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IoT Based Pulse Oximeter for Remote Health Assessment: Design, Challenges and Futuristic Scope

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ABSTRACT- The Internet of Things (IoT) comprises the networking, computing, and storage with analytics technologies that do wonders in every aspect of human life through its applications and turns their life style as smart as possible. The application of IoT in healthcare domain would transform the medical service to be timely accessible and affordable by all people. The cardiovascular diseases (CVD) are marked as one of the most common cause of death around the world. A research study states that CVD targets the public with age limit of 30 - 60 belongs to developing countries like India in an evidential growth. The continuous monitoring of human heart, which is a fist sized strongest muscle through invasive sensors helps in early detection and anticipating necessary treatment on time. This induces a design of IoT enabled pulse rate monitoring system to continuously track the patient at anywhere and better serve them at any time through any device. The device uses easy pulse sensor and is operated through Raspberry Pi. The effectiveness of the device is analyzed against one of the top brand fingertip pulse oximeter, suggested for home and clinical usage in practice. Further the non-invasive design of pulse oximeter which determines the blood pressure (BP) using electrocardiography (ECG) and photo plethysmography (PPG) sensors.

General Terms: Internet of Things (IoT), Remote health monitoring, vital sign monitor.

Keywords: Cardio vascular diseases, Cloud computing, Healthcare, Internet of things (IoT), Wireless sensor networks.

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1. INTRODUCTION

By promising the invasiveness of computers in place, the evolution of ubiquitous computing continuously improves the computational capacities of ordinary objects. The network integration of these objects allows for active data communication between them. Intense applications are presented as a service among this network of devices, containing the appropriate data analytics method to facilitate timely and intelligent actions. The Internet of Things (IoT) is a current trending technology that stems from machine-to-machine communication and provides automated smart solutions for numerous sectors and societal domains [1]. In simple terms, the Internet of Things (IoT) is a tool or a massive technology that delivers any service extended to use by anybody, irrespective of location *i.e.* anywhere, with any device, over any network, at any time [2]. The *figure 1* illustrates the definition of the Internet of Things.

Figure 1: Schematic Definition of IoT

IoT plays a critical role in improving people's lives through linked devices, and thereby bridges the physical world with digital world. To live healthy life style and stay away from the most common non communicable dis-eases (NCD) like cardio-vascular diseases, it is necessary to keep monitoring the pulse rate of human body which signifies the state of heart condition, and by maintaining historical data, alerts us in case of identified abnormalities proactively and avails immediate attention of medical experts through the application runs in their mobile device. The current solutions are based on the reactive approach which helps to manage the sickness upon its occurrences in the form of e-health and m-health applications. An e-health application offers a service that helps to administrate the

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treatment of patients over internet by maintaining their medical records, reports as electronic health records (EHR) and allows payments electronically [3-5]. Whereas m-health utilizes the power and efficiency of wireless technologies and provides the users' health related data and services over the mobile phones [6, 7]. The proposed design is intended to avail a proactive health care solution enabled through health trackers for the public users enriched with the qualities like cheaper in cost, comfort, durable, easy-to-use, reliable and remote access [8].

The paper is organized in the following way: *Section 2* discusses about various related work carried out. *Section 3* provides detailed description of materials used to design the prototype oximeter. *Section 4* discloses the framework of the proposed system. *Section 5* reveals the detailed discussion on obtained results of the system. Finally, *Section 6* concludes the proposed solution with the scope for an enhancement in further.

