Al-Kitab Journal for Pure Sciences (2025); 9(2):84-103.
https://doi.org/10.32441/kjps.09.02.p6

Al-Kitab Journal for Pure Sciences
ISSN: 2617-1260 (print), 2617-8141(online)

https://isnra.net/index.php/kjps

Assessment of IoMT-Based Remote Patient Monitoring Used to Support Healthcare System in Kirkuk City

Lamees S. Ahmed, Abdulrahman Ikram Siddiq*

Department of Electronic and Control Engineering, Technical College Kirkuk, Northern Technical University, Iraq.

*Corresponding Author: draisiddiq@ntu.edu.iq

Citation: Ahmed LS, Siddiq AI. Assessment of IoMT-based Remote Patient Monitoring used to Support Healthcare System in Kirkuk City. Al-Kitab J. Pure Sci. [Internet]. 2025 Apr. 29;9(2):84-103. . DOI: https://doi.org/10.32441/kjps.09.02.p6.

Keywords: Iomt, Iot, Healthcare, Remote Patient Monitoring, Telemedicine, Iot Cloud, Iot Platform, Reliability.

Article History

Received	31 Aug.	2024
Accepted	14 Oct.	2024
Available online	29 Apr.	2025

Abstract:

Recently, Internet of Medical Things (IoMT)-based telemedicine applications are acquiring increasing attention. This is due to their benefits, especially during pandemic circumstances. A popular example is the Remote Patient Monitoring (RPM) system, whose performance crucially depends on the components used, mainly the available Internet connectivity. Since similar RPM systems operating in different areas can perform differently, the reliability of these systems is questionable. Therefore, in this paper, the reliability of an RPM system is assessed and tested under realistic operation conditions in Kirkuk city. The purpose is to figure out to what extent the RPM system is applicable under the locally available technologies. Extensive tests by using a 12 Mbps optical Internet connection and two different cloud platforms show that the system encountered a maximum delay of about 59 seconds with an average availability exceeding 98%. The tests proved the robustness of the system, and it is henceforth recommended for practical application in Kirkuk city to support the healthcare system.

Keywords: Iomt, Iot, Healthcare, Remote Patient Monitoring, Telemedicine, Iot Cloud, Iot Platform, Reliability.

تقييم نظام مراقبة المرضى عن بعد المعتمد على تقنية IoMT المستخدم لدعم نظام الرعاية الصحية في مدينة كركوك

لميس سعدي احمد & عبد الرحمن إكرام صديق*

قسم تقنيات الإلكترونيك والسيطرة، الكلية التقنية كركوك، الجامعة التقنية الشمالية، كركوك، العراق

lamies.saadi23@ntu.edu.iq, draisiddiq@ntu.edu.iq*

الخلاصة:

تحظى تطبيقات التطبيب عن بعد المرتكزة على شبكات إنترنت الأشياء الطبية (IoMT) باهتمام متزايد. وذلك لفوائدها خاصة في ظل ظروف انتشار الامراض والاوبئة من الأمثلة الشائعة على ذلك نظام مراقبة المريض عن بعد (RPM) الذي يعتمد أدائه بشكل حاسم على المكونات المستخدمة، وخاصة جودة خدمة الاتصال بالإنترنت المتاحة وهذا يعني أن أنظمة RPM نفسها التي تعمل في مناطق مختلفة من العالم يمكن أن يكون مستوى اداءها متباينا، مما يجعل من موثوقية هذه الأنظمة موضع شك. تم في هذا البحث تقييم واختبار موثوقية نظام RPM في ظل ظروف تشغيل واقعية في مدينة كركوك. ان الغرض من ذلك هو معرفة مدى إمكانية تطبيق نظام RPM في ظل التقنيات المتاحة محليًا. أظهرت الاختبارات المكثفة باستخدام اتصال إنترنت بصري بسرعة ١٢ ميجابت في الثانية ومنصتين سحابيتين مختلفتين أن اقصى تاخير يبلغ حوالي ٥٩ ثانية و بمتوسط توفر (Availability) يتجاوز ٩٨٪. لقد أثبتت الاختبارات ان هذا النظام يتمتع باعتمادية عالية بالنسبة لتطبيقات مراقبة المرضى عن بعد ويمكن ان يدعم ويحسن نظام الرعاية الصحية في مدينة كركوك.

الكلمات المفتاحية: إنترنت الأشياء الطبية، إنترنت الأشياء، الرعاية الصحية، مراقبة المرضى عن بعد، التطبيب عن بعد، سحابة إنترنت الأشياء، منصة إنترنت الأشياء، الموثوقية.

1. Introduction

The Internet of Things (IoT) is a concept that encompasses the interaction between Internet-connected devices less need for human-to-human or human-to-computer communication. These devices can offer services globally [1], in ways that were previously unimaginable. In contrast to the conventional paradigm, all entities in IoT realm are regarded as intelligent objects that are interconnected [2]. However, IoT-based technologies have significantly contributed to the transformation of the healthcare sector into a technologically advanced domain, with the aim of enhancing patient care. The Internet of Medical Things (IoMT), is the result of applying IoT in healthcare. It combines different medical devices and sensors with the Internet to enable immediate gathering and examination of patient data [3].

The deployment of IoMT in the healthcare sector brings substantial advantages, such as the ability to provide effective and prompt medical assistance using precise and continuous monitoring data [1]. However, the concept of green hospitals evolving as a model for future hospitals [4], when equipped with IoMT technologies, can significantly enhance the healthcare ecosystem, particularly for individuals utilizing remote monitoring systems [5]. Remote monitoring systems rely heavily on the processing and analysis of real-time data obtained by bio-sensors [2].

The core of IoMT-based healthcare systems is the IoT platform. It provides the required services and applications such as data transfer, storage, and processing. The Arduino IoT Cloud and Blynk are popular platforms for developing IoT-based applications in the healthcare sector. The Arduino Cloud is the standard and compatible platform for Arduino controllers and peripherals. Also, the effectiveness of the Blynk platform has been emphasized through its successful usage in many IoMT applications [6]. Both platforms are widely applied in remote health monitoring systems due to their flexibility, ease of use, and very good compatibility with different types of sensors and devices [7]. The quality and reliability of these services highly depend on many factors, including the Internet connectivity and the sensors and actuators [8],[9]. Then, IoMT-based healthcare systems may encounter serious challenges such as delay and data loss when they use unstable Internet connectivity, which is the case in many places.

