Development of an IoT-Based System in Detecting Heart Attack and Continuous Monitoring of Heartbeat

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Abstract*— The main aim of this project is to develop a cohesive methodology for heart rate monitoring and heart attack notification system for any heart patients, especially the elderly and at risk. In this proposed system, a pulse sensor is used to measure a person's heart rate and post it on hardware as well as uploading it to cloud servers through the implementation of IoT. Mobility and compactness were also considered for this system, with a strap-on container for most of the components was also designed. Based on the heart rate data, the system also sends notification on mobile as well as emails any address about an emergency based on very high or low heart rate. Testing for the performance of this notification system, as well as general accuracy for the system was tested to be around 96% minimum when compared to at least another commercial device with heart rate measurement capabilities. The system limitations and recommendation have also been done for the system in this report.

***Keywords*— Internet of things (IOT), heart attack, heart rate data, Blynk, mobile application, ThingSpeak**

I. INTRODUCTION

The heart is one very vital organ in our body as humans, which are unarguably the smartest species that walk on planet earth. This is why we have been able to make leaps and bounds in advancing technology and continue to do so, even every single day. Technology can be useful for so many reasons and purposes, and one of the main aims would be to ensure the betterment of our healthcare. Internet of things, or IoT, is one of the biggest advancements made in recent technological times (Abdulla et al., 2020; Al-Gumaei et al., 2018; Eldemerdash et al., 2020; Haziq et al., 2022; Hon et al., 2020; Kalilani et al., 2021; Katemboh et al., 2020; Lakshmanan et al., 2020; Murugiah et al., 2021; Nazrin et al., 2021; Rasheed et al., 2021; Samson et al., 2020; Singh et al., 2021; Yong et al., 2020). A network or system of different sensors and devices collecting data and information and being able to send them over the internet, often to more complex systems that processes and/or stores the data for easy viewing and such, all being automatic and without the need of constant human overview or any human-to-human interaction is a very lucrative, amongst other things, system to have (GOPI & VAM, 2019) When it comes to the heart, the rate at which it beats in a given time can give very important information about a person's health condition and is thus a very valuable parameter to monitor over, especially for those who have heart problems and are at elevated risks. Even though generally there are a lot of hospitals or clinics to help patients with such monitoring, the fact of cost and the wastage of time if it is not something too serious is something to be considered (Abbasi-Kesbi et al., 2018).

This is where a relatively simple IoT device could be conjured so as to aid such people. The innovations and accessibility of such devices that could be worn by literally anyone can help monitor such an important health parameter such as heart beat and thus control it if possible, making them almost crucial to patients in helping them improve their quality of life by being able to reduce clinic visits for smaller reasons, and also allowing continuous data to be recorded which can then be reviewed by health experts. It also allows those professionals to take necessary actions as early as possible when the data might show worsening conditions and/or when the user is in a state of emergency (Majumder et al., 2019), as late diagnosis and treatment are two of the biggest reasons why the number of deaths for cardiovascular patients is so high (Patel et al., 2018). This is why the usage and implementation of connected health systems is important in providing users with more information about their health status anytime and anywhere for their own personal diagnosis and self-treatment, with chances of early detection for need of medical attention too (Majumder et al., 2019).

Cardiovascular disease is one of the biggest health issues around the world. Constant monitoring of heartbeat is one of the ways to not only detect possible problem and need of medical attention, but also for everyday awareness of one's health condition (Lin et al., 2017), something that is not possible since one has to go to set places for such data, which can be expensive and time-consuming. The goal is to make a relatively simple and smart system that is wearable by anyone for such purpose in their everyday lives (Abbasi-Kesbi et al., 2018). This system needs to be able to measure a person's heart rate in beats per minute in a reliable manner. This data also needs to be saved and uploaded in such a way that it is easily accessible to any healthcare professional, thus preferably creating a database of the person. The device not only needs to be able to detect abnormalities in heartbeat (Sethuraman et al., 2019), but also have a notification system that sends an alert to someone close to the user who could help the patient respectively. This device would be geared towards healthcare professionals as well so that they have access to round the clock continuous data on the heart that can be used to create a database or profile for patients that can be referred to when diagnosing a patient. The aim of the project is to design and develop a wearable device to measure and monitor heartbeat of people, with heart attack recognition and notification system.