2. RELATED WORK

In recent years, the potential for IoT applications in the healthcare domain has been examined. The potential for promising design techniques to narrow the gap between the public and medical services supported by experts is a serious concern [9, 10]. The provision of service necessitates the comfort zone of being treated outside of the hospital for uncomplicated diagnosis procedures and stages in the recovery of diseases in order to save people's lives on time. The previous demand or public interest in simple is ensured by regular monitoring of human vital indicators. The patient-centric health monitoring system was created with heart/pulse rate (HR/PR), blood pressure (BP), blood oxygen level (SpO2), breathing rate (BR), temperature, and weight as primary indicators that contribute to a thorough understanding of a person's health [3,4,11]. These physiological indicators are detected by calculating the mechanical activity of the chest wall using the Doppler Effect (DE) which is given in *equation 1*, or by employing thermal or video imaging, which are the most common approaches [12, 13].

$$\theta(t)=(4\pi / \lambda) * x(t) \quad (1)$$

Between the source and the observer, the Doppler Effect causes a shift in frequency in proportion to velocity. The reflected signal $\Theta(t)$ is computed by scaling the transmitted signal's wavelength λ to the chest displacement $x(t)$.

One of the most significant health parameters is the heart / pulse rate, which monitors the heart's ability to function properly. The heart beat is measured in beats per minute (BPM), whereas the pulse rate is utilized to capture the blood volume changes in tissue induced by the contraction of the heart, and they are both accounted for similarly.

The Photoplethysmography (PPG) and Electrocardiography (ECG) are two typical ways for measuring it in practice. ECG is performed by placing electrodes on the human body and analyzing electrical impulses to determine heart rate [8, 11, 13, 14, 15]. PPG is the measurement of blood volume change in tissue in relation to heartbeat using an optical sensing environment that includes a light source and detector [8, 12, 16, 17, 18, 19, 20].

Table 1: Summary of significant contributions in remote pulse oximeter

Contributing Authors	Methodology				Physiological Signs Measured				
	DE	ECG	PPG	Camera Imaging	HR	SpO2	BP	RR	BT
Al-Naji et al. (2017) & Hudoklin et al.(2017)	✓	×	×	×	✓	×	×	×	×
Chirakanphaisarna et al. (2018)	×	✓	×	×	✓	×	×	×	×
Lee et al. (2016), Arulananth et al. (2017), Shirzadfar et al. (2018) & Chong et al. (2019)	×	×	✓	×	✓	✓	×	×	×
Zhao et al. (2016) & Villarroel et al. (2017)	×	×	×	✓	✓	×	×	×	×
Prochazka et al. (2016), Bakhtiyari et al. (2017) & Gambi et al. (2017)	×	×	✓	✓	✓	✓	×	✓	×

Most of recent efforts used camera imaging of thumb as an input to ascertain the pulse rate of the person [21, 22]. The author named Ozcan et al. [23] developed physical therapy system for rehabilitation employing Kinect sensor in design. The summary of related work in obtaining pulse / heart rate through accumulating numerous contemporary to modern technologies is presented in *Table 1*.

3. PROPOSED DESIGN OF REMOTE PULSE OXIMETER

The proposed design of IoT enabled remote pulse monitor implements three tier architecture, in lined up with the previous contributions extended for bringing an IoT architectural design [24]. As shown in *figure 2*, it is meant to have three layers: device, processor, and application. The hardware components used to construct the pulse rate monitoring equipment make up the device layer. It employs the Raspberry Pi Zero W Case as a development board, the MCP 3008 as an Analog-Digital Converter (ADC), and a simple pulse sensor, all of which are detailed in the previous section.

The processing layer is built on top of a cloud platform and includes the components Thing Speak which is a data store that handles storage, processing and analysis as a single operation. Finally, a mobile device serves as an application layer for the presentation of results and the triggering of actions. As shown in *figure 2*, data is transmitted across either through the three layers using various networks such as Bluetooth, the Internet, or Wi-Fi. The significant components of the proposed system are discussed in the following sections.

