ECG Signal Acquisition System for Remote Healthcare Service With Telemetric Capability

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Abstract
Many of the tasks of daily life of human beings became easier with the advent of information communication technology. Complex tasks are becoming simpler with the application of this technology which ensures to meet the challenges with never-ending innovations. However its application in the field of healthcare is still lagging and geared up only in the last decade. In the field of healthcare service information communication technology has tremendous potential in bio-telemetry which is commonly termed as Telehealth or Telemedicine. Telemedicine makes the task easier for remote healthcare service where diagnosis of patients can be performed from remote places. As example, most of the rural areas are lacking of good physicians and healthcare services, and may be monitored by city hospitals through telemedicine. Hence healthcare community requires suitable low cost, low power yet affordable and sustainable gadgets compatible to biomedical signals. In this paper a development effort is presented to acquire ECG signal that is processed and transmitted over communication channel.
Keywords: Telehealth, Telemedicine, Information Communication Technology, Remote healthcare, Electrocardiogram, Biopentential
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1. INTRODUCTION

In this rapidly changing world, information communication is emerging as essential basic requirement of human beings. Accessibility and transfer of information have always been challenging that become easier day by day with the advent of technology and electronic communication. Information Communication technology has made easier many of the tasks of daily life of human beings like banking, education, online shopping, bill payment etc. The world of innovation ensures to meet the challenges to make complex tasks simpler and adoptable.

Ironically, Information Communication technology is still lagging in healthcare service. A person generally is forced to visit hospitals or doctors for traditional face to-face consultation for healthcare. Such visits to the hospitals and especially the follow-ups for prescription refills lead to increased cost of care as well as healthcare resources are under-utilised. The healthcare community requires improved delivery of healthcare and provide more qualitative healthcare within affordable, sustainable and accountable dimensions.

The remote delivery of health-related services and information via telecommunications technologies is termed as Telehealth or Telemedicine. It may involve a patient and a clinician or two clinicians. It includes an infinite variety of technologies, ranging from patient home monitoring systems to medicine dispensing machines [1]. Significant development has been observed worldwide in last decade towards adopting telemedicine applications, tools and techniques. Telemedicine is emerging as powerful medium adding new dimensions to healthcare, not only to render therapeutic healthcare but also educational, supportive and preventive care. There are numerous initiatives in Telemedicine in almost all the specialties with versatile modes of delivery using satellite, videoconferencing, telephone and even telehealth robots. Telemedicine has tremendous potential to change the dynamics of healthcare in rural region where 80% of the population of developing countries inherit, yet to receive proper healthcare service due to lack of specialist doctors and hospitals. The rural region may be connected to high-tech hospitals through telemedicine. Simple affordable and adoptable instruments are required to meet the requirements for this purpose. In this paper a heart monitoring system is described that can be used in remote healthcare service

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2. BACKGROUND

Heart beat is de-facto the signature tune of human life. Down comes the deadly silence over the lively eloquence of life and engulfs it as soon as the rhythmic beat of the heart comes to a dead stop. The contraction and relaxation of heart muscles produce electrical signals (biopotentials). This signal strength, duration of its different segments, repeatability are analysed to check the normalcy of heart condition and to diagnosis in case of abnormalcy. Electrocardiogram or ECG is the instrument to record and monitor these signal behaviour. Several types of ECG systems with different specification and accuracy levels are already in market. ECG system for telemedicine application must be simple, easy to operate, affordable and especially it must be of low power consumption that can be operated by battery, as electricity may not be available at remote region. Multi-lead ECG signals acquisition with telemetric capability has been developed by Shaikh et al [2]. Parin et al [3] demonstrated a solar based ECG system that may be used in the absence of electricity.

Conventional ECG comprises of 12 leads - unipolar limb leads (AVR, AVL, and AVF), bipolar limb leads (I, II and III) and the unipolar chest leads (V1, V2, V3, V4, V5, and v6). However four-lead system to obtain ECG in Einthoven triangle configuration as lead I, lead II, lead III is useful and can represent ECG information which is of less complexities and suitable for remote operation. Design and implementation of such system has been demonstrated by Naazneen et al [4]. Wireless portable ECG systems have also developed for remote healthcare service [5, 6].

