Obstructive Sleep Apnea Patient's Heart Beat Monitoring System from Android Smartphone using MQTT Protocol

Heru Nurwarsito, Firstian Satya Yulihardi

Abstract*: Sleep apnea disease is a disease at the respiration system in a human that dangerous and has a high mortality rate. There is two sleep apnea, the first is central sleep apnea and then obstructive sleep apnea, basically sleep apnea is a condition that somebody stop breathing when they were sleeping for a few second, sleep apnea caused by the relaxation of respiration muscle. When sleep apnea comes back, sleep apnea patients need to wake up from and breathe normally again. This system is made to provide some mechanism outside of the human body to help obstructive sleep apnea patient woke up from their sleep and breathe well. Furthermore, with this system, might patients could be monitored although they were not at a hospital. In its work, the system is using a microcontroller and smartphone that are connected with the MQTT protocol to help patients. The microcontroller is used for sensing patient heart rate by connecting it with the AD8232 module sensor wich then the signal would be classified to determine the condition of sleep apnea using the KNN classification method. The result of classification by the microcontroller be delivered to the user's smartphone to be the trigger for alarm, patient's monitoring system, etc. Research result shows that the MQTT protocol 100% successful to transmit the data with 39.74 ms delay. The patient, patient's family, and medic smartphone's apps can monitor and successfully show a notification when sleep apnea's patient recurring. Accurate of the sensor at sensing heart rate is 91.32% and the accuracy of the classification method is 86.6%. Other than that, the average processing speed from the sensing proses to classification is 1273.85 ms, and the time needed for data arrived at the user's smartphone is 1312.74 ms.

Keywords*: Sleep Apnea, MQTT, IoT, Monitoring, Smartphone Android.

I. INTRODUCTION

Obstructive Sleep Apnea (OSA) is one disease that is less known or known to people. Obstructive Sleep Apnea (OSA) is a disease that affects the upper respiratory organs [1]. OSA is experienced by sufferers when they sleep and not infrequently, people with OSA do not realize that they are sick.

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***** Correspondence Author
Heru Nurwarsito*, Faculty of Computer Science, University of Brawijaya, Malang, Indonesia. Email: heru@ub.ac.id
Firstian Satya Yulihardi Faculty of Computer Science, University of Brawijaya, Malang, Indonesia. Email: firstianss@student.ub.ac.id

When a patient with OSA sleeps, some parts of the upper respiratory muscles relax at a level where the airway collapses and obstruction occur [2].
When there is muscle relaxation in OSA sufferers, the patient will unconsciously wake up from sleep due to a lack of oxygen supply and return to normal breathing. However, in some cases, there are situations where the patient does not have the mechanism to wake up and fulfill the body's oxygen needs so that it can be fatal.
To make people with OSA to wake up during sleep, a real-time and fast external mechanism is needed. Nowadays almost everyone has a smartphone and also almost all smartphone users patronize internet services for their daily needs. With a smartphone, everyone can receive important information such as monitoring the condition of people with OSA[3].
Many protocols that can be used as a delivery protocol for a system include HTTP (Hypertext Transfer Protocol), UDP (User Datagram Protocol), RTP (Realtime Protocol), MQTT (Message Queue Telemetry Transport), etc.
Of the various existing delivery protocols, of course, not all of them are suitable for use in a monitoring system because several aspects need to be supported such as the weight sent, speed, accuracy of delivery, and others.
In some of the aspects mentioned, the MQTT protocol is very suitable for use in this system because it is light, fast, and precise. The MQTT protocol can send fast data, which can send 6 (six) times faster than the usual HTTP protocol sending. MQTT can be used as an option that can be used as a delivery protocol in an IoT system [4].
With that, this research was conducted to create a mechanism outside the body of people with OSA to wake up when they stop breathing.

II. BASIC THEORY

A. Obstructive Sleep Apnea

Obstructive Sleep Apnea (OSA) is a sleep disorder where there is an increased risk of metabolic syndrome, impaired cognitive function, and also cardiovascular disease [5].

