Pulse Sensor for Vital Sign Monitoring

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I. Introduction

Sensors are electronic devices that detect and respond to some type of inputs from the physical environment. A sensor receives a physical quantity and converts it into a signal suitable for processing (e.g.: optical, electrical, mechanical) and sends the feedback to a microcontroller or microprocessor.

In our project, we are planning to design a sensing element that detects the pulse rate. This pulse rate sensor is designed by using a reflection-type pulse sensor by emitting IR rays. Pulse rate is a vital sign for many heart diseases and some other diseases like hypertension. Thus, measuring pulse rate is important to map our body health. The heart rate or pulse rate is the number of times your heart beats per minute. Normal heart rate varies from person to person. Knowing the heart rate is important for heart health. The best places to measure heart rate are the wrist, inside the elbow, side of the neck, near the chest, and top of the foot. The most common locations used to measure heartbeat are at the radial artery in the wrist, back to the anterior chest wall, and the carotid artery in the neck.

There are a number of methods used to measure the pulse rate. The main four ways to measure heart rate are electrocardiogram, photoelectric pulse wave, blood pressure measurement, and phonocardiography. We have planned to measure the pulse rate by photoelectric pulse wave method which is classified into 2 types depending on the measurement method: transmission and reflection. Our project is based on the reflection of IR waves towards the body and measuring the amount of light reflected using a photodiode or phototransistor. Oxygenated hemoglobin present in the blood of the arteries has the characteristic of absorbing incident light, so by sensing the blood flow rate (change in blood vessel volume) that changes following heart contractions over time we are able to measure the pulse wave signal.

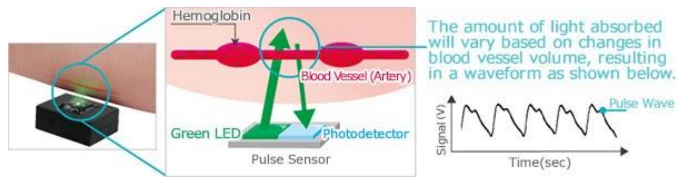

Fig. 1. Reflection type-optical pulse sensor

The main reason to select this method is the working principle. Because the ECG method and the optical method are the most accurate ways for pulse measurement. But the ECG method captures the electrical signal produced by heart activity directly. Thus, we have to fix the electrodes near the heart, and it is inconvenient for day-to-day life. But in the optical method the change in blood flow is measured. The transmission type-pulse wave measurement is limited to areas where light can easily penetrate, such as the fingertip or earlobe. But for the reflection method we can wear it at the wrist which is the best convenience part to wear. The IR ray which is the source of the sensor is constant for the body temperature. IR emitters and photodetectors are very cheap and easy to fix. The speed of IR is high therefore the response time for the sensor is low. These are the main answers for why we chose the IR reflecting method.

The reflection type pulse sensor is used in sleep tracking, sports watches, health bands, complex gaming consoles, remote patient monitoring or alarm system, Anxiety monitoring, etc.

II. Literature Review

A. Heart beat sensor using fingertip through arduino .[20]

- Working principle:- Real time sensors are used to monitor the heartrate, such as a heartbeat sensor, which is attached to the fingertip and monitored every second. The sensed data is sent to the controller, and if there is any difference in the data, an alert signal is sent to the medical personnel.

- Technology used: - First, the sensor is attached to human fingertip. When blood pumps to the fingertip, infrared light passes through the sensor to the photo diode via blood value to measure blood pressure, which is then sent to the Arduino controller. If there is a difference in the output, the controller analyzes the sensed value and the threshold value. The Arduino controller sends the signal to the user through GSM, and it also displays the value of the sensor output on the LCD display. The photo diode and IR sensor in the heartbeat sensor operate together to measure the pulse and blood count for 30 seconds. After IR is sent to the finger on one side and the photo diode receives the signal.

B. Medical-Grade ECG Sensor for Long-Term Monitoring. [21]

- Working principle:- With proper device placement on the chest, a very clear distinction of all electrocardiographic waves can be achieved, allowing for high-quality ECG recording suitable for medical analysis. Experimental results that elucidate the measurements from a differential lead regarding sensors' position, the impact of artifacts, and potential diagnostic value, are shown.