However, the application of IoMT in Kirkuk city in Iraq can be very beneficial to the healthcare system in the city. As the population and hence the demand for healthcare services increases, the infrastructure of healthcare in the city is overstretched. Also, access to specialized care can become difficult for people from far-flung areas or living far away from the city center, and thus, on-time access to healthcare gets compromised. Therefore, this entails that an effective and reliable telehealth monitoring system becomes very important in helping to surmount such challenges by providing a system through which healthcare providers monitor the health status of their patients remotely However, IoMT acquires more importance in cases like the spread of infectious diseases where it would be preferable to monitor patients remotely without having to visit health facilities and hospitals frequently except in a situation of critical need.

The objective of this study is to design, implement, and test the performance of a medical IoT-based remote patient monitoring system. In order to highlight the impact of the IoT platform on the performance of the system, the system is implemented and tested by using two popular IoT platforms, namely the Arduino IoT and Blynk platforms. Extensive tests under realistic operation conditions have been conducted. The system's real-time operation and reliability have been evaluated by focusing on several key numerical performance metrics such as maximum delay, maximum and average data loss, uptime, and availability. By conducting this evaluation, this study aims to show the significance of developing and deploying such a system in Kirkuk city.

The rest of the paper is organized as follows: A comprehensive literature review on the works related to the context of this paper is presented in Section 2. In Section 3, the IoMT system model is described in terms of implementation and workflow. Then, in Sections 4 and 5, the reliability metrics and the adopted test procedure are presented. Section 6 presents the results obtained from testing the system under realistic operation conditions. Reliability calculations and related comments are also given in Section 6. Finally, conclusions and recommendations are given in Section 7.

2. Literature Review

Many designs and implementations of Remote Patient Monitoring (RPM) that used different sensors and actuators were presented in the literature, such as **[3]**,**[10]**,**[11]**, and **[12]**. They collectively showed the advantages of IoMT-based RPM including: The ability of healthcare providers to collect and evaluate patient data from a distance, decreasing the necessity for frequent visits to healthcare institutions, real-time collection and updating of health data and triggering alerts and notifications to healthcare practitioners enabling them to stay informed about the health status of their patients even when they are not physically present in the hospital.

However, the performance of IoMT RPM greatly relies on the capabilities of the used communication infrastructure. Therefore, these reported advantages of IoMT cannot be directly generalized for all implementations of IoMT **[13]**. One main reason is that the performance of the RPM system is governed by the available Internet connectivity. Slow service can significantly cause undesired delays and data losses, even if the IoT platform is working properly. Such cases may cause serious hazards to patients' lives. Therefore, it is important to test and evaluate the reliability of the implemented RPM system for the specific components used to build the system, to know to what extent this system is dependable **[14]**.

Reliability is essential in healthcare operations as it ensures that systems can effectively manage and counteract external stresses, such as patient demand and resource availability. A reliable healthcare system contributes to performance enhancement and customer satisfaction, which are critical in delivering quality care **[15]**. Beyond life-threatening issues, unreliable systems can result in significant financial losses for healthcare providers. This can affect the overall reputation of healthcare institutions, making reliability a key factor in operational success. The increasing demand for new technologies necessitates robust reliability measures to ensure these systems can handle various scenarios without failure **[16]**. Healthcare systems are complex and high-risk, involving various components that must work together reliably. This complexity necessitates a thorough reliability analysis to identify weak links and potential failure points. Reliability analysis allows for the identification of weak links within the system, enabling targeted improvements. This process helps in redesigning systems to enhance reliability and reduce the likelihood of failures [17].

The study [18] emphasizes the reliability of IoMT-based biomedical measurement systems (BMS) through accurate measurements essential for diagnosing diseases like heart conditions and neurological disorders. Validation against standard methods shows promising results, with low mean absolute differences in blood sugar measurements. Advanced signal processing techniques significantly improve data quality, enhancing the reliability of ECG signal classification. Addressing environmental challenges and employing multidisciplinary approaches are crucial for maintaining consistent performance in real-world applications.

In [19], the importance of reliability in telemedicine systems was studied for real-time remote health monitoring. It proposed solutions to mitigate electromagnetic interference and packet delay. The study reported the need for secure, efficient, and effective communication systems to support healthcare delivery. Next, a complete design and implementation of a wireless clinical monitoring system was presented in [20] for measuring pulse and oxygen saturation from patients. A clinical trial was conducted over seven months in a cardiology unit with 41 patients. The system demonstrated high reliability with an average availability of 99.68%. However, the reliability of the sensors for measuring oxygen and pulse was lower at 80.85%, with occasional disconnections. The performance was improved by increasing the sampling rate and implementing a disconnection alarm system. The analysis showed that the system was effective in detecting clinical deterioration. The results indicate the feasibility of using wireless networks for patient monitoring in hospitals [17]. The study [21] presents a comprehensive analysis of IoMT applications, highlighting their reliability through systematic methodology, diverse applications, and technological support, while also addressing potential challenges that could affect their implementation in healthcare systems.

An experimental performance test was presented in [22]. The presented tests were conducted on what is called Health Monitoring for All (HM4All) with a remote vital signs monitoring system based on a ZigBee body sensor network (BSN). The system involved six ECG sensors operating in two modes: ECG mode, which transmits ECG waveform data and heart rate (HR) values, and HR mode, which only transmits HR values. The non-beacon-enabled star network maintained a 100% delivery ratio (DR) without hidden nodes. When the network topology was changed to a 2-hop tree, the performance slightly degraded, resulting in an average DR of 98.56%. However, further investigation revealed that individual sensing devices experienced transitory periods with low DR.

The study in **[23]** aimed to assess the reliability of a real-time health monitoring system in the homes of older adults. The "Mobile Care Monitor" system was installed in nine homes for two weeks, featuring a wireless wristwatch with sensors and additional devices. Results showed system reliability between 73% and 92%, with data concurrence exceeding 88%. Usability metrics ranged from 82% to 97% after a firmware update for the pulse oximeter. Watch-wearing adherence was about 80%, and the study achieved 88% effectiveness in collecting potential measurements, indicating the system's high effectiveness in providing accurate remote health data.

In **[24]**, the regional limitations were taken into consideration. The study evaluated what is called the "Mashavu" telemedicine system in rural Kenya. It was found that it provided about 90% of the same medical advice as face-to-face consultations, with a high level of diagnostic consistency. The system was capable of enhancing healthcare access, reducing travel costs, and creating job opportunities. At the same time, it faced limitations such as potential bias and diagnostic gaps. Future improvements were suggested to focus on quality control and expanding diagnostic capabilities.

However, COVID-19 has shown the significance of IoMT-based RPM systems. In **[25]**, an IoT-based health monitoring system was presented that is designed for individuals diagnosed with COVID-19. It created a prototype measuring instrument for blood oxygen levels that precisely measures oxygen levels with an average error of 0.01 to 1%. It was proved that the system was efficient and helpful in monitoring patients infected with COVID-19 remotely.