The role of bio-medical instrument to detect the cardiac disorder is of utmost importance and in the backdrop of alarming escalation of heart ailment even among the financially handicapped common people all the world over taking toll of their lives prematurely, **t**his paper primarily aims to provide low cost solutions to the problems encountered in acquiring Electrocardiograph (ECG) signals in monitoring mode (ECG bandwidth --0.5 to 35Hz) from the body, as well as providing remote transmission of ECG data through telemetry. The system mechanism also allows advance warning operations of heart abnormalities which will detect even the slightest deviation of heart function at the earliest stage and help taking precautionary measure before the problem goes out of control leading to premature death. The technical subtleties in developing the equipment is discussed sequentially with descriptions of methodology after thorough testing, taking into consideration of physical variables under different environment conditions we are encountered with.

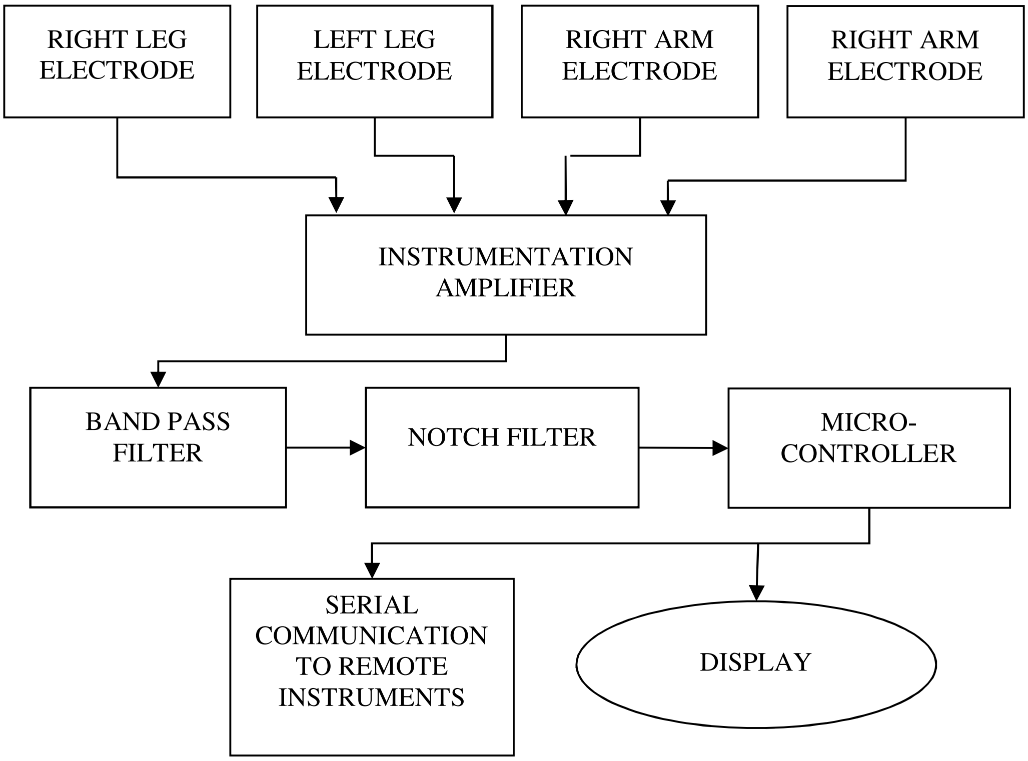

Figure 1: Schematic Diagram of ECG signal acquisition system

3. PROPOSED WORK

Conventional electrocardiogram waveforms are recorded by 12 leads system to observe detail cardiovascular activities, where biopotentials are acquired from right leg, left leg, right arm, left arm and six predesignated positions on the chest. However biosignals acquired from three basic limbs of left arm, right arm and left leg can represent the cardiovascular activities to the great extent. Four bipolar leads ECG system is proposed here to represent Einthoven's bipolar standard leads (I, II, III) to record the ECG in the frontal plane. Electrodes are applied to the left arm, right arm, left leg and right leg, and the bipolar leads represent a potential difference between two selected sites. Potential difference between left arm and right arm (LA-RA) represents LEAD I, potential difference between left leg and right arm (LL-RA) represents LEAD II, and potential difference between left leg and left arm (LL-LA) measures for LEAD III. Full scheme is illustrated by figure 1.

