Patient Monitoring and Disease Analysis Based on IoT Wearable Sensors and Cloud Computing

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Abstract — The number of patients to be treated in healthcare facilities is increasing over time due to the growing awareness and importance of formal healthcare. Most healthcare centers lacked modern automation systems, such as continuous patient monitoring, which of schedule the doctor or nurse's visits with the patient. This research is designed to implement a new method of patient monitoring system in a treatment room, using wearable sensors enabled by the Internet of Things (IoT) technology and patient data analysis in cloud computing. The proposed system consists of several sensors to retrieve patient information, such as body temperature, heart rate, blood pressure, Electrocardiogram (ECG), and motion sensor. Those parameters are used to analyze patient disease and healthcare during treatment with real-time monitoring to ensure medical professionals obtain the latest update on patient health. The system is designed in an embedded module that is applicable for mobile phones and connected through a Wireless Fidelity (Wi-Fi) system in healthcare facilities. All the patient data retrieved by IoT sensors is delivered to cloud computing to store the data and then analyzed using Long Short-Term Memory (LSTM) Algorithm to examine data related to the patient health and illness. Results show the performance of the IoT sensing system working well and are able to detect and send the data in real-time to healthcare centers globally through a mobile device. Based on real case scenario testing performance, the system accuracy ability to send data is more than 95% while any abnormality is readily detected. Overall, the system has enormous potential for further development and widespread use in the healthcare industry for efficient operations.

Keywords—Patient Monitoring, Wearable Sensor, IoT, Cloud Computing

I. INTRODUCTION

Progress within the medical industry has significantly increased as seen in many healthcare facilities and hospital structures over time. This is coupled with the raise of people awareness of the importance of formal medical treatment at healthcare facilities or hospitals especially in developing countries. Previously, the conventional method of medical treatment was implemented by consuming traditional medicine or staying at home for recovery due to the economic limitation of professional healthcare in some suburban and rural regions. Most healthcare facilities operated in semi digitalize systems; for example, the patient data record and appointments which were implemented via computerizing. However, other standard operations would be handled manually, such as obtaining patient information and data updates within person visits by medical staff or nurses. This is combined with the limitation of the number of medical staff and the lack of convenient time screening for both parties. In some cases, such as the Corona Virus Disease 2019 (COVID-19) pandemic, the conditions in healthcare facilities can be worsened due to the increasing number of patients. In this case, patients' visits were restricted to once a day or once in two days, or were unable to visit because of infected COVID-19 disease [1].

IoT is a state-of-the-art technology applied to many applications such as transportation, environmental, manufacturing, automation system, etc. IoT technology can be used as well for remote monitoring in the medical industry, specifically healthcare facilities. The IoT sensing system has the potential in improving medical infrastructure and quality of patient medical care. It made it possible by the use of wearable sensors to continuous monitoring of patient health. Furthermore, wireless connectivity as required in medical devices makes IoT systems strongly applicable for future development for healthcare device connectivity and data acquisition. Cloud computing is a technology integrated with the computerized system through the cloud to conduct analysis, storage, networking, and intelligent support.

The use of cloud computing for patient data analysis reinforces its' flexibility since data stored in the cloud becomes easily accessible from anywhere at any time. Continuous patient monitoring with multiple sensors to collect and analyze the patient information for all the patients in real-time requires a flexible and high-performance systems, and hence, cloud computing is highly suitable for this purpose. This research proposed a new technique of patient data collection through multiple wearable IoT sensors attached to the patient with data filtering and classification. The method purports to achieve faster response time and minimize memory usage during analysis with data classification at the front-end process instead of the backend as commonly applied.

Extensive research in patient health monitoring has been explored as discussed by [2-7]. The typical use of wearable sensors to monitor patients' health such as body temperature and ECG, are devices connected to the internet or computer systems through wireless or cellular data network. IoT-based technology for assisting patients monitoring as discussed in [8-12], involves the use of IoT system for patient data collecting in the healthcare center, with automatic data acquisition from sensors at a patient forwarded to the server. In addition, the use of IoT wireless polysomnography intelligent system for patient sleep monitoring in [13, 14] can continuously analyze and diagnose the health of patients during rest time. Integration and implementation of fog computing to IoT for patient monitoring is another method discussed in [15-19]. They discussed the use of fog computing to analyze patient data collected by IoT sensors. Several sensors have been applied according to the healthcare condition, specifically, in the intensive care unit (ICU) critical type of sensor has been used.

