whole body, and thus keeping us alive. The electric field generated due to the charge separation around the muscle fibres of heart is propagated through the composite aqueous dielectric and conducting medium of the human body and is available on the surface of the human body in the form of a time varying voltage signal. This when measured between a pair of suitable points and displayed in time using appropriate apparatus, is called an ECG. The ECG has particular shapes for particular combinations of points on the human body, which can be understood given the geometry and composition of the human body. It reveals the heart-beats, as well as the size and position of the chambers, presence of any damage to the heart and the effects of drugs or devices used to regulate the heart. ECG monitor has been a mature technology since Doctor William Einthoven in Holland detected human ECG first in the early nineteenth century. However, because of the technological and economic disparity between countries of the world, and commercialization of such equipment by manufacturers in only rich countries have caused an unwelcome situation whereby a majority of global population living in the deprived countries are yet to get the benefits of such modern methods of healthcare, even more than a hundred years after the invention of ECG equipment [1, 2]. We feel a remedy is only possible if such healthcare equipment are developed indigenously in each country. This was the motivation to develop an ECG monitor indigenously by developing our own technological expertise. We also chose to develop a PC based ECG equipment since this will reduce much of the hardware complexity required for storage and graphical display of data. Since low cost PC's are widely available in most of the Third World which can be easily maintained, such a design concept appears to be feasible as a reasonable solution to the above problem.

This equipment will reach the common people at an affordable price, and repair and maintenance will be guaranteed too, enabling the same equipment to be used for many years. The PC based data acuisition sytem of the device will also enable it to be further used as a work station providing the facility of post processing, online monitoring and telemedicine puposes. This paper will give a detailed overview of the design aspects of an ECG amplifier, data acquisition technique, the challenges, and the modes of the solution offered in the present work.

2. METHODS

2.1 Design considerations

Depending upon the system and types of analysis required, the most popular ECG setups have 3, 5 or 10 skin surface electrodes attached to various places on the body for sensing the signal. Amplitude of ECG signals range in magnitude from 100 µV up to 3 mV while the frequency content is between 1Hz and 100 Hz. However the signal is associated with noise, the main source being the 50Hz mains which falls within the ECG frequency band, and is typically 10 or 20 times larger. Therefore, if picked up and amplified conventionally with one input port that are used in most normal applications such as audio microphone amplifiers, this 50Hz noise will dominate and the ECG cannot be deciphered properly. Again, filtering out such a large 50Hz signal is not feasible since it will take out some information from the ECG signal itself. A differential amplifier can be used to advantage in this situation since the 50Hz noise voltage is almost the same throughout the body which is said to be in ‘Common Mode’. Taking the difference across the heart will pick up the ECG while discarding the common mode 50Hz noise to a great extent. A special type of differential amplifier, called an Instrumentation Amplifier with two inputs whose potentials are measured with respect to a common terminal, is used in practice. Subtraction of the two inputs results in elimination of the common mode noise. In this way, the common mode 50 Hz noise may be reduced by 80dB (10,000 times) or more, called the Common Mode Rejection Ratio (CMRR). The input impedance of such an instrumentation amplifier is very high which helps to overcome the voltage dropped across electrode contact resistances, which are typically of the order of 10kohms at low frequencies.

The electrical potentials on the body are picked up using metallic electrodes which essentially act as transducers since the ionic current inside the body has to be converted to an electronic current in the outer circuit. Such electrodes are associated with high contact resistance, as mentioned above, slow varying contact potential, and polarisation effect, posing some difficulty in sensing the desired potentials. The high contact resistance contributes to a drop of potential across it, reducing the measured value of the potential. This effect is minimized using an instrumentation amplifier with high input resistance, typically more than a few Mega ohms. A high contact resistance in the common electrode of the instrumentation amplifier also reduces Common Mode Rejection Ratio (CMRR) increasing the noise in the output.

If we simply place a dry metallic electrode on the skin the contact will not be good. Usually greasy materials and dirt are present which obstructs the current. Therefore the skin needs to be cleaned using alcohol, or at least using water soaked tissue paper or cloth. The characteristic roughness of skin produces air gaps with the electrode. Besides there is a dead skin layer (which is normally present for our protection) which if dry would not conduct current. Therefore we need a moist condition between the electrode and the skin, which can be affected by placing a pad of cloth or tissue soaked in tap water or in saline under the metal electrode. A conducting electrode jelly (available commercially) may also be used under a metal electrode.

