Monitoring heart rate and SpO_2 using Thingsboard IoT platform for mother and child preventive healthcare

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Abstract. This paper describes the development of heart rate and oxygen saturation (SpO_2) monitoring system using Thingsboard Internet of Things (IoT) platform. This research is part of development of IoT application for supporting mother and child health program in Indonesia. This IoT-based real time monitoring system enables preventive care and promotes automation to reduce the risk of human error. Measurement of heart rate and SpO_2 is done by pulse oximetry method using sensor module and Raspberry Pi. The Arduino-based sensor module collects, calculates and sends heart rate and SpO_2 data to Raspberry Pi for further analysis based on normal value reference table to detect abnormalities. Further heart rate, SpO_2 and its abnormality status are delivered to Thingsboard using MQTT (Message Queuing Telemetry Transport) protocol. The results show that the system is functioned as expected. Heart rate value (in beat per minute) and SpO_2 value (in percent) are presented while Photoplethysmogram signal (PPG) is presented as graphic on Thingsboard dashboard. The abnormalities status such as tachycardia, bradycardia and hypoxsemia are also featured on the dashboard. We also calculate uncertainity measurement of heart rate and SpO_2 by the sensor module which are $\pm$2.85 bpm and $\pm$0.28%.

1. Introduction

Monitoring patient's health remotely by collecting patient's data continuously can help preventive care and doctors can also diagnose acute complications earlier with Internet of Things (IoT). This can be done by employing sensors to collect patient's physiological information, send them to the cloud to analyze and store the information and forward the analysis to the caregivers [1]. E-health as on of the area in the application of IoT will play a leading role [2]. A comprehensive study of recent research in IoT for health care has been performed by Islam et al to show some issues that must be addressed [3]. Some researchers have tried to develop IoT application for health care which deliver data from medical sensors to server and view them on a PC or a mobile device while some others have done analysis on power consumption efficiency on various IoT and cloud-based health monitoring system [4]. Improving the quality of mother and child healthcare can be done by providing better healthcare service and maternal and child mortality rate can be reduced by implementing IoT technology in a government program [5].

Kadarina and Priambodo [5] have already design an IoT-based system to improve the quality of maternal and child health services in Indonesia. As part of the design of the system there is a portable medical device that serves to retrieve physiological data of mother and child from several sensors and send them to the cloud (shown in figure 1). Some of the physiological data include: heart rate, oxygen saturation (SpO_2), respiration rate, temperature, blood pressure, fetal heart rate, electrocardiogram

(ECG), photoplethysmogram (PPG), cardiotachogram (CTG) and blood glucose level. In this paper the current work of this research is described, two vital signs which are heart rate and oxygen saturation (SpO_2) are monitored using IoT platform. Portable medical device collect and calculate heart rate and SpO_2. Then the data is sent to the cloud via WiFi using the MQTT (Message Queuing Telemetry Transport) protocol. The data which already in the cloud can be further analyzed by medical specialists through mobile devices or paramedics at health facilities (puskesmas, clinic or hospital) via PC.

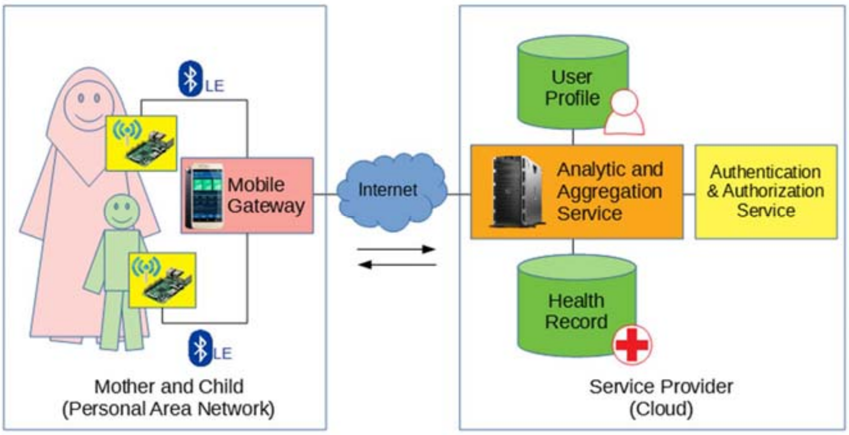

Figure 1. Portable medical device application architecture [5].

2. Methods

In this section some of related works and theoretical basis related to this research will be discussed. The design and implementation of the system are also described.