Application and implementation of machine learning for patient data analysis has been discussed in [20-22]. The main purpose to use machine learning and deep learning was to detect abnormal data retrieved by sensors and provide an early warning to the medical staff. Data encryption and classification is critical in the data server for the security and privacy of patient data. Big data techniques have been integrated into the IoT sensor system to collect patient data in healthcare for further analysis as elaborated in [23, 24]. The high volume of collected patient data has the potential to support and make a decision about the patient's illness and medical treatment. A smart disease classification based on patient data is discussed in [1]. An automatic evaluation of the patient database on body sensing and integration to a tri-axial accelerometer, a tri-axial gyroscope, and a tri-axial magnetometer. Energy efficiency and power saving for patient sensors needs to be applied in order to achieve a long-lasting patient sensing system as discussed in [25, 26]. The method to obtain energy efficiency in medical operations can be managed by conserving power of the device with sleep mode while being unused. A continuous patient monitoring with the centric agent for detecting patient disease is covered in [27-29]. End-to-end architecture from the sensing system to the database and data analysis is completely designed for patient treatment in a healthcare center.

The use of Virtual Reality (VR) for post-treatment and patient rehabilitation applied in healthcare centers is discussed in [30]. VR has the potential and ability to speed patients' recoveries and provide an effective assessment. Nowadays, there are rehabilitation treatments that use VR technology and accessible using mobile devices that patients can easily follow. Patient localization and movement monitoring through motion sensor is one technique to monitor patient health. During the COVID-19 pandemic, one of the symptoms is a cough, which can become one potential and highly suspicious variable of COVID-19 as elaborated in [31-33], in addition to other symptoms. Comprehensive machine learning techniques for patient health analysis is implemented and discussed in [34]. The machine learning techniques was mainly used for medical treatment and to discover the trend, and prediction for future diseases. Followed by a normal basic algorithm is used for patient data with less accurate results for the prediction and advanced algorithm required for this condition.

III. IoT System for Patient Monitoring

Continuous monitoring of the patient during treatment in the healthcare center requires to obtain real-time data and the latest update on the status of the patient. Currently, the most common method to monitor patient health is face to face in person visits with medical staff consisting of an interview to gather information which includes any concerns. Several methods to monitor patient status and obtain information consist of for example, the conventional method of scheduled patient visits or an automation system of attaching sensors to the patient body. The increasing number of patients impacted by the time and scarcity of medical professionals and doctors becomes an issue which results in delayed response time and patient information. Therefore, an automation system that propels patient data to the system using information technology is urgently needed at many healthcare facilities.

A. Patient Sensing System

Common parameters such as body temperature, blood pressure (systolic/diastolic), heart rate, and patient motion or movements are required by medical professionals as a basic indicator for further treatment and analysis. Fig. 1 shows a block diagram for the detection of basic parameters used for analysis to determine the potential illness. Internal signal conditioning and filtering are performed at this stage to avoid sending unnecessary data the cloud system. This method is applied to the proposed system to minimize storage and preserve data kept in the database. Raspberry Pi is used for data processing from a patient with multiple wearable sensors. Communication to backend system cloud computing, through Wi-Fi system that is normally available in many healthcare facilities.
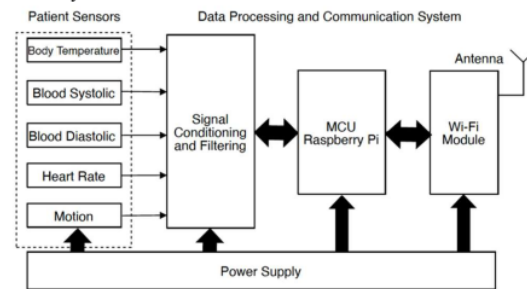

Fig. 1. Block diagram of pateint sensing system.

B. Architecture of Patient Monitoring System

The complete architecture of the patient monitoring system consists of many wearable sensors to achieve high accuracy data and real-time response. Cloud computing is also applied in this step due to the complex analysis and multi-sensors parameter of patient data. Fig. 2 shows a complete architecture of the patient monitoring system.
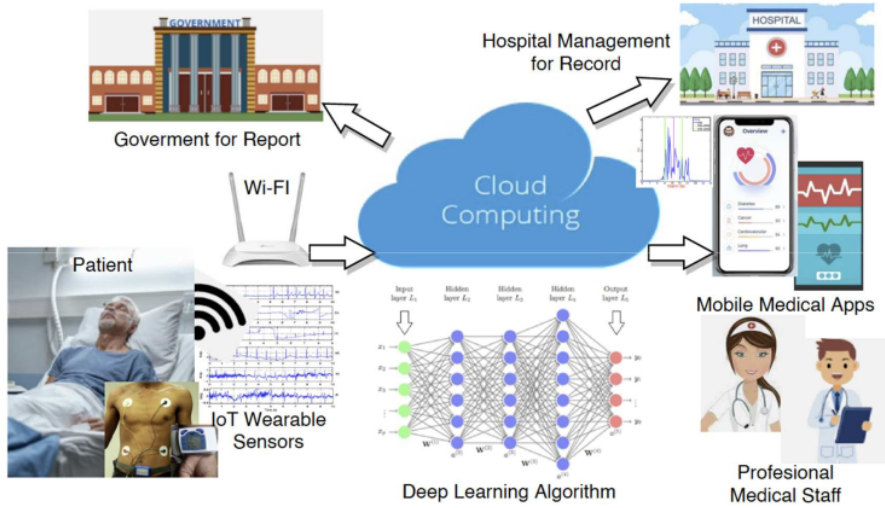
Fig. 2. The complete architecture of patient monitoring system using IoT wearable sensor.

