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Developing IoT Based Smart Health Monitoring Systems: A Review

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ABSTRACT

Internet of Things (IoT) based smart health monitoring system is a patient monitoring system in which a patient can be monitored 24 hours. In the present world, IoT is changing the infrastructure of technologies. By facilitating effortless interaction among various modules, IoT has enabled us to implement various complex systems such as smart home appliances, smart traffic control systems, smart office systems, smart environment, smart vehicles and smart temperature control systems and so on in very little space. Health monitoring systems are one of the most notable applications of IoT. Many types of designs and patterns have already been implemented to monitor a patient's health condition through IoT. In this paper, a review of IoT based smart health monitoring systems is presented. The latest innovative technologies developed for IoT based smart health monitoring system with their merits and demerits have been discussed. This review aims to highlight the common design and implementation patterns of intelligent IoT based smart health monitoring devices for patients.

1. INTRODUCTION

Internet of Things (IoT) is now a reliable technological standard and a heavily researched field. Sensors are being used almost everywhere in the present time, from everyday products to industrial monitoring systems. The use of IoT and sensor-based intensive health care systems are increasing rapidly [1]. IoT makes our life smarter, more efficient and easier. Using a smartphone as the data computing platform, the prototype model [2] provides user-friendly voice recognition and alert functionalities.

Several life-threatening diseases can be easily monitored by IoT based systems. Cardiovascular Disease (CVD) is a common disease which is the cause behind most of the deaths in the world. At present, with the revolution of information and technology, smartphone-based health monitoring systems are becoming more popular. These systems can be used to collect real-time health information and give feedback to patients and medical specialists [3]. Allowing every single person to examine their health, and advising them to find immediate treatment in case of emergencies, can result in saving that person's life. The use of these monitoring systems can decrease medical fees for the nation in the long run [4]. Nowadays, due to widespread mobile internet access, the combination of mobile internet with a health service system using android open-source design has become very easy [5]. In recent years, Electrocardiography (ECG) has become an easily accessible service for everyone. By recognizing the small difference in voltage generated by the cardiac muscle, an ECG can properly determine the heart's functionality. Using a smart device, doctors and patients can continuously observe the heart rate and can get important data and take proper steps to prevent severe damages [6]. Heart rate and body temperature are some of the most important traits of the human body which are major contributors to determining a patient's health condition. The number of heart bits per minute is denoted as the heart rate of the patient. It is also referred to as the pulse rate of the body. The normal pulse rate of a healthy adult is 60 to 100 beats per minute. The average human pulse rate is 70 beats per minute for males and 75 beats per minute are for females. Females aged 12 and older have faster heart rates than males [7]. The rate changes with illness, due to damage to body, heart, and exercise. Hence heart rate is essential in determining one's health condition. Diabetes is a very common disease throughout the world. According to the World Health Organization (WHO), there are about 422 million people in the world suffering from diabetes and the amount is increasing day by day [8].

Smart health monitoring devices determine the health condition i.e. rate of the pulse, body temperature, respiratory rate, blood glucose rate, the position of the body, ECG, EEG, and other things by using sensors. The sensors are connected and controlled through various microcontroller-based systems such as Arduino, raspberry pi, etc. The microcontroller collects the data using sensors. The collected biomedical data is usually stored in servers [9]. From the stored data, the device can decide whether the patient's condition is normal or abnormal. This device provides real-time health care observation for doctors and medical assistants where they can use the data anytime. Here the main advantage is that the device has low power consumption, better performance, high sensitivity and easy set up [10].

It is assumed that by 2020 there will be about 26 to 50 billion network-connected devices and 100 billion by 2030 [11]. Raspberry pi is the most common platform for IoT. It is a Linux-based low-cost device. Raspberry Pi and IoT have collectively ushered a new era in the field of healthcare systems. With the combination of sensors such as pulse rate sensor, temperature sensor, accelerometer, and respiration sensor, a Raspberry Pi can be transformed into a mini-clinic. These systems are being used in many parts of the world [12]. Microcontroller units (MCU) are being used as the main

controller of the systems but they do not support parallel data handling.

Handling multisensory data in a parallel way can reduce time. A field-programmable gate array (FPGA) is such a circuit that has a real-time performance and unique hardware logic control system. Hence, FPGA has now become more famous than MCU in multi-sensor data handling in the IoT environment. For these reasons, new advancements have been made using FPGA rather than MCU [13].

