Digital Twin For Real-Time Heart Health Monitoring

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Abstract- *Problems related to the heart may need constant monitoring, yet not all the time, a person can come to a hospital. This paper introduces a digital twin system of low cost and based on wearable equipment and cloud-support, which can provide real-time monitoring of the heart condition. The proposed system measures physiological indicators, i.e., heart rate, oxygen content in the blood, body temperature and electrocardiogram readings using an ESP8266-based device. These values are uploaded to a cloud system in which a simulation of the heart state of the patient is managed.The digital twin processes the information received through rule-based logic, which identifies homogenous cardio conditions, such as tachycardia, bradycardia, hypoxemia, stress due to fever, and heart activity anomalies. The cloud stores the results of the prediction and can be visualized in real time, which makes it possible to track the state of health constantly.The system was experimented in various physiological conditions and demonstrated high data delivery and detection of abnormal pattern in time.*

Keywords: Digital Twin, Heart Health Monitoring, Internet of Things, Wearable Sensors, ECG, Cloud-Based Monitoring, Remote Healthcare

I. INTRODUCTION

Heart diseases have been among the leading causes of health issues in the various age brackets. Heart diseases are chronic and do not exhibit any apparent symptoms at initial phases. It is due to this that constant monitoring of simplistic heart related signals is significant in early detection and prevention. Nonetheless, the conventional methods of monitoring frequently utilize hospital devices and repetitive visits of clinicians that are not generalizable in everyday life.

The recent in sensor technology and low-power microcontrollers have enabled the use of vital sign monitoring out of the clinical setting. Meanwhile, health data can be stored, processed, and accessed remotely via cloud platforms. A combination of these technologies is an opportunity to develop systems that monitor the state of health and report it as quickly as possible.

The idea of a digital twin provides an effective method of health monitoring. A digital twin is the digital representation of a real-life system that is updated by real-time data. The concept of a digital twin may be considered in healthcare in relation to the existing physiological conditions of a patient and help recognize the patterns reflecting abnormalities. This kind of model is not used to substitute medical diagnosis, but it helps in early awareness and decision making.

This paper introduces a heart health monitoring system on digital twins that is based on low-cost hardware and cloud platform. The wearable sensors can measure heart rate, oxygen saturation, body temperature, and ECG of the user using a wearable microcontroller based on ESP8266. The information is sent to the cloud where a digital model of the twin is executed to assess the health of the patient based on pre-existing set of rules. The presented project can offer an easy, convenient, and unrestricted heart monitor that can be used remotely.

II. LITERATURE SURVEY

Digital twin has been applied to healthcare to depict the condition of a patient with real-time sensor data. It has been indicated in the existing research that cardiovascular digital twins can be used in continuous real-time monitoring and the detection of early dangers in combination with wearable and cloud devices [1], [5]. There are a number of models that combine digital twins and cardiovascular disease detection based on learning models. The high prediction accuracy of deep neural network-based methods has been proven to be costly to analyzed data sets and computation power which restricts their application in low-cost systems [2], [10].

Internet of Healthcare Things (IoHT) digital twins frameworks are focused on the architecture of the system, data flow, and integration with the cloud [3], [13]. Although these ways are better at scaling and increasing the efficiency of monitoring, some of them are more theoretical than practical implementation of wearables. The digital twin systems presented in the form of wearables also emphasize the role of constant vital measurements with the help of the ECG, heart rate, SpO2, and temperature sensors [6], [9]. Nonetheless, sensor noise, signal quality, and the cost of deployment are of major concern.

Microcontrollers such as ESP32 have also been used to include IoT-based cardiovascular monitoring systems that can be effectively used to collect real-time data [8], [14]. Such systems are, however, typically not provided with a digital layer of twin of health states interpretation.

According to recent surveys and market research, there has been an increase in the need of affordable and deployable digital twins in the medical sector, specifically with remote and home based monitoring [7], [15], [16]. These results encourage the creation of a weightless digital twin platform with a reasonable balance between utility and constant monitoring of heart health.

III. METHODOLOGY

The procedure used in this publication is systematized into freight purchase, freight passage, digital twin examination, and alert creation. The stages will be simple to use and provide reliable monitoring.

3.1 DATA ACQUISITION

A series of physiological sensors are used to collect physiological data which is fed to an ESP8266 microcontroller. The pulse oximeter is used to measure the level of heart rate and blood oxygen saturation, whereas the ECG sensor records electrical activity occurring within the heart. Body temperatures are recorded using a temperature sensor. These sensors are constantly sampling data on a regular basis. Noise is also separated by basic filtering before subsequent processing of the signal, particularly ECG signals.