The impact of using different data transmission protocols was investigated in **[26]**. The delays were measured in remote patient monitoring systems using Advanced Message Queuing Protocol (AMQP) and Constrained Application Protocol (CoAP) protocols. The findings indicated that the AMQP protocol can perform better for larger data packets and high-load scenarios, while the CoAP protocol was more efficient for small, frequent updates. The study underscored the need to select appropriate protocols to ensure effective and reliable data transmission in remote patient monitoring systems. With the aim of improving healthcare delivery in rural areas, the research in **[27]** presented an IoT-based real-time RPM system. The system used the MQTT data transmission protocol to transmit ECG data to a web server, enabling remote monitoring via smartphones or computers. The conducted experiments showed no packet loss or errors in both private (LAN) and public (WAN) networks. It supported both real-time and store-and-forward ECG monitoring, with real-time mode facing challenges like transmission delays. The use of Message Queuing Telemetry Transport (MQTT) protocol ensured low bandwidth and low power consumption.

The study [28] emphasizes the importance of reliable data delivery in the Internet of Things (IoMT) for applications like smart hospitals and traffic monitoring. It highlights the challenges of higher bandwidth and computational resources compared to traditional IoT devices, and the impact of increasing multimedia data on transmission, processing, and storage. The study also highlights the subjective quality of experience (QoE) as a significant factor in network performance evaluation, influencing perceived service reliability.

Based on the presented literature so far, it is clear that the effectiveness of IoMT-based RPM systems depends heavily on the performance of system components, mainly on the Internet service and IoT platform. Therefore, it is crucial to thoroughly test and evaluate the reliability of the specific components used in the system to ensure dependability and to recommend the system for suitable healthcare services.

3. System model

3.1 System Design: The schematic diagram of the designed healthcare IoMT system is shown in **Figure 1**. The system can be divided into three main parts. The first is the cloud platform, which serves as the system's backbone, providing communication infrastructure, data storage, retrieval, analysis, and security for all devices connected to it. The second is the healthcare room, which is designed to accommodate the patient. The medical sensors are connected to a microcontroller equipped with a Wi-Fi module. This microcontroller collects data from the medical sensors and sends it to the cloud. Another microcontroller collects environmental data and sends it to the cloud. All controllers can receive commands from a remote healthcare provider to control patient and environment-related actuators such as valves of nutrition bags, lights, and fans. Each patient microcontroller is connected to a local display screen, which displays sensor readings and emergency situation suggestions.

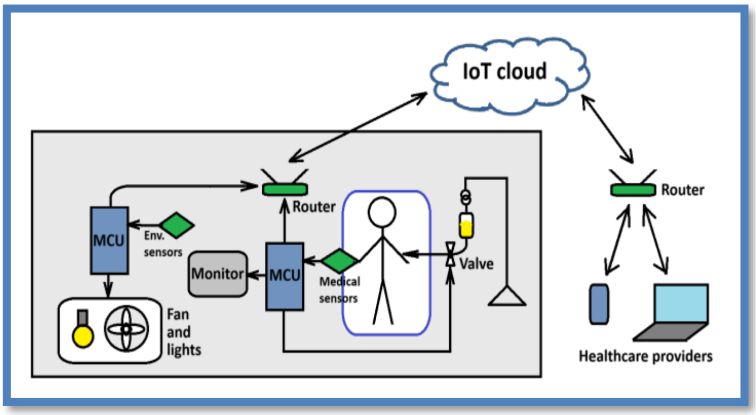

Figure 1: The designed IoMT system.

The third part of the designed system is the remote healthcare provider devices. Healthcare providers (like doctors, nurses, and home health agencies) use devices connected to the IoT platform through the Internet to receive patient data and cloud alerts. These devices have simple, clear, and user-friendly interfaces for monitoring patients and issuing control commands.

3.2 System Workflow: The designed IoMT system uses data collection, transmission, storage, and analysis mechanisms to ensure that the data is accurate, reliable, and secure, enabling effective remote patient monitoring and healthcare delivery. Before the system is operational, the microcontrollers are set to be connected to the Internet through a local Wi-Fi wireless router. The microcontrollers are also well defined within the cloud platform, such that suitable cloud variables are assigned to the streams of collected data initiated from medical and environmental sensors. The available cloud options and services are suitably customized to correctly accommodate and display the data on the dashboards of the platform. Control buttons are added to the dashboards as a means for the healthcare providers to control actuators.

The privacy and security of data access from both sides of the designed system (sending data to the cloud and accessing dashboards for monitoring and control) are achieved by limiting access to authorized devices only according to their Media Access Control (MAC) addresses. The collected sensor data on the cloud server is analyzed, and in accordance with notifications and alerts, is generated to inform healthcare providers when abnormalities and emergency cases occur. These alerts are determined by setting upper and lower bounds for the normal ranges of every measured parameter. Alerts are initiated by the cloud server once a value exceeds normal limits. In similar systems, a monitor is also used to display the sensor readings of each patient. In this research, the function of this monitor is extended to display suggestions and recommendations in abnormal situations, and most importantly, in the case of losing Internet connectivity. These suggestions are pre-programmed inside the patient microcontroller, and they are related to the reading of the sensors according to recommendations obtained from specialized consultants.

The designed system is easily scalable. It is open to deal with more patients by just iterating replicas of the hardware and software modules used for one patient. The cloud platform can easily be modified to accommodate more patients (and maybe more sensors and functions) by upgrading the usage plan according to the available options.

3.3 System Hardware Implementation: The designed IoMT-based healthcare system is implemented using hardware and software modules to perform its specified functions. The utilized hardware components are as follows:

1. Microcontrollers: Three Node MCU esp8266 modules are used, two for patient circuits and one for environmental parameters. The characteristics of this microcontroller and

the integrated Wi-Fi module make it a suitable choice for connecting sensors and actuators.

2. Medical sensors

- The MAX30100: is a device that monitors heart rate and pulse oximetry, using light-emitting diodes and an Infra-Red sensor. It uses an analog signal processing unit to improve output signal quality and operates on input voltages from 1.8V to 3.3V. The sensor has an accuracy range of 96.17%-97.67% for blood oxygen saturation level and 92.35%-99.65% for heart rate.

- DS18B20: is a digital thermometer that offers 9-bit to 12-bit Celsius temperature measurements, with an operating temperature range of -55°C to +125°C and accuracy of ±0.5°C. It connects via a one-wire bus, requiring only a single data line and Vcc and GND for microcontroller interfacing.

3. Room environment sensors

- The DHT11: is a temperature and humidity sensor with a calibrated digital output. It measures temperature in the 0°C to +50°C range with a ±2°C accuracy and relative humidity in the 20 to 90% range with a ±5% accuracy.

