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Design and Implementation of Photo-induced Heart Beat Monitoring System

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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Abstract

This study presents the design of photo-induced heart beat monitor that uses cheap and readily available materials unlike most of all the rather sophisticated heart beat monitoring devices that uses complicated designs and therefore needs the help of an expert to carry out the exercise and also to do the interpretation for users, this device is simple, portable, affordable and easy to operate. This is based on principle and technique of measuring the heart beat with the method of photo induction, through a fingertip using a PIC16F877A Microcontroller interface to a Digital Display for data logging and further analysis of signals generated as a result of such activities. The circuit designed is made up of different stages which involve sensing the Finger Tip through Infrared Receiver; Filtering the Signal, thereby measuring the Heartbeat with the PIC16F877A Microcontroller; calculating through the connected Local Clock Signal and displaying the Result through the 2 X 16 Liquid Crystal Display (LCD) Output. It is therefore a useful design for everyone that wishes to stay healthy and monitor their heart rate for early detection of hypertension and heart related ailments. This design is highly versatile and economical. It can be used everywhere at anytime. It is safe, convenient and easy to use.

Keywords: Photo-induced; PIC16F877A Microcontroller; data logging.

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1 Introduction

The heart and rate at which the heart pumps blood is a very vital issue to individual as it perhaps determine the continuing existence of man or conversely its apparent extinction. Heart rate is a very important phenomenon as it speaks volume about the soundness of mind of individual well being in relations to the cardiovascular system. After series of investigations it was discovered that too many innocent lives have been lost as a result of lack of prompt and regular visit to the hospital for medical checkup due to their unawareness or inability to foot the bills. A heart beat Monitor is a personal monitoring device that allows one to measure ones heart rate in real time or record the heart rate for latter study [1]. It is largely used by performers of various types of physical exercises, old aged, and patients suffering one kind of heart disease. Modern heart rate monitors usually comprise two elements: a chest strap transmitter and a wrist receiver or mobile phone (which usually doubles as a watch or phone) [2,3]. In early plastic straps, water or liquid was required to get good performance [4,5]. Later units have used conductive smart fabric with built-in microprocessors which analyze the EKG signal to determine heart rate [6].

Strapless heart rate monitors now allow the user to just touch two sensors on a wristwatch display for a few seconds to view their heart rate. These are popular for their comfort and ease of use though they don't give as much detail as monitors which use a chest strap. More advanced models will offer measurements of heart rate variability, activity, and breathing rate to assess parameters relating to a subject's fitness. Sensor fusion algorithms allow these monitors to detect core temperature and dehydration [7].

Another style of heart rate monitor replaces the plastic around-the-chest strap with fabric sensors - the most common of these is a sports bra for women which include sensors in the fabric. In old versions, when a heart beat is detected a radio signal is transmitted [2], which the receiver uses to determine the current heart rate. This signal can be a simple radio pulse or a unique coded signal from the chest strap (such as Bluetooth, ANT, or other low-power radio link); the latter prevents one user's receiver from using signals from other nearby transmitters (known as cross-talk interference).

Newer versions include a microprocessor which is continuously monitoring the EKG and calculating the heart rate, and other parameters [6]. These may include accelerometers which can detect speed and distance eliminating the need for foot worn devices. Heart rate can be measured either by the ECG waveform [8] or by the blood flow into the finger (pulse method). The pulse method is simple and convenient. When blood flows during the systolic stroke of the heart into the body parts, the finger gets its blood via the radial artery on the arm. The blood flow into the finger can be sensed photo electrically. To count the heart beats, here a small light source will be used on one side of the finger (thumb) and observe the change in light intensity on the other side. The blood flow causes variation in light intensity reaching the light dependent resistor (LDR), which results in change in signal strength due to change in the resistance of the LDR.

2 Design Methodology

The design and construction of photo- induced heart beat monitor, utilizes the principle of photo induction. It uses the PIC16F877A of microchip to control the various activities of the various stages and design circuitry involved. Heart rate of the subject is measured from the finger using optical sensors and the rate is then averaged and displayed on a text based LCD. The computer interface that is incorporated into this design provides ample Graphic display of the signal in the form of waves that can be analyzed.

Heart rate is simply and traditionally measured by placing the thumb over the subject's arterial pulsation, and feeling, timing and counting the pulses usually in a 30 second period. Heart rate (bpm) of the subject is then found by multiplying the obtained number by 2. This method although simple, is not accurate and can give error when the rate is high. This describes the design of a versatile and highly economical device which measures the heart rate of people by clipping sensors on one of the fingers and then displaying the result on a text based LCD as well as showing the results graphically on a computer screen for further analysis and storage.