The proposed system for patient monitoring application applies to a healthcare center such as a medical clinic or hospital. Currently, a Wi-Fi network is a common infrastructure in many buildings or offices available as a medium to connect to the Internet. Accordingly, this system is designed with internet connectivity through Wi-Fi, where all the information detected by IoT sensors is forwarded to cloud computing via a Wi-Fi network. Once data is available in cloud computing, a process to analyze patient data is achieved at this level and valuable information can be accessed by respective institutions. It can be accessed by hospital management for patients' records updates and by government for reporting, as well as by medical professionals who can use mobile applications for reports and follow up patient support.

C. Deep Learning Algorithm

Deep learning, which is a subset of machine learning, enables processing of data in high variety and volume. Many types of algorithm are invented according to the application and prediction problems. Long Short-Term Memory (LSTM) is a deep learning algorithm invented by Hochreiter and Schmidhuber [35] to address problems of the aforementioned drawbacks of the Recurrent Neural Network (RNN), by adding additional interactions per module or cell. LSTM is a special model of RNN, that is capable of learning in long-term dependencies and remembering information for prolonged periods as a default. The ability to do analysis based on long-term data and actively change in short-term of data made LSTM algorithm suitable to apply in any case and achieve high accuracy results. Fig. 3 shows an architecture of the RNN-LSTM model which consists of several main blocks called "cell" such as the "input gate, output gate, and forget gate". In the dense output layer, the sigmoid activation function classifies the values in probabilities for the two predefined classes. The output named h_t is decision-based

input and pre-processing in every step is identified "forget gate" with function of f_t.
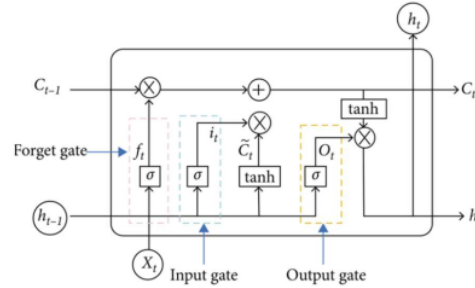

Fig. 3. The structure of RNN-LSTM algorithm

Moreover, the LSTM model can be elaborated as short-term memory which acts when the information is being acquired, retains that information for a few seconds, and then destines it to be stored for longer periods, or discarded. Long-term memory permanently retains information, allowing its recovery or recall. It contains all autobiographical data and all knowledge. Refer to the architecture of the LSTM model which consists of three major cells and the calculation of each cell in which the process can be written as equation (1) to (6).

$$f_t = \sigma \left(W_f \cdot [h_{t-1}, x_t] + b_f \right) \qquad (1)$$

$$i_t = \sigma \left(W_i \cdot [h_{t-1}, x_t] + b_i \right) \qquad (2)$$

$$\grave{C}_t = \tanh \left(W_c \cdot [h_{t-1}, x_t] + b_c \right) \qquad (3)$$

$$C_t = f_t * C_{t-1} + i_t * \grave{C}_t \qquad (4)$$

$$o_t = \sigma \left(W_o [h_{t-1}, x_t] + b_o \right) \qquad (5)$$

$$h_t = o_t * \tanh \left(C_t \right) \qquad (6)$$

LSTM model can handle the problem with long-term dependencies of RNN which the RNN algorithm cannot do in the prediction of the information stored in the long-term memory, but can give more accurate prediction from the recent information. LSTM can use by default, to retain the data for a long-term period, which isnormally used for predicting, processing, and classifying, based on time-series data.

IV. RESULTS AND DISCUSSION

The patient monitoring system has been designed and implemented. Multiple testing scenarios has been conducted to check the performance of the sensors and proposed system. The sensors are attached to the patient body to detect human body temperature, blood pressure (systolic/diastolic), ECG (one pair), and movement or motion sensor. Fig. 4 shows complete sensors attached to the patient and console with a module of microcontroller to detect patient data. Collected data then is retrieved with a filtering feature before it is forwarded to the cloud computing. Therefore, placement of sensor is very important to achieve high accuracy data retrieved by all the sensors including system calibration. Valuable patient information is retained in local memory, even though the system is not connected to the Internet, however, once the system and connectivity are ready all the data will be forwarded to the cloud computing via a Local Area Network (LAN) or Wi-Fi system in a healthcare centre.