Four leads attached with compatible electrodes are placed at right arm, left arm, left leg and right leg to capture bio-potentials from the body. Signal received from electrode of right leg is considered as reference signal. Signals from other electrodes are analysed with respect to this reference signal. According to Einthoven postulate, the vector sum of the lead I, lead II and lead III potentials is zero. The R-wave amplitude of QRS complex of ECG at lead II equals to the sum of R-wave amplitudes of leads I and III. Typical lead I, II and III waveforms of ECG are shown at figure 2. The biopentential captured from the limbs as mentioned here are initially processed through preamplifiers that are accomplished by isolation amplifiers or instrumentation amplifiers, followed by amplification to the desired level. Instrumentation amplifier has the unique feature of high input impedance and capable of amplifying very low signal and hence it is applicable to process the biopotentials. Three sets of preamplifiers are used to process the difference signals of left arm to right arm, left leg to right arm and left leg to left arm. The differential signals are now passed through bandpass filter and notch filter (bandstop filter). Three signals lead I, lead II and lead III are thus processed individually and fed to a microcontroller.

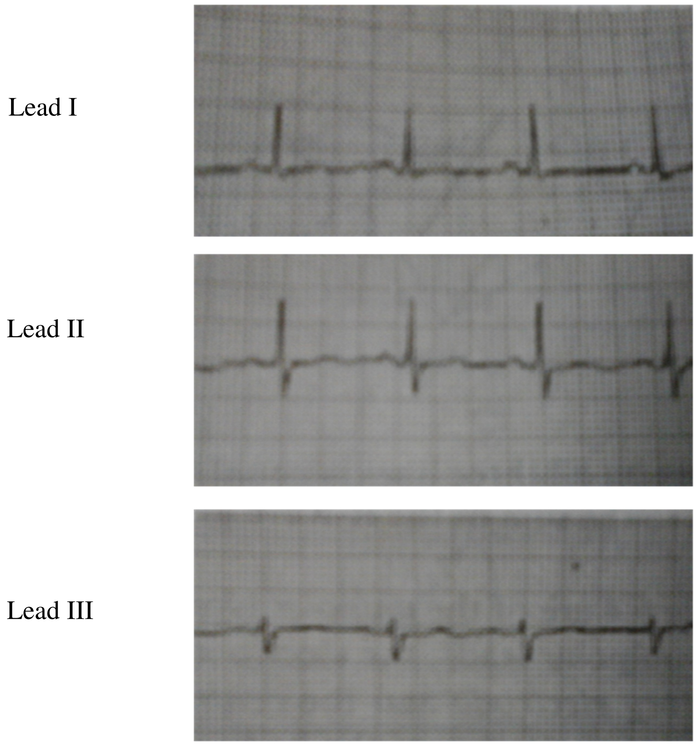

Figure 2: Typical Lead I, II and III waveforms of ECG

Microcontroller is chosen such way that it comprises of at least three analog to digital converter in-built, thus reducing the external ADCs as well as circuit complexties. All the three signals are acquired at the same instant of time. Lead I, II and III signals are further processed by the microcontroller and are displayed as well as one of the port of it is assigned for serial communication of the processed data that may be connected to computer and transmitted to other places.

4. IMPLEMENTATION

4.1 *Signal acquisition*: As biopotential is of very low amplitude in the range of few microvolts, it can be contaminated by noise easily and actual signal information is very difficult to be segregated. Traditional general purpose differential amplifier is not suitable to process the signal. Instrumentation amplifiers are employed here as preamplifiers which have the characteristics of high input impedance and capability of capturing very low amplitude signals. These can be configured by the general purpose operational amplifiers as shown in the figure 3. IC LM324 comprising of four operational amplifiers is used to form instrumentation amplifier configuration. In the proposed scheme three sets of instrumentation amplifiers are used and the gain of each set may be adjusted to approximately 1000.