The beneficiaries of this project can basically be said to be literally every single person in the world, especially patients with cardiovascular disease, which seeing as how it is the number one global cause of death (Lin et al., 2017) should be more than enough of a reason to work and invest on such systems. The fact that researchers found that a person's heart rate alone is an independent cardiovascular risk factor, and that monitoring and controlling the heart rate to be in the normal range (for most people of average age) of 60-100 beats per minute (bpm) (Patel, Patel & Patel, 2018) is one of the goals for treatment (Lin et al., 2017) definitely helps the cause. Moreover, this system helps to get a robust, accurate and purpose-built heartbeat measuring device into the hands of more people who are not fortunate enough to constantly go to a hospital or clinic to spend time and money for monitoring purposes. It also helps the professionals of healthcare to keep tabs on their patients by getting access to continuous data of the heart round the clock and make a database/profile for patients that could be looked over when problems arise.

(Patel et al., 2018) proposed and built a system that would be able to identify a potential heart attack, by the usage of IoT to monitor a person's heart rate. This system would allow patients suffering a heart attack to theoretically get diagnosed faster, meaning chances of survival would then be potentially increased as well. (GOPI & VAM, 2019)proposed to design an effective system using IoT and available sensors, that can perform surveillance of a patient's heart rate. This would allow monitoring of heart rate without the supervision of a nurse and that it can be done at any time or anywhere, with the system also being proposed as being cheap and easily accessible. (Sethuraman et al., 2019)proposed an IoT-based system that would be capable of monitoring heart rate, which would allow doctors and the user alike to be able to evaluate, in the long term, the functioning of one's heart and thus help with retaining a better heart shape; as well as detecting any abnormality of heart rate in which case the system would send an alert to the doctor.(Abba & Garba, 2019) proposed a system that claimed to have created an intelligent, user-friendly framework for monitoring and controlling of heartbeat rate that aimed to be accommodating, dependable and private as well using a network of sensors working together with IoT to be applied into the medical field to ease the work of doctors and nurses. (Beach et al., 2018)proposed a system integrating ECG sensors, into a customizable, physical, wrist-watch style body for the system that is built to last a long time without need of charging. This system is to be connected to SPHERE (a Sensor Platform for HEalthcare in a Residential Environment), which is a recognized IoT structure in the UK providing the platform for the incorporation of the wearable data. (Wan et al., 2018) proposed a system, named WISE (Wearable IoT-cloud-baSed hEalth monitoring system) that utilizes the body area sensor network (BASN) which falls under the IoT infrastructure, to make a health monitoring system that works in real-time, with the hope that these data help users be more wary of their personal health status. The system also aimed to bypass usage of smartphone and be able to send all data to the cloud servers directly. (Goel et al., 2018)proposed a system using simple components to make a device able to measure and monitor heartbeat rate of healthy people as well as heart patients. This is useful for keeping an eye on heartbeat rate and the health and performance of the human cardiovascular system.

II. System Implementation

A flowchart was created to help define and visualize the different aspects present in the building of the system for this research work as shown in Fig 1.