- MQ-135: is a gas sensor that detects harmful gases and smoke using both digital and analog output pins. The digital output gives a high signal when gas concentration exceeds a threshold, while the analog output voltage ranges from 0 to 4.2V. The detection range varies based on the gas being measured.

4. Actuators: The designed IoMT system consists of two actuators and two electronic switches. They are controlled by the healthcare providers through the control buttons on the dashboard. Two of these actuators are used to control the solenoid valves for the purpose of controlling the flow of nutritional fluid into the patients' bodies. The two switches are implemented by relays to control the ON/OFF operation of the fan and lights in the healthcare room.

4. IoMT reliability metrics

The undesired effects of communication impairments on the performance of the implemented IoMT system are the delay in data delivery, data losses and inaccuracy of received data. These effects can be measured and the reliability of the system can be assessed by evaluating several key numerical metrics. These metrics help in forming a clear idea of the extent to which the system is performing as expected. These metrics include:

A. **Latency and Response Time:** Calculating the average and maximum time required to deliver a data entity. These metrics help in understanding the range of response times and identifying any outliers or extreme delays. This metric is essential for assessing how quickly and efficiently a network operates, impacting user experience and system quality. A low reaction time indicates rapid task handling by the network. However, if it's high, it could indicate that the network is crowded, has experienced problems, or has become ineffective [29].

B. **Uptime and Availability**

- Mean Time Between Failures (MTBF): This metric measures the average time the system operates without failure. It is calculated by dividing the total operational time, called the uptime, by the number of failures [30].

$$\text{MTBF} = \frac{uptime}{number\ of\ failures} \quad (1)$$

- Mean Time To Repair (MTTR): This metric measures the average time taken to repair the system after a failure. It is calculated by dividing the total time of failure, called the downtime, by the number of failures [31].

$$\text{MTBF} = \frac{downtime}{number\ of\ failures} \quad (2)$$

- Availability: Often expressed as a percentage, availability is calculated by using the formula [32].

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF+MTTR}} \times 100\% \quad (3)$$

C. **Data Integrity:** Sometimes known as the Error Rate and it is the number of errors detected in the data transmitted or stored, usually expressed as errors per million (EPM) or simply as a percentage ratio of the number of errors to the total number sent data items [29].

5. Test procedure

In order to measure the previous metrics, the following procedure has been applied:

1. Software tools have been implemented to measure the system performance defined by delay, data loss, and EPM. The *Teraterm* serial port monitor software is used to record the values of the transmitted sensor data, together with the transmission time, to be used as a reference for the measurements. Also, as one facility offered by the cloud platform, the data on their exact arrival time is recorded.
2. The system operated for 24 hours for 10 days, and the system performance parameters were measured and recorded to observe how the system performs under various realistic network conditions. The sensor's data are replaced by previously recorded real patient data obtained from the same sensors. The data represent the sensor readings for 24 hours. The data were stored and fed to the system continuously and repeatedly throughout the period of the system test. This is done because of the difficulty in performing this test on a human for this relatively long period, and since the focus of this research is to evaluate the impact of communications impairments on system performance.
3. The collected data is systematically analyzed according to the metrics defined to assess the reliability of the system.
4. The procedure is repeated for two different cloud platforms.

6. The Results

According to the test procedure, the implemented IoMT system is first tested over the Arduino IoT platform. Artificially generated data representing the medical and environmental sensors is generated and sent to the cloud sequentially. The system is supplied by an uninterruptible power source to maintain continuous operation for 24 hours for 10 days. Internet connectivity is maintained through the popularly available optical service, with a maximum bit rate of about 12 Mbps. So, the system will operate under real conditions, and the recorded measurements can give a reasonable idea about its reliability.

The first measured parameter is the time delay, defined as the period between data transmission and reception time. The maximum delay is the performance-limiting parameter, so it is measured as shown in **Table 1**. Although in detailed tests the delay is measured for each received data item, in this table only the maximum delay within each test hour is recorded. This is because some sent data items are lost. It can be observed that there is no regular pattern. This is because the delay is the result of many interrelated parameters. The significant conclusion from this table is that the maximum encountered delay didn't exceed one minute, making the implemented system suitable for telemedical applications that allow a delay time not exceeding a minute.

Table 1: Maximum delay (sec) by using the Arduino IoT platform.

Hour	Test day									
	1	2	3	4	5	6	7	8	9	10
0	10.968	40.231	**46.987**	12.456	30.985	0.762	9.542	22.876	33.761	0.987
1	10.959	14.13	4.891	20.987	31.987	0.981	10.988	20.988	33.981	**39.987**
2	12.902	**43.099**	4.89	33.761	40.987	0.543	10.988	19.876	10.987	38.876
3	10.924	14.046	4.883	28.991	15.672	0.877	12.987	17.988	15.987	**35.876**
4	10.91	14.036	4.878	30.987	**41.988**	0.988	15.988	17.999	16.987	34.987
5	18.179	13.992	4.873	31.771	23.765	12.988	17.543	18.988	16.976	**33.769**
6	10.823	14.004	4.866	**33.991**	23.987	13.988	19.679	13.988	20.876	23.981
7	10.961	**43.742**	4.864	19.987	28.876	14.988	18.988	13.988	21.988	19.987
8	10.903	14.021	**58.397**	12.877	17.987	15.988	19.987	12.988	22.876	30.877
9	10.974	14.028	**58.351**	12.543	20.871	12.987	12.988	20.987	23.876	31.988
10	25.681	14.163	2.575	17.988	22.987	19.988	11.658	23.987	24.987	**31.658**
11	25.633	14.913	9.106	17.987	**42.987**	19.988	10.877	22.765	25.987	30.469
12	25.627	35.334	9.16	20.988	**43.988**	20.987	12.988	22.765	25.987	29.437
13	25.571	35.29	23.103	21.988	**42.987**	23.988	19.987	21.982	22.987	40.987
14	46.342	15.175	46.687	48.333	11.368	31.678	**49.721**	16.46	11.952	10.365
15	46.329	13.405	46.68	48.32	11.257	31.656	**49.705**	22.482	10.346	8.802
16	46.315	13.582	46.669	48.311	47.078	31.652	**49.69**	17.885	10.397	8.708
17	46.298	13.438	46.656	48.298	11.395	33.432	**49.68**	18.174	10.398	8.751
18	46.305	13.493	46.645	48.292	12.881	2.324	**50.275**	16.535	36.402	47.362
19	46.321	13.538	46.625	48.276	12.829	0.338	**50.224**	16.535	37.502	47.35
20	46.266	13.914	46.618	**48.264**	12.801	0.478	9.238	18.361	37.685	47.34
21	48.539	14.029	46.608	**49.397**	12.783	0.443	9.367	18.958	36.197	47.294
22	**50.772**	21.275	46.597	15.205	12.77	0.243	13.432	16.502	36.141	26.959
23	25.749	28.381	**38.862**	15.114	13.788	0.408	9.266	26.953	36.157	28.976

In order to take the variation in Internet quality of service during the day, the maximum and average time delay at each test hour (averaged over the 10 test days) are plotted in **Figure 2** versus test time ranging from 0 (12 AM) through 23 (11 PM). The general pattern shows increased delay during the times of intense use of the Internet around 9 AM and the evening period, but without exceeding 59 seconds for the whole test period. Also, the tests show an average delay between about 16 and 32 seconds over 24 hours.