Sleep apnea is the blockage of airflow in the upper respiratory tract, which lasts for about 10 seconds or more, which occurs repeatedly, reaching 20-60 times per hour.

This causes a decrease in oxygen saturation of more than 4% [6].

In sleep apnea sufferers there is a decrease in oxygen which causes acidosis, besides that there is also an increase in blood pressure and also a prolonged and vasoconstriction of the coronary arteries repetition which resulting in a different heart rate condition than in healthy people.

B. Electrocardiogram (ECG)

An electrocardiogram (EKG) is a signal generated by heart activity that triggers electrical signals. In the ECG signal, important information can be taken in the form of an electrical signal generated by the heart which forms waves commonly called PQRST which are then used as parameters to see the state of the heart to determine whether the heart is normal or abnormal [7].

In the ECG signal, there are various variables including frequency, amplitude, and period. Frequency is the number of waves per second. The amplitude is the highest value of the wave and the period is the length of time it takes one wave to travel. There is a difference between the ECG signal generated by normal people and those with apnea where the ECG signal in people with apnea has a greater amplitude and R interval than normal people as shown in Fig. 1 [8].

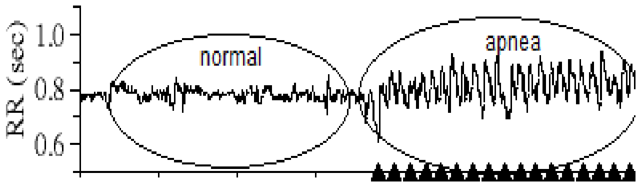

Fig. 1.Difference Between Normal and Apnea ECG.

C. K-NN Algorithm

Determining the classification of data by doing data learning which already exists using the k value is the method classification algorithm KNN [9]. In the process of doing classification, the KNN method, the smallest Euclidean Distance of K was searched on training data. The KNN method is suitable for use on data with non-informative and low dimensional variables. In the Euclidean distance search process, using mathematical equations (1).

$$Dxy = \sqrt{\sum_{i=0}^{n}(X_i - Y_i)^2} \qquad (1)$$

Explanation:
D: Nearest Neighbor
X: Data Training
Y: Data Test
n: Features
i: Counter i start from 1 to n.

D. MQTT

The Message Queue Telemetry Transport (MQTT) protocol is a publish-subscribe based protocol that sends light messages where this protocol runs on top of the TCP / IP protocol. Besides being lightweight (lightweight) this protocol also requires little power. Besides, MQTT is opensource which makes it easy to implement and develop, this is ideal for implementation in communication for the development of the Internet of Things (IoT). Based on the publish-subscribe in the MQTT protocol, this protocol requires a broker to be responsible for distributing messages from sensors [10]. The message on MQTT is sent by the publisher and contains a specific topic to the broker. Then the message broker will be forwarded to the subscriber based on the topic requested by the subscriber.

MQTT also has many of the following features [11]:

- Publish-subscribe message pattern that can send from one to many and do application decoupling
- Transport agnostic messaging.
- Using TCP / IP
- Based on three levels of Qualities of Service (QoS) in delivering messages.

III. DESIGN AND IMPLEMENTATION

A. General Description of The System

In this study the monitoring system for people with OSA disease has several mechanisms that run for system requirements, besides that, it also requires several supporting devices that have their respective functions in the process of running the system. When the system starts running and the microcontroller that is connected to the sensor used by the patient, the system will run in real-time and analyze the patient's condition through a sensor that gets input from the patient's heart rate which will be the output processed by the microcontroller.

When the microcontroller works, the data generated by the sensor will be processed and analyzed. If the results of the analysis of the patient's heart rate find an abnormality, namely a symptom of the emergence of Obstructive Sleep Apnea Based on existing training data, the microcontroller will automatically send special data which processed by a smartphone, then the patient, connected family and also the patient-nurse will be notified via their respective smartphones. In addition to providing notifications, the patient's smartphone will automatically call the closest family.

