# Internet of Things (IoT) and Data Analytics for Realizing Remote Patient Monitoring


**A. Bharath and G. Merlin Sheeba**

**Abstract** In the wake of recent advancements in technologies such as 5G, the Internet of Things (IoT), and Artificial Intelligence (AI), unprecedented smart solutions are made possible. Plenty of IoT use cases that have not been practical so far. IoT is being used to realize eHealth and mHealth applications to enable Ambient Assisted Living (AAL) in the healthcare domain. The health of human beings has been given the highest importance and there are many practical issues in the existing healthcare domain. The problems include delays in healthcare service and high costs involved in the procedures. Many prominent personalities died of heart attacks due to delays in medical intervention. Therefore, the need of the hour is to have real-time patient monitoring and treatment without causing delay. IoT has brought its grace to realize applications like remote patient monitoring (RPM). Wearable devices (biosensors) with IoT integration transmit the vital signs from patients to doctors in real time, enable to initiate treatment immediately. The phenomenon RPM has the potential to save time, healthcare costs, and improve the quality of life of patients and the quality of healthcare services as well. This paper throws light on the present state of the art on RPM using IoT and paves the way for identifying potential research gaps for leveraging RPM systems. The proposed IoT-integrated RPM for patient health monitoring employs an algorithm called data analytics for remote patient monitoring and presented experimental results that lead the system to analyze patient health details.

**Keywords** Remote patient monitoring · Data analytics · Personalized healthcare · Internet of Things

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## 1 Introduction

Technology innovations like the Internet of Things (IoT) became very significant as it influences people and organizations. With IoT technology, there are other existing technologies used for realizing many use cases. For instance, sensor networks and Radio Frequency Identification (RFID) besides other wireless communication technologies play vital roles in IoT. Since IoT use cases produce large volumes of data, this technology is linked to cloud computing and also big data [1]. It also is capable of exploiting technologies like fog computing and edge computing [15]. IoT can be used in different industries such as transportation, healthcare, and supermarkets to mention a few. However, in this paper, our focus is on the remote patient monitoring (RPM) use case associated with the healthcare industry. Since health is wealth, as the saying goes, there is a need for innovative approaches to providing health services. RPM has the potential to revolutionize healthcare services in the real world as it can save the lives of people and provide healthcare services with minimal expenditure and waste of time. Many politicians and VIPs in India lost their lives lack of RPM usage. If that is used, there will be no deaths due to heart attacks as such cases grow in certain periods. In the traditional approach, there is a time gap between the onset of symptoms to the initiation of treatment. In the meantime, people are losing their life.

To overcome the aforementioned problem, there are many existing systems for RPM as found in the literature. It is explored in [1, 2, 4], to mention a few, for realizing personalized remote healthcare services. It needs an ecosystem that can help in realizing RPM. Many researchers exploited different technologies like IoT, cloud computing [2, 3, 6], fog or edge computing [15, 27, 31], wearable technology [1, 9, 11], blockchain technology [14, 15, 20] besides data analytics and AI [21, 25, 26]. RPM has the potential for making its highest impact on the lives of people. It is realized with IoT and other technologies. There are several existing RPM systems and the usage of different technologies. Therefore, it is important to ascertain and get insights from the state of the art. Toward this end, our contributions to this paper are as follows:

1. A review of the literature is made on IoT-enabled RPM systems to ascertain insights on the present state of the art.
2. Research gaps are identified besides bringing out useful insights on RPM and related technology usage in the existing applications including AI.
3. Proposed a methodology for remote patient monitoring with IoT integration.

The remainder of the paper is structured as follows. Section 2 covers the significance of IoT in light of the literature. Section 3 reviews existing RPM approaches. Section 4 summarizes technology usage dynamics in the RPM systems. Section 5 throws light on the relevance of data analytics for RPM as one of the IoT use cases. Section 6 covers the summary of findings while Sect. 7 provides some important research gaps. Section 8 presents the proposed RPM system. Section 9 presents the results of experiments while Sect. 10 concludes the paper and gives directions for the future scope of the research.