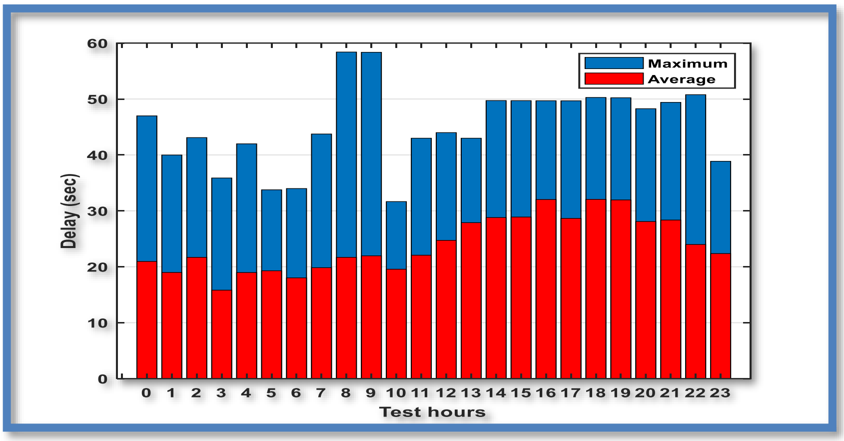

Figure 2: Delay per hour for Arduino IoT platform.

Similarly, to consider the possible daily variation in Internet service quality, the maximum and average delay within each test day, are plotted in **Figure 3**. The plot shows that the delay is not constant over different days, but instead, it is affected by the Internet service. The importance of this plot is that it gives practically encountered delay ranges, which are beneficial in evaluating and making decisions whether the implemented system is suitable for a specific telemedicine application or not.

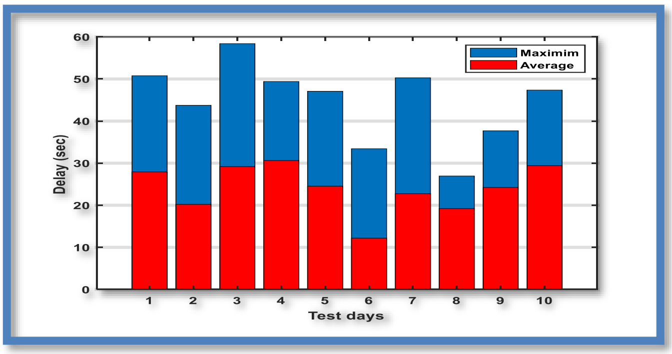

Figure 3 Delay per day for Arduino IoT platform.

Next, data loss is measured. A data item is considered to be lost if it was sent from the microcontroller and wasn't received at the platform. The percentage of the amount of lost data within each test hour is measured as shown in **Table 2**. From the first overview, it may be stated that the implemented system with the Arduino IoT platform could deliver the sensor readings with limited losses. However, odd cases of high loss percentage may practically occur, like

88.33% at hour 19/ day 7, due to unexpected interruption in Internet service, but the tests over a continuous 10 days showed that such a severe case is very rare. The data loss measurements also show the correlation with the Internet usage load. That is, relatively more data losses are expected in the morning and evening periods, which are the periods of high activity of Internet users.

Table 2: Percentage data loss for Arduino IoT platform.

Hour	Test day									
	1	2	3	4	5	6	7	8	9	10
0	0	0	**1.66**	1.66	0	0	0	0	0	0
1	0	0	0	0	**3.33**	0	0	0	0	0
2	0	0	0	1.66	0	**3.33**	0	0	0	0
3	0	0	0	0	0	0	0	0	0	5
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	**1.66**	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	**15**	0	0	0	0	0	0	0
9	8.33	0	**13.33**	0	0	0	0	0	1.66	0
10	**5**	0	3.33	0	0	0	1.66	0	0	0
11	0	**35**	1.66	0	0	0	0	0	0	0
12	0	**11.66**	0	0	3.33	0	0	0	1.66	0
13	**1.66**	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	**1.66**	0
17	0	0	0	0	0	**5.00**	0	0	0	0
18	0	0	0	0	**16.66**	1.66	0	0	5.00	6.66
19	0	0	0	0	0	0	**88.33**	0	0	0
20	0	10.00	0	0	0	0	**16.66**	0	0	0
21	6.66	0	0	**31.66**	0	5.00	0	0	0	0
22	3.33	0	3.33	**6.66**	0	0	0	0	0	0
23	0	0	0	**18.33**	1.66	0	0	3.33	0	0

In addition to the amount of data lost, it is important to take into account the time periods during which data loss fully occurs, known as the downtime, because it is one of the direct factors that determines the reliability of the system. **Table 3** shows the system reliability calculations. The uptime is the sum of the time periods during which the system is properly operational. The downtime is measured as the length of the periods during which data was being lost. Each separate downtime period is considered as a single failure, regardless of how many data items were lost within this period. For example, if the system is operating properly and suddenly a single data item (or more but continuously) is lost and then system resumed correct operation, this is considered as a single failure. On this bases, the MTBF, MTTR and hence the system availability are calculated as shown in **Table 3**. The results show that the availability ranges from 95.76% to 99.79%, with the daily average percentage data loss, calculated as the EPM, in the range from 4.44% to 0.21%. These results indicate a high level of reliability of the implemented system under realistic operation conditions.

Table 3: Reliability calculations for Arduino IoT platform.

