IoT Based ECG Using AD8232 and ESP32

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ABSTRACT

Good qualities ECG are utilized by physicians for interpretation and diagnosis of cardiovascular diseases. The rural hospitals of Nepal lack necessary equipment and need modern medical devices. This article is about an IoT-based ECG device in which AD8232 is used for the ECG signal acquisition, MATLAB for filtering and ESP32 for processing and communicating with the Internet.

Keywords: ECG, Cardiovascular Diseases, ESP32, IoT, Wearable, AD8232

1. INTRODUCTION

In many parts of the world, a good amount of funds are invested in research works to design efficient equipment for the diagnosing health problems. Nowadays medical expert systems are increasing daily, comprising smart transferrable diagnosing and nursing devices, one of which is ECG. The world's population is growing steeply. Still, the number of health professionals is limited. Monitoring patients health conditions in real time is very important for doctors to know about the severity of patients and act accordingly. This design helps doctors know patient's condition remotely from wherever they are, being connected through the Internet.

A large number of people suffer from cardiovascular diseases. A significant amount of time is spent visiting a doctor. Several steps have been taken to improve the health condition of the people of Nepal directly and indirectly by the government of Nepal, NGOs, and INGOs. In most cases, an early diagnosis of the symptoms related to heart disease can help save lives through timely treatment. Cardiovascular diseases lead to disabilities and even death of people. People living in all parts of the country can suffer from heart-related disease. It is seen that there is 60% increase in deaths from heart diseases in comparison to the data in 1990 (Nepal Health Research Council (NHRC 2021). The number of patients visiting Shahid Gangalal National Heart Center alone has now reached 500-600 per day.

The big companies tend to make complex designs and miniature parts intended to protect the patented design and make them less repairable so that the consumers have to buy new products whenever they get a small problem with their device. This has led to the production of much electronic waste, and people and countries face trouble buying those products. In rural parts of the world where even paracetamol doesn't reach on time, it's hard to expect that the expensive medical instruments reach the hands of health professionals working in a few small clinics and hospitals.

The extreme medical conditions, disabilities, and deaths can be reduced significantly by early symptoms diagnosis. For an early diagnosis of diseases related to the human body's complex organs, such as the heart, a doctor needs sophisticated instruments and tools. ECG is an approach that measures and records the heart's electrical activity. It can be sensed by monitoring electrodes that are placed on the body surface. The basic information that can be measured from the ECG signals is the heart rate and heart rhythm. For example, a normal heart rate for adult is from 60 to 100 beats per minute and has a specific pattern of expansion and contraction caused due to electrical activity in the cardiac muscles. Clinicians try to detect the presence of any abnormal pattern recorded in an electro-cardiograph. Each electrical activity of the heart has a distinctive waveform.

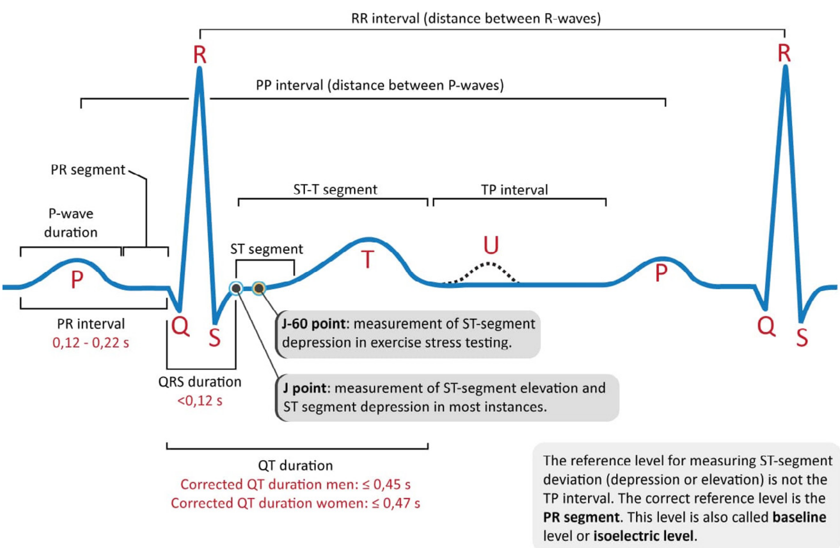

Fig: 1. Normal ECG

The fig. 1 shows that a normal ECG signal consists of a P wave, QRS complex and T wave. The first one is called the P wave which represents the depolarization of atria from the sinoatrial node to the atrioventricular node. Depolarization is the change in the cell's membrane potential to a positive value. This change generates the electrical impulse that starts the heart's contraction, so the P wave can be related to the contraction of the atria. The QRS wave, which looks like a small dip followed by a large spike and another dip, represents the depolarization of the ventricles which can also be thought of as the contraction of the ventricles. One thing can be noticed is that the P wave is smaller than the QRS complex. That is because the ventricles are the muscle pumps of the heart compared to the atria. After the QRS complex, there is the T wave representing the ventricles repolarization. Repolarization is the opposite of depolarization which returns the membrane to a negative state. (Elizabeth & Satyanarayana 2016).