## 2 Significance of Internet of Things

IoT is an amalgamation of many technologies working together. It is an emerging technology that enables connectivity among things. In other words, it provides seamless integration between digital objects and physical objects in the real world. It also exploits Machine to Machine (M2M) integration without human intervention. Thus it is going to make revolutionary changes and has impact on the society and contributes to value creation [13]. With Internet of Things it is possible to have integration among businesses with M2M connectivity. It makes use of sensing technologies, communication technologies, and others. It is likely to produce huge data. In order to process such data, it needs to use resources of cloud. IoT can also be integrated with social networks and healthcare industry. IoT has emerged with long evolution as presented in Fig. 1 (adopted from [18]).

Internet has been around for many years with growing technologies to connect people. However, through Internet the IoT enables networking of things. Here things may be anything in the world both physical and digital. With Radio Frequency Identification (RFID) any object in the real world can participate in computing. With sensing devices connected to IoT it is possible to have plethora of new applications. New business models are possible. Before Internet came into existing people interacted with other people physically or through mobile communication technologies. Then we got World Wide Web (WWW) to support Internet of Content. Afterward we got Internet of services and Service Oriented Architecture (SOA) with Web 2.0 technology. Then with social media we achieved Internet of people as Internet is connecting people across the globe seamlessly with virtual communities. The M2M integration with different technologies, like identification, monitoring, metering, automation, sensing, actuation, payments, etc., are used to realize Internet of Things (IoT). Improvements in the sensing became Sensing as a Service as discussed in [16]. As explored in [37] IoT is the suitable technology for agriculture in terms of decision making and disease monitoring. As discussed in [38] big analytics associated IoT data are useful in realizing many IoT use cases. With IoT technology capabilities to integrate physical and digital worlds, it is explored for remote patient monitoring in this paper.

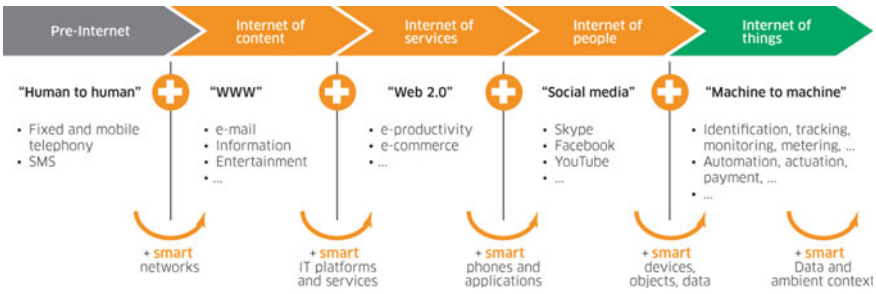


**Fig. 1** Evolution of IoT

## 3 Existing Remote Patient Monitoring Approaches

This section covers many existing RPM systems found in the literature covering the approaches used in the systems.

### *3.1 Remote Patient Monitoring Systems*

Kang et al. [2] made a review of IoT-enabled patient health monitoring systems available. They also discussed about cloud-based approaches to health monitoring. Mathew and Abubeker [4] proposed a system for real-time RPM using Raspberry Pi 3. They have used different sensors such as ECG sensor, temperature sensor, and blood pressure sensor. Alshamrani [5] made a survey on IoT and AI-based RPMs. They discussed about IoT infrastructure, its protocols like CoAP, health services design, and implementation of healthcare applications that are technology driven. Juyal et al. [6] proposed an RPM for monitoring skin health based on cloud and IoT technologies. They also used AI-based methods such as CNN for data analytics. They used supervised learning model for skin disease severity detection. Raza et al. [7] proposed a system for indoor monitoring of Alzheimer's disease patient based on IoT technology. It is an intelligence monitoring system that is supported by AI.