Day	Total Up time (minutes)	Total Down time (minutes)	Number of failures	MTBF (minute)	MTTR (minute)	Availability (%)	EPM (%)
1	1425	15	5	285	3	98.96	1.04
2	1406	34	3	468.67	11.33	97.64	2.36
3	1417	23	6	236.17	3.83	98.40	1.6
4	1404	36	4	351	9	97.50	2.5
5	1425	15	4	356.25	3.75	98.96	1.04
6	1431	9	5	286.2	1.8	99.38	0.62
7	1379	61	3	459.67	20.33	95.76	4.44
8	1437	3	2	718.5	1.5	99.79	0.21
9	1434	6	4	358.5	1.5	99.58	0.42
10	1433	7	2	716.5	3.5	99.51	0.49

Moreover, in order to figure out the effect of the adopted IoT platform, the same implemented system with the same hardware and software modules has been tested over a different IoT platform, namely the well-known Blynk IoT platform. The same test procedure is applied, and the system is again tested for 24 hours for 10 days. The delay measurements are presented in **Table 4**. Fortunately, the maximum encountered delay is also less than 59 seconds, but it should be noted that on average, the system suffered from less delay time. So the implemented system over the Blynk platform seems to be relatively faster than the case of the Arduino platform. As shown in **Figure 4**, the average delay ranges from 5.5 to about 17 seconds, which is less than that in **Figure 2**. Similar comments also hold for the daily-based delay measurements shown in **Figure 5** and **Figure 3**.

Table 4: Maximum delay (sec) by using the Blynk IoT platform.

Hour	Test day									
	1	2	3	4	5	6	7	8	9	10
0	0.325	2.654	0.795	0.431	10.872	0.221	2.871	2.761	20.431	**24.651**
1	0.35	0.323	1.792	0.981	13.987	0.297	2.971	2.871	12.871	**23.541**
2	0.347	0.372	1.75	0.432	6.971	0.371	4.981	1.761	**21.981**	20.761
3	0.354	0.357	1.789	0.543	15.871	0.541	6.981	2.321	**25.981**	21.871
4	0.641	0.372	0.79	0.411	**20.761**	0.193	4.871	1.981	19.981	17.987
5	0.372	0.388	0.788	0.521	**21.876**	0.479	7.981	1.871	20.991	21.651
6	0.386	0.402	1.76	0.763	9.761	0.179	7.543	2.981	29.981	**33.549**
7	0.614	9.591	0.786	0.659	22.871	0.183	5.348	3.981	**32.853**	32.651
8	0.397	0.433	0.784	0.459	23.654	0.198	3.541	3.761	**33.871**	23.548
9	0.606	0.446	1.781	0.329	**22.951**	0.461	3.841	10.871	20.439	18.651
10	0.602	0.796	7.418	0.981	**21.295**	0.279	2.981	15.654	18.571	19.981
11	3.278	0.541	24.276	1.92	9.942	0.628	2.251	1.679	**38.622**	24.666
12	0.279	0.481	9.255	1.097	16.046	0.635	0.771	1.664	**38.614**	24.682
13	0.272	0.504	25.228	1.105	19.079	0.632	0.772	**58.773**	38.604	24.708
14	4.247	0.493	3.601	0.179	7.096	0.646	8.224	**58.783**	38.594	24.716
15	1.244	0.385	1.586	0.141	2.083	0.646	1.225	**58.814**	21.905	40.241
16	0.245	1.359	1.57	0.205	0.9399	0.683	2.212	**58.808**	25.09	41.23
17	1.231	0.358	1.55	0.174	2.318	0.693	2.209	4.355	**25.688**	24.725
18	0.931	0.34	1.532	0.199	14.698	0.69	0.805	4.345	21.566	**24.737**
19	0.926	0.32	1.513	0.203	1.678	0.447	0.815	3.342	21.574	**24.741**
20	0.92	0.3	1.496	0.219	0.668	0.47	0.823	**51.491**	21.574	24.788
21	**28.22**	0.278	1.477	0.234	0.652	0.472	0.83	26.633	21.583	24.784
22	1.771	0.259	1.456	0.248	**27.922**	0.465	0.994	2.632	21.608	24.788
23	1.763	0.24	1.441	0.264	11.056	0.534	1.005	2.603	21.61	**24.807**

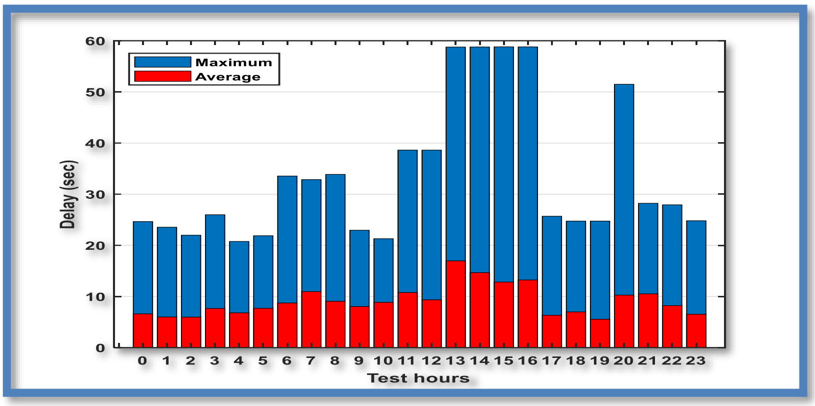

Figure 4 Delay per hour for Blynk IoT platform.

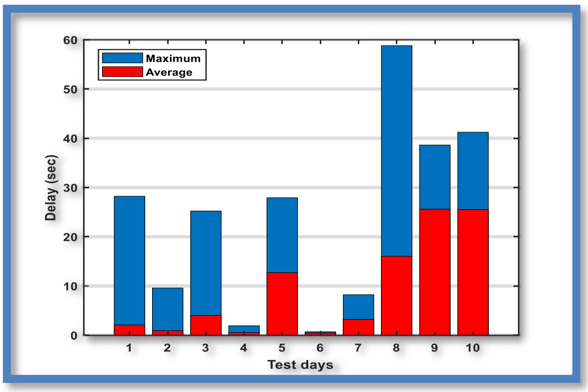

Figure 5 Delay per day for Blynk IoT platform.

Additionally, an important consideration when evaluating system latency is its comparison to commonly accepted standard latency values for various IoMT-based applications. **Table 5** outlines the key telemedicine applications and their acceptable delay thresholds. The implemented system is categorized under non-critical periodic monitoring. Based on the extensive testing, the overall average delay values not exceeding 32 and 17 seconds observed in the system fall well within the acceptable range for this class of telemedical applications.

Table 5 Latency of main telemedicine applications.

Application class	Latency requirement	Reason	Example
Critical	**Low**, typically less than 330 ms. [33],[34]	These applications require immediate feedback or action to ensure patient safety.	Remote surgery and urgent emergency response systems.
Non-Critical Monitoring	**Moderate**, typically up to several seconds. [35], [36]	These systems can tolerate delays without compromising patient safety or care.	Routine patient monitoring and wearable health devices for fitness tracking.
Long-Term Data Analysis	**High**, can tolerate delays of several minutes or even hours. [35]	These applications are typically not time-sensitive and are used for long-term health management rather than immediate interventions.	Predictive analytics and historical data review.