Fig. 4. Analysis diagram of real-time sensor data to forecasting number

Measurement and experiment were conducted as initial testing at one medical clinic with 10 volunteers with both male and female participants of varying ages. The measurement of human body parameters as a simulation for every participant over the duration of 5 hours, included all data and information in the monitoring system. During testing all the sensors were attached to the volunteers' person to record some basic scenarios such as walking, and sleeping, to obtain various information according to the activities. Table 1 displays complete information of volunteers in the testing phase, representing different genders chosen, different results of human, other parameters such as age, height, weight, and background or history of previous illness. The total time to collect information is 5 hours, which is an estimate to achieve human properties as a normal patient and other additional features.

TABLE I. DETAIL OF VOLUNTEER IN EXPERIMENTS

No	Volunteer	Gender	Age (Years)	Height (cm)	Weight (Kg)	History
1	A	Male	42	160	68	Normal
2	B	Male	35	158	63	Normal
3	C	Male	45	163	73	High Blood
4	D	Female	46	155	56	Normal
5	E	Male	65	162	70	Normal
6	F	Male	28	165	73	Asthma
7	G	Female	31	153	56	Normal
8	H	Female	54	150	50	Normal
9	I	Female	44	155	60	Normal
10	J	Male	38	160	62	Coronary

Then results from the system collect information about the patient and send data to the cloud with the number of information as patient parameters from the sensor. Fig. 5 shows the graph data collection consisting of patient body temperature, blood pressure (systolic/diastolic), heart rate, and movement. The results as in Fig. 5 are in normal condition with data flow during collection within 5 hours that the volunteer requested to relaxed position and less movement.
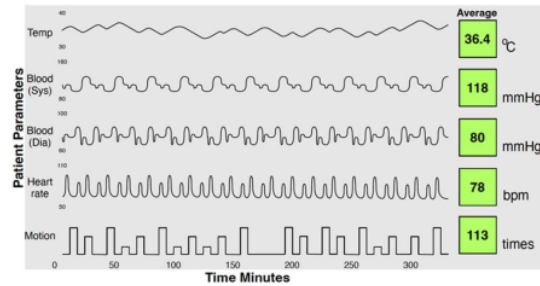

Fig. 5. Patient data detected by sensors in normal condition

Another experimental scenario involved the request of the volunteer in an atypical stance, for example, demonstrating exercise to increase heart rate and blood pressure, such as a little bit of walking and increased movement to obtain simulation data in high as well as the abnormal graph. This scenario tests and checks whether the system can detect abnormal conditions based on data received and the sensitivity of the system. Fig. 6 shows the data received from the sensor as plotted in a graph with some abnormal points detected by the system and highlighted as alert from patient.
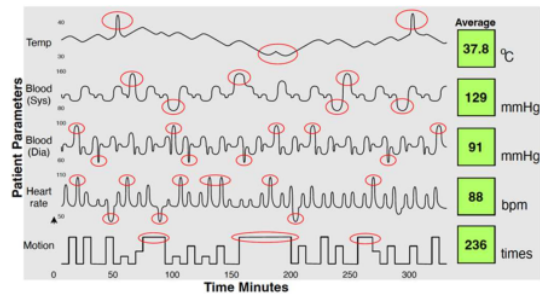

Fig. 6. Patient data detected by sensors in abnormal condition in red circle

Further, a mobile application was developed to assist medical staff, where medical doctors and/or nurses checked and monitored patient status. The proposed system using an IoT sensor monitors multiple patients simultaneously using IoT network and sends data to cloud computing. Once data is available and processing is done in the cloud the mobile device accesses the patient information from the cloud with an identity number based on the patient's information. This method is not only helpful for the healthcare facilities' patient data management but also for the exchange of information with the respective institution or government. Likewise, Fig. 7 shows a sample of mobile application to monitor patient data and information referring to the data uploaded to cloud computing. as well as subsequent processing displaying the latest information.

Fig. 7. Mobile application of patient monitoring system

V. CONCLUSION

Ultimately a system for patient monitoring has been designed and developed to retrieve continuous patient health information. Several sensors are used to obtain valuable data from the patient, and pre-processing is applied to filter unnecessary data kept in cloud computing. Moreover, deep learning algorithms implemented in the cloud computing to analyze patient data achieve high accuracy in the decision-making process. Results reveal that all the patient data was detected and forwarded to cloud computing with a success rate of more than 95%, while error occur due to internet connectivity through Wi-Fi, all the data was successfully received by cloud computing but there is a delay in the data transfer. Overall patient data analysis is able to determine abnormal data including the status of the health or illness of the patient. Future development to achieve more detailed diseases and symptoms to patient potentially are next steps to consider, while also acknowledging how alertness of patient abnormality have been addressed in this initial stage.

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