Shahjalal et al. [8] proposed a smart home monitoring system with AI and IoT. Their AI-based cloud server performs data analytics. Baig et al. [9] explored a wearable patient monitoring system and benefits in healthcare industry. Uddin et al. [10] focused on different technological innovations that led to the system for continuous patient monitoring. Toward this end, they proposed a notion of Patient Centric Agent (PCA) which takes care of monitoring dynamics. It also incorporates secure communications. Su et al. [12] proposed an RPM based on IoT, MQTT protocol, and REST API. They used KEPServerEX as communication platform to reap benefits of built in communication mechanisms. It has publisher and subscriber paradigm to provide services pertaining to healthcare. Baig et al. [9] focused on patient monitoring systems that exploited wearable technology.

Hathaliya et al. [14] proposed a blockchain-based RPM as part of Healthcare 4.0. They used blockchain technology as it provides secure storage and access to sensitive data. Besides it makes the healthcare data immutable. Their framework has provision for RPM and saving the results to blockchain-based distributed repository. Moghadas et al. [15] proposed a decentralized patient agent for RPM. The agent controls storage and accessing of data using blockchain technology. It makes use of fog and edge computing resources and involve in data analytics as well. The system is integrated with IoT, blockchain, and data analytics in order to have different services including security. Motwani et al. [17] proposed a system known as "smart patient monitoring and recommendation (SPMR)" for patient monitoring and generate recommendations. It is equipped with data analytics to support analysis and intelligence. Griggs et al. [20] proposed an IoT-enabled system with blockchain

and smart contracts for RPM. It makes use of sensors in order to capture patient data and the data stored in blockchain repository for security. It not only fulfills RPM needs but also takes care of secure communications.

Krishna et al. [21] proposed healthcare application using IoT technology. It has mechanisms to deal with ML algorithms and ensemble model for acquiring knowledge to help patient in avoiding recurrence of the stroke. Fazio et al. [22] exploited FIWARE cloud and IoT for realizing RPM. It makes use of wearable technology for obtaining patient details. It has web-based front end in order to have access to the patient details. It also has a security layer to ensure secure communications in the system. Mohammed et al. [23] proposed an RPM with web services and cloud computing technologies integrated with IoT. It has provision for a mobile app to capture ECG data. There is data analysis and the information is logged into personal workspace of patient in public cloud. Archip et al. [24] exploited sensor technology and IoT to capture patient vital sings in RPM which is implemented using web services with web interface. It has mobile application to show health condition with visualization.

El-Rashidy et al. [25] discussed about RPM for monitoring chronic diseases. It also focused on sensors used for capturing data from patients and communication technologies. They made a systematic review of the literature to explore different RPM systems. Hassan et al. [26] proposed a hybrid RPM model with cloud-assistance and machine learning. It has provision for learning using ML and evaluation of the data from time to time besides generating health data from monitored patients. Azimi et al. [27] focused on RPM for continuous monitoring of arrhythmia in patients. It makes use of ECG signals in order to find the abnormalities. It has data analytics provision to support analysis of massive amounts of data and bring about trends in the health related data. Dineshkumar et al. [28] proposed a healthcare monitoring system which exploits big data analytics. Since IoT sensors produce data continuously, it leads to big data and the data analytics provide required knowledge for decision making related to patients. Dhillon et al. [29] explored Complex Event Processing (CEP) technique and incorporated it in the RPM system. It makes use of IoT, web services, and CEP for patient monitoring.

Uddin et al. [30] proposed an intelligent system for patient monitoring with IoT and wearable technologies. Verma and Sood [31] developed a fog assisted system for patient monitoring associated with smart homes. Moghadas et al. [32] incorporated fog computing and machine learning to monitor Cardiac Arrhythmia of remote patients. Jeyaraj and Nadar [33] proposed a system known as smart-monitor for patient monitoring. It is equipped with deep learning and IoT technology. Shanin et al. [34] proposed a system for patient monitoring using IoT and RFID technologies. It provides healthcare services that help in assessing health problems by patients. Dridi et al. [35] used semantic technologies to realize personalized healthcare using smart IoT platform. Plageras et al. [36] exploited big data and IoT to have data analytics to deal with large volumes of healthcare data.

