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A novel three-tier Internet of Things architecture with machine learning algorithm for early detection of heart diseases☆

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ABSTRACT

Among the applications enabled by the Internet of Things (IoT), continuous health monitoring system is a particularly important one. Wearable sensor devices used in IoT health monitoring system have been generating an enormous amount of data on a continuous basis. The data generation speed of IoT sensor devices is very high. Hence, the volume of data generated from the IoT-based health monitoring system is also very high. In order to overcome this issue, this paper proposes a scalable three-tier architecture to store and process such huge volume of wearable sensor data. Tier-1 focuses on collection of data from IoT wearable sensor devices. Tier-2 uses Apache HBase for storing the large volume of wearable IoT sensor data in cloud computing. In addition, Tier-3 uses Apache Mahout for developing the logistic regression-based prediction model for heart diseases. Finally, ROC analysis is performed to identify the most significant clinical parameters to get heart disease.

1. Introduction

In recent years, there has been a perceptible increase the number of wearable devices for monitoring the patients' health, fitness and activities on a continues basis [1]. This has a long term impact on the recording of health, administration and clinical service to patient's physiological information. This advancement also helps the provision of more details relating to the daily routine and physical examination. During the health monitoring period, IoT wearable devices are attached with the human body to track the various health metrics that include blood pressure, heart rate, body temperature, respiratory rate, blood circulation level, body pain and blood glucose level [2]. The data collected from the IoT-based wearable devices are stored in a clinical database for necessary action when the patients' health condition deteriorates.

In general, traditional structured query language based databases are used in IoT health monitoring system to store clinical data. There has been an increase in the variety and quantity of IoT-based health monitoring devices in recent times. Hence, the traditional data processing methods and tools are not being used to store sensor data of huge volume generated by various IoT devices [3]. Scalable NOSQL (non structured query language) databases have to be used in the IoT-based health monitoring system. Researchers have started the use of big data and NOSQL technologies in various IoT applications. For example, Hassanalieragh et al. have used cloud computing with big data technologies to store the clinical data generated

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by various IoT devices [4]. In this application, the proposed health monitoring system continuously observes the individual's health condition. When, the health metrics such as ECG, respiratory rate, heart rate, sweating, skin temperature, blood pressure and heart sound go beyond standard values, the IoT devices send an alert message with the observed health measures to the doctor and other care holders.

Sun et al. have developed the IoT-based tailings dam monitoring system to monitor emergency situations in a tailings dam [5]. In this approach the cloud computing based scalable approach is used for taking the necessary action when situations of emergency arise. Rohokale et al. have developed IoT-based health monitoring system to observe health parameters such as hemoglobin (HB), blood pressure (BP), blood sugar and abnormal cellular growth [6]. The existing approaches use only traditional databases and tools to process the huge volume of sensor data generated from IoT devices. Hence, there is a need to develop an efficient and scalable architecture that stores as well as analyzes the huge volume of clinical data. This paper proposes a scalable big data based IoT health monitoring system for addressing this issue.

The proposed IoT-based framework is interconnected with cloud computing technology to increase scalability and availability. In addition, the proposed architecture uses Apache HBase to store the huge volume of the sensor data in the cloud. The individuals' health data is collected with the help of RFID and 5G mobile networks. In addition, Apache Mahout is used in the proposed health monitoring system for building the logistic regression-based prediction model for heart diseases. Finally, the performance of the prediction model is comparatively analyzed with the help of various performance evaluation metrics. The computed results such as throughput, sensitivity, accuracy and f-measure are used for demonstrating the efficiency and performance of the proposed IoT-based continuous health monitoring system.

The proposed IoT-based continuous health monitoring system is explained as follows: Section 1 describes the introduction to IoT-based health monitoring system. Section 2 reviews the recent works done in IoT-based healthcare systems. The proposed IoT-based continuous health monitoring system is explained in Section 3. Result and discussion, and performance evaluation are described in Sections 4 and 5 respectively. Section 6 concludes the paper.

2. Related work

The Internet of Things (IoT) is an interconnection of various physical objects for observing the physical events on a continues basis. The connected IoT devices communicate with each other with the help of advanced wireless networks and sensors [7]. IPv4 Internet was used in the last decade to transfer data at high speed. Advancements in network connectivity have helped enhancement of IPv4 Internet to IPv6 Internet with reduced delay and response time. IoT-based frameworks follow the layered architecture for transfer of the signal and communication between the devices. The layers that play an important role in network connectivity include Application Layer, Communication Layer, Security Layer, Embedded Layer, Hardware Layer, Integration Layer and DB Layer. RFID tags, sensors and actuators are used widely in IoT-based frameworks. Unique addressing schemes are used in IoT technology for mutual interaction between IoT devices [8].

The use of IoT technology in various fields has been on the increase. For example, Bäumer et al. have discussed the potential opportunities in using Internet of Things in a business organization [9]. CodeBlue project is the healthcare project developed by Harvard University. The essential role of the CodeBlue project is in the monitoring of the individuals' health parameters such as ECG, EKG, EMG, SpO2, pulse oximeter and Mica2 motes. Various electronic devices such as PDAs, laptops and personal computers are used in the CodeBlue project for necessary action from doctors and care holders when the patients' health condition deteriorates [10]. Published and subscription architecture are used in the CodeBlue project to deliver the health status of the patients in continues manner [11–13]. Researchers from the University of Virginia have developed the Alarm-Net framework to monitor the patients' health on a continues basis. The three-tier network architecture is used in the Alarm-Net project to sense the physiological parameters. IoT devices such as ECG, accelerometer and SpO2 sensors are attached to the human body in the first tier phase. The second tier focuses on observing the environmental parameters such as heat, moisture, movement and brightness [14]. Environmental sensors are attached to living things to observe environmental parameters. Tier-3 architecture is used for providing the network connectivity between the gateways. Tier three phase uses the internet protocol (IP)-based network to enable the wireless connection between source and destination [15,16].

The first tier of Alarm-net is used for sensing the physiological parameters from a patient and transferring the clinical data from the single-hop to the second tier phase. The second tier focuses on sending the clinical data from tier two to the third tier using the shortest-path-first routing protocol. This project is widely used for predicting the emergency conditions of the patients on the basis of the prior health records. Similarly, MobiCare is another healthcare project developed by Chakravorty et al. [17]. The project finds extensive use in the monitoring of patients' health over a wide-area. This project observes the clinical measures of the patients meticulously and sends the physiological values to the doctor and the care holder with the help of fog and cloud computing. The IoT wearable sensor devices used in the MobiCare project include SpO2, ECG and blood oxygen [18,19].

The MobiCare project senses the individuals' physiological information efficiently and sends it to the doctor and the care holder through a mobile phone and PDA. CDMA or GPRS/UMTS wireless technologies are used for transfer of the clinical data collected from the sensors to the doctor. The project uses HTTP POST protocol for sending the physiological data between the source and the destination. Similarly, PAM project developed by Blum et al. help observation of the mental health

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