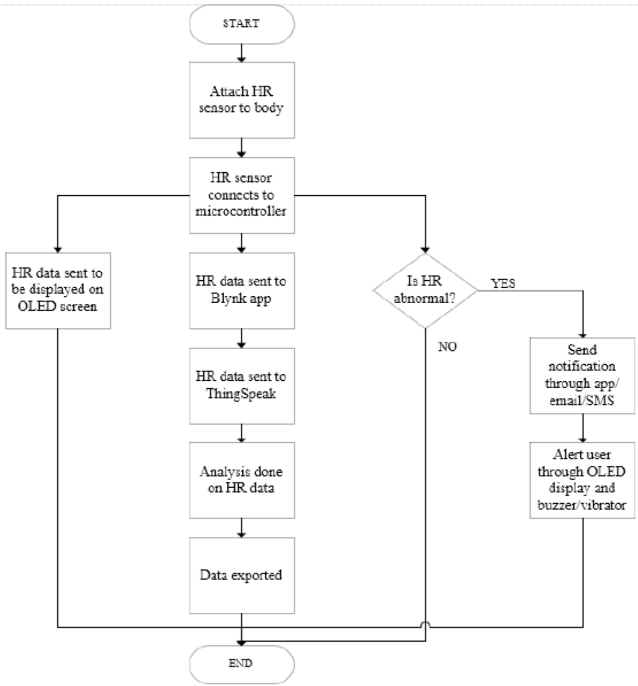

Fig. 1. Flowchart of the project system

Fig1. shows the flowchart made to outline all the different aspects of the methodology of this project. It starts with the heart rate sensor being attached to part of the body, namely around the wrist or to the index fingertip for better accuracy, using an elastic strap that fits either. The microcontrollers are also put into a compact box that can be strapped to the upper arm that would make the system portable.

The sensor sends the measured HR data, in terms of BPM, to the microcontroller, which is the NodeMCU that was chosen. Coding was done for the various tasks to be done by the microcontroller and is thus updated with the source code. The microcontroller connects to the internet using the on-board Wi-Fi module and sends the data to Blynk servers. This is done so that the HR data which is only received at intervals of 20 millisecond can be received by Blynk and data is shown in real-time on the app. Since ThingSpeak can update only once every 15 seconds, it is difficult to post data directly to it from the microcontroller, as data from sensor seemed to get lost and the webserver would fail to update.

Thus, Blynk is used to post the HR data, in which case ThingSpeak is updated with the latest, correct reading from Blynk itself. ThingSpeak is supported by MATLAB analytics, which is useful for analysis of the data that is sent to the servers. Thus, MATLAB coding is done to be able to process extra information based on the HR data that is sent and stored on ThingSpeak over time. Examples of extra informational details that can be gotten are the maximum and minimum HR values measured by the sensor in a span of 24 hours, the average HR in the same time and so on. The accumulated HR data can also be exported using the available function on ThingSpeak, which can allow user or anyone to download the HR data in a report-like format in an excel sheet (if user wants) with date and timestamps for each reading.

A) Overall Block Diagram

Fig 2. shows the block diagram of the final system that was made. The block diagram was derived for the same system, with the same components and working principle. A smart pulse rate sensor from Gravity brand was used as the input device. This sensor measures the user's heartrate by measuring the pulse/beat per minute, with this input being fed into a NodeMCU microcontroller. This is connected to an OLED screen and a buzzer, both of which are output devices, one showing the results of the sensor directly on hardware, and the other sounding off based on the sensor reading being higher or lower than set values.

An external battery is connected to the microcontroller to supply the power to the system while making the system mobile. The microcontroller is coded using software to manipulate the hardware as necessary by the project, and thus connects to the internet using Wi-Fi since it contains an on-board Wi-Fi chip and uploads the data the cloud servers' sites accordingly and on a timely manner.

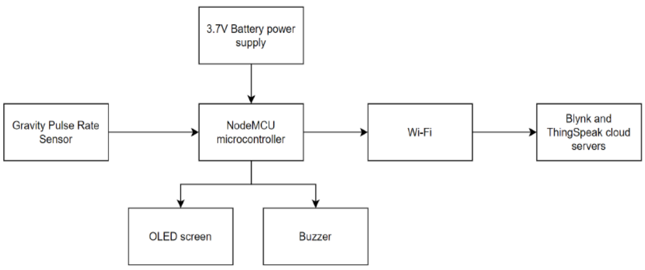

Fig. 2. Block diagram of the system

The microcontroller is also connected to the OLED screen for the user to be able to see the HR reading in real-time directly from the physical system without logging in to phone or webserver every time. Also, in the coding for the microcontroller lies the conditioning system that compares every data output gotten from sensor against the set maximum and minimum HR limits.