3.2 DATA TRANSMISSION

The ESP8266 uses the HTTP requests to connect to a wireless network and transmit sensor values obtained to a cloud platform. The uploaded data is then set at a regular frequency of time to conform to the limitations of the platform. Every physiological parameter corresponds to a particular data field of the cloud channel. This provides an orderly storage and easy retrieval to be analysed.

3.3 DIGITAL TWIN MODEL

Cloud-based analysis scripts are used to implement the program of the digital twin. The incoming sensor values are the present state of the physical system, and the digital twin compares the sensor values with set values.

The conditions of high or low heart rate, low oxygen level, elevated temperature, and the odd patterns of ECGs are noted to be detected using rule-based logic. Every diagnosed condition is coded as a number and registered in the form of the output of the digital twin.

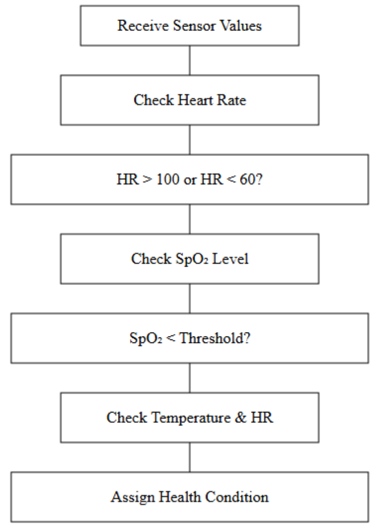

Figure 2. Decision flow of the digital twin health evaluation model

3.4 GENERATION OF FEEDBACK AND ALERTS

Feedback is also provided locally and remotely based on the output of the digital twin. The cloud platform can show real-time graphs and status indicators that can be used to monitor. Visual alerts to indicate the abnormal conditions are produced on the device side by use of the LEDs and an OLED display. This closed-loop design is going to make sure changes in the physical system are reflected right away in the digital twin and reported to the user.

IV. PROPOSED SYSTEM

The offered system is a digital twin-based heart health monitoring system that is aimed at monitoring vital physiological parameters in real time. The system integrates wearable sensors, a microcontroller, with minimal cost, and a cloud platform to provide a virtual organizational image of the heart condition of a patient. The primary objective is to offer sustained monitoring and early warning of the typical heart-related anomalies without the use of sophisticated health tools.

The physical component of the system is an ESP8266 microcontroller, with several sensors attached to it. To record the electric movements of the heart, an ECG sensor is worn. A pulse meter and oximeter detect heart rate and blood oxygen saturation whereas temperature sensor registers the body temperature. The choice of such parameters is due to the provision of helpful information related to cardiac stress and health cardiovascular health. The sensor information is collected and pre-processed by the microcontroller and transmitted to the cloud.

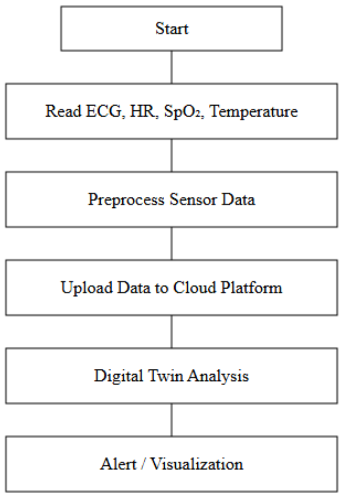

Figure 1. System flow of the digital twin heart monitoring framework

The cloud layer is the digital counterpart of the physical system. Data provided by sensor on the device is stored and analysed in real time. A rule-based evaluation model is one that compares the values that are received and compared against preset physiological thresholds. According to the given comparison, the system detects such conditions as tachycardia, bradycardia, hypoxemia, stress-induced fever, and irregular heart activity. Each condition is modelled in the cloud in the form of a digital state that shows the present condition of health of the user.

There is also the feedback mechanism that is part of the system to create timely awareness. Abnormal values are issued as indicated LEDs and an OLED display on the device on the occurrence of visual alerts. Simultaneously, the cloud platform will offer them graphical representation of sensor trends and prediction performance. The closed-loop form of design enables the physical system and its digital twin to be synchronized so that any alteration in physiological condition would be r

eflected instantly in the interface of the monitoring system.

The proposed system will be focused on simplicity, low cost, and perpetual functioning. It can be implemented in home-based monitoring and remote observation especially in the settings with less access to the regular clinical facilities. It also has a modular structure that can be improved in the future to include learning-based analysis or other physiological sensors.

V. SYSTEM IMPLEMENTATION

The application of the system is aimed at bringing together the sensing unit, the communication unit and cloud based digital twin to work together in a single system. It was implemented gradually so that there would be a steady operation and proper data processing.

The sensing unit is designed on ESP8266 microcontroller that is the main controller of all sensors connected to it. The analog input of the controller connects with the sensor of ECG that records changes in the heart signals. Pulse oximeter uses I2C interface to relay the values of a heart rate and oxygen saturation. Body temperature is the measurement done with a digital temperature sensor. These sensors are non-stop and can send physiological readings in real time.