2.1. Related works

We found that Kanva *et al* [6] use a mobile phone's camera to estimate pulse oximeter (SpO_2) level and heart rate. Chao Li *et al* [7] have develop IoT-based heart disease monitoring system for pervasive healthcare service. The system monitors the patients' physical signs such as blood pressure, ECG, SpO_2, as well as relevant environmental indicators continuously. They used an Android smart phone as IoT platform. Adiputra *et all* [8] have developed a low cost and wearable SpO_2 device for health monitoring using finger sensor and Node MCU. The data sent to the server, stored in the database and can be displayed on the website.

The concept of fog computing in IoT health applications is described in detail by Dubey *et al* [9]. Fog computing is a service-oriented intermediate layer on IoT, providing an interface between sensors and cloud servers to facilitate connectivity, data transfer, and local databases. The specialty of fog computing is computing nodes that are low power, intelligent, wireless, and embedded and can perform signal conditioning and data analysis of raw data collected from medical sensors. In addition it provides an efficient way to serve telehealth applications. They apply and test fog computing systems using Intel Edison and Raspberry Pi that enable the acquisition, computing, storage and communications of various medical data such as pathological speech data from a person with speech impairment, Phonocardiogram (PCG) signal for pulse estimation, and detection of Q, R, S from electrocardiogram (ECG) signal. In this research we also use Raspberry Pi to perform some computation in the fog.

Studies of various IoT platform have been done by [10] [11] [12]. Pratim [10] has a survey of 26 IoT cloud platforms. In [11] a comparative study of several IoT platforms including Google Cloud platform, IBM BlueMix, ThingWorx, Microsoft Azure Cloud, Thingspeak, and others. Jasmin *et al* [12] conducted a comparison of IoT platform architecture. Based on the study, Thingsboard is selected as an IoT platform used in this research.

2.2. Heart rate and SpO_2 measurement using pulse oximetry method

Pulse oximetry is a non-invasive method used to measure heart rate and oxygen saturation. Pulse oximeter, device using pulse oximetry methods, has a sensor consisting of two LED lights that emit in the red (650nm) and infrared (950nm) spectrum. This sensor is usually placed on the fingers or ears, or on the skin which is not too thick so that both the light frequency can easily penetrate the tissues. After that the absorption of red and infrared light is measured by photodiode. The amount will depend on the amount of oxygen in the blood. Oxygen rich hemoglobin (oxyhemoglobin) absorbs more infrared light, while those without oxygen (deoxyhemoglobin) absorbs red light. The results of recording readings of red and/or infrared light values are referred to as photoplethysmogram signals (PPG). The ratio between red and infrared light will be different. From this ratio can be determined oxygen levels in the peripheral hemoglobin or so-called oxygen saturation levels in the peripheral blood (SpO_2). To detect a heartbeat only one of the PPG signal from a red or infrared beam is required. [13]

In this research, heart rate was obtained from the infrared PPG signal processing by counting each peak of the PPG signal in beats per minute. Calculation of heart rate value and SpO_2 is done by microcontroller on portable medical device sensor module.

Heart rate and SpO_2 values can be analyzed to detect abnormalies of the patient. Acording to [14], the normal heart rate by age is shown in table 1. Bradycardia is a condition where a heart rate is below the normal rate while tachycardia exceeds the normal resting rate [15].

Normal arterial oxygen level is approximately 75 to 100 milimeters of mercury (mmHg). Therefore values under 60 mmHg usually indicate the lack of oxygen in blood. Pulse oximeter readings (SpO_2) for normal condition usually range from 95 to 100 percent. So that values under 90 percent are considered low. Hypoxemia is a condition where the level of oxygen in the blood, specifically in the arteries, is below normal. This condition can cause low oxygen in tissue or hypoxia. Four distinct levels is possible to be used to divide the symptoms and manifestations of hypoxia: mild, moderate, severe, and extreme as it is shown in table 2. [16]

Table 1. Normal heart rate by age (beats/minute) [14].

Age	Awake Rate	Sleeping Rate
Newborn to 3 months	85-200	80-160
3 month -2 years	100-190	75-160
2–10 years	60-140	60-90
> 10 years	60-100	50-90

Table 2. Levels of hypoxia symptoms [16].