On the nurse's smartphone, apart from getting notifications, they can view the patient's heart rate data for further analysis by the patient's doctor. In the process of sending, data that has been analyzed by the microcontroller will be sent to the user's smartphone via the internet using the MQTT protocol were between the microcontroller and the smartphone there is a node called a broker which is useful for transmitting data from the microcontroller to the smartphone. Diagram of the system as in Fig. 2.

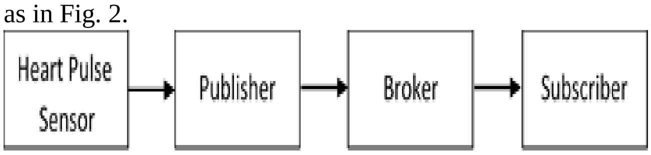

Fig. 2.System diagram

B. Node Sensor Design

The sensor is responsible for retrieving the patient's heart rate data as well as processing the data including the K-NN classification process and also as a publisher. An overview of the working flow of the sensor node as in Fig. 3.

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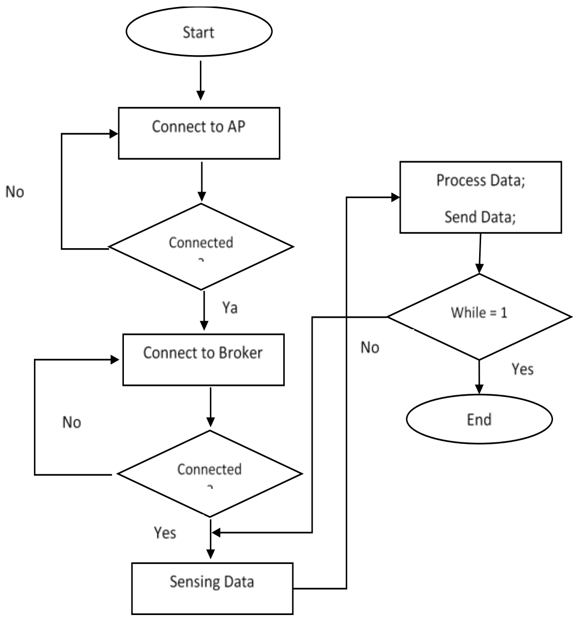

Fig. 3.Node Sensor Flowchart.

C. Broker Design

The broker works when getting sensing and analyzing data from the microcontroller. In the process, the broker temporarily receives the data sent by the publisher and then immediately sends the data to the smartphone. The following is a flowchart from the broker in Fig. 4.

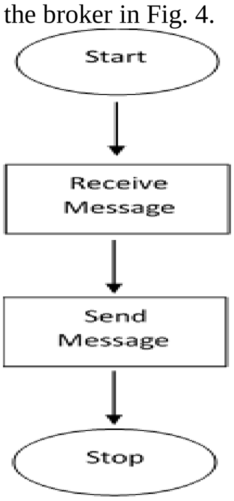

Fig. 4.Broker Flowchart.

D. Android Design

The patient's android smartphone serves as a subscriber in the process of monitoring the heart rate of people with OSA. First of all, Android operates a function so that Android is connected to the system, in this case, it is connected to the same Broker as the microcontroller.

Once connected, Android will receive data from the broker which contains the results of sensing heart rate.

Then, when OSA is detected, the apps will push a notification to help the patient wake up. Flow chart of android as in Fig. 5.