Next, the percentage data loss for the Blynk platform is measured as shown in **Table 6**. As compared with the case of Arduino IoT platform, the Blynk based system suffered from slightly more amounts of data loss. Although a maximum loss of 75% happened at hour 17/ day 10, it is clearly a rare situation related with a temporary degradation in Internet service. But, in total, the losses in the Blynk platform are more as compared with the case of the Arduino IoT platform. This can have a negative impact on reliability.

Table 6: Percentage data loss for Blynk IoT platform.

Hour	Test day									
	1	2	3	4	5	6	7	8	9	10
0	**3.33**	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	**5**	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	**1.66**	0	0
5	0	0	0	0	0	**1.66**	0	0	0	0
6	0	0	0	**1.66**	0	0	0	0	0	0
7	0	0	0	0	**3.33**	0	0	0	0	0
8	**15**	0	0	0	0	0	5	0	0	0
9	13.33	**41**	15	0	0	0	0	0	0	1.66
10	3.33	**45**	16.66	0	0	0	0	0	0	0
11	0	0	1.66	0	**3.33**	0	0	0	0	0
12	0	0	0	0	**6.66**	0	0	0	0	0
13	0	0	1.66	0	3.33	0	0	**20**	0	0
14	0	0	0	0	0	0	0	0	**1.66**	1.66
15	0	0.66	0	0	**13.33**	0	0	0	0	1.66
16	0	0	0	0	0	0	0	20	1.66	**26.66**
17	0	0	0	0	10.00	0	0	0	25.00	**75.00**
18	**10.00**	0	0	0	0	3.33	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	**15.00**	0	0
21	**3.33**	0	0	3.33	0	0	0	3.33	0	0
22	0	0	0	0	**1.66**	0	1.66	0	0	0
23	0	0	0	0	0	0	0	0	0	0

The reliability calculations are shown in **Table 7**. The relatively large loss peak at the tenth test day has reduced system availability to 95.56%, which is by itself can be considered as a high percentage. For the rest of the test days, the availability is higher and reaches 99.79%. However, as a way of validation for the availability results and the related reliability metrics, the EPM is calculated as the average loss per day from **Table 6**. As shown in **Table 7**, the EPM perfectly complements the availability values.

Table 7: Reliability calculations for Blynk IoT platform.

Day	Total Up time (minutes)	Total Down time (minutes)	Number of failures	MTBF (minute)	MTTR (minute)	Availability (%)	EPM (%)
1	1411	29	7	201.57	4.14	97.99	2.01
2	1388	52	4	347	13	96.39	3.61
3	1419	21	4	354.75	5.25	98.54	1.46
4	1437	3	3	479	1	99.79	0.21
5	1415	25	11	128.64	2.27	98.26	1.74
6	1437	3	2	718.5	1.5	99.79	0.21
7	1436	4	2	718	2	99.72	0.28
8	1404	36	8	175.5	4.5	97.5	2.5
9	1420	20	4	355	5	98.61	1.39
10	1376	64	5	275.2	12.8	95.56	4.44

Based on the presented results and findings, it can be stated that the implemented system can be relied on as a successful remote patient monitoring tool built by using the available Internet service and technical components in the local region of Kirkuk city. It can positively contribute to the healthcare sector as described in section 1. Finally, it worth noting that the specifications of the implemented system in terms of sensors types, accuracy, delay, loss rate, etc., may fit many telemedical applications whose requirements match these specifications. But at the same time, it may be not suitable for others. That is, the implemented IoMT system becomes not suitable for telemedical applications that are delay sensitive and do not have the suitability to withstand such values of time delay, data loss, etc.

7. Conclusions

In this paper, an IoMT system has been designed and implemented for remote patient health monitoring. The system has been tested to evaluate its reliability under practical conditions. Two different popular IoT platforms, namely the Arduino and Blynk, have been used to compare their impact on the performance of the system. The conducted tests have provided a practical experimentation results for the implemented system under realistic operation conditions and locally available facilities. Data is sent in this system with a variable time delay depending on the connection status, but it does not exceed 59 seconds in the worst circumstances. The tests show the Blynk IoT platform cause less delay as compared with the Arduino IoT platform. Also data transmission involved losses, and although rarely, high loss rates may appear. But the tests for 24 hours over 10 days have shown that the system can achieve average availability of more than 98% for both of the tested platforms. Therefore, as a conclusion, it can be stated that the tested platforms seem to be equivalently reliable, with Blynk having an advantage in terms of the delayed time.

However, the implemented system is not without limitations. On the shelf sensors were used for two reasons: first to prove the concept with a limited budget, second their accuracy is suitable for the target RPM system. Even though, the used sensors and circuitry have enabled a high reliability system.

Possible future work may be applied to test different system configurations to suit different telemedical applications, such as tele-surgery, requiring more accurate sensory, less delay and less loss rate. However, performance improvement by examining selective system customizations could be a wide field of many future works. The cost of the system may be studied and analyzed to optimize system resources according to different requirements and practical limitations. Further system performance improvement may be investigated by examining the individual and collective effects of specific factors and system components.

In summary, the implemented system has been built by using locally available resources. The tests showed it is accurate enough and reliable for RPM with limited delay and loss rate. It is customizable to suit a wide range of medical applications. Therefore, a possible collaboration with the healthcare agencies in Kirkuk city may be held in order to bring the system into actual practical operation to support and improve the healthcare system.

8. References

[1] Ree MD, Vizár D, Mantas G, Bastos J, Kassapoglou-Faist C, Rodriguez J, editors. A Key Management Framework to Secure IoMT-enabled Healthcare Systems. 2021 IEEE 26th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD); 2021 25-27 Oct. 2021.

[2] Al-Turjman F, Nawaz MH, Ulusar UD. Intelligence in the Internet of Medical Things era: A systematic review of current and future trends. Computer Communications. 2020;150:644-60.

[3] Khan MA, Din IU, Kim B-S, Almogren A. Visualization of remote patient monitoring system based on internet of medical things. Sustainability. 2023;15[10]:8120.

[4] Alkaabi A, Aljaradin M. Green Hospitals for the Future of Healthcare: A Review. Al-Kitab Journal for Pure Sciences. 2022;6[2]:31-45.

[5] Abdullah A, Ismael A, Rashid A, Abou-ElNour A, Tarique M. Real time wireless health monitoring application using mobile devices. International Journal of Computer Networks & Communications (IJCNC). 2015;7[3]:13-30.

[6] Hasan D, Ismaeel A. Designing ECG monitoring healthcare system based on internet of things blynk application. Journal of applied science and technology trends. 2020;1[2]:106-11.

[7] Chinnamadha N, Ahmed RZ, Kalegowda K. Development of health monitoring system using smart intelligent device. Indonesian Journal of Electrical Engineering and Computer Science (IJEECS). 2022;28[3]:1381-7.