As mentioned before, the current inside the body is carried by ions while in the outside metallic wires it is done by electrons. So the electrode essentially acts as an interface between two types of conduction. This metal-electrolyte interface is essentially a half of a battery cell (called half-cell in Chemistry). The electrochemical processes that are of concern here are the *Contact Potential* and *Polarisation*. Contact Potential is essentially a dc potential created at the interface because of initial transfer of charges between the metal and the electrolyte creating a double charge-layer (similar to that in a semiconductor pn-junction), which block further transfer at equilibrium. In any potential measurement we use two similar electrodes which ideally should have the same contact potential and should cancel each other when put into a closed circuit. However, body fluids underneath the electrodes are not stable contributing to small drifts in the contact potential which manifest as low frequency (~ 0.01 Hz) noise in the measured signal. In most of the signals like ECG, EMG and EEG, the lowest frequency content is much above this value and therefore it is possible to filter out the noise due to contact potential drifts using a high pass filter.

Polarisation arises due to generation of gas bubbles (H_2 and O_2) at the electrodes during the charge transfer processes if there is a net dc current in the measuring circuit. This happens because input circuitry of any amplifier will have some input dc bias current, however small. The generated gas molecules attach themselves to the electrodes forming insulating layers, thus gradually increasing the electrode resistance. The best way to eliminate polarisation is to use Silver-Silver Chloride (Ag-AgCl) electrodes which actively participate in the charge transfer process, and no gases are produced. An alternative is to have a high input resistance of the amplifier and to keep the input bias currents negligibly small. Integrated Circuit (IC) amplifiers with bias currents of the order of nA or less are needed.

In our case we have used an integrated (IC) instrumentation amplifier named AMP-02. This IC amplifier has a CMRR of more than 100 db at DC. Of course the CMRR decreases slightly with frequency, and any mismatch between circuit parameters of other components in the dual input circuit will contribute to a degradation of the CMRR. Therefore all these parameters, even the physical layout of the components, have to be considered in detail to get a good quality ECG system.

Safety to patients is also an important consideration. Normally it takes about 75mA (at the main line frequency of 50Hz) to cause a fatal shock if a person touches an electrical wire with hands. At about 10mA, we just feel a mild sensation, the threshold. All electrical equipment have leakage currents much lower than these. However, some accidents with electrical equipment in hospitals led to the discovery that if a direct electrical connection from the heart muscles is brought out (as done before the fitting of an artificial pacemaker) and if only a minute amount of current (~50µA) at or around the main line frequency of 50Hz flows though it, the patient may die of an electrical shock. This was termed Microshock and all hospital equipment should have leakage currents much below this value. This increased the challenge and sophistication of hospital equipment very much. To ensure patient safety the circuit has to be divided into two parts- isolated and non-isolated. The patient is connected to the isolated part of the circuitry which has to be electrically isolated from ac mains connected non-isolated part of the circuit. This cannot be avoided if the Computer as used here is mains powered. In the present work it was decided to operate the isolated section using a battery and to optically couple the signal to the non-isolated part of the circuitry.

2.2 Design of the PC based ECG system

Fig. 1 shows a block diagram of the developed system. Three electrodes attached to the patient are connected to the front-end section of this amplifier the output of which is taken to an opto-isolator unit. The electrical output of the opto-isolator is further amplified and filtered and is fed to an Analogue to Digital Converter (ADC). The ADC is interfaced to a Personal Computer (PC). Data acquisition, data storage, analysis and graphical display are all performed through software, developed in the present work.

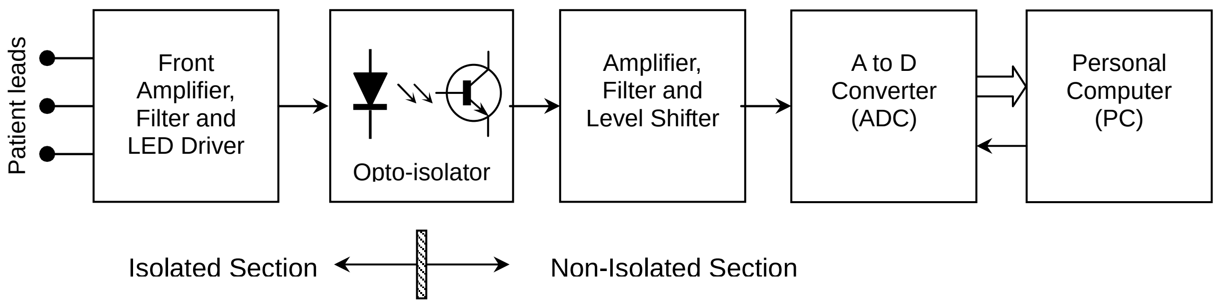

Fig. 1: Block diagram of total PC based low cost ECG system

In the developed system the isolated front end section was powered by a battery, thus no isolation circuitry was needed for power. However, the analogue ECG signal has to be eventually transferred to the mains ac powered non-isolated part of the circuitry, and this also needs isolation. For this purpose an optical isolation system was developed which passes the analogue signal without having any direct electrical connection between the two sides.