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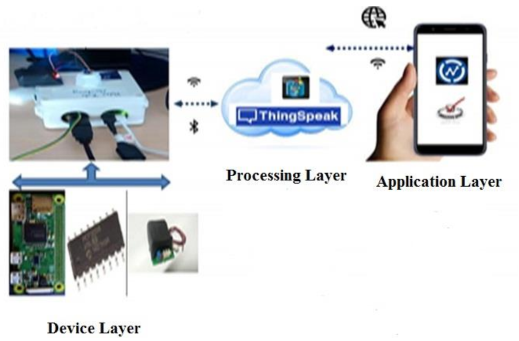

Figure 2: Architectural framework of instantaneous pulse oximeter using IoT

3.1 Raspberry Pi Zero with case

In the view of promoting basic computer science in schools, Raspberry Pi was developed. It is a credit card sized, single board computers include a system on chip (SoC) incorporated with ARM-compatible central processing unit (CPU) and graphics processing unit (GPU). With the existence several versions (up to 3), after its first appearance by February 2017, Raspberry Pi Zero W Case is chosen as a development board because of the promising characteristics like smaller in size, reduced input/output (I/O) circuitry design with Bluetooth and Wi-Fi capabilities. It extends the peripheral support through the ports attached directly on SoC. It uses two micro universal serial bus (USB) port, a miniaturization of USB interface to link tight mobile devices, here the ports are intended to enable power and input. It uses one high-definition multimedia interface (HDMI), which is a connector allows high speed data streaming between the devices connected either through the built-in Bluetooth or Wi-Fi potentiality.

3.2 Heart rate sensor with algorithmic design

The suggested pulse rate monitor employs the TCRT1000 as a heart rate sensor, which operates on the PPG principle. The infrared light emitter and phototransistor are situated apart on the TCRT1000, which is enclosed by a leaded package to decrease the impact of ambient light in the environment. The fingertip is chosen as the region of interest (ROI) to avoid motion artifacts and other related problems [25]. When a fingertip is placed over the sensor surface, the output is a PPG waveform with two components: direct current (DC) and alternating current (AC), as shown in *figure 3.*

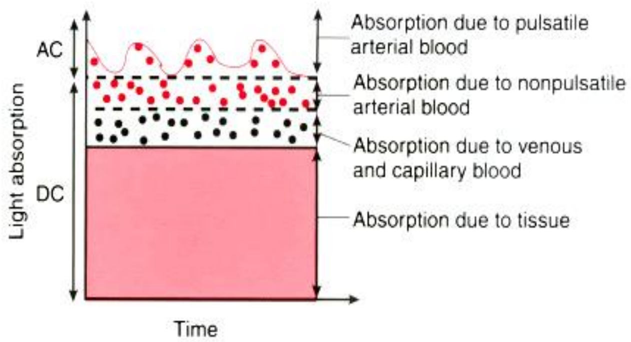

Figure 3: Light intensity diagram of PPG observed through finger

The AC component provides pulsatile arterial blood that is in sync with the heart rhythm. The AC component is superimposed atop a substantial DC component, which assesses tissue and capillary blood absorption. The undesirable DC value with high frequency noise up to 60Hz must be eliminated to get only valuable AC information. It reduces the signal-to-noise ratio (SNR) using two layers of filtering and amplification circuit and generates the frequency of pulses (f) aligned with heart rate out from PPG signal by using formula given in *equation (2).*

$$Heart\ Rate\ (HR) = f * 60 \quad (2)$$

The entire process flow of the heart rate sensor is captured in the *Table 2*. The sensor collects the input signal by way of the fingertip of the user.

Table 2: Summary of significant contributions in remote pulse oximeter

Input: User finger on sensor
Output: Heart Rate (HR) in BPM
1. Place the finger on the sensor
2. Yield the PPG signal from the sensor
3. Design first signaling stage to filter the noisy signals in PPG
a. Place a high-pass filter (HPF) with the cut-off frequency as 0.7Hz
b. Set an active low-pass filter (LPF), made of an Op-Amp circuit with the gain as 101 and the cut-off frequency as 2.34 Hz respectively
c. Amplify the low amplitude pulse signal (AC component) 101 times
4. Use a 5K potentiometer to control the total gain of signaling stage not exceeding 10201 (101*101)
5. Design a second signaling stage to filter the noisy signals in PPG
a. Repeat the design specified in Step 3
6. Extract the output frequency of pulse (f)
7. Obtain a heart rate in beats per minute (BPM) as in Equation (2)