2. LITERATURE REVIEW

Electrocardiography noticeably started evolving from its primitive form to its experimental use in medicine in the year 1872 after Alexander Muirhead used wires attached to the wrists of his patients to obtain the electronic record of their heartbeat. But the use of electrocardiography in medical sciences began only in the 20th century after a Dutch physiologist named Willem Einthoven built the first lead EKG machine using very sensitive string-galvanometer that could measure very small electrical signals in the human body for which he was awarded the Nobel Prize in Medicine later in the year 1924. Einthoven not only built the device, but also categorized the waves of signals from the heart as P, Q, R, S, and T and the illnesses accordingly (Conover 1996).

Rene Descartes in his work Treatise on Man (French: L'Homme 1664) published posthumously in 1662, had described different movements of the human body in terms of threads, pores, passages, and animal spirits. The name of the waves P, Q, R, S, and T, originating from the human heart given later by Einthoven, were inspired from the concept of Descartes about the physical movement of the human body. In 1664, Jan Swammerdam, a Dutchman, conducted experiments on frog to find out that the idea of animal spirit given by Descartes was wrong. He further tried to demonstrate that there was electrical stimulation in the flesh. There were prominent physiologists, physicists, physicians and engineers working in developing a device later known as an Electrocardiogram (ECG or EKG) during the 18th and 19th centuries but a considerable forward leap occurred only at the beginning of the 20th century.

Einthoven was the first one to record ECG by using a string galvanometer. In his publication (1906) he described hypertrophies in atria and ventricles, U wave, QRS notch, premature beats, ventricular premature beats and complete heart attack. (Rivera-Ruiz, Cajavilca, & Varon 2008) In 1910, Walter James, Columbia University and Horatio Williams, Cornell University Medical College, New York publish the first American electrocardiography review. It defines ventricular hypertrophy, atrial and ventricular ectopia, atrial fibrillation and ventricular fibrillation. The demos were sent from the wards to the electrocardiogram room by cables (Cohn & Horatio 1955). In 1912, Einthoven addressed the Chelsea Clinical Society in London and described an equilateral triangle formed by his standard leads I, II and III, later called 'Einthoven's triangle'. In 1920, Hubert Mann of the Cardio Graphic Laboratory, Mount Sinai Hospital, described the derivation of a 'monocardiogram' later to be called 'vectorcardiogram' in his book "A Method of Analyzing the electrocardiogram". In the same year, Harold Pardee, New York, published the first electrocardiogram of acute myocardial infarction in a human and described the T wave, among others.

In 1928, Ernstine and Levine showed that using vacuum tubes could amplify the signals in place mechanical galvanometer. Ernstine AC, Levine SA described in the book "A Comparison of records taken with the Einthoven string galvanometer and the amplifier-type electrocardiograph". In 1928, Frank Sanborn's company updated their table model electrocardiogram machine into their earliest convenient version weighing 50 pounds and powered by a 6-volt automobile battery. In 1934, Frank Wilson defined a new terminal electrode known as Wilson's central terminal to be attached to patient's left foot. The combined lead acts as an earth and is attached to the negative terminal of the ECG. An electrode attached to the positive terminal becomes 'unipolar' and can be located anywhere on the body. For the electrodes to be connected on patient's body, VR, VL and VF. In 1938, the American Heart Association and the Cardiac Society of Great Britain expressed that the chest's standard positions and wiring leads V1 - V6. The 'V' stands for voltage. In 1947, Claude Beck, a pioneering cardiovascular surgeon in Cleveland, successfully defibrillated a human heart during cardiac surgery. The patient was a 14-year-old boy and six other patients had failed to respond to the defibrillator. His model defibrillator followed tests on defibrillation in animals by Prof. Carl J. Wiggers from Western Reserve University.

In 1949, Montana physician Norman Jeff Holter developed a 75-pound backpack that record the wearer's ECG and communicate the signal. The Holter Monitor system is later significantly reduced in size, shared with tape / digital recording and used to record ambulatory ECGs. In 1950, John Hopps, a Canadian electrical engineer, and researcher for the National Research Council, together with two physicians (Wilfred Bigelow, MD of the University of Toronto and his trainee, John C. Callaghan, MD) showed that a coordinated heart muscle shrinkage could be stimulated by an electrical impulse delivered to the Sino-atrial node. The device, the first cardiac pacemaker, measures 30cm, runs on vacuum tubes, and is powered by household 60Hz electrical current.