The device has the advantage that it is microcontroller based and thus can be programmed to display various quantities, such as the average, maximum and minimum rates over a period of time and so on. Another advantage of such a design is that it can be expanded and can easily be connected to a recording device or a PC to collect and analyze the data for over a period of time.

3 Principle of Operation

Photoelectric, photo-induced heart beat monitor's operation is typically based either on the light scattering principle (light can be scattered due to particles reflection) or the light obscuration principle (reduction of light passing through particles). As far as this design is concerned, the photo induced heartbeat monitor works based on light scattering. Photo-induced heartbeat/Photoelectric light scattering particles (objects) detectors consist of an infra-red light source, or technically put, infra-red transmitter and a receiver, infra-red receiver. When particles enter the light path, light collides with these particles and is reflected at the photo-sensitive device, causing the detector to respond. This particle or object or more appropriately put, obstruction in the part of the infrared light passage is the blood flow as explained and illustrated in the introduction and literature review. The block diagram of Fig. 1 is useful to explain the detailed principle of operation of the Photo-Induced heartbeat monitor, using photoelectric effect.

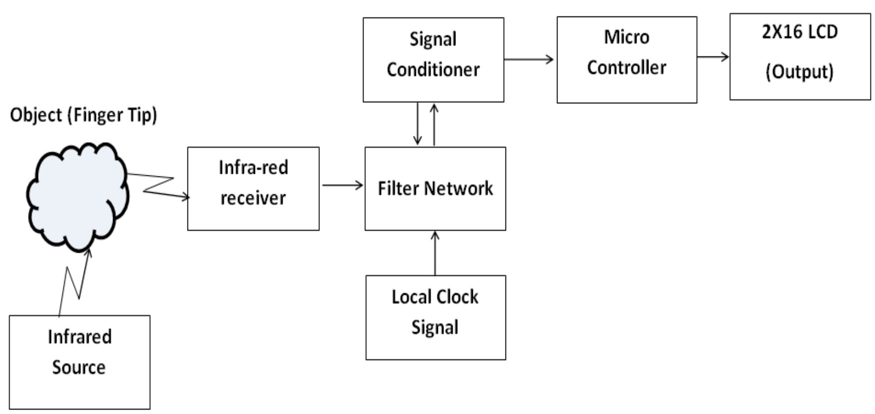

Fig. 1. Block diagram of photo-induced heartbeat monitor

3.1 Infra-red source

The infra-red source consists of an infra-red transmitter and some passive semi-conductors carefully arranged to generate a train of pulses at a frequency of 38 kHz. It made use of NAND gate, connected as an inverter (with its two input wired together) and a transistor to switch the infra-red transmitter itself because the signal from the NAND gate (or oscillator now) is not strong enough to drive the infra-red transmitter directly.

3.2 The finger chamber

This is a hallow place carefully perforated to accommodate the finger. It serves as temporary storage of "blood flow" so that the infra-red transmitter can hit the hand tissue (That contains the blood and varies in translucency based on the rate at which the heart pumps blood) at an appropriate angle and the ray can be diverted to the infra-red receiver side. If the chamber is not appropriately designed or the finger is wrongly positioned, to cause proper dispersion of light rays then the design would be at risk of mal-function and false counting of heartbeat may occur.

3.3 Infra-red receiver

The main function of the infra-red receiver as the name implies is to collect the signal passing through and from the transmitter. As a result of the obstruction to the flow of the infrared signal as a result of the pumping of blood to the finger, the received signal from the receiver varies in repeated steps of high and low. These signals are very weak and are often affected by noise and other environmental conditions. To reduce loss and to minimize the effect of these unwanted signals, the signal is passed to a filter.

3.4 Filter network

A filter is a device designed to attenuate specific ranges of frequencies, while allowing other to pass, and in so doing limit in some fashion the frequency spectrum of a signal. The frequency ranges, which are attenuated, are called the stop band, and the range, which is transmitted, is called the pass band. There exist four main types of filters: low-pass, high-pass, band pass, reject band filters. Using a low pass filter: For low frequencies, $w<1/RC$ (w is frequency, R is resistor and C is capacitor), the signal is not allowed to pass after a certain determined frequency. The cut off frequency is 10 Hz this is done to extract the needed frequency components of the signal. This filter is characterized by having one capacitor connected to the ground.