If a reading were to be higher or lower than those thresholds, the Blynk app is set to send a notification through the app, as well as email/SMS (optional) to alert people of the potential abnormality. An alert message is also displayed on the OLED screen, with the help of a choice between a buzzer or a small vibration motor (according to user) to alert the user from the hardware itself and not dependent on phone app which can be out of reach.

B) Concept Design

While the system in this project is done to the best of capabilities, a few assumptions do need to be stated. The first assumption that needs to be stated is that, even with the system working well with good output, it should not be treated on the same level as a professional-grade medical device, as errors will still be present, even as an inherent flaw from the sensor itself. Another assumption is that the user needs to be still to get a good reading from the hardware. The accuracy testing between two commercial devices, one using PPG and one ECG, showed that even though the results for HR gotten from PPG device while moving and stationary was much better than the ECG device, the percentage of correctly measured HR dropped from 89% while stationary to 76% while moving (Pietilä et al., 2018). Thus, the project can also be expected to have an accuracy of about ±10 BPM and similar accuracy, which nevertheless will still be tested with final hardware against other devices.

To build the concept hardware circuit connections virtually, a software known as fritzing was used. The circuit design is shown in Fig 3.

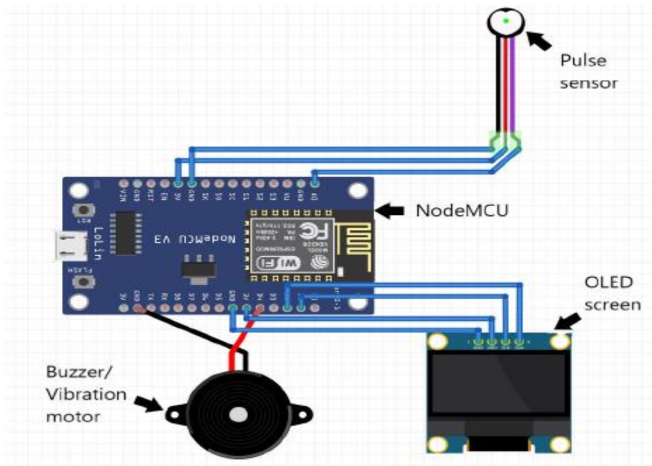

Fig. 3. Circuit design for the hardware

As can be seen from Fig 2., the pulse sensor is connected to the NodeMCU to get "5V" and "GND" connections for the power supply to sensor, with the signal pin of sensor connecting to the single analog pin "A0". This is where data information is exchanged and fed into the microcontroller. The OLED screen is also wired for power similar to the sensor, with its data ports "SCL" and "SDA" connecting to digital pins "D1" and "D2" respectively for the data exchange. The buzzer shown in the figure, which can also be a simple vibration motor, is connected to ground and digital pin "D4" which is set as an input for the buzzer to function as intended.

Coding was done for the NodeMCU to get the heartrate value from the sensor, which the chosen sensor already sends in digital form in terms of BPM, display it on the OLED screen, as well as send it to the mobile and web GUI. Conditioning codes were used to send alerts for when and if very high or very low heartrate is detected by comparing the incoming measured HR value against the set threshold values.