### *3.2 Remote Patient Monitoring for COVID-19 Patients*

Taiwo and Ezugwu [1] proposed a smart health monitoring system meant for COVID-19 patients who are in quarantine. Their system is known as "a remote smart home healthcare support system (ShHeS)". IoT is integrated with the system with many wearable sensors to monitor patient's vital signs. It has provision for remote monitoring of patients and thus patients get advice from doctors without burdening hospitals in the pandemic situation. It also includes smart home feature to control appliances at home and also support for health information in smart phone. Patient is able to use the mobile application that provides notifications. Sharma et al. [11] proposed an ontology-based IoT-integrated system for remote patient monitoring, particularly for COVID-19 patients. They used wearable sensors with patients to capture health data and provide IoT-based remote monitoring mechanism. They designed the system in such a way that it gets COVID-19 related health conditions and thus it helps doctors to suggest treatment to monitored patients. It is supported by an Android mobile application to serve the stakeholders of the system.

## 4 Technology Usage Dynamics

**Internet of Things**: It is crucial for combining physical objects and digital world leading to plenty of use cases including RPM. **Cloud Computing**: It is the technology that enables users to make use of shared computing resources through Internet without time and geographical restrictions. **Edge Computing**: It is the computing phenomena that brings computing resources closer to the data for improving performance. **Fog Computing**: It is similar to edge computing which enables nearby resources to be used by devices. It helps IoT use cases to have workflow applications and improve performance. **Wearable Technology**: It is the technology that enables wearable sensors that can be used to obtain patient's vital signs. **Data Analytics**: It is the domain which covers machine learning, deep learning, and even AI for discovering knowledge from data.

As presented in Table 1, the technology usage dynamics in the RPM systems found in the literature are provided. It, by a glance, lets us understand the utility of each technology as reflected in the literature.

## 5 Relevance of Data Analytics for RPM as IoT Use Case

Data analytics is the domain which helps in mining data and providing required knowledge or business intelligence (BI). In healthcare systems including RPM, it is essential to implement data analytics to reap its benefits. Mahmud et al. [3] advocated the need for data analytics and visualization. They proposed a framework toward this

**Table 1** Shows summary of technology usage in RPM

| Technology Usage in RPM | References |
|---|---|
| Internet of Things | [1, 2, 4–8, 10–12, 15, 20–36] |
| Cloud computing | [2, 3, 6, 8, 22, 23, 26], |
| Edge computing | [15, 27, 31, 32] |
| Fog computing | [15, 27, 31, 32] |
| Wearable technology | [1, 9, 11, 14, 15, 20, 22, 24, 25, 30] |
| Data analytics or AI | [3, 5–8, 15, 17, 21, 25–28, 31–33] |
| Blockchain technology | [14, 15, 20] |

end. Alshamrani [4] explored ML algorithms to detect anomalies in health data. They envisaged that AI-based methods play vital role in healthcare industry. Juyal et al. [6] proposed a skin monitoring system with AI-based methods for data analytics. Particularly, they explored CNN model for skin health monitoring. Raza et al. [7] explored AI for finding abnormalities in Alzheimer's disease patient's health condition. Shahjalal et al. [8] used AI for finding discrepancies associated with smart home system. Moghadas et al. [15] used data analytics in the RPM based on blockchain technology. Motwani et al. [17] implemented deep learning in their RPM for data analytics. Krishna et al. [21] used data analytics with ensemble approach to know the probability of recurrence of stroke in stroke affected patients. El-Rashidy et al. [25] explored the utility of AI in RPM systems. They discussed the need for ML algorithms for acquiring knowledge from healthcare data.