3.5 Signal conditioner

The output from the filter cannot be passed to the digital input of the Microcontroller directly, a signal conditional is used. The purpose of the signal conditional is to change the un-damped analog signal at the output of the filter to a digital form as near as possible.

3.6 Local clock signal (NE555 timer)

The aim of this section of the design is to create a pulse at a frequency that can be adjusted by the user, (between the frequency of 200 and 20,000 Hertz). It is attached to the filter network and as the user varies this pulse or frequency as the case may be. The purpose of this stage is to provide a train of pulses that samples digitally and breaks the filtered signals into smaller lumps for easy operation of the signal conditional. In other words the local clock generates a working time base for the filter as well as the signal conditional at a pace determined by the values of the passive semi conductor used. In [9], Table 1 summarizes some desirable properties and parameters useful in actualizing this design.

Table 1. Data table of NE555 timer

Parameter	Symbol	Value	Unit
Supply voltage	Vcc	16	V
Lead temperature (Soldering 10 sec)	T_{LEAD}	300	°C
Power dissipation	P_D	600	mW
Operating temperature range	T_{OPR}	0 to +70	°C
Storage temperature range	T_{STG}	-65 to +150	°C

Absolute Maximum Ratings (TA = 25°C)

3.7 The microcontroller

The PIC16F877A features 256 bytes of EEPROM data memory, self programming, an ICD, 2 Comparators, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I²C™) bus and a Universal Asynchronous Receiver Transmitter (USART). A Microchip microcontroller PIC16F877A is used to collect and process data and then stores it in a serial EEPROM as shown in Fig. 2. This microcontroller had been used before at the laboratory and gave good results. It has RISC architecture and can use oscillators for frequency up to 20 MHz. Its power consumption is about 25 mW (at 4 MHz), thus it is ideal to be used as an embedded system. The conditioned and filtered signal is fed to the A/ D converter within the PIC16F877A. The sampling rate of the system is 1KHz which means 1000 samples were acquired in a second and then processed in order to detect zero crossings.