On the device level, basic signal conditioning is done. ECG signals are smooth to lessen noise and baseline drift, and invalid values of the heart rate and oxygen saturation are filtered. This preprocessing is useful in enhancing reliability of data to be transmitted with no added complexity to the system.

To communicate the ESP8266 attaches itself on to a wireless network and uploads sensor readings to the cloud platform after a set duration of time. The transmission of data is conducted with the help of the HTTP requests to provide compatibility with the cloud service. Every physiological parameter will be related to a particular data field whereby it can be stored in an easily accessible format to be analysed further.

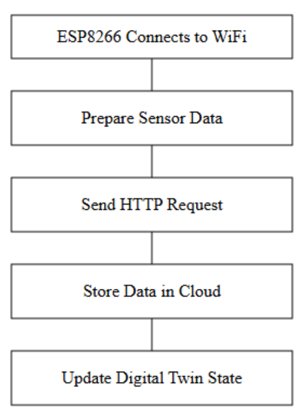

Figure 3. Data transmission process between device and cloud platform

The cloud-based implementation of the digital twin is done through a program of analysis that considers the data as it comes in. The script makes comparisons with physiological limits of real time sensor values. To derive the memory of the current health status, according to this comparison, the system assigns a condition code to it. The code will be an interpretation of the physical system by the digital twin of that time.

To get the immediate feedback, the sensor values are projected onto an OLED screen. They trigger alert indicators when detection of abnormal conditions occurs. Simultaneously, the cloud platform displays the historical patterns and up-to-date health indicators that allow being seen remotely. This execution will make sure that the physical sensing unit and the digital the same thing, the twin work at the same time.

VI. RESULTS AND DISCUSSION

The digital twin system proposed was tested and assessed by using various conditions that were physiological in nature. Sensory data were recorded in different sessions and sent to the cloud server without the data being lost. The stability of the communication system within the network proved when there was a network connection and the system was able to provide a reliable form of real-time monitoring.

The pulse oximeter acquires headdress rate and oxygen saturation measurements which exhibited consistent behaviour under the usual conditions. The system picked up the changes in case of simulations like higher heart rate or lower levels of oxygen and adjusted the state of the digital twin. ECG data also indicated some variation in the irregular conditions of signals, which meant that the system could detect irregular heart-related activity, according to preset parameters.

The digital twin was a cloud-based system that handled incoming data in the shortest possible time. Predictions of health condition were created within the predicted bound of updating and it was stored in the cloud appropriately. The visualization tools gave unambiguous trends of physiological parameters and were helpful in seeing progressive changes as opposed to individual values. This time series tracking increased the reliability of health condition.

The development of local alerts was successful. The device had visual displays that reacted instantly to unhealthy conditions (higher heart rate, low oxygen saturation, higher body temperature, etc). This instant feedback comes in handy when the user is not always looking at the cloud interface.

Despite the superior performance shown by the system, there were some limitations which were realized. The precision of detecting the condition relies on sensor location and signal quality especially with ECG measurements. Although it is easy and clear, the rule-based analysis technique does not have the ability to depict complicated patterns existing in actual clinical data. Moreover, the system depends on a constant internet connection to have cloud syncing.

Overall, the findings suggest that the system under consideration can provide sufficient assistance in sustaining heart health by utilizing the low-cost hardware solutions and the cloud-based analysis. The digital twin system ensured an opportunity to model the real-time physiological behaviour and produce valuable health information. These results indicate that those systems can be applied as auxiliary measures to provide early diagnoses as opposed to clinical diagnosis substitute.

VII. CONCLUSION

The paper has made a proposal of a digital twin-based solution to monitor the status of a heart in real time using low-cost sensors and cloud computing. The system was to continuously acquire physiological measurements including heart rate, blood oxygen level, body temperature, ECG signals and render them in the form of a virtual model in the cloud. This computer-based twin model was indicative of what was happening to the physically existing system and enabled the recognition of the abnormal trends in time.

The implementation proved the balanced data gathering on the one hand, the strong wireless communication, and the successful analysis of the data in the clouds on the other hand. The evaluation approach that is based on the rules was able to detect the prevalent heart-related conditions and deliver immediate feedback both in the form of local alert and cloud visualization. The characteristics render the system applicable to the round-the-clock operation of the non-clinical setting.

Although the proposed solution does not intend to substitute the work of the professional medical diagnosis, it provides viable assistance in early recognition and remote monitoring. The findings indicate that a digital twin structure coupled with straightforward hardware can be used to enable available and ongoing heart health surveillance. The next phase of development can be devoted to analysis accuracy and system capabilities as soon as possible, which should make the system more flexible to real healthcare usage cases.

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