Hassan et al. [26] used several ML algorithms like SVM with MapReduce programming paradigm in distributed environments for discovering knowledge from healthcare data. Azimi et al. [27] performed data analytics to know health condition of patients and monitoring trends in health from time to time. Dineshkumar et al. [28] focused on big data analytics in health monitoring system where the data is subjected to analytics to arrive at useful knowhow.

## 6 Summary of Important Findings

This section presents the summary of findings of the literature in terms of techniques used for RPM and their advantages and limitations.

As presented in Table 2, the techniques used in the health monitoring research and their merits and demerits are provided.

**Table 2** Summary of important findings

| References No/ Author, Year | Techniques | Advantages | Limitations |
|---|---|---|---|
| [2] Kang et al. (2018) | Internet of Things (IoT), cloud computing, and big data technologies for patient health monitoring | Highly secure, efficient, scalable exchange of health data from a variety of sources | More of theoretical in nature. No practical approach |
| [4] Mathew and Abubeker (2017) | Raspberry Pi 3 and IoT integration for remote patient monitoring | Remote observation of patient's vital signs | It still needs some data analytics module for required intelligence |
| [9] Baig et al. (2017) | Wearable technology, RPM, eHealth, and mHealth | Affordable healthcare solution to patients | More of theoretical in nature. No practical approach |
| [11] Sharma et al. (2021) | RFID, RPM, ontology-based technique | Monitoring patients remotely and preserving privacy | It has no machine learning and data analytics |
| [12] Su et al. (2019) | Remote patient monitoring methods | Provides overview of different approaches to remote patient monitoring | Medical knowledge-based system is yet to be realized |
| [18] Ahmed and Kannan (2021) | IoT-based RPM | Improving QoS with ability to monitor patients remotely | Focus is on secure communications and privacy |
| [26] Hassan et al. (2018) | RPM realized with hybrid approach | Faster and accurate RPM solution | It depends on the synthetic data and simulations |
| [31] Verma and Sood (2018) | IoT-enabled RPM and notification techniques | Temporal mining improves real-time statistics | Needs enhancement to have real-time alerting system |
| [32] Ehsan et al. (2020) | IoT, fog computing, and data mining for RPM | Accurate and reliable diagnosis | It still needs to be improved for different workloads of the application |
| [35] Dridi et a. (2017) | IoT and semantic technologies for personalized healthcare | Patients can view their health information | Data mining is not used |
| [13] Swaroop et al. (2019) | RPM using IoT | Improved healthcare | Lacks in required data analytics |

## 7 Research Gaps

From the review of literature, it is ascertained that there are plenty of efforts in realizing remote patient monitoring (RPM) using Internet of Things (IoT) integrated approaches. Swaroop et al. [13] proposed an RPM with multi-mode communication option considering messaging, web and mobile application. It could overcome the problem of its predecessors having single-mode communication. However, it has specific drawbacks. First, it does not have patient fall detection and lacks in garnering business intelligence (BI) using machine learning approaches. It is also found in the literature [4, 11] that there are IoT-based RPMs that are costly from patient point of view. There is need for cost-effective approach. Su et al. [12] on the other hand proposed an RPM with multiple roles and agent-based system for effective communication. However, it lacks knowledge discovery or BI for making strategic decision making. With the inclusion of BI and its underlying methods, it is possible to leverage the utility of their system. Based on these findings, the aim of the proposed research and objectives are considered.

## 8 Proposed System

We proposed a framework for realizing remote patient monitoring as shown in Fig. 2. According to the framework, patient has wearable sensors to read heart rate, blood pressure, and temperature. The data captured by the sensors is saved to IoT infrastructure or IoT middleware in cloud server.

The data stored in IoT middleware is subjected to data analytics in order to find any abnormalities in the patient's vital signs. The findings are sent to doctor and doctor takes care of interacting with patient toward necessary treatment.