C) Constructional Details

Fig 4,5,6 shows the 3-D design done for the box in SolidWorks software. Fig 4. shows the general isometric view of the design. The slots on the sides allows for the container to be ventilated properly, otherwise components like the NodeMCU would get very hot and throttle. The slits on the lid, which is shown to be opening by sliding in Fig 5., also has slits, which is designed but also has function as it allows the jumper cables for the OLED screen to pass through. This allows the display to be attached to the outside, front face of the container while the NodeMCU and others are all inside. The backside of the box as shown in Fig 6. also shows two slides on either side of the box lengthwise. These are made so that a rubber strap with Velcro could be passed through them as a loop. This is done so that this box could be fastened to the user's upper arm, or anywhere comfortable. This would obviously mean that not only would the user be mobile, but also would not have to carry all the components around by hand, which is definitely not ideal. The container was to be printed using a 3-D printer, and would be made of plastic, which helps keep the wight down. A rubber texture pad is attached to the bottom-side of the box so that it would not be too uncomfortable for users to wear it over bare skin.

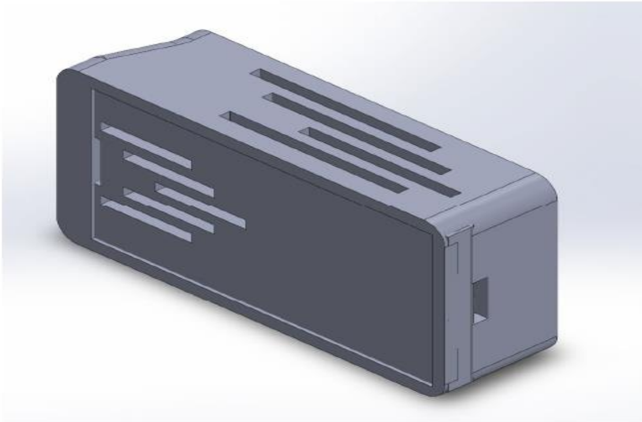

Fig. 4. Front (isometric) view of 3-D printable container

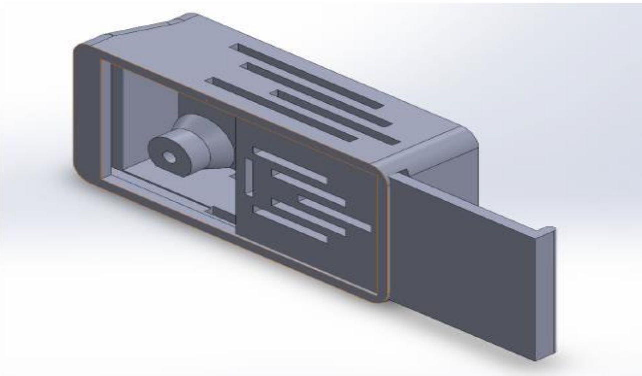

Fig. 5. Front (isometric) view of 3-D printable container with sliding door open

Fig. 6. View of backside of the container

Fig. 7 shows a picture of the complete hardware circuitry that is all connected according to construction details in the Fritzing diagram. The whole system is connected and powered by the battery as remote power supply and thus is completely mobile and not attached to anything like a laptop. As soon as the user wears the pulse sensor, after a small delay of connecting to the Wi-Fi and self-calibrating for the reading, the system will automatically start posting their heartrate on the display as well as send the values over to Blynk. The GUIs that were developed for the system included one on a mobile app made with Blynk, as well as a GUI on ThingSpeak webserver.