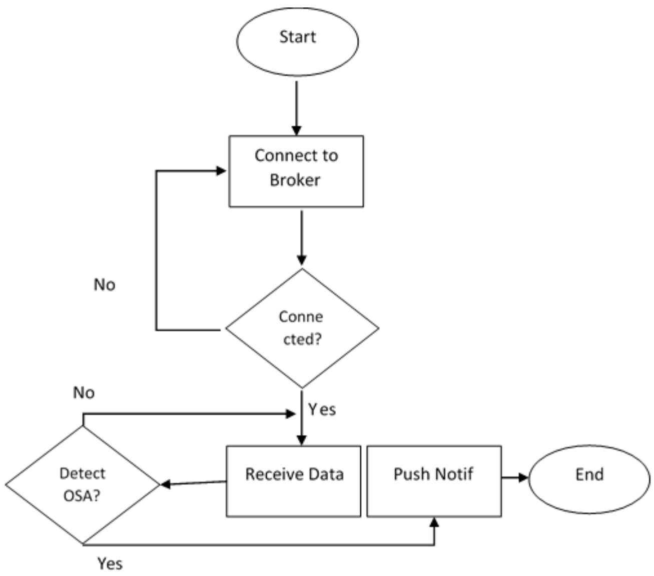

Fig. 5.Android Flowchart.

E. Hardware Implementation

Before it can be used, hardware devices such as *NodeMCU*, and the AD8232 sensor module must be assembled to work as a system which in this study takes place as a publisher. The following is a wiring table between the AD8232 sensor and *NodeMCU* in Table I and the implementation results are as shown in Fig. 6.

TABLE I. WIRING TABLE

No	AD8232	*NodeMCU*
1.	VCC	3.3V
2.	LO-	11
3.	LO+	10
4.	Sdn	-
5.	GND	GND
6.	OUTPUT	A0

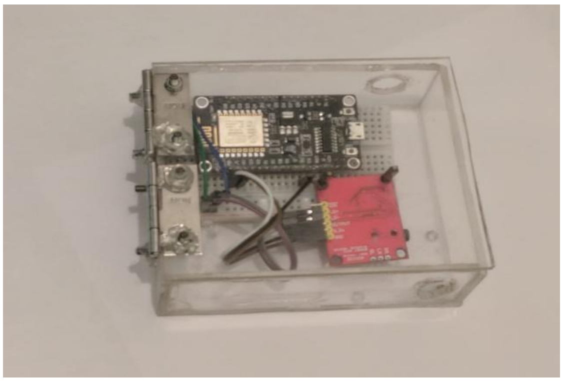

Fig. 6.Sensor Node Implementation

F. Broker Implementation

In this study, the broker used was *CloudMQTT*. *CloudMQTT* is used because it can be obtained and used for free. In use, it only needs to be run so that when the function is called, it will automatically run. The *CloudMQTT* display is as shown in Fig. 7.

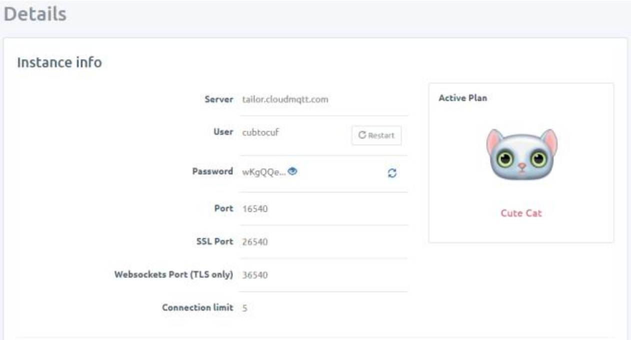

Fig. 7.CloudMQTT Configuration.

G. Android Implementation

When the system is running and the start button has been pressed, the smartphone will automatically subscribe to an appropriate topic. When subscribing, the application received the data displayed in a graphical form as shown in Fig. 8. In a case, when there is a sleep apnea state, the application will provide notification as in Fig. 9 and specifically on the patient's smartphone after receiving a notification it will make a call to the family as shown in Fig. 10. Besides, the nurse application will automatically be able to save the history of the patient's heart rate when a relapse is shown in Fig. 11.