3.3 Analog to digital converter (ADC): An interfacing unit

Because of Raspberry Pi Zero W Case only has analogue connections, the MCP3008 is a 10-bit, 8-channel ADC with a low cost and less power consumption (425A in operation, 5nA in standby). It is meant to link with any microcontroller for enabling digital output. It connects to the Raspberry Pi either through software serial peripheral interface (SPI) or hardware. The SPI is more flexible since it can work with just about any pin on the Pi, however hardware SPI is less adaptable because it can only work with particular pins but is probably faster. The suggested system is based on software SPI, and the complete interface design is shown in *figure 4.*

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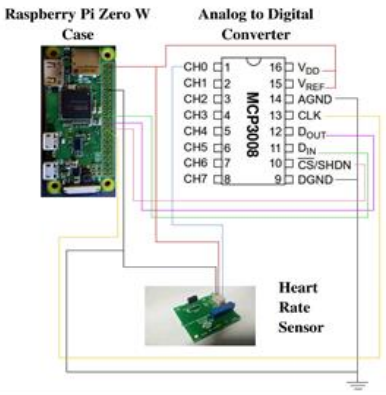

Figure 4: Light intensity diagram of PPG observed through finger

On Raspberry Pi, heart rate sensor is interfaced with ADC for its data flow. The data generated from the device is progressed through cloud without configuring the network as because the processor itself provided with a built-in support of communication over Bluetooth or Wi-Fi.

3.4 Thing Speak

Thing Speak is an application programming interface (API) for IoT devices that allows data to be stored and retrieved as an open service from the device layer to the processing layer. As long as the device layer is networked, it can connect with any sort of CPU. By creating an account, we will be able to attach our application data to the appropriate channel of our account, as well as set the channel as private or public, depending on the access privileges enabled by us. Though the channels, anybody can download or upload sensory data online or offline, analyze the information with MATLAB, envision the interesting trends observed using spline charts, or create events to be notified based on processed output over the web, Twitter for instant alerts, or to the gadget itself for self-monitoring and provoking a few time controlled activities [26, 27].

3.5 Thing View

Thing View is a Google Play mobile application that allows us to see the output of any application handled using Thing Speak on any mobile device, from anywhere, at any time, as long as the device is connected to the internet.

4. RESULTS AND DISCUSSION

The HR is a health indicator that measures the number of heart beats per minute. *Table 3* lists the typical heart rate benchmarks for each age group.

Table 3: Regular heart rate by age

Age	Heart rate (in BPM)
New-born	100–160
0–5 months	90–150
6–12 months	80–140
1–3 years	80–130
3–5 years	80–120
6–10 years	70–110
11–13 years	60–105
14–20 years & above	60–100

HR differs depending on age, eating habits, emotional acts, gender, position and other factors. The components, mode of testing, and performance highlights of the evaluation scenario are explained further down.

4.1 Choicemmed- A Commercial Pulse Oximeter

The *figure 5* depicts the performance evaluation of the proposed device using one of the best commercial pulse oximeters' on the market, the fingertip pulse oximeter MD300C2. The subsequent survey on the best home use pulse oximeter, based on reviews and a buying guide, shows that the Choicemmed fingertip pulse oximeter is ranked third and is small and accurate. Its finger chamber is designed to be extremely adaptable, as it can be used by both adults and children, uses less battery, and has an auto-off function after six minutes of inactivity. The performance evaluation of the proposed device is done with one of the best commercial pulse oximeter named fingertip pulse oximeter MD300C2 in market and is captured in *figure 5*. The resultant survey on best home use pulse oximeter evaluated through reviews and buying guide confirms that the Choicemmed fingertip pulse oximeter is secured third position and found to compact and accurate [28-30]. Its finger chamber is designed as so versatile, can be used by both adults and infants, consumes less battery and provided with auto-off mechanism after six minutes of inactivity.