Level	SpO_2 reading (%)	Effects
Mild hypoxia	100-80	Normal brain function
Moderate hypoxia	80-60	Increasing degree of brain disfunction
Severe hypoxia	60-40	Total muscle paralysis results in apparent unconciousness
Extreme hypoxia	< 40	unconsciousness and eventual death

2.3. Thingsboard

Thingsboard is an open source IoT platform. We can use Thingsbard to monitor and collect data from IoT device, show telemetry data on its dashboard, trigger something or the data can be consumed by another application. IoT devices can connect using MQTT, CoAP or HTTP protocol provided by Thingsboard to send sensor data. Rules can be set to handle the incoming data, is it going to trigger an alarm, how it will be visualized, or accessed by other application. Incoming values can be visualized with graphics or just numbers. We can use any available widgets or create our own data visualization. Each device sending data to Thingsboard has a unique access token so it can be organized by its profile and ownership.[17]

Thingsboard has a dashboard to show data visualization and provide number of options to visualize our data like line chart to show time series data or gauge bar to show a single value. These available features in Thingsboard are suit to the need of PC-based medical workstation which is needed to show data in real-time and an alarm for early detection. Device profiling is also needed to identify data ownership and the protocols used for connecting the device is widely supported by many programming language. In this research we used MQTT protocol and a library from Paho Eclipse for programming the application with Python language.

2.4. MQTT

Message Queuing Telemetry Transport (MQTT) is a lightweight protocol widely used in IoT applications. It is suitable for continuous transmission of message from devices with low power and resource with limited bandwidth. MQTT has minimum packet size and also minimum size of application.[18]

MQTT works with publish-subscribe mechanism where in this research IoT device will act as publisher sending message to message broker with certain topic. Thingsboard which act as message broker will manage subscriptions where the message will be forwarded to. Collected message which contains data from portable medical device data will be visualized in dashboard as configured.

2.5. System architecture

Figure 2 shows the high level architecture of the system. While Kadarina and Priambodo [5] have designed the complete system this research only focus on the development of portable medical device and data visualization on pc-based medical workstation using open-source IoT platform. The portable medical device will have the ability to measure heart rate and SpO_2, define abnormality status and send them to server where caregivers will have access to view the data visualization. This research simulated the system in local network instead of the cloud.

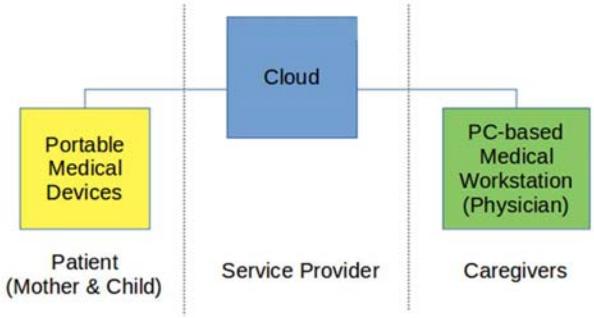

Figure 2. High level architecture of the system [5].

2.6. Service and application

We implement service application in computer and used local network to simulate connectivity between portable medical device and service application. Figure 3 shows health information service model (derived from [5] with highlights).