[8] Turcu CE, Turcu CO. Internet of things as key enabler for sustainable healthcare delivery. Procedia-Social and Behavioral Sciences. 2013;73:251-6.

[9] Saini P, Ahuja R, Sai V. Wireless Sensor Networks and IoT Revolutionizing Healthcare: Advancements, Applications, and Future Directions. Emerging Technologies and the Application of WSN and IoT: CRC Press; 2024. p. 228-50.

[10] Malasinghe LP, Ramzan N, Dahal K. Remote patient monitoring: a comprehensive study. Journal of Ambient Intelligence and Humanized Computing. 2019;10:57-76.

[11] Vishnu S, Ramson SJ, Jegan R, editors. Internet of medical things (IoMT)-An overview. 2020 5th international conference on devices, circuits and systems (ICDCS); 2020: IEEE.

[12] Guntur SR, Gorrepati RR, Dirisala VR. Internet of Medical things: Remote healthcare and health monitoring perspective. Medical big data and internet of medical things: CRC Press; 2018. p. 271-97.

[13] Jabirullah M, Ranjan R, Baig MNA, Vishwakarma AK, editors. Development of e-health monitoring system for remote rural community of India. 2020 7th International conference on signal processing and integrated networks (SPIN); 2020: IEEE.

[14] Moore SJ, Nugent CD, Zhang S, Cleland I. IoT reliability: a review leading to 5 key research directions. CCF Transactions on Pervasive Computing and Interaction. 2020;2:147-63.

[15] Hejazi T-H, Badri H, Yang K. A Reliability-based Approach for Performance Optimization of Service Industries: An Application to Healthcare Systems. European Journal of Operational Research. 2019;273[3]:1016-25.

[16] Gawanmeh A, Al-Hamadi H, Al-Qutayri M, Shiu-Kai C, Saleem K, editors. Reliability analysis of healthcare information systems: State of the art and future directions. 2015 17th International Conference on E-health Networking, Application & Services (HealthCom); 2015 14-17 Oct. 2015.

[17] Zaitseva E, Levashenko V, Kostolny J, Kvassay M. New methods for the reliability analysis of healthcare system based on application of multi-state system. Applications of Computational Intelligence in Biomedical Technology. 2016:229-51.

[18] Ahmed I, Balestrieri E, Lamonaca F. IoMT-based biomedical measurement systems for healthcare monitoring: A review. Acta IMEKO. 2021;10[2]:174-84.

[19] Albahri OS, Albahri AS, Mohammed K, Zaidan A, Zaidan B, Hashim M, et al. Systematic review of real-time remote health monitoring system in triage and priority-based sensor technology: Taxonomy, open challenges, motivation and recommendations. Journal of medical systems. 2018;42:1-27.

[20] Chipara O, Lu C, Bailey TC, Roman G-C, editors. Reliable clinical monitoring using wireless sensor networks: experiences in a step-down hospital unit. Proceedings of the 8th ACM conference on embedded networked sensor systems; 2010.

[21] Dwivedi R, Mehrotra D, Chandra S. Potential of Internet of Medical Things (IoMT) applications in building a smart healthcare system: A systematic review. Journal of oral biology and craniofacial research. 2022;12[2]:302-18.

[22] Fernandez-Lopez H, Afonso JA, Correia JH, Simoes R. Remote patient monitoring based on zigbee: Lessons from a real-world deployment. Telemedicine and e-Health. 2014;20[1]:47-54.

[23] Charness N, Fox M, Papadopoulos A, Crump C. Metrics for assessing the reliability of a telemedicine remote monitoring system. Telemedicine and e-Health. 2013;19[6]:487-92.

[24] Qin R, Dzombak R, Amin R, Mehta K. Reliability of a telemedicine system designed for rural Kenya. Journal of primary care & community health. 2013;4[3]:177-81.

[25] Gunawan I, B. A. C P, Suhartini, Sudianto A, Sadali M, Faturrahman I, et al., editors. Prototype Health Monitoring For Quarantined Covid 19 Patients Based On The Internet Of Things (IoT). 2022 International Conference on Science and Technology (ICOSTECH); 2022 3-4 Feb. 2022.

[26] Tsvetanov F, Pandurski M. Delay of Transmitted Data in the Remote Patient Monitoring System through AMQP and CoAP. International Journal of Online & Biomedical Engineering. 2024;20[7].

[27] Yew HT, Ng MF, Ping SZ, Chung SK, Chekima A, Dargham JA, editors. Iot based real-time remote patient monitoring system. 2020 16th IEEE international colloquium on signal processing & its applications (CSPA); 2020: IEEE.

[28] Zikria YB, Afzal MK, Kim SW. Internet of multimedia things (IoMT): Opportunities, challenges and solutions. Sensors. 2020;20[8]:2334.

[29] Miracle NO. The role of network monitoring and analysis in ensuring optimal network performance. International Research Journal of Modernization in Engineering Technology and Science https://doi org/1056726/irjmets59269. 2024.

[30] Thawkar DR. Down Time Analysis In Process Industry-A Case Study. Weekly Science Research Journal. 2013;1[24]:1-10.

[31] Aguilar A, editor Lowering Mean Time to Recovery (MTTR) in Responding to System Downtime or Outages: An Application of Lean Six Sigma Methodology. 13th Annual International Conference on Industrial Engineering and Operations Management; 2023.

[32] Todmal YS, Shinde P, Sisodia V, editors. Analysis of breakdowns and implementing optimal maintenance of engine cylinder block machines for improving operational availability. Proceedings of the International Conference on Industrial Engineering and Operations Management Presented at the 2nd Indian International Conference on Industrial Engineering and Operations Management, Warangal, India; 2022.

[33] Bailo P, Gibelli F, Blandino A, Piccinini A, Ricci G, Sirignano A, et al. Telemedicine applications in the Era of COVID-19: telesurgery issues. International Journal of Environmental Research and Public Health. 2021;19[1]:323.

[34] Xu S, Perez M, Yang K, Perrenot C, Felblinger J, Hubert J. Determination of the latency effects on surgical performance and the acceptable latency levels in telesurgery using the dV-Trainer® simulator. Surgical endoscopy. 2014; 28:2569-76.

[35] Alam MM, Ben Hamida E. Surveying wearable human assistive technology for life and safety critical applications: Standards, challenges and opportunities. Sensors. 2014; 14[5]:9153-209.

[36] Fadhel AA, Hasan HM. Reducing Delay and Packets Loss in IoT-Cloud Based ECG Monitoring by Gaussian Modeling. International Journal of Online & Biomedical Engineering. 2023;19[6].