4.2 *Signal processing*: Acquired signals are contaminated with unwanted signals of various frequencies. These unwanted signals must be eliminated. Elimination of noise and artifacts from low amplitude signal is always a challenge. ECG signals have the bandwidth of 0.5 Hz -100 Hz. Any signal beyond this frequency range is considered as noise which can be removed by precision bandpass filter. It is desirable that the filter characteristics have sharp cut off. Second order filter has been employed here. However higher order filter gives better performance of sharper cut off. Another possible attribute of noise is at frequency of around 50 Hz. This is due power line frequency as all the equipments are generally operates AC power line. Therefore at the next stage a notch filter of bandstop filter of stopband of 45 Hz to 55 Hz is employed to remove the power line frequency. Three sets of bandpass and bandstop filters are used for processing signals from three leads.

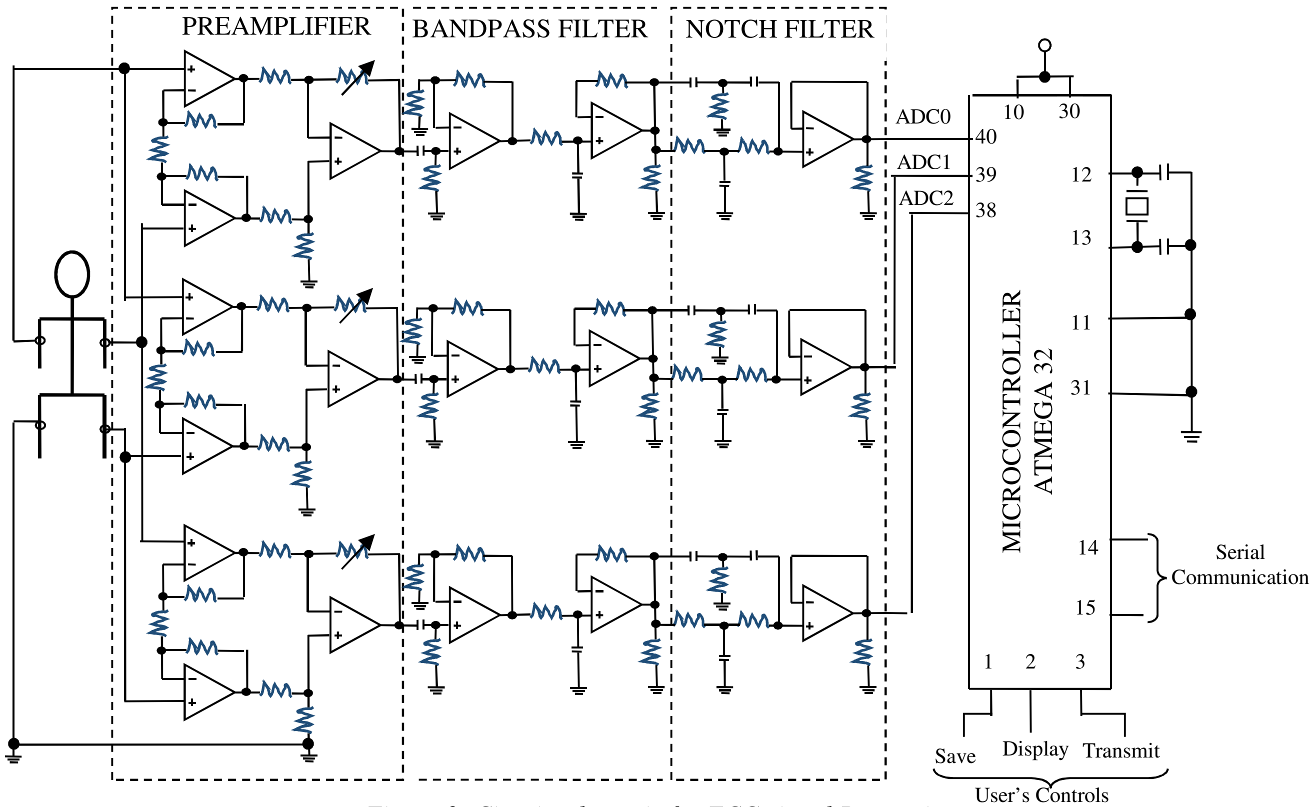

Figure 3: Circuit schematic for ECG signal Processing

4.3 *Processing in microcontroller*: The processed signal is now fed to a microcontroller. Atmega 32 microcontroller is used here, as it comprises of eight numbers of inbuilt ADC (analog to digital converter). Acquired signals are analog in nature which are to be digitally converted to be processed by the microcontroller. However three ADCs are used here for processing of ECG signals as shown in the circuit diagram at figure 3.

Signals are acquired sequentially in sampling basis. First to acquire is lead I signal and thereafter lead II and lead III. All the three signals are acquired almost at the same instant of time. After receiving a set of three signals, amplitude of lead II signal is compared with the summation of amplitudes of lead I and lead III signal. If this difference is within tolerable limit signals are considered to be valid. For invalid signals, microcontroller is activated to receive another set of signals immediately. Valid signals are stored or displayed or transmitted. To ensure the validity of signals, it is essential that all the three sets of preamplifiers, bandpass filters and bandreject filters are identical with same gain and characteristics. Obviously it is impractical to achieve due to tolerance of components, temperature drift and variable environmental conditions. Furthermore microcontroller cannot record all three signals at the same instant. A few nanosecond time differences exist due to processing time of the microcontroller. Therefore some tolerable limit is introduced in the processing in microcontroller.

Next set of signals is received after one millisecond that gives the sampling frequency of 1 KHz which is sufficient to process and reproduction of ECG signal as its bandwidth is 100 Hz (Sampling time is 1 msec). Similar processing is performed on these signals and wait for one millisecond to receive next set of signals. The whole process is repeated for 180000 sets of samples ensuring three minutes of ECG waveform which is adequate for diagnosis. The complete algorithm is explained by a flowchart as in figure 4.