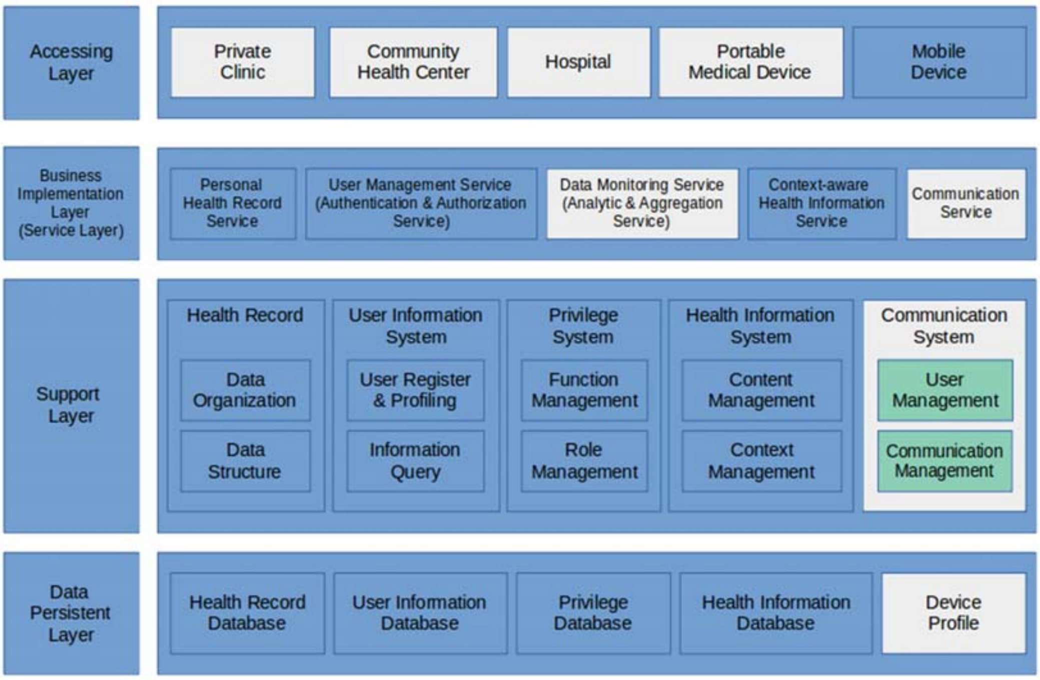

Figure 3. Health information service model [5].

IoT healthcare services for mother and child in this research consist of : accessing layer, business implementation layer (service layer), support layer, and data persistent layer. There are two platforms in the acessing layer on which we setup our application to have access to the services. On the web plaftorm we use Thingsboard dashboard to provide data visualization for caregivers. Access to the data visualization dashboard will be provided over local network and caregivers can view the dashboard on a browser in their PC. So in this scenario of mother and child health care, this interface

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can be used in this following locations: private clinic, community health center and hospital. Portable medical device will also has access to the service over network. In this research we will use Local Area Network (LAN) over Wi-fi to provide connectivity.

Two services we implemented in business implementation layer (service layer) for this research are data monitoring service (analytic and aggregation service) and communication service. Data monitoring service is a service to manage incoming data from sensors and visualize them on a dashboard. Communication service in Thingsboard includes MQTT, CoAP and HTTP for communication with the devices. We used MQTT for portable medical device sending sensor data.

Support layer which we implemented is communication system. The communication system consists of user management and communication management. User management is a service for managing user access or in this case is the credential for the device to send sensor data to server which is provided by Thingsboard. Thingsboard will provide a unique access token for each device so it can also identify where will the data come from. Devices are managed and organized by its owner/tenant.

For the communication management, we used MQTT for communication protocol between Thingsboard and portable medical device. Message broker is provided by Thingsboard and it is part of the platform. Portable medical device can send MQTT publish message to the same machine as Thingsboard with default value for the port. Thingsboard will subscribe to get telemetry data from the device.

For data persistent layer, there were no sensor data kept in database as we did not set any database. We only set device profile which was also part of Thingsboard device management. Health record database and health information database is beyond the scope of this research.

IoT healthcare application for mother and child in this research consist of portable medical device and mobile gateway. Portable medical device as defined in [5] worked independently to collect data with its sensor and send them to server via a gateway. In this research, as shown in figure 4, portable medical device consists of:

- Heart rate and pulse oximetry sensor to read parameters required to calculate heart rate and SpO_2.
- Arduino Uno will retrieve raw data from sensor, calculate heart rate and SpO_2 before sending them to Raspberry Pi via USB serial cable.
- Raspberry Pi which has the ability to more advance processing has a local database to store reference table for heart rate and SpO_2. An application wil compare the value received from the sensor to decice if it below or over the normal value. The normal or abnormal status will be sent together with the raw data, heart rate and SpO_2 values to server. This where the fog computation will happen to provide information for caregiver to make decision from the early detection.

Mobile gateway in this research is handled by Raspberry Pi which is part of portable medical device. An application in Raspberry Pi will continuously receive data from sensor module, process the data, and then forward them to server using MQTT protocol.

Figure 4 shows diagram of portable medical device while figure 5 shows how it worked. Arduino Uno acquired data from sensor, applied filter and did calculation to get heart rate value and SpO2. The result was then forwarded to Raspberry Pi for further process. In Raspberry Pi heart rate and SpO2 values were compared to a reference table to decide if it’s below or above normal values. After finish processing, all data were sent to server.

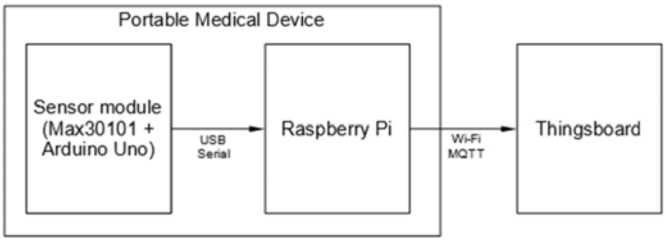

Figure 4. Portable medical device block diagram.