The front-end section of the isolated amplifier includes an instrumentation amplifier, filters and driving circuitry for the following opto-isolator section. The opto-isolator also helps reduce the mains ac borne noise. The output of this opto-isolator connects to the non-isolated part of the system that eventually links to the mains powered PC. Firstly the opto-isolator output is amplified and filtered further, and conditioned through voltage level shifting to suit the input requirements of the following ADC circuitry. The ADC is finally interfaced to the PC through its parallel printer port. On program control the PC sends commands to the ADC and acquires data as designed. The data is stored, further analysed and displayed graphically on the PC monitor.

In the present design the isolated segment is powered by a two miniature 9V rechargeable batteries making a total of 18V. Obtaining power from a battery makes the power isolation simple. The front end circuitry needs a dual power supply with both positive and negative rails. This was achieved using electronic circuitry which provided + 9V and -9V with a common ground, or zero potential by dividing the 18V battery supply. This could have been done through the two 9V batteries directly, however, the above design was chosen for user friendliness and practicality as described below. In the developed system the battery charger was external, and the use of a single battery voltage will need only two wires in a socket for charging both the batteries, which keeps the circuitry and the connections simple. Keeping the charger outside the main box was also deliberate. Since the battery charger derives power from the mains, it cannot be kept connected to the ECG unit while the patient is connected during a study. The charging should be done only when the unit is idle, not connected to

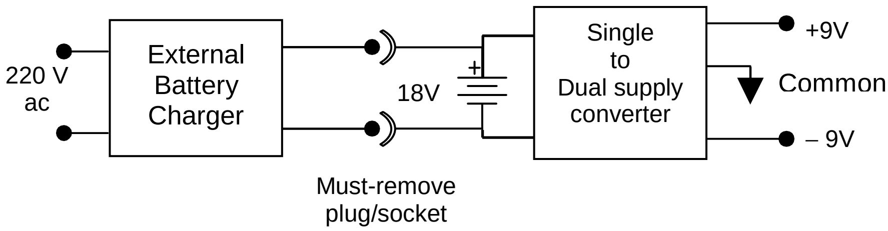

Fig. 2: Design of rechargeable battery based isolated dual rail power supply

any patient. To ensure this a further design idea was incorporated. The input leads to the patient and the connections to the external battery charging unit was taken out from the same socket with multiple pins. This provides for a 'must-remove plug and socket' arrangement, i.e., the charging connector plug has to be removed to connect the patient lead plug, leaving no room for human error. This power supply arrangement is shown in Fig. 2.

Fig.3 shows the details of the circuitry developed. As mentioned above, an AMP-02 instrumentation amplifier IC takes the input from the patient. However, for patient safety, two well matched high resistors R, about 470kΩ each, should be put in series at the two inputs as shown. This is a safety against the rare situation when the low voltage dc power comes directly to the patient leads accidentally, or due to the IC failing. Even with a 5V dc, tissue burn may occur under such situations. The high resistor limits this current to a safe level. Alternatively, two CR high pass filters with a cut-off at about 0.1Hz could be placed at these two inputs to block the dc. However, the components at these two inputs should be very well matched to avoid degradation to CMRR.

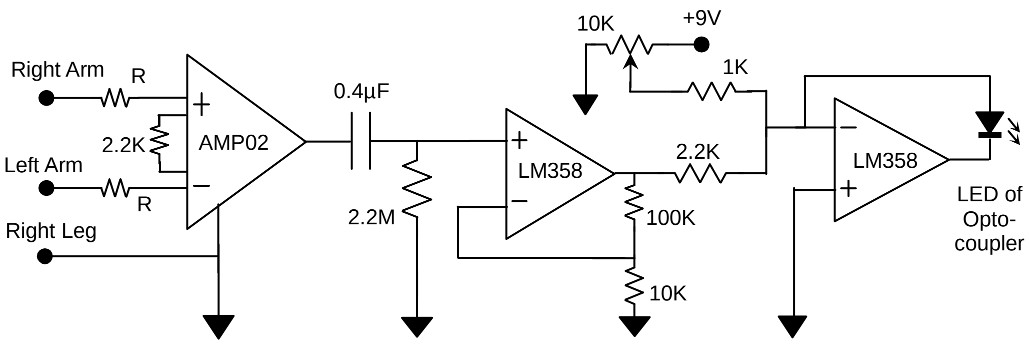

Fig. 3: Circuit details for the isolated part

AMP-02 has a high CMRR and its gain may be controlled using an external resistor R_{ext}, which in the present circuit was 2.2 kΩ. The gain for AMP-02 is given by [3],