In 1963, Baule and McFee were the first to sense the magneto cardiogram, which is the electromagnetic field produced by the heart's electrical activity. It is a process that can detect the ECG without using skin electrodes. Even though it was a valuable technique, the idea of using it in clinical diagnoses was dropped because of its expenses. In 1999, Researchers from Texas showed that 12-lead ECGs transmitted via wireless technology to hand-held computers are feasible and can be interpreted reliably by cardiologists.

In 2005, Danish cardiologists described the successful drop in the time between the onset of chest pain and primary angioplasty when the ECG of patients was transmitted wirelessly from the ambulance to the cardiologist's handheld PDA (Personal Digital Assistant). The clinician can take the immediate decision to redirect patients to the catheter lab, saving time in transfers between hospital departments. Since then, many researchers across the globe have been trying to get efficient measures to use wireless technology to collect the electrocardiographs of patients.

The recent developments in the field have grown successful commercial products with advanced technology. The wireless monitoring system has even reached tiny sensors with electrodes fitting in hands and transmitting ECG signals to smart phones or computers in the real-time.

3. WORKING MECHANISM

3.1 AD8232

It is a signal- lead, heart rate monitor sensor. It helps to measure the electrical activities of heart over some time of the patient and extract the signal. The AD8232 is an integrated frontend for signal conditioning of cardiac bio potentials of heart rate monitoring. The sensor's signal is sent to ESP32 for further processing or directly monitored using the serial monitor. It consists of a specialized instrument amplifier (IA), an operational amplifier (AI), a right-leg drive amplifier (A2), and a mid-supply reference buffer (A3). There is also the inclusion of leadoff detection circuitry and an automatic fast restore circuit that returns the signal shortly after leads are reconnected.

It operates at 3.3 volts. AD8232 has nine connection points' shutdowns (SDN). LO+, LO-, OUT, 3.3V, and GND are the most required pins during communication with the development board such as Arduino, Raspberry Pi, Esp32 etc.

Parameters	AD8232
Company	Analog Devices
CMMR	80 dB
Output Impedance	10Gohm
Gain	100 v/v
Features	Rail-to-rail output
Price	$19.95

3.2 ELECTRODES

Electrodes are devices that convert ionic potentials into electronic potential. They are generally composed of lead (for conduction of electrical current), a metal electrode, and electrode-conducting paste or gel for surface electrode. Electrodes are used to detect the electrical changes. The three electrodes are placed on the Right, Left, and Right legs. Here, electrodes placed on the right arm provide negative input and electrodes placed on left arm provides positive input to the instrumentation amplifier of the AD8232, where the electrodes placed on right acts as a ground for the ECG.

3.3 ESP32

ESP32 is used for the processing and transmission of signals. The output obtained from the AD8232 is sent to microcontroller ESP32 where the raw signal is processed. ESP32 integrates WIFI and Bluetooth module which is one of the best modules for IoT applications. It integrates an antenna switch, filters, power amplifier, and power management modules. ESP32 is designed for mobile, Internet of Things (IoT), and wearable electronics applications.

3.4 UBIDOTS

UBIDOTS is an IoT platform empowering innovators and industries to prototype and scale IoT projects to production. This allows creating applications using the IoT without having much knowledge of programming or databases. It is accomplished in many internets connected projects across healthcare, energy, and manufacturing the various small characteristics of IoT and cloud that enable digital transformation. It provides cloud and storing services and basic information analysis on the measured variable in real-time. In this project UBIDOTS is used as cloud service to store and analyze information form sensors and in real-time. The users can use it by entering the designated credentials such as username, e-mail, and password.

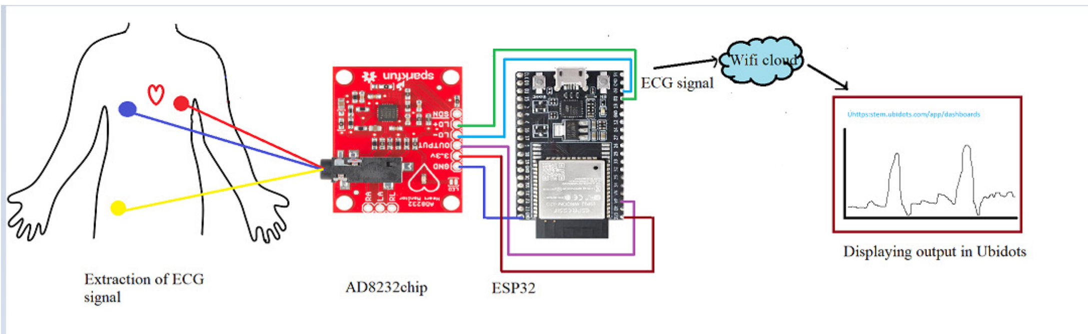

Fig 2: Block Diagram of portable ECG

Table 2 shows the connection between AD8232 and ESP32

The Connection configuration between AD8232 and ESP32 is shown in Table 2.