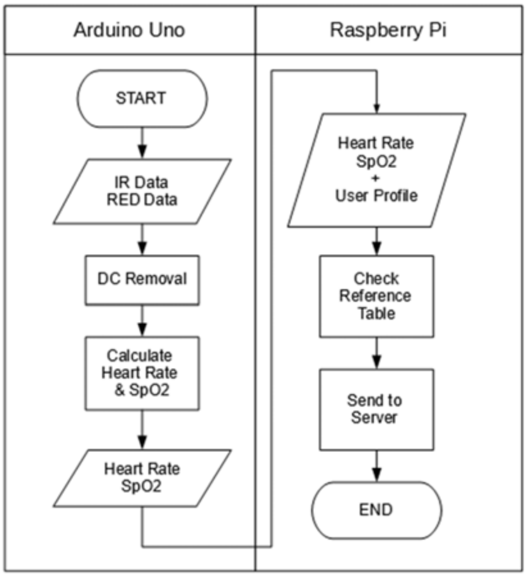

Figure 5. Flow chart of portable medical device software.

Reference table in Raspberry Pi was stored in database. We stored in database normal heart rate reference values as in Table 1 and user profile to store personal information required to do the processing. Table 3 shows user profile table and Table 4 shows heart rate reference table. As for SpO_2 we did not need a reference table since we only need to compare with a single reference value.

Table 3. User profile.

No.	Field Name	Data Type	Remarks
1.	user_id	INT	Primary Key
2.	nama	VARCHAR(100)	
3.	tanggal_lahir	DATE	
4.	status	TINYINT	

Table 4. Heart rate reference.

No.	Field Name	Data	Remarks
1.	ref_id	INT	Primary Key
2.	from_age	INT	
3.	to_age	INT	
4.	awake_rate_below	INT	
5.	awake_rate_above	INT	
6.	sleeping_rate_below	INT	
7.	sleeping_rate_above	INT	

3. Results and analysis

Several tests were conducted on each module and the system as a whole. The portable medical device was testing by using adult's finger with normal condition. The red and infrared light from the sensor reading was acquired and processed by Arduino Uno to find the heart rate and SpO_2 value. As shown in figure 6, the obtained value of heart rate and SpO_2 are vary. Therefore, we calculate uncertainty measurement using standard deviation. For heart rate measurement we achieved at $\pm$ 2.85 bpm and SpO_2 at $\pm$ 0,28%.

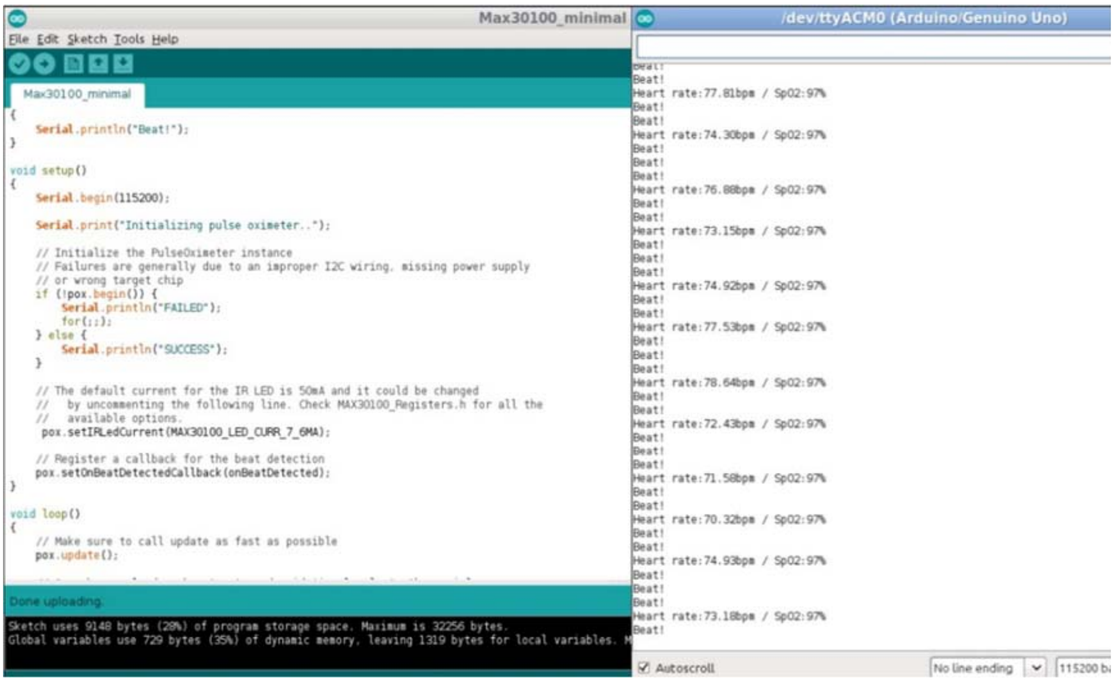

Figure 6. Data from sensor reading.