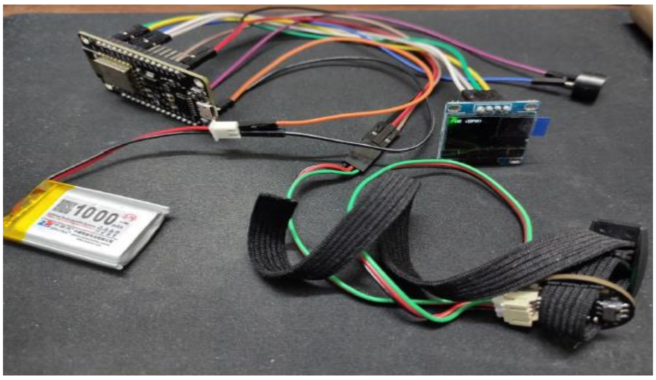

Fig. 7. Image taken of full hardware circuit

Fig 8. shows the layout of the different parameters to be displayed as well as a few functional widgets. The first widget is used to transmit the heartrate values to be displayed, which refreshes a few times per second, in accordance with the rate of the data transmission from the microcontroller and sends the data to the virtual pin "V0". These values are saved in Blynk servers, which is why they can be used to plot a graph of the heartrate over a certain time passed, which can be selected by user's choice, as well as also showing a live graphical representation of the incoming data.

Fig. 8. Blynk GUI

The reports widget allows for the data that is being saved by the servers to be exported to a choice of file types, e.g. in excel with date and time stamps for each entry, which can be useful. The notification and email widgets are present corresponding to the coding done in Arduino IDE for the microcontroller, which allows the app to push notifications on the mobile device, as well as send emails to the given address. The last widget used is called "WebHook", which is essentially used to integrate third party application from Blynk itself. This is what is used to send data to ThingSpeak, which can only refresh once every fifteen seconds, and thus tends to miss the output given by the sensor, which is much faster. Thus, sending the data through Blynk, which already catches almost every reading onto its server, ThingSpeak can take whatever reading is the latest at every fifteen second interval. This is also allows for very efficient and simpler coding for the microcontroller, since the widget actually handles the whole process all by itself, given the widget settings are input with the necessary correct information, like the ThingSpeak API URL, the virtual pin to get the data from and such.

Fig 9, shows the GUI that was made on ThingSpeak platform. As explained already, this GUI provides a web server for the heartrate data to be saved and can be accessed from any web browser. The first GUI feature shows the graphical representation of the heartrate data over time that is saved. The timescale of the graph can also be changed by user for better or broader scale of values to be shown. The second widget shows the latest heartrate data retrieved from Blynk servers, which updates every 15 seconds from ThingSpeak side.

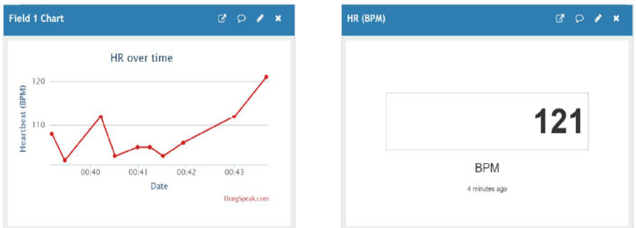

Fig. 9. ThingSpeak GUI

III. Testing of the Proposed System

A) *Pulse Sensor test*

The first test that is done for the project system was to check and get the input data of the system, namely the heartrate values of a user in unit of beats per minute (BPM) with the usage of the pulse sensor hardware. The pulse sensor is attached to either a user's index finger, or fastened around the wrist part of their hand, preferably the left one, according to the user's choice. At least 10 consecutive readings are taken and then averaged out to a value for each of the 5 subjects. This is done twice, one set of data with the subjects being at rest, and the second set is taken after some light and common exercise amongst the subjects. Table I as shown below shows the mean heartrate for each of the 5 subjects, firstly at rest and secondly after some light exercise.

TABLE I. Measured Mean Heartrate at Rest and After Exercise

Person	Mean Heartrate at rest	Mean Heartrate after exercise
1	75	126
2	78	131
3	68	109
4	69	114
5	71	119

The heartrate data shown in Table I is taken and plotted into a graph for better visualization. The x-axis shows the person number, and y-axis shows the heartrate. The blue dots mark reading when at rest, while orange marks readings after exercise. Observing the graph shows that, across the board, the project hardware system is able to take the readings and reflect changes in pacing of a person's heart based on their activity. This makes sense, since the most natural and more importantly a healthy way to increase one's heartrate is by doing exercise, which is shown by the test here and thus is the inference.