- Technology used: - The concept behind a wireless ECG sensor is the concept of differential lead or differential ECG, which can be measured as a potential difference between two channels in a MECG or a standard 12-lead ECG. The leads in MECG, as well as the standard 12-lead ECG, are referenced to the Wilson central terminal (WCT). In this case, if the electrodes of the body sensor are positioned as two multi-channel electrodes, then the ECG signal is equal to the algebraic voltage difference of the two multi-channel leads. Because the electrodes of a differential lead can be in close proximity, the concept of a single unit is feasible. However, as the distance between the ECG and the noise increases, the ECG signal becomes smaller while the noise level remains constant. As a result, the electrodes should be kept at a sufficient distance to provide a reliable signal with a good signal-to-noise ratio.

C. Heart beat rate monitoring using optical sensors: [22]

- Working principle: - The microcontroller is an electronic circuit component that consists of a CPU, RAM, ROM, and input/output ports embedded in a small chip. A microcontroller is a controller that is embedded in a variety of devices such as home appliances, automobiles, medical devices, and others. The function of the microcontroller is that it receives the signals and then responds according to the type of signal. Input and output devices associated with microcontrollers include sensors, displays, switches, and so on. The microcontroller can receive data from a sensor and convert it to an electrical signal, which it then uses to perform a specific function on the device.

- Technology used: - A smart wearable device that detects heartbeats from the body is a heartbeat monitor. This intelligent instrument employs photoplethysmography (PPG) technology and includes two sensors. The first sensor detects light, while the second detects motion. Its function is to irradiate the skin with light from an LED, and then the light reflected from the body hits the detector, where changes in heartbeat and body movement are measured.

D. Heart Beat Detector using Infrared Pulse. [24]

- Working principle: - It is a pulse detector constructed with a few basic simple materials and an Arduino. This circuit employs the PPG method. while blood is pumped through our body. while blood is pumped through our body. The volume of blood in our body increases and decreases with each heart rate. This method employs a light source and a detector to determine variations in the amount of blood in our extremities. This method employs a photo source and a detector to determine variations in the amount of blood in our extremities.
- Technology used: - A finger cuff with an Arduino board and an infrared LED and a photodiode are located on opposite sides of the finger. The IR LED shines light through the finger, while the photodiode on the other side detects it. The photodiode detects changes in the amount of light as blood pumps in and out of the finger. An IR emitter/detector combo measure the amount of IR light reflected b terminal device blood circulating in our finger. The output is cleaned up by two op-amps amplified by a three (transistor) and then connected down a wire where an oscilloscope can read it.

TABLE I. COMPARISON OF THE ABOVE-MENTIONED DEVICES

Devices	Advantages	Disadvantages
1.Heart beat sensor using fingertip through arduino.*[20]* (Infrared method)	Cost effective. Easy to use. (Not complicated) Can be built using basic principles. Compromise between affordability and efficiency	Less accuracy Compared with ECG sensors.
2. Medical-Grade ECG Sensor for Long-Term Monitoring[21]	More accurate than PPG, IR used devices. Because ECG sensors do not require long settling times, meaningful readings can be obtained very quickly after the device is turned on. Low power consumption than PPG sensor used devices (NeuroSky's BMD101 ECG approx.2.5mW) Utilizes the software more efficiently.	Hard to build, High cost compared to devices that uses PPG sensors. The sensors should be placed appropriately (at least 3 places)
3. Heartbeat rate monitoring using optical sensors.[22]	Easy and convenient Low cost High speed High precision Easy transportation	Low accuracy compared with ECG sensors. High power consumption (Approx. 30Mw
4. Heartbeat Detector using Infrared Pulse.[24]	Simple and not complicated design Easy to use Created by basic principles Components are gettable Expenses of the device is less compared to ECG technology devices	We need proper contact between our skin and emitter and detector for proper measurements Less accuracy compared to ECG

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III. METHODS

In a deep study about heart, it could be able to observe some changes all around the body which are totally displaying the heartbeat pattern. An electric signal, sound wave, vibration and the blood vessel motions (contraction and expansion) are those parameters which display the heart beat vital sign.