(a) (b)

Figure 5: Evaluation setup presenting a) commercial product (Choice med) and b) prototype device

4.2 Evaluation Strategy

A total of 40 healthy volunteers between the ages of 25 and 45 were evaluated to record the functional characteristics of the proposed device and its consistency with real life commercial products. Following their consent, each participant was invited to use both devices at the same time after being educated about the act's purpose and scope. Each participant was given a 3-minute time frame for the examination and was in a relaxed mood

4.3 Performance Analysis

The visible form of the detected pulse rate by the suggested device, which was acquired via Thing Speak in the cloud platform.is provided in *figure 6*.

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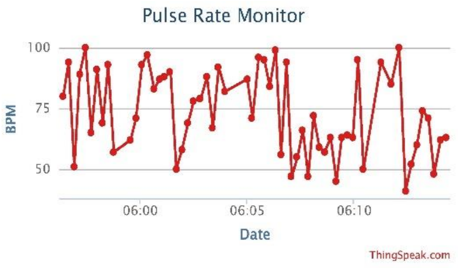
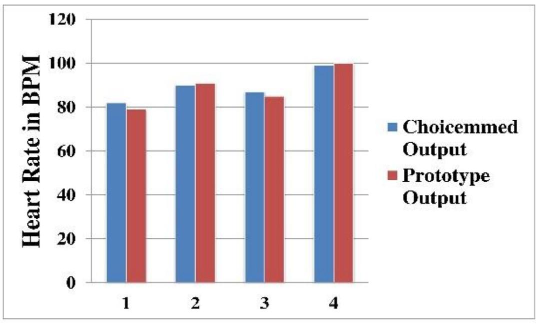
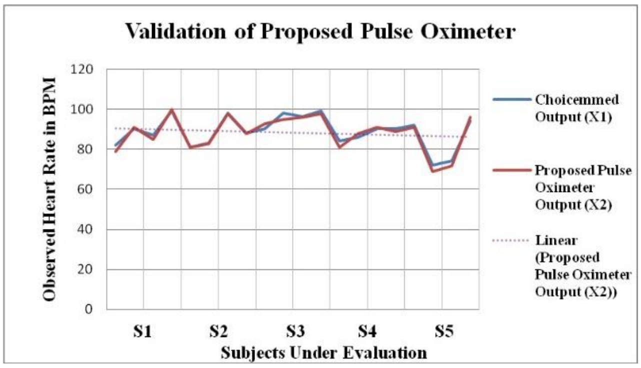


Figure 6: Observed pulse rate via Thing Speak

The evaluated output over the sample volunteers gathered in a respected test bed in accordance with the terms of usage mentioned in the evaluation method is projected as the graphic in *Figure 7*.



(a)



(b)

Figure 7: Evaluation results representing a) on single volunteer and b) over sample volunteers

No one was determined to have abnormal heart rates during the evaluation period, according to the findings. The accuracy and error rate are calculated to predict the correlation of proposed against commercial product performance. The formulas used in computing error rate and percentage accuracy are presented in *equations (3) and (4)*, respectively. The output of a commercial product (x1) is compared to the suggested system's output (x2). The *Figure 8* shows the difference in pulse rate between the commercial and designed pulse monitors over the volunteer individuals, as well as their relative accuracy and error rate estimation.