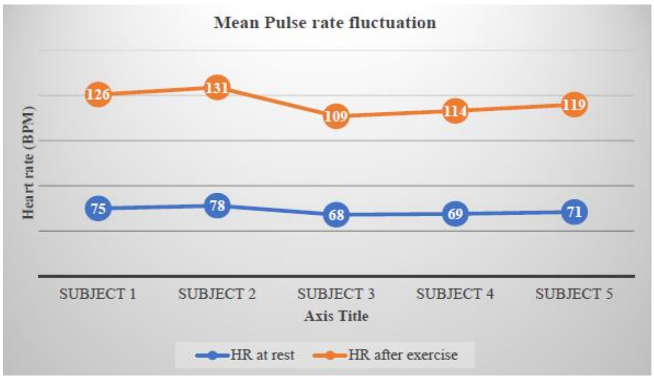

Fig. 10. Graph plot for mean pulse rate fluctuation test

B) *Blynk App Notification Test*

The second test was done to see the use and performance of the Blynk app on a smartphone. This is done to see the possible effectiveness of the app in notifying users of their heartrate readings, in normal cases as well as in possible emergency scenario. During the test, the subject is to go from rest state to trying to increase their heartrate up to a more abnormal value (with exercise) and seeing how the app logs as well as notifies when the safe heartrate threshold value is crossed. The system hardware is setup normally, the pulse sensor being attached to the left wrist or index finger and turning the system power supply. Some time is given for the NodeMCU to connect to the Wi-Fi, as well as the pulse sensor to calibrate itself and start reading the user's heartrate properly. For this test, the sensor is allowed to run, as the user tries to increase their heartrate with some light exercise to see how the app shows the increase and notifies a user through the app notification. The system is allowed to run for a while, as the user tries to move around a bit to increase the heartrate to get the notification, which was gotten as shown in the figure below after a few minutes of monitoring.

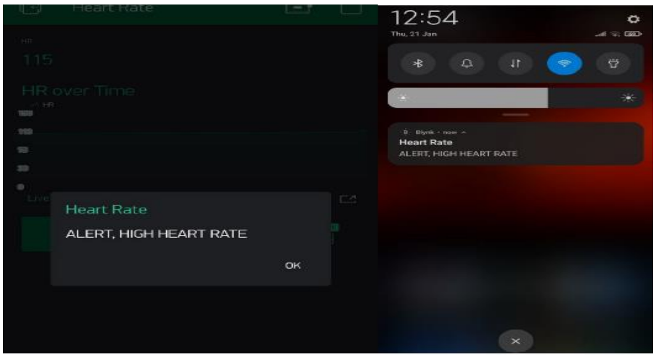

Fig. 11. Blynk App Notification system test

As can be seen from Fig 11., when the safe heartrate threshold value of 110 was crossed by the user, the app promptly sends a notification through the app, alerting the user, and anyone with the app installed on their phone and logged in with the same account. This helps improve chances of awareness of the wearer's possibly detrimental condition and other than showing up as high heartrate on the OLED screen that is pretty much attached to the wearer, thanks to the powerful and easy integration of IoT and cloud services working even without the users spending any money on them (at least in the case for this implemented system).

C) *ThingSpeak Analysis and Email Notification Test*

The third test was to examine the usage of ThingSpeak and its suite of data analysis tools on the sensor data values. This test was to get the results from the MATLAB analysis and visualization coding that was done for the hardware as a part of the data analysis section of the project and running it with the hardware and on on the database of values stored on the ThingSpeak servers. The hardware is setup normally as intended, with the pulse sensor on the index finger or the wrist of the left hand, and just making sure the NodeMCU is connected to the Wi-Fi. To test the email notification system, the user is to perform some light exercise to get the heartrate a bit higher than the normal threshold values, and test the system. Two of the MATLAB analysis apps coded were run during the test, the figures below showing the results for each of the analyses and the email that is sent from ThingSpeak to the given email address in the system.