A. *Sensing Electric Signal*

The systolic and diastolic movement of heart is induced by an electrical signal generated on the SA node and end up at AV node of the heart. In between small amount of current is conducted all around the body. But, it can be perfectly sensed in some specific points (12 points) on the body.

Using some electrodes placed at some specific points on the body, it could be able to sense the electric current responsible for the heartbeat. Minimum three electrodes should be placed at specific points in the body to obtain highly accurate readings. Since the body current is very small, it can be recorded after amplification process. This is the most accurate method for pulse observation. Because, the body resistance against electric conduction is comparatively lower than the other physical parameters (sound, vibration and blood volume change). Therefore, we could be able to clearly observe small variations in the heartbeat. This will result a detailed representation of heart and body condition. Even though, the noise of the ECG signal will be high, while in motion. Muscular movements and motion due to exercise will cause artefacts on the ECG signals. These artefacts might have same features as cardio electric signal. This will make complication on filtering. The problem during everyday use is the amount of unreadable or unclassifiable rhythms will increase due to the chemical and physical deformations on electrodes. This will affect overall performance of the sensor. And also this electrodes might cause irritation on skin by its composition. Even though this is the most accurate method, it is available and suitable for monitoring a bed patient and for a short term usage.

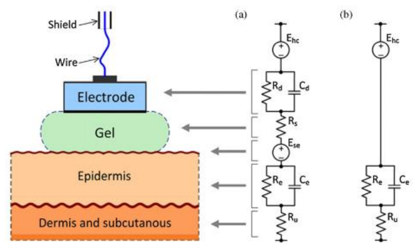

Fig. 2. Structure of an electrode

According to faradays' law, magnetic flux could be found around the body due to the electric impulses by heart. Since electric current is impulse form, magnetic flux will fluctuate and course electromagnetic induction while placing a metal coil near to the skin at those specific points. The advantage is it calculate pulse rate without physical contact with the patient. Therefore, it will be very comfortable on usage. But, it has practical difficulties on implementation. Since, the heart impulse current is very small value, the flux is also very small. Thus, inducting current using this small flux will not be possible. To obtain the induced output current in readable range, a huge number of coils should be winded in the iron core. It is not possible to wind that much coil for our day to day purpose. Moreover, due to the induced current in the coil an eddy current might be induced in the skin surface. This will affect the succeeding readings. Therefore it is not a suitable method to develop an accurate pulse sensr.

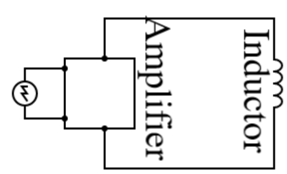

Fig. 3. Sample structure of the inductive model sensor

B. *Sensing Heartbeat Sound*

On the process of systolic and diastolic movement of heart, there is a kind of sound wave is produced by the heart muscles.

Manually a doctor observe pulse rate using stethoscope, which senses the pulse using beat sound. While implementing it in electronic system, external noise will affect the readings a lot. When noise filter circuit is implemented to avoid external noise, the heart beat sound wave also get modified. Pulse rate will be calculated by counting the number of peaks. When the wave form get modified, it will be harder to observe the actual heartbeat pattern. Therefore, the accuracy of the beat sensor will be low. Moreover, this method is only applicable for pulse rate calculation. Not to monitor other parameters related to heartbeat such as atrial depolarization, ventricular depolarization, ventricular repolarization, early ventricular repolarization and AV conduction time.

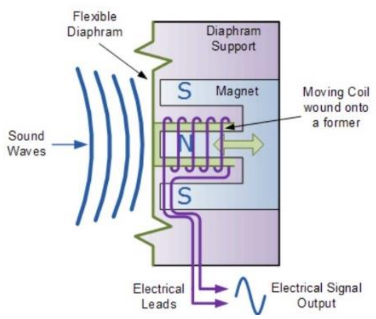

Fig. 4. Sample structure of the heartbeat sound sensing model

C. *Sensing Heart Viberation*

Due to heartbeat, a vibration is produced and transferred to external skin through the muscles. This can be clearly sensed around the chest.