$$ErrorRate = ((x1 - x2)/x1) * 100 \quad (3)$$

$$Accuracy = 100 - abs(ErrorRate) \quad (4)$$

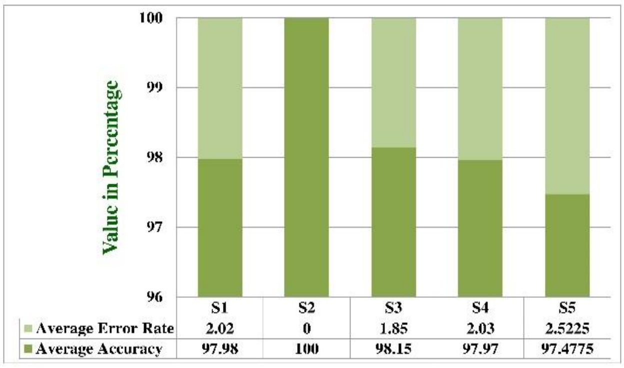


Figure 8: Performance analysis of proposed pulse monitor

Finger thickness, skin colour, hemoglobin content, and temperature are all factors that influence oximeter inaccuracy. When all parameters are considered, the error rate is between ±4 BPM, regardless of age, gender, or physical condition.

4.4 A Non-Invasive BP Monitor: Scope of Future Design

The investigation over the association between HR and BP increases the possibility of non-invasive methods to measure BP. The interdependence element is pulse transit time (PTT) and that is estimated from acquired signals of ECG and PPG as portrayed in *figure 9*.

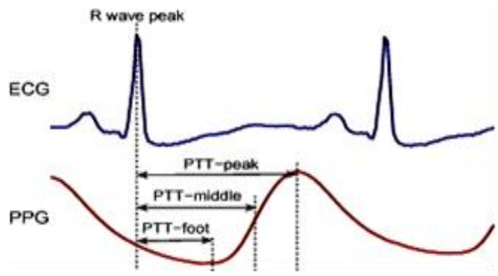


Figure 9: Estimating BP from PTT

PTT is accounted as the time gap estimated between the generation of pulse wave in cardio aortic and its transmission towards artery peripherals [31]. In simple terms, PTT is defined as the difference between the initialization and appropriate dissemination to periphery as pulse arrival time (PAT). The PTT is denoted as mathematical expression as given in *equation (5)*.

$$PTT = PAT_1 - PAT_0 \quad (5)$$

The two points PAT0 and PAT1 give the proximal and distal location. Aligned with *figure 9*, the presence of R-peak in acquired ECG signal is always marked as a proximal point (PAT0). With reference to PPG, the observed immediate peak or fall is considered as an end signal that results the systolic and diastolic BP respectively PTT-foot (PTTf) and PTT-peak (PTTp) as indicated in *figure 9* and expressed as Equation (6).

$$PTT_p = Systolic\ BP\ \&\ PTT_f = DiastolicBP \quad (6)$$

The above equation estimates the BP by drawing the PTT referring PPG wave with ECG waveform guide lined with significant related efforts [32, 33].

5. CONCLUSION

The implementation of instantaneous pulse rate monitor collaboratively uses the programming skills, applies in medicine, provided a low cost health care IoT service as a final product. This influences the quality of life of public and opens a door for proactive diagnosis, a new paradigm of medical services. The performance is associated with commercial product under test at some extent while at the resting stage of the public within the age group of 25 - 45, providing the error rate in the range of ± 4 BPM and assuring overall accuracy of 95%.

Irrespective of person's age and sex, the same design can be extended to validate the estimation of signs including their active modes / motion artifacts like walking, jogging and running and to be evaluated among huge population to arrive valid result.

6. FUTURE ENHANCEMENT

Further it can be enhanced with adding the following features:

1. The design of motion – tolerant pulse oximeter is possible by annotating algorithms which reduces motion artifact noises from the calculation
2. Feeding artificial intelligence and big data analytics to such devices within or closer to its proximity range promises speedy evaluation and adds smartness in the direction of device accuracy with context aware recommendations in place
3. A complete health tracker yet to be in market. By identifying the correlation with the other health indicators BP, SpO2, BR and applying the IoT will bring a complete health monitoring kit with promising accuracy, reduced circuitry design and cheaper in cost.

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