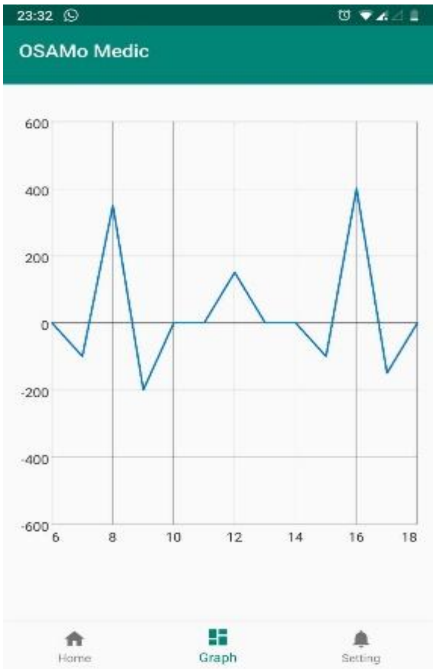

Fig. 8.Graphical View

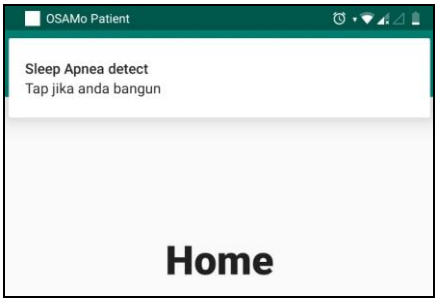

Fig. 9.Notification View

Fig. 10. Calling Action

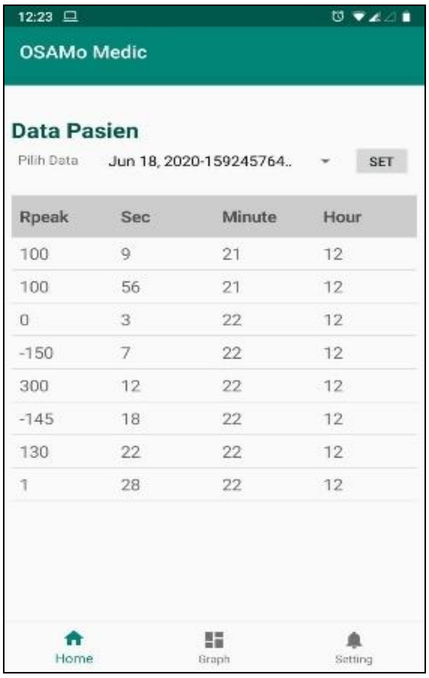

Fig. 11. Heart Rate History

IV. RESULT AND DISCUSSION

In this chapter, we will discuss the result and discussion of system performance. Testing is carried out starting from testing the delivery protocol including delivery speed. Then testing the accuracy of the ECG sensor readings compared to manual heart rate calculations. The next test is to test the accuracy of the classification process to determine whether the patient is sick or not. Then the third is the process of testing the process speed and speed of sending data from the publisher to the subscriber.

A. Transmission Testing

Data delivery testing discusses the sending process to test the integrity of the MQTT protocol as a sending protocol. This test is done by sending some data from the publisher, namely the *NodeMCU* module to the subscriber, namely *MQTTLens*. Based on the tests carried out, the results are shown in Table II.

TABLE II. DATA TRANSACTION

No	Data Sent	Data Received
1.	974	974
2.	574	574
3.	972	972
4.	973	973
5.	455	455
6.	720	720
7.	468	468
8.	891	891
9.	583	583
10.	921	921

B. Testing Delay Transmission

TABLE III. DELAY TRANSMISSION

No.	Total Data	Delay (*ms*)
1	1504	39.89
2	1487	40.34
3	1593	37.66
4	1528	39.26
5	1471	40.78
6	1526	39.31
7	1539	38.98
8	1506	39.84
9	1497	40.08
10	1452	41.31
Average		39.74

Delay testing is done to determine the delivery time required to send data from the microcontroller to the user's smartphone. From the tests conducted, it was found that the average delay was 39.74 ms, which according to Tiphon was in the very fast category. The results of the delay test are shown in Table III.

C. Accuracy Testing

Accuracy testing will discuss several accuracy tests including testing the accuracy of the heart rate generated by the ECG sensor and data classification process. Accuracy testing is done by comparing the results of the hardware with manual calculations. The results of the test obtained an ECG sensor accuracy of 91.32% and a classification accuracy of 86.6% as in Table IV and Table V.