When external forces cause distortion in the crystal, electric charges will be formed within the crystal. Excess negative and positive charges appear on opposite sides of the crystal face. While placing the piezoelectric crystal on or near to the body (wrist, chest, waist, ankle and neck) the crystal distortion by the vibration and the potential different due to the distortion will change linearly to the vibration. Through sensing the potential difference across the crystal, it could be able to display the heartbeat pattern. The disadvantages conclude resonant frequency, vulnerable to interference from the external environment, high output impedance, weak output signal which requires amplification through the amplifier circuit and detection by detecting circuit. It is smaller, light weight and more cost and power efficient compared to ECG sensors. Moreover, piezo sensors do not require skin contact when they measure SCG on the chest or waist while ECG sensors always need skin contact. It only works when a patient is in static activities such as sitting, standing still and lying. This is because piezoelectric sensors are sensitive to all kinds of body motion artifacts. Therefore, the large motions will totally collapse the weak heartbeat signal when the user is moving.

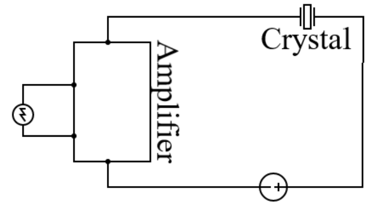

Fig. 5. Sample structure of the piezoelectric viberation sensing model

D. *Sensing Blood Vessel Movements*

The blood which pumped out of the heart while one complete systole and diastole of heart is passed through the blood vessels. Each bundle of blood fluid is collected between two adjacent valves and released to next chamber. In the collection process, the blood vessel walls between the corresponding chamber will expand while the blood get collected and relax while they get released.

The amount of the reflected IR light concentration and the transmitted IR concentration will change proportionally with the blood volume through a specific length of blood vessel. While placing an IR emitter and receiver adjacently (to sense reflected IR concentration) or in opposite ends (to sense transmitted IR concentration), it could be able to display the pulse pattern by displaying the reflected or transmitted IR concentration. This method is the most accurate method next to electrode method. It is the most suitable method to implement on portable devices and long term continuous monitoring purposes (patient with phase makers, heart patients, while exercising….). Accuracy of pulse calculation could be affected by ectopic beats, body motion, fluctuating environmental conditions, as well as adequate blood flow, among other factors. Even though, IR sensors have several advantages over traditional electrode based systems. IR sensor structures are simple structures to implement and implementation cost is low. It could be operated with single IR emitter and receiver pair. This will not affect patient's flexibility. In addition, they can be operated more effectively if they are placed at specific easily accessible anatomical positions such as the earlobe and fingertip where the desired signals are collected with higher quality. But, this method is only applicable for pulse rate calculation. Not to monitor other parameters related to heartbeat such as atrial depolarization, ventricular depolarization, ventricular repolarization, early ventricular repolarization and AV conduction time. This is the most preferable method to build a pulse sensor, because, most of the applications requires patient's flexibility (pulse monitoring due to workouts or exercise) and long term usage.

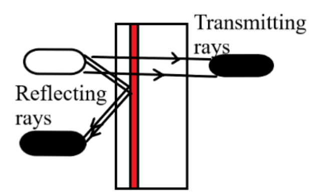

Fig. 6. Principles of IR based sensing model

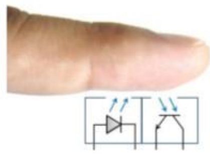

Fig. 7. IR reflection based sensing model

Due to the volume change of blood vessels, the dielectric constant of the finger will also change. While place two metal plates in both sides of the finger or wrist, we could observe the capacitance value is varying in a rhythmic pattern linear to the pulse pattern. Using the oscilloscope wave pattern it could be able to find the pulse rate. It may have noise in the output due to the air gap capacitance variation. Since, the permittivity and the capacitance of air were low, the pulse rate calculation won’t be affected but the wave pattern will be. Thus, this method is only applicable for pulse rate calculation. Not to monitor other parameters related to heartbeat such as atrial depolarization, ventricular depolarization, ventricular repolarization, early ventricular repolarization and AV conduction time.