A general architecture of a smart health monitoring system has been illustrated in Figure 1. Different types of sensors have been used in different types of health monitoring systems. In Figure 1, the sensors collect data from the patient and send those data to the processing unit. The processing unit compares those data with previously-stored cloud data and detects the health condition of patients. The system provides feedback after determining the condition of the patient.

In this paper, we are going to focus on IoT based healthcare systems that employ sensors, smartphones, and microcontroller unit based approaches, working procedures of the reviewed systems, the limitation and the working capability of each system.

The remainder of the paper is organized as follows: Section II describes IoT in health care systems. Section III describes the literature on developing healthcare systems including taxonomy and components. Section IV, V and VI demonstrate sensor-based, smartphone-based and microcontroller-based healthcare systems. The discussion and future recommendations are provided in Section VII. Finally, the review is concluded in Section VIII.

Table 1. Summary of the reviewed smart health monitoring systems

Author	Year	Feedback Device	Major Hardware Components	Uses	Cost
Moser and Melliar-Smith [4]	2015	Smartphone	Blood pressure sensor, body weight sensor, pulse oximeter, glucometer, accelerometer	Chronic disease progression	Cost- effective
Kong et al. [5]	2016	Mobile phone	Wi-Fi module, Bluetooth, RFID, ECG, blood pressure	Chronic disease	Low cost
Turner et al. [6]	2017	Smartphone	Heart rate sensor, Bluetooth, microcontroller, electrode pads, display	Cardiovascular disease	Costly
Kumar et al. [9]	2017	Monitor	Arduino Uno, temperature sensor, heart rate sensor, body position sensor, Wi-Fi module,	Heart problem, noise detection	High cost
Penmatsa and Reddy [10]	2016	Smartphone, laptop, VGA display	ECG, Bluetooth, temperature sensor, heart rate sensor, Arduino, bio-sensor	Detecting abnormalities in heart	Low cost
Kumar and Rajasekaran [12]	2016	Monitor	Raspberry pi, heartbeat sensor, temperature sensor, respiration sensor, accelerometer	Respiration rate monitoring	Expensive
Desai and Toravi [13]	2017	LCD display	CPLD,ARM7TDMI-S, temperature sensor, gas sensor, heartbeat sensor, raspberry pi	Pulse, temperature and smoke detection	Expensive
Wu et al. [18]	2019	Smartphone	Raspberry pi, Lo-Ra module, temperature sensor, humidity sensor, pulse sensor, WSN, WDM, UV, CO_2 sensor	Hearing loss, headache, rapid pulse rate detection	Costly
Ahouandjinou et al. [19]	2016	Monitor	ECG, pulse sensor, temperature, camera, environmental sensor, Bluetooth, ZigBee, RFID	Heart problem, fever detection	Costly
Mehta et al. [22]	2012	Smartphone	Accelerometer, voice sensor, microphone,	Hyper functional disorder detection	Low cost
Gao et al. [23]	2013	Smartphone	ECG, Bluetooth, heart rate sensor,	Cardiovascular disease	Low cost
Trivedi and Cheeran [25]	2017	Mobile app	Body temperature, Bluetooth, Arduino Uno	Fever, hypothermia	Cost- effective
Sabbir et al. [26]	2016	Mobile app	Arduino Uno, glucometer, Bluetooth, display	Diabetes mellitus	Low cost