$$G = (50k\Omega/R_{ext}) + 1$$

which for the 2.2 kΩ R_{ext} is about 24. This low gain was chosen to avoid saturation of the amplifier due to relatively large and slow varying dc potentials developed at the contacts. Next a passive first order high pass filter followed by a unity gain buffer eliminated unwanted dc and low frequency noise generated by contact potentials of electrodes as mentioned above. This also eliminates dc offset voltages developed by AMP-02. The values of R and C chosen gives an expected cut-off frequency of 0.18 Hz. The signal was then taken to the following opto-coupler stage.

An opto-coupler may be used in either digital or analogue mode. The ECG signal may be converted to a binary digital signal of some sort using a voltage to frequency converter, and then transferred to the mains ac driven side using the opto-coupler, and then reconverted back to the analogue signal again. This scheme does not have any errors due to temperature changes, but the circuitry is complex and the maximum frequency of operation is somehow limited. The other alternative is to use an analogue scheme, where the ECG signal directly modulates the LED current in the opto-coupler, and the output of the photodiode or the phototransistor is also analogue. The circuitry is simple but one needs to think about temperature compensation circuitry if a high degree of accuracy is desired since light output of LED's vary slightly with temperature. However, it was argued that the slope of the analogue transfer curve of the opto-coupler would remain essentially unchanged with temperature, and since ECG does not have any dc component, this slope would be of interest rather than the absolute value of transfer parameters, and therefore, temperature changes will not affect the performance appreciably. Therefore, for simplicity, the analogue scheme for using the opto-coupler was chosen.

In this analogue mode, the forward drive current to the LED of the opto-coupler is modulated by the analogue signal. It is to be mentioned that the ECG signal may have both positive and negative voltage components while the LED needs current to be unidirectional. This was achieved through a current summing circuitry where one component is obtained from the desired ECG signal through the 2.2 kΩ resistor while a controlled dc offset current was obtained using a 10kΩ potentiometer and a series 1 kΩ resistor as shown in Fig.3. The potentiometer was adjusted to give the necessary dc offset.

The phototransistor of the opto-coupler is biased as shown using the non-isolated power supply. Here, a non-isolated +5V supply was obtained through an USB port of the PC. The output at the collector gives the ECG with a dc bias of about 2.5V, maintained through the amount of light from the LED, controlled by the 10kΩ potentiometer, and the collector resistance of the phototransistor. All electrical lines of the non-isolated side, including the ground, had to be separate from any lines in the isolated part.

The single to dual power supply converter, as mentioned before, is shown in details in Fig. 4. It is essentially a voltage divider with equal resistors, followed by a unity gain buffer. The output has the mid-voltage of the power supply to the op-amp, which is defined as the common of the isolated part of the circuit. The positive and the negative rails of power then give the desired dual supply with respect to the common terminal. However, the maximum current through this arrangement is somewhat limited to about 10mA, which is adequate for the application in this work.

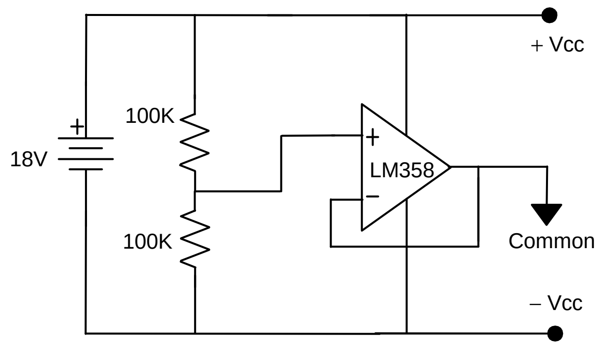

Fig. 4: Single to dual supply conversion circuit

The non-isolated part of the developed circuitry is shown in Fig.5. The design of this part is based on the requirement of the ADC IC chosen. Through a search of different available IC's the ADC0820, made by National Semiconductors, was chosen based on its simplicity of use, speed of conversion and low price [4]. It is an 8-bit converter and uses flash converter technique. However, a conventional 8 bit flash converter will need a large number of components and would be very expensive. This flash converter uses a special trick to achieve lowering of parts count, and hence cost. It uses two flash converters instead of one, each for the two nibbles, and a switching of the appropriate nibble is provided through a comparator circuit, based on the magnitude of the input voltage. The conversion time of this IC is about 1.5 µS, and the price is low, about US $ 2.00. A resolution of 8 bit may not be adequate for medical equipment with high specifications, but for the application envisaged it is adequate. If the input signal covers the full dynamic range, the digitization error is 1/256, or less than 0.5%, which is adequate for an ECG monitor.