The heart rate and SpO_2 value then received by an application in Raspberry Pi. The application compared the received value to the normal criteria in the reference table stored in database based on user profile like age and sleeping/awake status. These processes were running along the time providing real-time data reading and processing. The integration of portable medical device and Thingsboard IoT platform was successfully developed ini local network. Thingsboard received all data sent by Raspberry Pi and display them in single dashboard for visualization. Figure 7 shows data visualization on Thingsboard dashboard. Red and Infrared readings was visualization in a line chart graphics as PPG signal. Heart rate and SpO_2 values displayed as numeric value and a gauge bar to visualized level while its status displayed as text with a predifined text label. For the heart rate status: Normal, Below Normal (Bradycardia), or Exceed Normal (Tachycardia) and for the SpO_2 status : Normal or Below Normal. Hypoxemia is detected when SpO_2 is lower than 90%. In this measurement test the status of the heart rate and SpO_2 shows normal condition.

As we see on graphics, PPG signal shows there is motion artivact in this measurement. This limitation cause measurement error in heart rate calculation. That is why we achieved uncertainty measurement in heart rate calculation at $\pm$ 2.85 bpm.

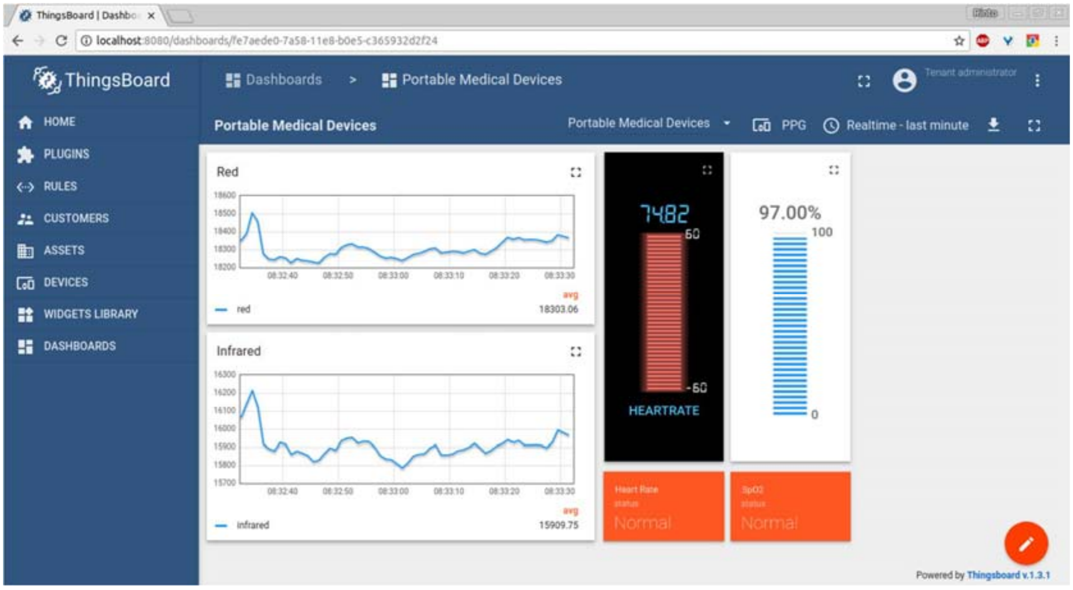

Figure 7. Data visualization on Thingsboard dashboard.

4. Conclusions

The development of portable medical device and its integration to Thingsboard wa able to facilitate remote monitoring for heart rate value and oxygen saturation level (SpO_2) in blood, showed PPG signal, and status if heart rate or SpO_2 is normal, below normal, or exceed normal. We achieved standard deviation of heart rate measurement at 2.85 bpm and SpO_2 at 0.28%. These error shows uncertainity measurements caused by motion artifact. Some of digital filtering and further signal processing will be needed for improvement.

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