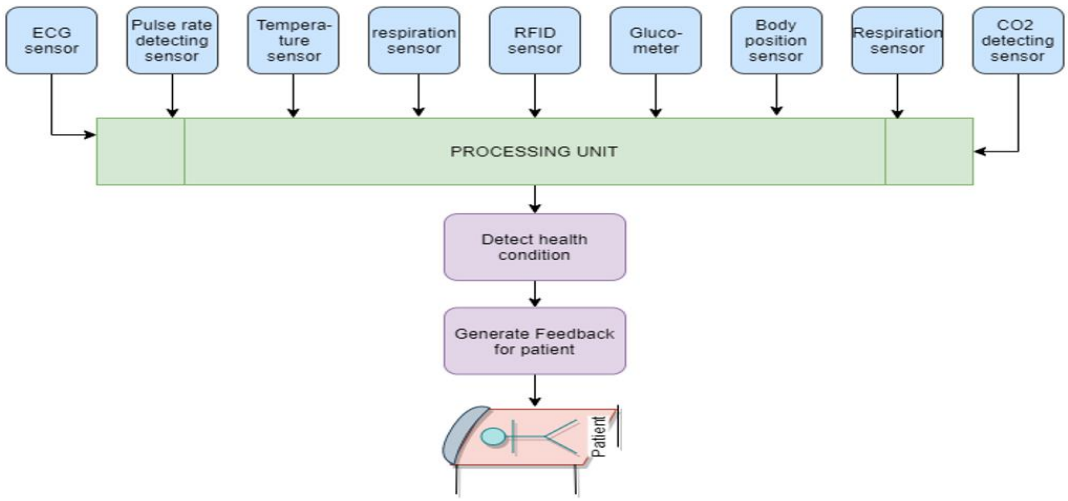

Figure 1. System architecture of the health monitoring systems

2. IOT IN HEALTH CARE SYSTEM

IoT in the health monitoring system has given us a big advantage in the development of modern medical treatment [14]. Due to advances in VLSI technology, the sensors have become smaller which has enabled the development of wearable solutions. Due to consistent internet connectivity, the devices are becoming more efficient and powerful. IoT based health monitoring devices monitor a patient 24/7. At any crucial moment, the devices generate necessary signals by analyzing statistical data [15]. As IoT based devices are constantly connected to the internet, the patients can be remotely monitored and necessary measures can be taken in case of an emergency. IoT based devices can thus provide both detection and emergency response services.

There are significant differences between normal health monitoring systems and IoT based health monitoring systems. Incorporating IoT in health monitoring systems is a challenging task [16]. Some of the challenges are discussed below:

Most of the IoT initiatives have not been successfully implemented yet.

IoT generates a massive amount of data, which requires specialized big data and data warehouse systems for proper management.

Security is a big issue for IoT systems. Hackers can easily obtain sensitive private data of users in case of buggy or outdated security protocols.

Obsolete infrastructure can generate problems as they are not up to date with recent security protocols.

3. LITERATURE ON DEVELOPING HEALTH MONITORING SYSTEM

In recent times, many health monitoring systems have been developed to monitor the health condition of patients. We are reviewing some recent works developed in this field.

In this review, all the systems have been classified based on the priority of hardware components, that is, which components have been used more than the others. Therefore, all the systems have been categorized into three different categories as follows:

(1) Sensor-based health monitoring systems,
(2) Smartphone-based health monitoring systems,
(3) Microcontroller-based health monitoring systems.

The taxonomy of the reviewed smart health monitoring system is shown in Figure 2.

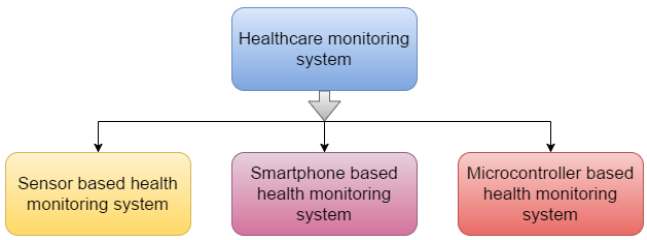

Figure 2. Taxonomy of the reviewed smart health monitoring systems

4. SENSOR-BASED HEALTH MONITORING SYSTEM

The sensor-based health monitoring system gathers information about the patient's health condition through an electronic data signal and notifies the patient via an audio alarm. Among the various types of sensors, ECG, temperature and pulse rate sensors are widely used. Most of the health monitoring devices used body temperature sensors (Max 30205), pulse rate sensor, temperature sensor (BME 680) [17]. In some health monitoring systems, other sensors such as humidity sensor, RFID sensor, biochemical detecting sensor such as a glucometer, body position sensor, and respiration sensor, CO2 sensors are also used. Wu et al. [18] proposed a wrist wearable body area network (WBAN) architecture for the healthcare system using cloud computing. The system works in both industrial and home environments. However, the developed system is wire connected. Making the device wireless would increase the flexibility of the system. Ahouandjinou et al. [19] proposed a Radio-frequency identification (RFID) based smart intensive care unit (ICU) system that collects medical data in a real-time system. The system has three layers. They are the physical layer, logical layer, and application layer. The physical layer consists of the sensors used for data collection purposes. The data collected by the sensors in the physical layer is processed in the logical layer. The logical layer handles the media access management tasks and inter-sensor communications. The application layer takes actions based on the processed data generated by the logical

layer. However, the condition and behavior of the patient cannot be determined in the reviewed system as the system used irrelevant data.