The ADC0820 IC operates between 0V and 5V and has a further advantage of having a differential reference level for its inputs. The choice in the present work was made between +1V and +3V, with the mean at +2V. Thus the bidirectional analogue ECG signal should have a dc bias of +2V. This was simply achieved by a clever trick, of taking the lower terminal of a high pass filter to +2V instead of the ground terminal in conventional circuitry. This high pass filter is shown on the left side of Fig. 5.

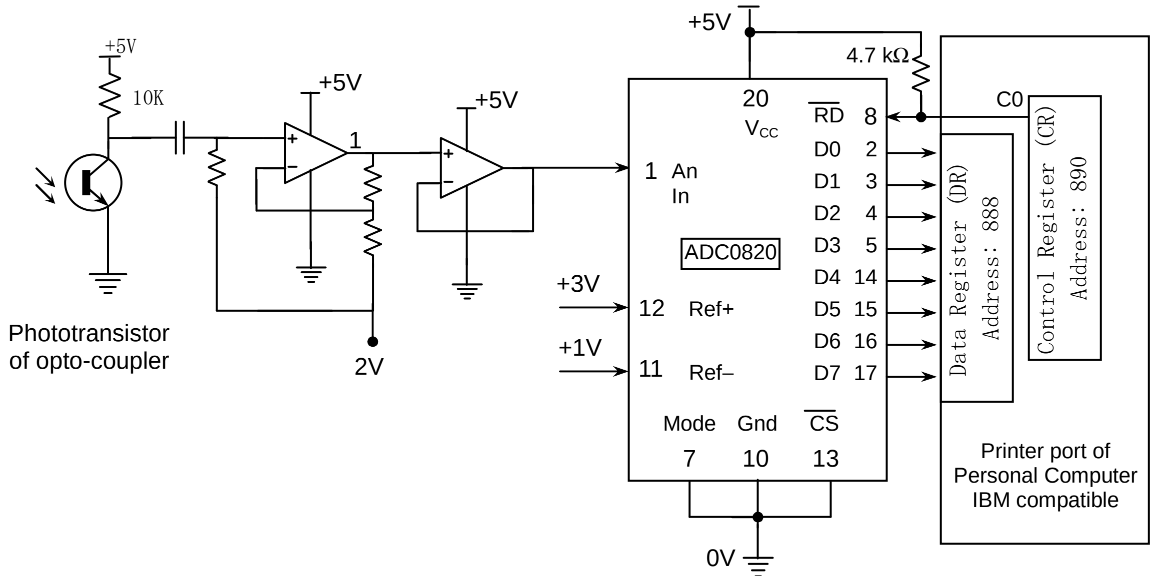

Fig.5: Non-isolated part of the circuitry

The signal is further amplified using a non-inverting op-amp stage, where again the +2V reference was used for the feedback network to preserve the bias. Finally after a buffer stage the output was fed to the input of the ADC.

All the connections made to the ADC are shown in Fig.5. Other terminals which are not connected to anything and which are not used in this application have not been shown. A description of the used terminals and their names are given below.

$\overline{CS}$ *'Chip Select'*: This enables the particular ADC when low, and disables when high. This is useful when multiple ADC's are used. In the present case since only one ADC is being used, it has been made permanently low by hardware connection to ground.

An In: This is the analogue input. The active input range is differential as mentioned before, falling between voltages applied to 'Ref −' and 'Ref +' voltages as described below. In the present work the above reference inputs were set at +1V and +3V respectively, making this the range of input for the developed system.

Ref +: This is the reference-high input. If the input is equal to this value, binary 255 will be presented at the 8 bit digital output.

Ref -: This is the reference-low input. If the input is equal to this value, binary 0 will be presented at the 8 bit digital output.