**Algorithm 1** Data Analytics for Remote Patient Health Monitoring

**Algorithm**: Data analytics for remote patient health monitoring

**Input**: Patient data as p, Machine learning models as M

**Output**: Results as R

1. Start
2. Input Patient data (p)
3. $F \leftarrow$ Pre-processing (p)
4. $(T_1,T_2) \leftarrow$ Splitting ($F$)
5. Extract features from training set ($T_1$)
6. For each model m in M
7. Train model m ($T_1$)
8. End for

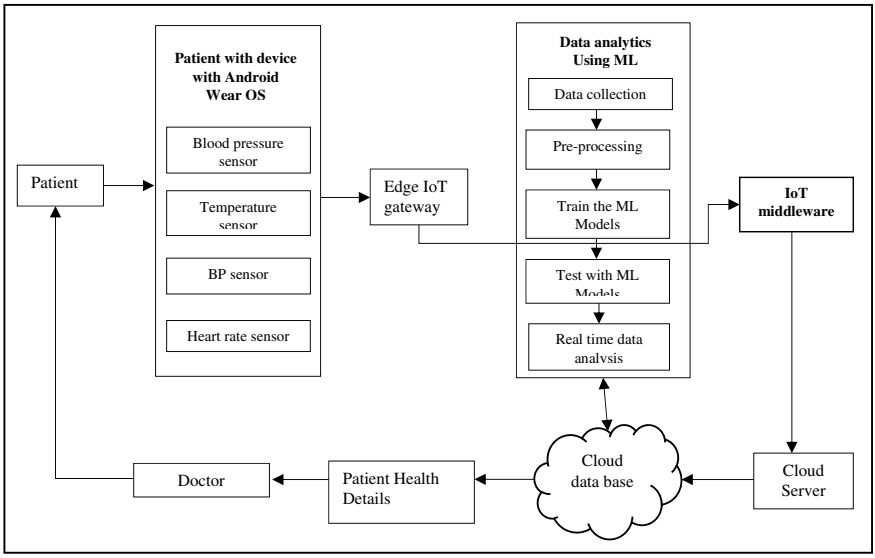


**Fig. 2** Proposed framework for IoT-enabled remote patient monitoring

9. For each model m in M
10. Test model m ($T_2$)
11. Predict the results
12. Evaluate
13. End for
14. Real-time data analysis (m)
15. Store local data
16. End
17. Return R.

As presented in the Algorithm 1, the patient data collected through sensors is subjected to pre-processing and then data analytics is done in order to find any abnormalities. It is supervised learning-based phenomenon which predicts possibility of health issues.

## 9 Experimental Results

With respect to remote health monitoring, patient's vital signs like body temperature and heart beat are monitored and observed. The temperature is measured in foreign heat while the heart beat is measured in number of heart beats per minute. As presented in Fig. 3, the time of the observations of patient's body temperature is

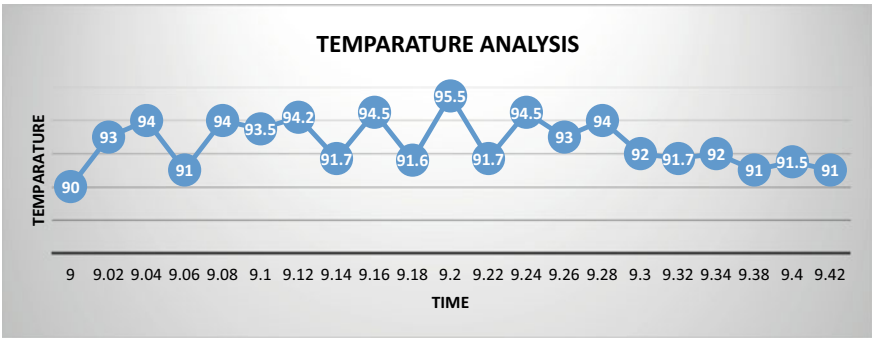


**Fig. 3** Temperature monitored by the remote health monitoring system (Patient 1)

shown in horizontal axis. The vertical axis shows temperature in foreign heat. From the results, it is understood that the body temperature changes from time to time. When the body temperature is monitored, it is possible to understand whether the patient is suffering from different ailments that may reflect symptoms in the form of body temperature. As the body temperature is one of the vital signs considered in healthcare industry. It helps physicians to know the effectiveness of the treatment being given to patient. Often fever is the stimuli specific to disease. It provides important input to the physician in making well informed decisions. As the body has its own defense mechanism in place, normal temperature is changed in order to support it.