Fig. 12. Maximum and minimum heartrate after MATLAB analysis

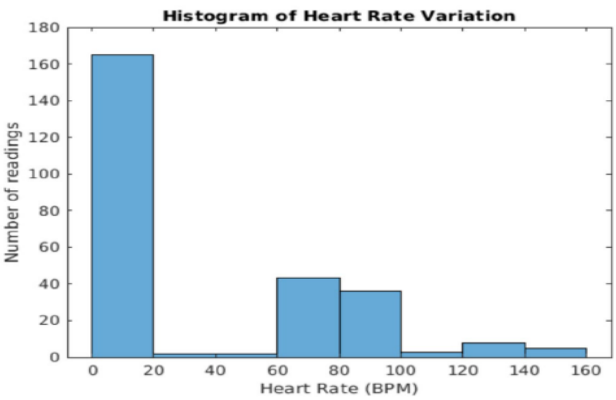

Fig. 13. Histogram for heartrate variation over a period of time

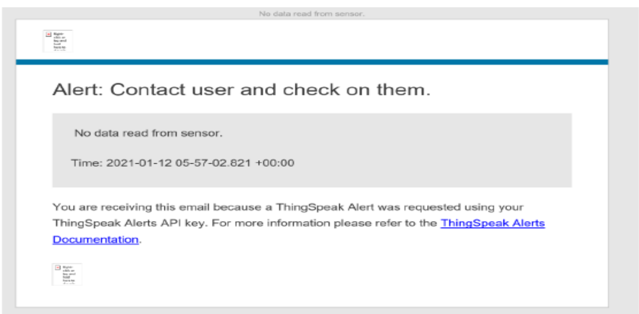

Fig. 14. Email notification sent to given address

Based on the results gotten in Fig 12,13,14, it could be said that the ThingSpeak implementation for the system is working quite well. Fig 12. showed that when the MATLAB analysis app that was coded was run for the sensor data stored on their servers, in the past 24 hours of data saved, the highest heartrate recorded was 148 BPM, although the lowest heartrate shows zero, which was probably an outlier value that was recorded by the sensor during the day. Fig. 13 shows the MATLAB visualization app that was coded, that takes the past 24 hours of data and summarizes all of the many readings that can be taken by the system. This histogram shows the frequency of the range of the heartrate which was the highest in the given time. In this case, the user left the system running without wearing it for a while, which is why the 0 to 20 BPM range is shown as the highest. But while he wore it, ranges of 60 to 80 and 80 to 100 BPM was higher, which can show normal heartrate throughout most of the day. Fig. 14 shows the email that was received from ThingSpeak server due to the email notification system checking the database and notifying someone through an email if the heartrate goes too high or too low, while stating the last recorded measurement. This would be useful if something terrible had happened and the heartrate of the user fell to zero, which could mean heart failure. Here however, it said no data was recorded, which was just due to the fact that the user took off the sensor just before the email was sent. The checking is done at 15 minutes interval, something that can changed according to the user's wish, thanks to the TimeControl setting that runs the analysis code at a set interval.

IV. CONCLUSION

As a conclusion to the project, it is imperative that the objectives that were set at the start for this project is achieved. Blynk for mobile application as well as ThingSpeak for any web applications were chosen to not save the data in the cloud to be accessed from anywhere but also created simple GUIs for anyone to interact with. The notification system was also divided into two sections for better ease of access, with the app notifying anyone with the app installed and logged in directly on their phone notification about the wearer's update on if their too high or too low. The same went for ThingSpeak that, based on the database entries would send email to any address put into the system. Since heartrate is a complex way to judge a person's health since it can be very subjectively different for everyone on what is normal for each of them, certain analysis methods using MATLAB coding tools were used to extract a little bit more data out of the normal, which would otherwise mean spending an impossible amount of time sifting through the many values that gets stored on the database.

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