Microcontroller operates in three modes – save, display and transmits. In save mode the microcontroller saves complete information and transmits or displays whenever necessary. In display mode the signal may be displayed immediately after acquiring the ECG information or later whenever required. In transmit mode the acquired ECG information may be sent instantly or later. This mode is the most essential in the remote healthcare service.

5. DISCUSSION

Above scheme has been developed in the laboratory, where hardware circuit as of figure 2 is attached to desktop computer yielding very good result. However there are scopes to improve the performance of the scheme and remove the drawbacks. Firstly, to check the validity of the signal, a tolerable limit has been introduced. For the sake of simplicity, here limit is considered as 5% of the amplitude of R wave, which is set by trial and error method. In actual case, linear prediction method may be applied to judge the acceptance of signal data. Linear prediction algorithm may be introduced without any hardware change of the circuitry; modification of programming software can take care of this as the microcontroller used here is very powerful and versatile.

Second major issue is the memory management. Generally ECG waveform of three minutes duration is desired for diagnosis. Therefore, for a single subject, with the sampling rate of 1 KHz, 3x60x1000x3 ≈ 540 Ksamples are to be analysed and stored, i.e., 540 Kbyte memory locations are to be assigned for only for the data storage. This much memory requirement is manageable in case of direct transmission or direct attachment with computer or laptop. However direct transmission facility, computer or laptop may not be available all the time in remote healthcare service. Higher memory location in the gadget itself helps tackle the situation. Data card or pen-drive may be used externally, or memory expansion is to be done internally for memory enhancement. Other method is to introduce a suitable data compression technique in the programme software itself.

In the laboratory, the system has been developed with 5 VDC regulated power supply which is stepped down from AC power lines (circuit diagram for regulated power supply is not shown in the diagram). It will work on 6 VDC supply also with the use of four 1.5 V batteries, in the absence of AC power lines.

Sampling frequency affects the reproduction quality of ECG waveforms. Higher sampling rate gives better quality of reproduction, however memory requirement increases.

For direct transmission of ECG data, a transmitter unit is necessary. ECG data may be arranged by the microcontroller maintaining the standard protocol of data transmission to interface with mobile communication system.