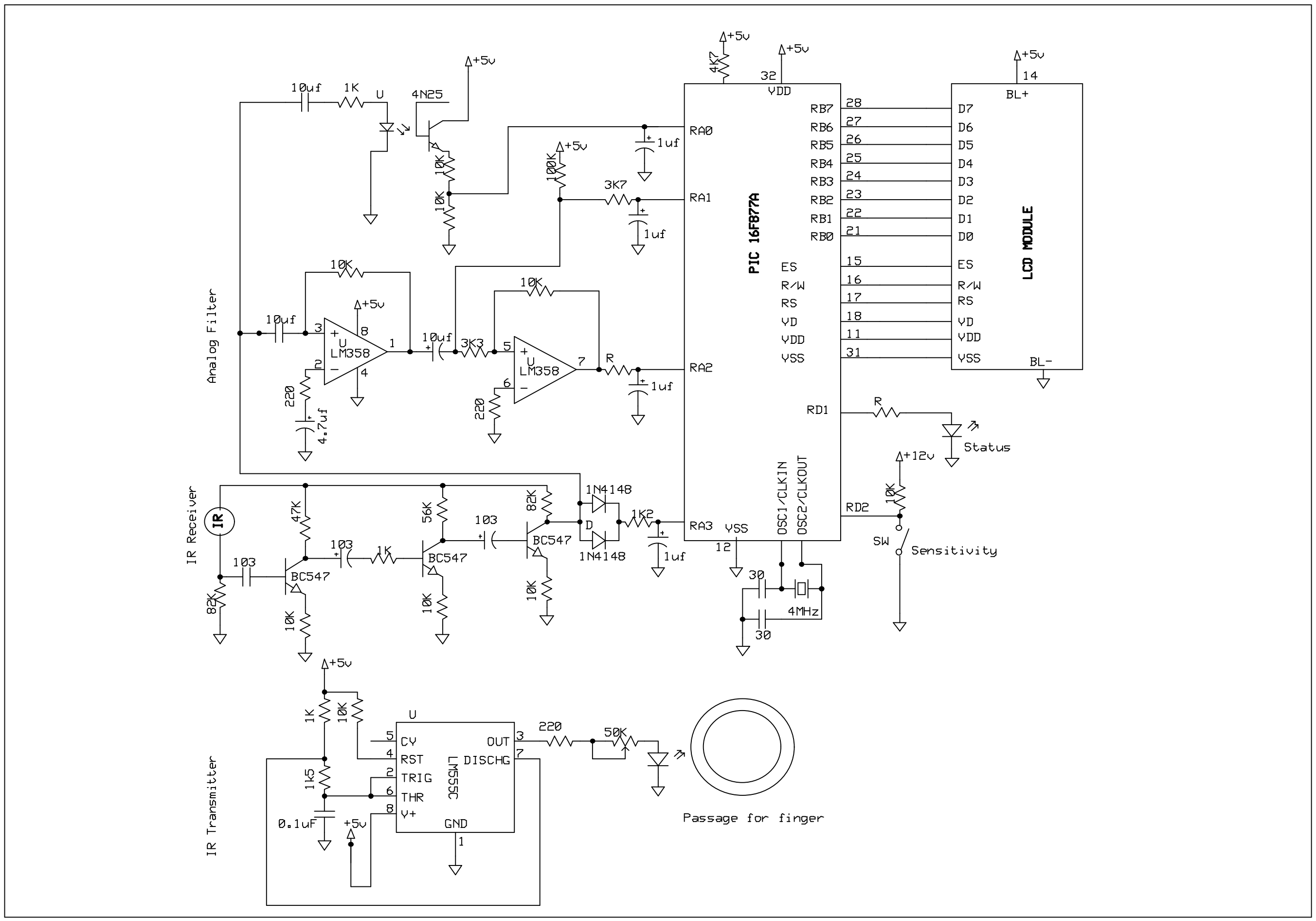

Fig. 2. Photo induced heart beat monitoring system

The internal timer is used to emulate real time clock. In this case, the received signal is processed, if six consecutive zero crossing were detected and separated by at least 40 ms (40 simples), then the process increments a register called ZCC (zero crossing counter). Memory requirements are 1k of program memory for storing the system operation program, and 256 bytes of data EEPROM for storing up to 80 different heart diagnosis conditions. Only three bytes are required for each diagnosis (two bytes for the time and one byte for the heart condition). The number of samples of signals stored depends on the available memory.

3.8 2X 16 LCD output

In [10], a liquid-crystal display (LCD) is a flat-panel display whose IC's is shown inside Fig. 2 representing Photo Induced Heart Beat Monitoring System that uses the light- modulating properties of liquid crystals. Liquid crystals do not emit light directly. LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden, such as preset words, digits, and 7-segment displays as in a digital clock. The same basic technology used in this design to display the precise heart beat rate value of user on screen.

4 Results and Discussion

4.1 Testing

Some of the various inputs and outputs of each stage were tested and analyzed for uniformity, compliance, reliability and conformity using electronic workbench simulation application software. After carrying out all the paper design and analysis, the design was implemented and tested to ensure the working ability, and then finally constructed to meet desired specifications. The process of testing and implementation of this design, the photo Induced Heart Beat monitor involved the use of some equipment stated below.

(i) **Bench Power Supply:** This was used to supply voltage to the various stages of the circuit during the breadboard test before the power supply for the circuit was built. Also during the soldering of the design the bench power supply was still used to test various stages before the D.C. power supply used in the design was finally constructed.