There are many places suitable for measuring body temperature. They include forehead, armpit, mouth, ear, and rectum. The body temperature between 97.7° foreign heat and 99.5° foreign heat is considered to be normal. If the temperature is beyond this range, it is considered to be fever or fever caused by other disease. The observations are related to patient 1.

As presented in Fig. 4, the time of the observations of patient's body temperature is shown in horizontal axis. The vertical axis shows temperature in foreign heat. From the results, it is understood that the body temperature changes from time to time. When the body temperature is monitored, it is possible to understand whether the patient is suffering from different ailments that may reflect symptoms in the form of body temperature. As the body temperature is one of the vital signs considered in healthcare industry. It helps physicians to know the effectiveness of the treatment being given to patient. The observations are related to patient 2.

As presented in Fig. 5, the time at which observations are made is taken in horizontal axis and the vertical axis shows the heart rate of patient 1. Heart rate is the count of heart beat per minute. In other words, it is the number of heart beats per minute. It is also known as pulse rate. Heart rate varies from person to person. However, its monitoring provides the data to physicians that helps in understanding whether there are any signs of heart disease. Heart rate depends on different parameters like body size, medications, consumption of nicotine or caffeine, emotions, standing up, and weather. For adults it is from 60 to 100 when resting. As the heart rate is provided

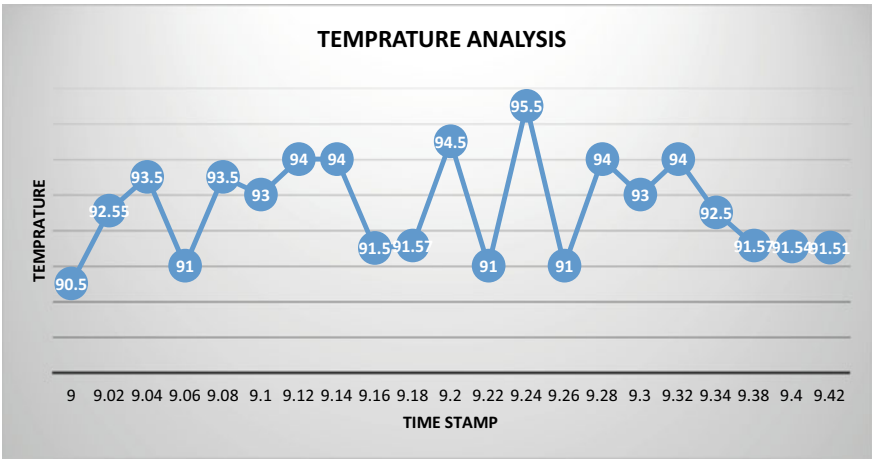


**Fig. 4** Temperature monitored by the remote health monitoring system (Patient 2)

by the remote health monitoring system, it is an important sign that helps physicians to make decisions. When the heart rate is abnormal, it is essential to take measures to rectify patient's health problem.

As presented in Fig. 6, the time at which observations are made is taken in horizontal axis and the vertical axis shows the heart rate of patient 1. Heart rate is the count of heart beat per minute. In other words, it is the number of heart beats per minute. It is also known as pulse rate. Heart rate varies from person to person. However, its monitoring provides the data to physicians that helps in understanding whether there are any signs of heart disease. Based on the heart rate, it is possible to know