Mode: When grounded (as done in the present design), 'Read mode' or 'RD mode' of the ADC is activated. In this mode initially the $\overline{RD}$ input (pin 8) has to be kept high. When $\overline{RD}$ input is made low the ADC takes an analogue input voltage sample, and starts converting it to the corresponding binary digital value. During the conversion process (taking about 2.5 μsec) it stores the output digital value in a tri-state output buffer register (memory element). After conversion is complete the tri-state output register is automatically enabled so that the digital data is available in the 8-bit parallel output lines. This is the digital data that has to be read by the PC. By pulsing $\overline{RD}$ input low momentarily when required, a series of 8 bit digital data representing analogue input values at those points in time may be acquired by the PC. By sampling at equal intervals of time, it is possible to build up a time series of a continuous analogue data, which may be stored in a computer for further processing and use.

D0-D7: These provide the 8 bit binary digital output.

GND: GND is the reference potential of 0V.

V_{CC}: The usable range is +4.5V to +8V. In the present work +5V have been used, obtained through the USB port of the computer itself.

The reason for choosing the range 1V to 3V for the input to the ADC is also simplicity from practical viewpoint. Not all ADC's have similar differential input range features; ADC0820 has, and this has been used to advantage. This has allowed the use of a single +5V supply available from the PC USB port to run all the analogue circuitry in the non-isolated part as well. Op-amps need a dual supply, with both positive and negative rails, if an output going down to exactly 0V is required. Most ADC IC's have an input range from 0V to a chosen positive voltage value. Therefore, these make it necessary to provide a negative non-isolated supply as well. On the other hand, using the +1V to +3V range with a mean of +2V, the output has to be at 2V when the input ECG signal is at 0V. Thus the op-amps used in this circuitry may be operated directly using the 0V to +5V supply from the USB port, thus simplifying the circuitry and its power requirements.

In the present design, to obtain the three reference voltages, the +3V reference was produced first using a variable voltage regulator IC (LM317). The +1V and +2V were then obtained through voltage division using a chain of three exactly matched resistors and unity gain buffers. This +2V rail has been used to provide a reference to the op-amps as mentioned before so that all the ac coupled signals are shifted to a base of +2V.

The output of the ADC0820 was connected straight to the parallel printer port of the PC (IBM compatibles) for interfacing and acquisition of data. The parallel port of the PC will have to be in the Enhanced Printer Port (EPP) mode which has to be set through BIOS at the very beginning. It has to be done only once in a PC and will not be needed to do it again unless the setting is changed.

2.3 Computer interfacing

The computer interfacing to the ADC was performed through the parallel printer port (LPT1) of the computer. Parts or whole of three 8-bit registers (memory) in the parallel that are accessible through terminals in the port socket are given below with their respective addresses for software implementation [5].

Data Register (DR)	: memory address 888 (decimal), 378 (Hexadecimal)
Status Register (SR)	: memory address 889 (decimal), 379 (Hexadecimal)
Control Register (CR)	: memory address 890 (decimal), 37A (Hexadecimal))

In the present work the 8 bits of the DR has been used to input 8 bit data into the computer from the ADC and these are connected directly (D0 to D7) as shown in Fig. 5. The SR has not been used in this arrangement. Only one output bit from the CR (C0) has been used in the present design to provide a control pulse to the ADC through its $\overline{RD}$ input. This input is 'active low'. Therefore it is normally kept high through connecting it to +Vcc through a 4.7kΩ resistor as shown. A 'low' pulse, sent from the computer under software control, initiates a data acquisition procedure. This arrangement was chosen from a number of modes in which the ADC0820 can operate by connecting the 'Mode' terminal of the ADC to ground.

The DR is normally configured for output of data (uni-directional), the natural thing for a port to send data to a printer. However, if the computer is configured for EPP bi-directional mode by setting the BIOS (at starting up of the computer) the DR may be used to input 8-bit data as well, as is required in the present work, but it will require a further software command just before the action is called for. To configure the DR for data input, a '1' has to be placed at the 6th bit (C5) of the CR through the data acquisition software.

2.4 Computerised data acquisition

This is achieved using a software developed for the purpose based on the hardware connections made between the ADC and the computer as mentioned above. The procedure is briefly described below.