TABLE IV. ECG SENSOR ACCURACY

No	Manual Count	Sensor Count	Difference	Accuracy
1	70	76	6	91.42
2	68	61	7	89.70
3	69	64	5	92.75
4	69	73	4	94.20
5	70	61	9	87.14
6	68	62	6	91.17
7	69	63	6	91.30
8	70	65	5	92.85
Average				91.32

TABLE V. CLASSIFICATION RESULT

No	Sensor ECG		Training Data	Classification	Result
	R-Peak	Interval R			
1	507	902	Normal	Apnea	False
2	431	775	Normal	Normal	True
3	456	707	Normal	Normal	True
4	443	734	Normal	Normal	True
5	467	748	Normal	Normal	True
6	448	802	Normal	Normal	True
7	477	734	Normal	Normal	True
8	475	800	Normal	Normal	True
9	439	815	Normal	Normal	True
10	424	775	Normal	Normal	True
11	570	998	Apnea	Apnea	True
12	489	856	Apnea	Normal	False
13	600	980	Apnea	Apnea	True
14	570	936	Apnea	Apnea	True
15	620	1005	Apnea	Apnea	True
classification accuracy					86.6%

D. Testing Process Speed

Process speed testing is done by marking the start time of the process and when the process is complete. From Table VI it is known that the average processing time is 1273.85 ms.

TABLE VI. PROCESS TIME

No	Process Time (ms)
1	1270
2	1280
3	1264
4	1269
5	1280
6	1273
7	1281
Average	1273.857143

E. Android Data Processing Testing

Data processing testing is carried out to test the functions available on the user's smartphone device whether it is functioning or not based on the data received.

There are 2 types of data received, namely heart rate data and data when sleep apnea is indicated, namely a value of 1. Based on testing the patient's smartphone device, family, and nurses function properly and generate notifications and can also monitor patients. The data sent is shown in Table VII.

TABLE VII. ANDROID DATA TRANSACTION

No	Data Sent	Data Received
1	100	100
2	0	0
3	-150	-150
4	300	300
5	-145	-145
6	130	130
7	1	1

V. CONCLUSION

From the results of the implementation that has been made, the following conclusions:

- The MQTT protocol has been successfully implemented in a heart rate monitoring system to detect OSA.

- In addition to being implemented, the MQTT protocol has an accurate delivery quality which results in 100% data similarity. In addition to accurate delivery, the average delay obtained from the delivery process based on the Thipon category is also very fast, which is 39.74 ms.
- Data received from sensors can be processed properly on the user's smartphone. When a sleep apnea patient relapses, the sensor sends data with a value of 1 and the application manages to process the data to become a trigger in bringing up notifications both on the patient, family, and nurse applications to help users wake up from sleep. Besides, the nurse application also manages to store the history of patient heart rate data when sleep apnea disease recurs.
- The system can run well with a heart rate sensor accuracy of 91.42% then the classification process accuracy rate with a value of 86.6%. The processing time from sensing to completion of classification is 1273.85. So the system takes about 1313.59 ms to be able to change the input from the patient's heart rate to a notification when Sleep Apnea relapses. With the time obtained, it is hoped that it can help the patient to wake up quickly when a relapse.

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AUTHORS PROFILE

Heru Nurwarsito was graduated from Electrical Engineering University of Brawijaya in 1989 and continued at Informatics Engineering in the Institute of Technology Sepuluh Nopember for the Magister Program. He was a lecturer in the Department of Electrical Engineering, University of Brawijaya from 1987 until 2009, then a lecturer in Faculty of Computer Science, University of Brawijaya from 2010 until present. His research area focuses on computer networking, Software engineering, the Internet of Things, and Applied of Smart Technology.

Firstian Satya Yulihardi was an undergraduate student of Computer Science Faculty, University of Brawijaya, Malang, East Java, Indonesia. His research area focuses on computer networking and the Internet of Things