5. SMARTPHONE-BASED HEALTH MONITORING SYSTEM

Smartphones are one of the most useful resources in the world. A smartphone normally contains 14 types of sensors [20] and many more sensors are going to be added in the future. The voice monitoring system in a smartphone is a significant feature. Many hardware systems have been developed leveraging the flexibility of this feature. Some of the sensors that are included in a smartphone are the wireless sensor, Bluetooth module, Accelerometer, Fingerprint sensor, Gyroscope, Magnetometer, Barometer, Proximity, GPS tracker, Camera, NFC-near field sensor which are widely used in developing health monitoring systems [21]. Another main advantage of a smartphone is the mass storage facility of a smartphone. Modern smartphones can easily store the patient's data in primary storage. Android-based smartphones can be used for data streaming, device information management, and easy interaction.

Mehta et al. [22] developed a mobile voice health monitoring system using a smartphone that uses the accelerometer sensor. In the reviewed system a miniature accelerometer is used as a voice sensor and the smartphone is used as the data acquisition platform. The system is placed around the neck of the patient. Although this system utilized the frame based vocal parameters, the raw accelerometer data can also be used for monitoring purposes. Gao et al. [23] proposed a multi-lead ECG health monitoring system based on a smartphone. In this system, seven lead real-time ECG is used for acquiring the signal. The sampling rate is up to 500 Hz. Due to the massive amount of ECG data, it is very hard for doctors to detect abnormalities. So, an automatic alarm system is used. The alarm turns on if the system detects abnormal ECG data. However, an average alarm delay (13.37sec) occurs in this system which reduces the accuracy rate. Moser and Melliar-Smith [4] proposed a personal health monitoring system using a smartphone named WellPhone. The device uses speech synthesis and speech recognition technology to communicate with the user. It keeps a record of the semantics and big-data that are related to the data obtained from the measurement device. The data is also stored on the mobile phone. However, the data of Well phone is non-clinical.

Kong et al. [5] designed a mobile phone-based wireless health service system. The system is designed for family health treatment. This system has three parts namely: data communication designation, android mobile client designation, and system server designation. The data communication system processes the communication between the server and the android terminal. The mobile client designation works on the intelligent terminal of the android system. The system server is the webserver which is responsible for the control center and the back-end data management system. However, as the amount of data is huge, SQLite cannot provide satisfactory results. MySQL can be used to overcome this limitation. Turner et al. [6] introduced a continuous heart rate monitoring system. It is an embedded system that uses wireless signals for transmitting the heartbeat of an individual to a smartphone. As the device tracks the continuous heart rate, patients can easily get their real-time heart rate info from the device monitor. However, it doesn't track heart rate continuously and cannot detect cardiovascular disease properly.

Most of the reviewed systems used Android-based smartphones. Android is a mobile operating system based on a modified version of the Linux kernel and other open-source software, designed primarily for touchscreen mobile devices such as smartphones and tablets. Android provides easy access to sensor data of smartphones compared to other proprietary operating systems, which is required for easy development of smartphone based health monitoring systems. There are now more than 2.5 billion active Android devices. Android devices now hold 75.85% of the total mobile operating system market share. So, the development of android-based healthcare systems is very feasible.

6. MICROCONTROLLER-BASED HEALTH MONITORING SYSTEM

Microcontrollers are the most common and used devices in health monitoring systems throughout the world. MCU's are very useful for the fast processing of raw sensor data. FPGA is widely used for parallel processing of huge amounts of data. An MCU was used to interface among the sensors [24]. Due to the very small size of microcontrollers, it is effectively used for portable solutions. Today, raspberry pi is one of the most commonly used microcontroller-based platforms in the field of health monitoring systems.