To avoid cross infection problem, inexpensive disposable electrodes are to be used to capture the signals.

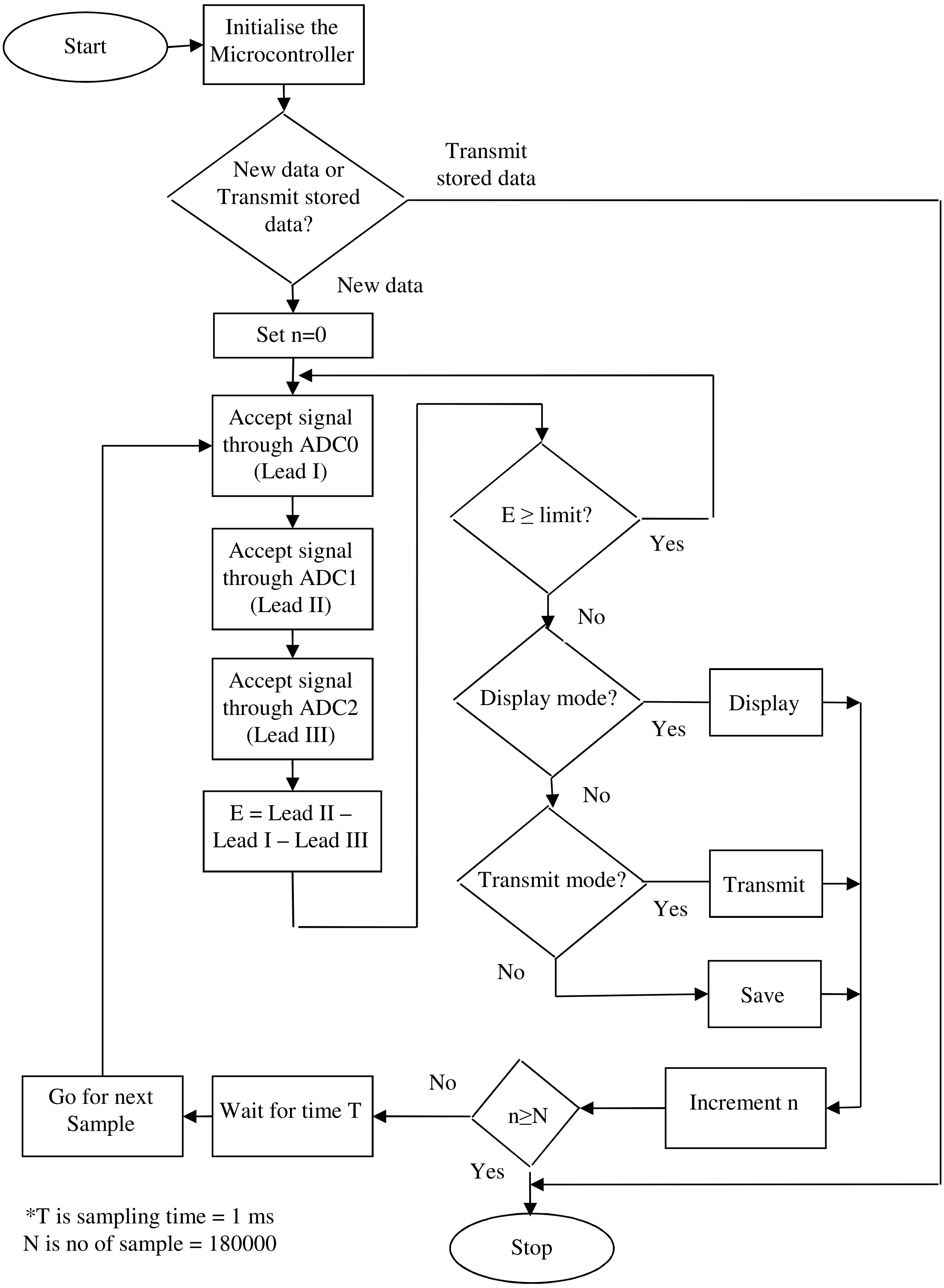

Figure 4: Design Flow Chart

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