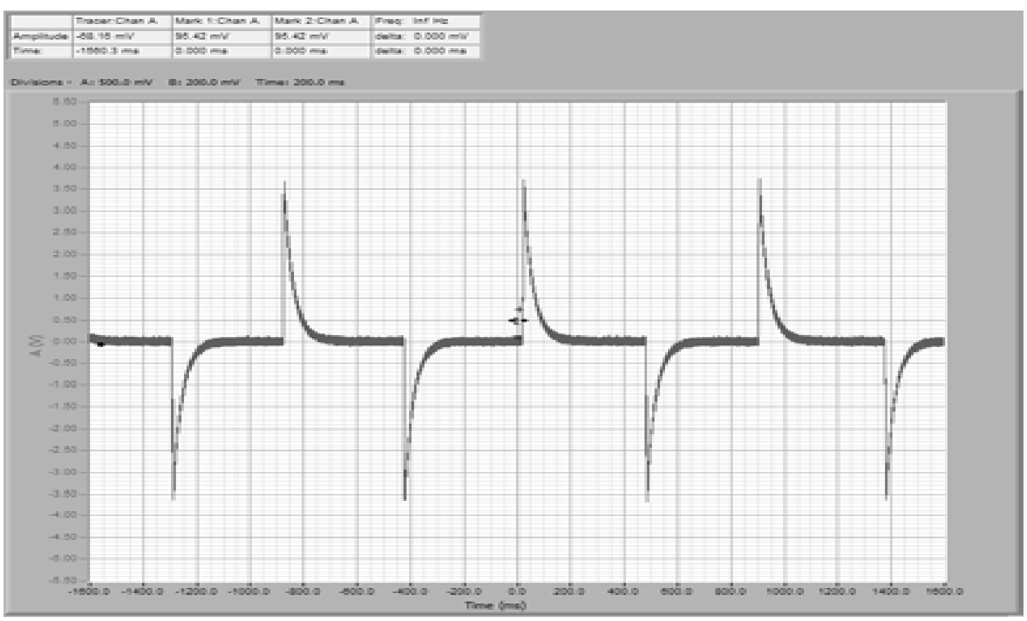

Fig. 3. Ripple in power supply waveform from oscilloscope

(ii) Oscilloscope: The oscilloscope was used to observe the ripples in the power supply waveform as shown in Fig. 3 and to ensure that all waveforms are correct and their frequencies are accurate. It was also used to monitor and view the signals from the filter output as well as the digital signal from the output of the signal conditioner.

(iii) Digital Multimeter: The digital multimeter basically measures voltage, resistance, continuity, current, frequency, and temperature and transistor current gain (Hfe). The process of implementation of the design on the board required the measurement of parameters like, voltage, continuity, and resistance values of the components and in some cases frequency measurement. The digital multimeter was used to check the various voltage levels of the various stages; continuity of the various stages and also the output current level was tested using the DMM (Digital Multimeter).

4.2 Discussion and display

A normal heart rate depends on the individual, age, body size, heart conditions, whether the person is sitting or moving, medication use and even air temperature. Even emotions can have an impact on heart rate. For example, getting excited or scared can increase the heart rate. But most importantly, getting fitter lowers the heart rate, by making heart muscles work more efficiently. Knowledge about the heart rate can help monitor fitness level, and it may help spot developing health problems if experiencing other symptoms. An athlete who is training and is having symptoms such as dizziness, then knowing the heart rate is important.

Resting heart rate is the pulse when calmly sitting or lying. It’s best to measure resting heart rate in the morning before getting out of bed, according to the American Heart Association (AHA). For adults 18 and older, a normal resting heart rate is between 60 and 100 beats per minute (bpm), depending on the person’s physical condition and age. For children ages 6 to 15, the normal resting heart rate is between 70 and 100 bpm, according to the AHA. A heart rate lower than 60 doesn’t necessarily mean there is a medical problem. Active people often have lower heart rates because their heart muscles don't need to work as hard to maintain a steady beat. Athletes and people who are very fit can have resting heat rate of 40 bpm.

A resting heart rate lower than 60 bpm could also be the result of taking certain medications. Many medications people take especially medication for blood pressure, such as the beta blockers, will record lower heart rate. If coupled with symptoms, a low heart rate may signal a problem. A low heart rate in somebody who is having dizziness and lightheadedness may indicate that they have an abnormality that needs to be looked. A person's target heart rate zone is between 50 percent and 85 percent of his or her maximum heart rate, according to the AHA. Figs. 4 to 6 shows the display and operations guide for the Photo Induced Heart Beat Monitor.

Most commonly, maximum heart rate is calculated by subtracting the age from 220:

- 220 - Age. For a 30-year-old person, for example: 220 - 30 = 190.

The target zone for a 30-year-old person would be between 50 and 85 percent of his or her maximum heart rate:

- 50 percent level: 190 x 0.50 = 95 bpm
- 85 percent level: 190 x 0.85 = 162 bpm

The formula for maximum heart rate works well for people under 40 but for older people it may overestimate their maximum heart rate, Bauman said. For older people, a better formula for the maximum heart rate is:

- 208 – (0.75 x Age)