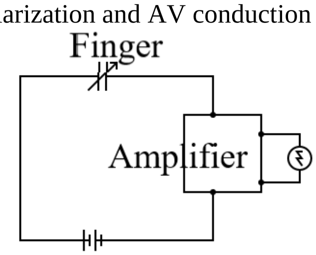

Fig. 8. Sample structure of capacitance based sensing model

The switch system; which mechanically opens and closes according to the blood vessel expansion and contraction (pulse), may sense the movements of body. Since this is a digital output system, it is not possible to differentiate the impulse due to pulse and body movements and also it could be used to calculate the pulse rate only. Other parameters related to heart signal can’t be pictured. Moreover, this switch system should be opened and closed in very minute (nanometer) gaps which are more likely to a closed circuit. Therefore, the input voltage should be step downed to avoid lightning effects between the switch. This is a simple circuit to implement, Even though, possibilities for error is high and it is only applicable for bed patients who are not capable of moving.

Resistance has a feature that it is proportional to the length. Using this feature, the pulse rate could be measured.

$$R = \frac{\rho l}{A}$$

$$R \propto l$$

While applying flexible resistor (flexi resistors) sticker on some particular points (wrist, chest, neck, ear lobes, and waist) where the heart vibration or the blood vessel expansion could be clearly observed, the resistor sticker will expand and contract according to the vibration and blood vessel movements. By picturing the current or voltage change across the resistor, it could be able to observe the pulse wave. This is more simple and easy structure to implement. Even though, while using flexi resistors, it might expand due to body temperature fluctuations. Since the resistance change due to pulse is very small, the resistance will be sensitive to the temperature fluctuations. Therefore, there will be more possibility for erroneous readings. Moreover, the resistor may read the movement of muscles and bones. This will lead to chaos pattern in the output. Thus, it will not possible to extract the pulse pattern.

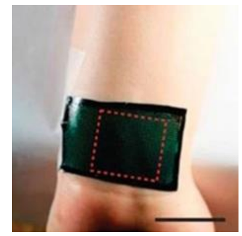

Fig. 9. Flexible resistor sticker model for pulse sensing

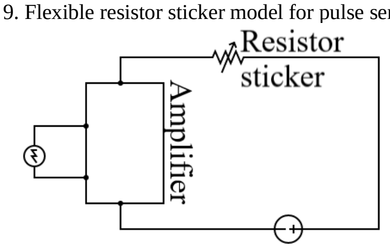

Fig. 10. Sample structure of resistance based sensing model

By surrounding the finger or wrist with a thin soft walled tube which filled with an incompressible fluid, it could be able to sense the blood vessel expansion and contraction. While the blood vessel expands, the fluid tube will distort and a little fluid will try to escape from the tube opening. Through measuring pressure variations on the opening, it could be able to display the approximate heartbeat pattern. Thus, this method is only applicable for pulse rate calculation. Not to monitor other parameters related to heartbeat such as atrial depolarization, ventricular depolarization, ventricular repolarization, early ventricular repolarization, AV conduction time. It has more practical difficulties, even though it has a simple and easy structure to implement. The tube can also get distort by external forces, muscular and bone motions. Distortion by pulse can’t be filtered from these. Therefore, this method is only applicable for the patient at rest and it could monitor the body at relaxed position and the hand on the air. Therefore it is more erroneous method than the others.

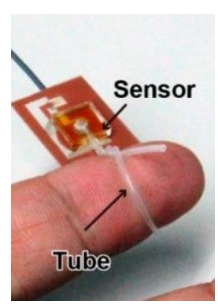

Fig. 11. Sample structure volume change based sensing model

IV. Specifications

- Power supply : 5V
- Working current (IR off) : <5mA
- IR driving current : 0-50mA
- Operating temperature : -40-50 degree Celsius
- Heart rate range : 30 to 250
- Plug and play type
- Attachment with wrist

This is a plug & play sensor mainly designed for Arduino boards that can be used by makers, students, developers, artists who can utilize the heartbeat information in their projects. The sensor will be embedded with a development board for more processes. The most common development board Arduino UNO needs 5V power to run. Thus, the power supply for the sensor is also nearly 5V. When the current through the light emitter is less than 5mA it does not work and 50mA is enough for the circuit. If the current flow is more the power consumption is more and the circuit gets damaged by temperature increment. The wrist is the most convenient place for a wearable. Then, the heart rate of a human is between 30-250bpm.

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