Trivedi and Cheeran [25] proposed an Arduino based health parameter monitoring system controlled by a smartphone application. All the data obtained from sensors are in analog form. The data is sent to the Arduino Uno board. The collected analog values are converted into digital by inbuilt analog to digital converter. The digital values are transferred to a smartphone through Bluetooth. The system used a Bluetooth module which doesn't cover a large area. Sabbir et al. [26] developed an m-Health solution for diabetes patients. It is a home environment system. This device allows a diabetes patient to monitor his/her health condition, physical activities, control diets, insulin dose and to consult with doctors. However, the developed system has no clinical validation. Kumar et al. [9] proposed an IoT based smart health monitoring. The system application is divided into three layers. They are the detecting layer, the application layer, and the transportation layer. In the detecting section, a DS18B20 sensor has been used for detecting body temperature and a pulse sensor is used for detecting a pulse. In the transportation layer, the information is uploaded into the cloud from Arduino through the Wi-Fi module and Ethernet shield. At last, the application layer collects information from the server. However, the microcontroller in Arduino Uno is not suitable for handling too many sensors at the same time.

Penmatsa and Reddy [10] developed a system that detects abnormalities in ECG and transmits the signal via Bluetooth. It is a low-cost device. Here, three lead ECG signals are acquired. The signals are then sent to a circuit and finally presented in an oscilloscope. However, the small range of the used Bluetooth module is a limitation of the system. Using the Wi-Fi or IR modules might overcome the range limitation. Kumar and Rajasekaran [12] proposed an IoT based patient monitoring system. Raspberry Pi is the main logic unit of the system. The signals of sensors are sent to the raspberry pi through an amplifier circuit and signal conditioning unit (SCU). Using the internet, the data of the raspberry pi can be accessed from any

part of the world. However, the system only works in indoor conditions.

Desai and Toravi [13] designed a smart home and heartbeat monitoring system using a wireless sensor network (WSN). The system used Spartan 3 with FPGA architecture for parallel data computation. All the sensors are connected with a microcontroller and an LCD shows the result provided by the MCU. However, all the components of the system are not embedded in a single device.

7. DISCUSSION AND RECOMMENDATION FOR FUTURE DEVELOPMENT

The summary of this review is done based on some criteria such as feedback devices, major hardware components, uses, and cost-effectiveness. Different frameworks employ different feedback systems. The summary of the reviewed system is depicted in Table I with the aforementioned criteria.

The system designed used a raspberry pi as MCU and the Lo-Ra module for data transmission and detection of hearing problems, headache, and rapid pulse rate, and used RFID tags for security and ZigBee for data transmission. It detects heart problems and body temperature [18, 19]. Some scholars discussed that an accelerometer, a voice sensor, and a microphone have been used for detecting the hyper-functional disorder and the system detected cardiovascular disease through ECG and heart rate sensor [22, 23]. The system discussed used a pulse oximeter, blood glucometer, and accelerometer for detecting chronic disease progression and used a Wi-Fi module for data transmitting [4, 5]. It detected various chronic diseases and used RFID for the security system. Electrode pads were used for detecting cardiovascular disease in the system [6]. The Arduino Uno based system has been used to detect hypothermia [25]. The system introduced used a mobile app and glucometer for detecting diabetes mellitus [26]. The high-cost device detected heart diseases [9]. Smartphone, laptop, VGA display have been used as a feedback device [10]. The system detects abnormalities in the heart. The respiration rate was monitored by using a respirator and accelerometer [12]. The system used various gas sensors to provide the health monitoring facility [13].

Though extensive works have been done to implement smart healthcare systems that are summarized in this paper, various sensors can be employed for health system monitoring for further development. The future developed systems can employ Wi-Fi and IR sensors to overcome the range limitations of Bluetooth devices. Smartphones can be used as a health monitoring system as it makes the interaction between multiple sensors very easy. Various machine learning algorithms can be used to make the systems more accurate. In microcontroller-based systems, raspberry pi can be used for easy presentation of the monitoring data on websites.

8. CONCLUSIONS

In this review, the use of IoT in health monitoring systems has been summarized. Although IoT is being used in all sectors of medical science, there is room for further improvement and research. The early identification of any health problem can help the patient to take necessary emergency measures, which can potentially save the patient's life. IoT can help in this regard. IoT based health monitoring systems can monitor the patients in real-time and warn the patient of any abnormalities. However, the IoT architecture must have the facilities to ensure the proper security of sensitive data. Also, the used sensors must be small in size so that they can be easily incorporated into various systems. Finally, the use of various machine learning and deep learning algorithms might make the systems more accurate and robust. The idea of a smart health monitoring system using the IoT architectures is a novel contribution in the field of medical science and it will reduce health issues and unwanted deaths.

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