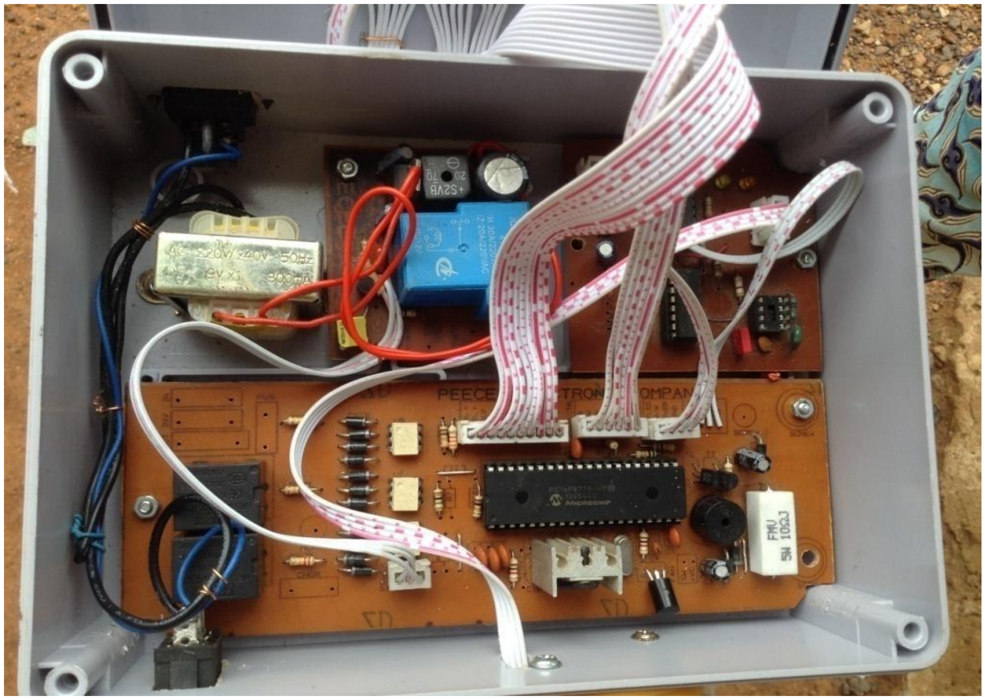

Fig. 4. Inside view of the photo induced heart beat monitoring system

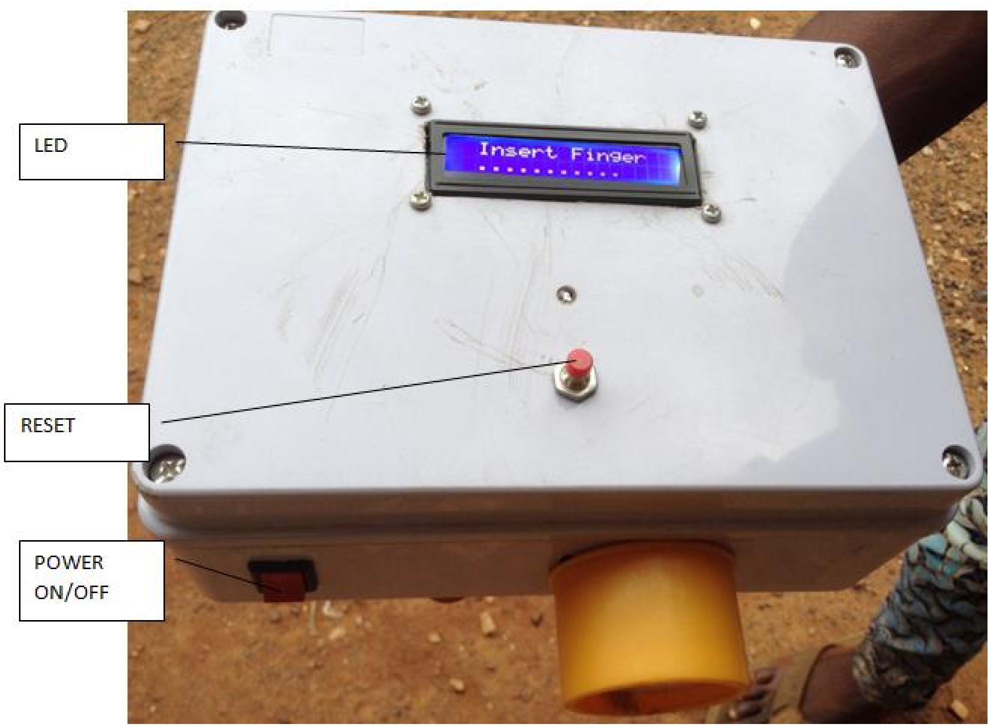

Fig. 5. Top view of the photo induced heart beat monitoring system

Fig. 6. Front view of the photo induced heart beat monitoring system

4.3 Results

The results from the use of the Photo Induced Heart Beat Monitor with 6 different categories of people from Babies to Aged was taken and a average sample from four samples was displayed in each category as shown in Table 2 with their respective comments. The picture samples to confirm the results are also shown in Figs. 7 to 12. It is found accurate compared with an Electrocardiogram and it is easy to operate, whenever lower or higher heart beat is recorded, it signifies symptoms which need to be taken care of; such as the athletes and cyclists that are not meeting requirements or going extreme. It shows how sensors can be used to implement different functions as related to health.