1. *Setting up of the computer:* As mentioned before, the DR has to be configured to allow inversion of its normal direction of data flow through the DR. This is done by configuring the computer for Enhanced Printer Port (EPP) bi-directional mode by setting the BIOS at starting up of the computer. This is to be done only once for a computer if this set up is not changed in its lifetime.
2. *Setting data direction inwards:* To configure the DR for data input, a '1' has to be placed at the 6th bit (C5) of the CR through the data acquisition software. However, one needs to revert the direction back 'outwards' by making C5 low after the work is done, to revert the printer port back to its normal functioning. Making C5 high will need writing of decimal '32' (hex: 20) into the CR, and reverting it back to normal will need the writing of '0' to CR.
3. *Handshaking:* To initiate sampling of the analogue data appearing at the input of the ADC, the $\overline{RD}$ input of the ADC is to be activated, i.e., it has to be brought low momentarily as mentioned above. This pulse is to be sent through the first bit C0 of the CR at address 890 (hex: 37A). However, one needs to know that C0 output is hardware inverted, i.e., a '1' written to C0 in software will make pin $\overline{RD}$ 'low' and a '0' written to C0 in software will make pin $\overline{RD}$ 'high'. Therefore the software has to be designed accordingly.
4. The ADC will take about 2.5μsec to convert the sampled data and to present it at its output

tristate buffer, which is also simultaneously enabled as described in details before.

5. The 8 bit data will then need to be read into, and stored in a specified computer memory, through the developed software.
6. To collect a series of data, the data acquisition software is looped around as many times as desired and each of the data value is stored in elements of a memory array in the computer, again through the software.
7. In the present design for the ECG, sampling intervals of 1msec was adequate, and in less demanding applications like online monitoring, even 10msec interval may be adequate. The ADC was obviously very fast in this respect. In the present design of the software this sampling interval was obtained through the use of dummy waiting loops within the main data acquisition loop.

2.5 Software

The program was developed to implement the above mentioned data acquisition procedure as well as to perform storage of raw data, further analysis to give beat rate, and draw graphs in real time in the monitor. This was done in QBASIC language under DOS operating system as it is very easy to access ports directly in MSDOS. However, software may easily be developed by an expert programmer in any other language under any other operating system.

As a rule of thumb, the sampling frequency should be at least twice the highest frequency of the input signal (Nyquist Criterion). Since the highest frequency content of an ECG signal is 100Hz, the required minimum sampling frequency will be 200Hz, corresponding to a sampling interval of 5msec. However, for better reproduction, the sampling interval may be reduced further, and a 1msec interval would be good enough for ECG. Even this1msec is quite a large time interval for the ADC to convert the data and for the computer to acquire this value, to store it in a specified memory location, and to process and display the value graphically on a display monitor. Thus it is possible to display the ECG signal almost instantaneously as the data are collected (of course, with a delay of about one msec, which human beings cannot notice), and this is called a *Real Time Display*. The horizontal display of ECG on the monitor screen was chosen for 500 pixels, and from a practical point of view this was chosen to correspond to 3 to 5 seconds of ECG data, giving about 4 to 6 ECG pulses for a normal person.

2.6 Calibration

To evaluate the sampling interval, and to calibrate the graphical display, a sinusoidal signal of appropriate and known frequency was fed into the system from a signal generator. As mentioned before, a display running for 3 to 5 sec was desired. Thus from a display of the known signal it was possible to determine whether the display timing was correct or not. The number of dummy delay loops in the main data acquisition program was adjusted to get the right display timing.

3. RESULTS AND OBSERVATIONS

3.1 Hardware

The CMRR of the AMP-02 IC was quoted at 115dB. Through practical measurements in the laboratory it was found to be 100dB at 100Hz, which is a reasonable performance. The gain of the different amplifier sections and the frequency response of the filters were found to be within reasonable limits of the theoretically desired values. The whole circuitry was mounted and soldered on a copper clad prototyping matrix board (Veroboard), and mounted within a grounded metallic cabinet to provide shielding from external noise. The isolated section was mounted carefully so that none of its electrical parts or contacts came to within 3mm of any metallic part of the non-isolated section. Plastic sheets was mounted through large cutouts made in the metallic cabinet (which is non-isolated) to mount switches and sockets of the isolated section.

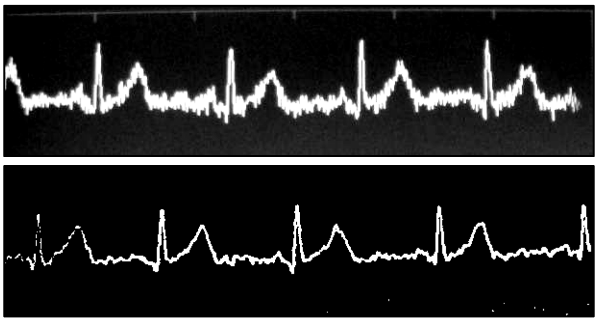

Fig. 6: ECG obtained using the developed equipment. Upper trace: raw data. Lower trace: smoothed data from the last acquired batch

3.2 Software

The rudimentary software in QBASIC language, developed to acquire 500 data points in a window of 3 to 5 seconds is presented below. Explanation to each line of the program appears on the right.