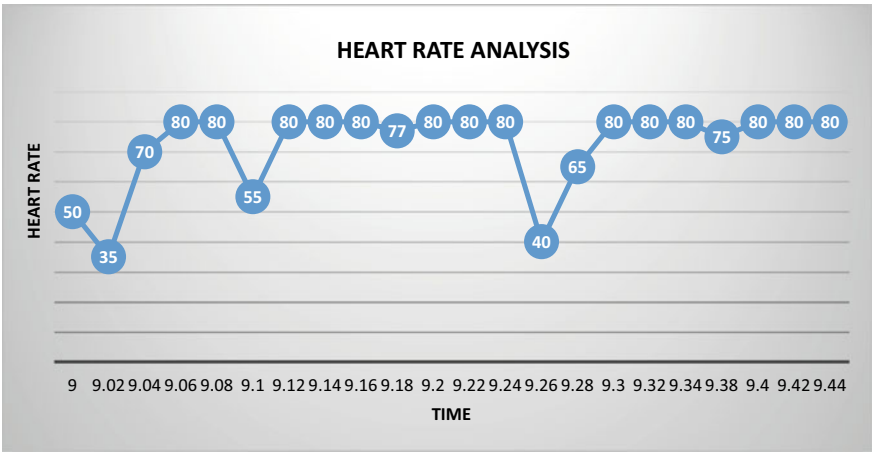


**Fig. 5** Heart rate analysis of patient 1 with the remote health monitoring system

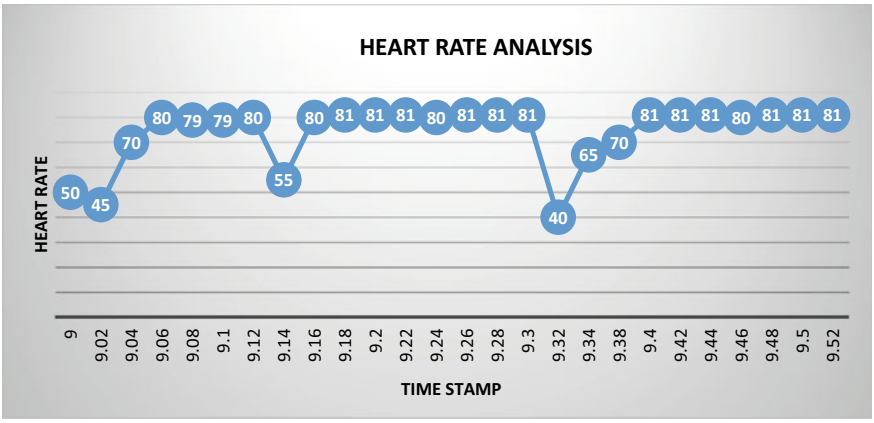


**Fig. 6** Heart rate analysis of patient 2 with the remote health monitoring system

whether the patient is suffering from any heart related ailments. The rationale behind this vital sign is that heart disease is the main cause of concern and it is on top of the reasons for death across the globe.

## 10 Conclusion and Future Work

This paper proposed a methodology for IoT-integrated remote patient monitoring system. It has support for data analytics using machine learning for analyzing patient health. From the literature on the present state of the art associated with IoT-enabled RPM systems, it is understood that IoT technology influences different industries and related use cases. Literature also reveals many existing RPM systems and their benefits and technology usage perspective. Different technologies are identified to be most significant in realizing RPM systems. They include IoT, cloud computing, edge computing, fog computing, blockchain technology, wearable technology, and AI. It also throws light on the utility of data analytics or machine learning for RPM use cases. It is ascertained that AI-based approaches like machine learning and deep learning have a role to play in healthcare applications associated with RPM for discovering hidden know-how from data. It provides a summary of important findings besides covering significant research gaps. We proposed an algorithm known as data analytics for remote patient health monitoring. Experimental results revealed that the proposed system can analyze patient health details. However, the system is at its very initial stage and needs further improvements. There are many directions for future work. First, it is desirable to build cost-effective usable RPM with minimal overhead. Second, there is a need for incorporating data analytics by defining appropriate algorithms for health data analysis. Third, it is also desirable to have mechanisms for secure end-to-end communications in RPM use case.

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