Fig. 7. Baby 1 year – 102 bpm

Fig. 8. Toddler 3 years – 73 bpm

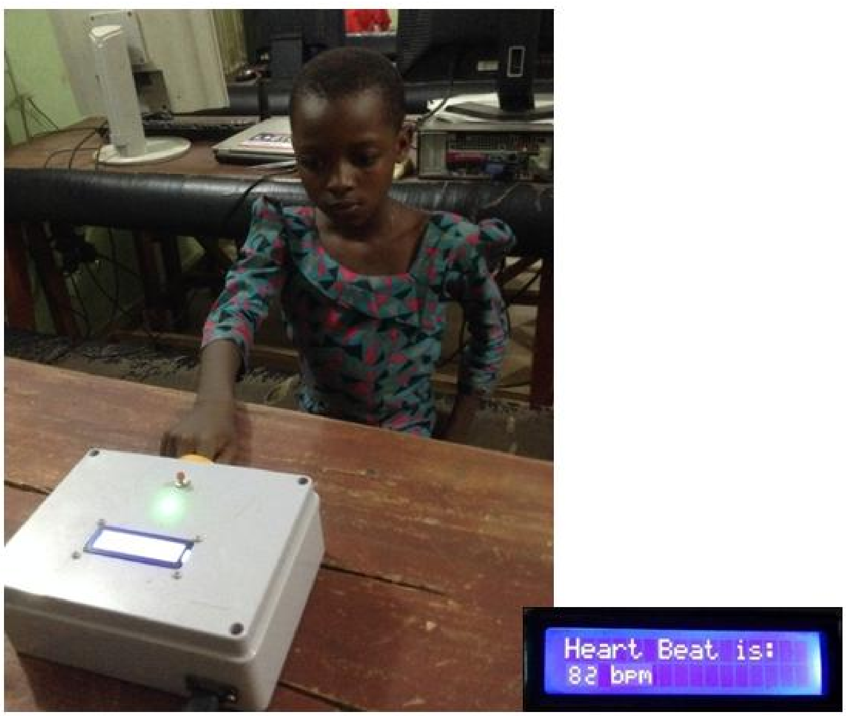

Fig. 9. Children 6 years – 82 bpm

Fig. 10. Teenager 19 years – 77 bpm

Fig. 11. Adult 26 years – 93 bpm

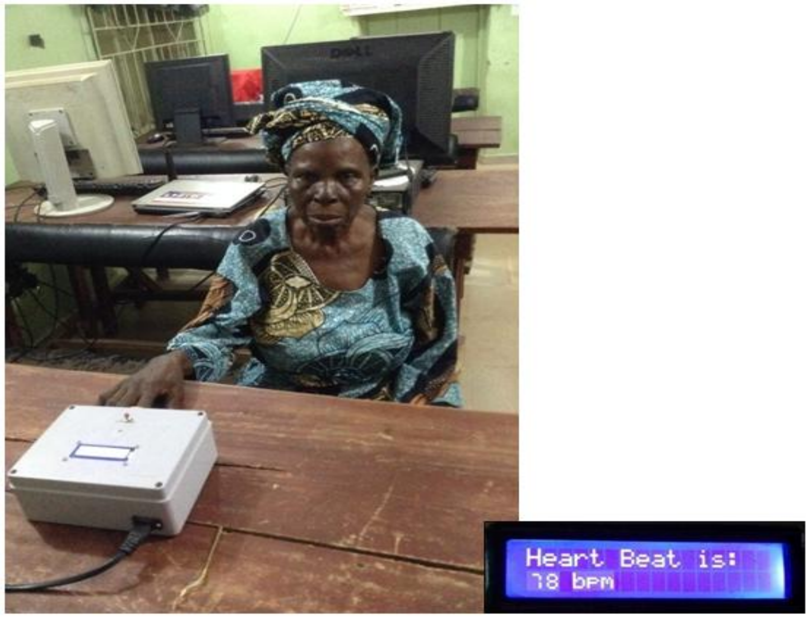

Fig. 12. Aged 86 years – 78 bpm

Table 2. Result obtained from random use of the photo induced heartbeat monitor

S/N	Category of people	With photo-induced heartbeat monitor (bpm)	Comment
1.	Babies (0-2 years)	80 - 110	- Higher than Adults due to Panic, Cry and worry.
2.	Toddlers (2-4 years)	70 - 85	- Lower than Babies because they undergo Physical activities.
3.	Children (4-12 years)	78 - 92	- They are very playful and restful
4.	Teenagers (13-19 years)	75 -98	- They can control themselves but are full of activities.
5.	Adults (20-50 years)	74 -95	- They are aware of how important is it to monitor their heart beat as they keep track.
6.	Aged (50 years and above)	60 - 78	- They are at relaxed mind; any hike in the heart rate is a symptom.

Table 3. Accuracy comparison of the photo induced heartbeat monitor with an electrocardiogram

S/N	Category of people	Electrocardiogram (bpm)	With photo-induced heartbeat monitor (bpm)	Error rate (%)
1.	Babies (1 year)	100	102	2
2.	Toddlers (3 years)	73	73	0
3.	Children (6 years)	80	82	2.5
4.	Teenagers (19 years)	76	77	1.3
5.	Adults (26 years)	91	93	2.5
6.	Aged (86 years)	79	78	1.27

This shows that Photo- induced Heart beat Monitor gives virtually equal result compared to older Heartbeat Monitor and comes with user interactive/interpretable display.

5 Conclusion

Photo-induced heart beat monitor is designed based on the theoretical and practical knowledge gained so far. It is constructed using low cost electronic components, the available and reliable component was used rather than the more expensive and unavailable ones. It helps in improvement of life; it reduces human power and supervision. Both analog and digital signal processing techniques are combined to keep the device simple and to efficiently suppress the disturbance in signals. Simulations showed that heart rate can be detected from changes of blood flow through an index finger. Experimental results showed that the heart rate can be filtered and digitized so that it can be counted to calculate an accurate pulse rate. The device is able to detect, filter, digitize, and display the heartbeat of a user ergonomically.

6 Contributions to Knowledge