DIM y(500)	[Reserves 500 memory locations in an array for y]
SCREEN 12	[Makes a graphic screen with resolution 640 x 480]
CLS	[clears the whole monitor screen]
PSET (0,0)	[draws a point at (0,0), to provide a starting point]
FOR i = 1 TO 500	[does the following, i.e., collect data and plot line for 500 times]
OUT 890, 32	[configures DR for data input by making C5 bit of CR high]
OUT 890, 33	[Starts data acquisition process by making C0 bit of CR high (as in text)]
FOR j = 1 TO 10: NEXT j	[dummy loop, provides some time delay for ADC output to stabilize]
y(i) = INP (888)	[Reads i^{th} data and store in an array variable y(i)]
LINE -(i, y(i))	[plots a line from the previous co-ordinate to the current one]
FOR j =1 TO 1000: NEXT j	[dummy delay loop to provide desired sample interval]
NEXT I	[repeats the procedure for the next data point]

Further improvements in the software was made to draw coloured boxes around the graph, to draw calibration marks on the axes, to label the axes, to calculate the beat rate per minute by analyzing the data and to display this value using large numerals, to smoothen the graphical display by removing high frequency noise through digital signal processing techniques, and to draw smoothed data, acquired in the last window of 3 to 5 seconds, graphically in a lower display. Fig. 6 shows an ECG display obtained using this equipment. The upper trace is that of the raw data, and the lower trace shows smoothed out data using a running average technique, collected in the previous window period.

4. DISCUSSION

The necessity of developing modern devices for healthcare indigenously is now being felt world over. The existing practice of procuring these from manufacturers in the economically advanced countries is not giving the desired solution of providing healthcare to the masses, particularly in the economically disadvantaged countries. Developing such equipment locally in each country will result in affordable equipment giving a cost effective healthcare service. Besides, equipment will serve people over a much longer period since local maintenance and repair will be available at low cost. The main reason of medical equipment being expensive is their low volume of production and use, and the very high cost of R&D manpower in the economically advanced countries. Since R&D manpower cost in countries like Bangladesh is considerably low, such equipment can be developed and made at low cost.

The ECG equipment designed and developed in the present work is targeted towards the above objective. The design was kept as simple as possible so that the equipment may be maintained and repaired by local expertise. It was based on a PC since PC's are widely available in countries like Bangladesh, and these can be maintained well as spares and expertise are widely available locally.

Some of the IC's used in the present work are specialized, but can be made available widely if the locally developed equipment gets a wide acceptance. However, care was exercised in the choice of the IC's, to optimize performance and cost. Thus keeping a stock of these IC's is also not unaffordable.

In developing the equipment expertise developed at Dhaka University over the last three decades have contributed to its success. This was also supported by academic links with Universities in the UK. Many subtle technological points need to be addressed in designing and developing such a sophisticated medical device, since it deals with health, life and death. For example, the issue of safety to patients from micro-shock is not always clear to a new designer, and both scientific knowledge and technological expertise are necessary to provide solutions. Unless all these issues are well understood and put into practice in designing and fabricating medical equipment one should not present these for public use.

This paper has tried to present the design of this ECG equipment by highlighting most of the safety features and technological issues, so that other designers can appreciate the points. One point that was not discussed was the issue of a dc current hazard through the electrodes if the IC at the input got damaged, and the dc supply got through directly to the electrodes. In this case a tissue bun will occur if the current is too high. This is usually eliminated by placing equal resistors of a few hundred kilo-ohms in series with the input electrodes, or placing a capacitor-resistor based high pass filter at the input end. However, this filter should have a cut-off frequency much lower than the lowest frequency content in the signal, and typically should be about 0.1Hz for an ECG equipment.

Another design variation that may be tried is the right leg drive. This drives the residual common mode noise to the body by inverting the phase, in order to reduce the common mode noise, here 50Hz from mains line, further.

However, if electrodes are attached with care, and the patient is kept away from mains driven equipment, a reasonably good signal may be obtained as shown in Fig.6. In this case, a simple running average scheme, implemented in the software, has improved the display significantly. The use of a PC has given more power to the equipment, because such post processing to the signals can give out more diagnostic information. Besides, digital data stored in the computer can easily be transferred through various transmission media including internet, allowing telemedicine to be developed indigenously, which has immense potentials in the Third World.

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