AD8232 pins	Pin Functions	ESP32 connection
GND	Ground	GND
3.3v	Power supply	3.3v
OUTPUT	Output signal	A0
LO-	Leads-off detected –	11
LO+	Leads-off detected+	10
SDN	Shut down	Not Used

3.5 Overall Architecture of the System

Portable: small size, light weight, easy to carry, meets the patient's use needs in any scene.

A high degree of information: The device has many communication interfaces, such as USB, Bluetooth, TF card etc. The data can not only be sent to the PC side via USB or the mobile phone side via Bluetooth but also be stored in the TF card as the file format, which is conducive to long-term monitoring and analysis of the patient's condition.

4. RESULT AND DISCUSSION

Connecting first two leads on two wrists (one on each) and a third on the right ankle, the signals were obtained and amplified in the AD8232 chip and passed to the computer through ESP32. Each sample of 10 seconds was recorded in the computer. In the obtained ECG, proper P, Q, R, S, T and U waves were clearly visible as shown in fig 3. MATLAB was used to process and filter the information as shown in fig 4. Digital filters and techniques such as High-Pass Filter and Continuous Wavelet Transform worked very well and noise was considerably reduced. Some noise re-appeared in the signal when it was taken very close to the AC supply. The prototype worked with a supply voltage of 3.6 V.

Deep Learning with convolutional neural network architecture (Alexnet) was used for analysis of the signal. It was trained on MIT data and was used for disease classification. However, further research is needed for better results in disease prediction.

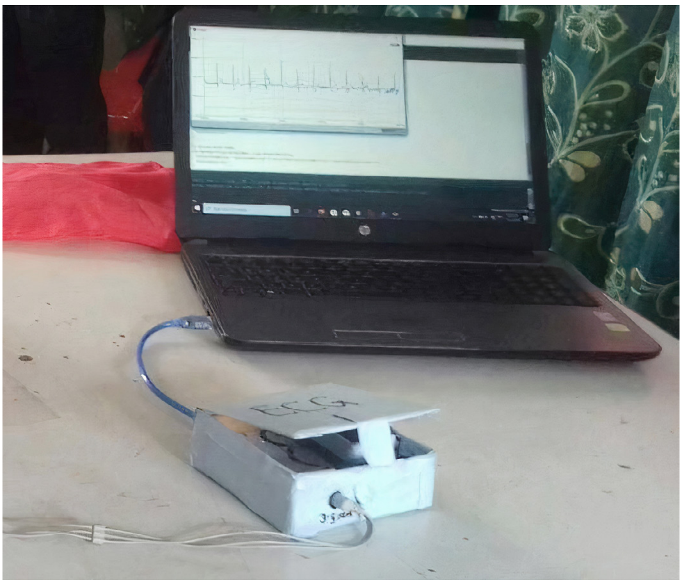

Fig 3: Prototype with ECG signal of person

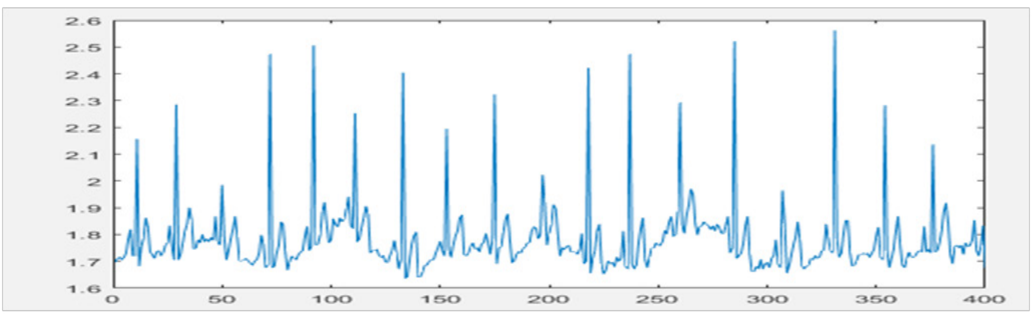

Fig 4: Signal Obtained in Matlab

5. CONCLUSION

An AD8232-based ECG prototype that reads ECG signal from a patient and displays it in an oscilloscope and on a computer screen through Arduino has already been designed, developed, and tested as a final year project in the Bachelor of Engineering in Electronics and Communication by the authors at Nepal Engineering College. The data obtained are recorded, filtered, and uploaded to the cloud. The prototype lasts for 48 hours on a battery of capacity 1,020mAh. It shows the standard ECG signal pattern. It is, however, affected by electromagnetic and some noise can be seen in the signal when taken near live wires even after filtering. Due to its portability and internet compatibility, the design can be useful for medical purposes in the diagnosis, prevention and remote monitoring of cardiac diseases.

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