Photo- induced heart beat monitoring system enables individual to get aware of the essence of heart beat monitoring and the ranges of heart beat per minute a specific age group must record. It also reduces stress of visiting the hospital at all time for checkups as it is easily accessible, compact, easy to operate and non-hazardous. It can be taken across schools and offices for regular checkups as it is a standalone system that does not require any interpreter or interface.

7 Recommendations

This design is recommended for use in hospitals and homes for individuals who are prone to cardiac arrests or any form of cardio-vascular infection/disease. Patients with hypertension can be placed on medication thereby using the heart beat monitor to watch the responsiveness with time. Pregnant women can use this device at regular interval to know when there is deviation from the Normal Heart rate for proper attention. Athletes, footballers, cyclists and all those who involve themselves with tedious activities can also make use of this device. For future development, the device can be reconfigured and interfaced with the GSM modem and Bluetooth technology.

Consent

All the subjects of this research paper belong to author’s family. Therefore, no formal consent is required.

Competing Interests

Author has declared that no competing interests exist.

References

[1] Edwards S. Heart rate monitor book. Leisure Systems International; 1993.

[2] Chen Y. Wireless heart rate monitor with infrared detecting module, US2005075577-A1; 2005.

[3] Shim H, Lee JH, Hwang SO, Yoon HR, Yoon YR. Development of heart rate monitoring for mobile telemedicine using smartphone. 13th International Conference on Biomedical; 2008.

[4] Hampton JR. The ECG in practice. Churchill Livingstone; 2003.

[5] Houghton AR, Gray D. Making sense of the ECG. Hodder Arnold Publishing; 2003.

[6] Landaeta RG, Casas O, Areny RP. Heart rate detection from plantar bio impedance measurements. 28th IEEE EMBS Annual International Conference, USA. 2006;5113-5116.

[7] Malik M, Camm AJ. Heart rate variability. Futura Publishing Co. Inc; 1995.

[8] Schamroth C. An introduction to electro cardiography. Blackwell Science Publishing, 7th Edition; 2001.

[9] NE555.
Available:http://www.linuxfocus.org/common/src/article239/NE555.pdf
(Retrieved Jan., 2016)

[10] LCD.
Available:https://en.wikipedia.org/wiki/Liquid-crystal_display

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