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Artificial Intelligence of Things (AIoT) for Cardiac Healthcare: A Real-Time Monitoring Solution

Sanam Nayab[1*], Sadia Zahra[1], and Hina Mahjabeen[1]

[1]Department of Computing, National University of Modern Languages (NUML), Islamabad, Pakistan.
[*]Corresponding Author: Sanam Nayab. Email: sanam.nayab@numl.edu.pk

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Abstract: Cardiovascular diseases are one of the most common causes of death worldwide, and it often occurs very suddenly without any chance for medical intervention. These kind of scenarios can be mitigated by proactive monitoring. The current cardiac monitoring solutions for Cardiac IoT groups are typically limited to a set of parameters to be tracked, which fails in integrating AI and often requires physical presence during health data tracking while most patients prefer being checked from their homes so that they can avoid the hospital environment especially during global pandemics like COVID-19. Currently, in Pakistan there is no AIoT (Artificial Intelligence of Things) integrated system for a real time cardiac monitoring. This study introduce AIoT-enabled Cardiac Healthcare Monitoring System, intended for real-time monitoring remotely of vital cardiac parameters. It uses Heart Rate (HR), Oxygen Saturation (SpO_2), Body Temperature and Blood Pressure as key parameters along with presence of a Electrocardiogram signal to provide intelligent monitoring and predictive capabilities. Furthermore, the system generates alerts for anomalous readings and sends data on a cloud server so doctors can access patient history anywhere in the world – ensuring timely medical intervention and cost-effectively enabling healthcare delivery to vulnerable populations far from urban hospitals.

Keywords: Artificial Intelligence; Internet of Things (IoT); Cardiac; Healthcare.

1. Introduction

Cardiovascular diseases (CVDs) are a broad category of heart and blood vessel conditions that constitute the primary cause of death globally. The World Health Organization (WHO) projected that 17.9 million fatalities worldwide were expected to be caused by cardiovascular illnesses in 2021 [1]. Arrhythmia is primarily responsible for erratic heartbeats and cardiac arrest [2]. Bradycardia, tachycardia, and premature heartbeat are three specific subtypes of this illness, each with a unique etiology. According to the WHO's most recent statistics, arrhythmia accounts for at least 15% of instances when the major cause of death is identified. Cardiovascular illnesses are to blame for almost 80% of all unexpected deaths [3]. Atrial fibrillation is a disorder that may result in a stroke. Cardiac arrest is generally caused by blood vessel congestion, while ventricular tachycardia is predominantly accountable for the termination of usual cardiac activity and the subsequent rapid death. Heart patients need to be regularly looked after to ensure prompt medical attention in the event of an emergency. The existing methods of cardiac monitoring have many shortcomings. These include dis-integrated sensors, long wait times, expensive costs, and the challenges faced by elderly people who have to travel far to access medical services [4] [5]. The use of IoT technology in healthcare is one promising solution to these issues. The potential for the Internet of Things (IoT) to revolutionize cardiac care is that it can provide low- cost, round-the-clock patient monitoring. Recently, there has been a lot of buzz in the cardiac healthcare industry about AIoT-based systems. AIoT allows for the monitoring, analysis, processing, and control of vital signs such as temperature, blood pressure, oxygen saturation (SpO2), heart rate, and electrocardiogram (ECG) [6]. By using an AIoT-based cardiac healthcare monitoring system, it is feasible to enhance the delivery of cardiovascular care. Cardiac patients may see improvements in areas such as long wait times, expensive medications, and the need for rapid treatment during crises as a result of the expansion of AIoT applications in healthcare. Intelligent and integrated cardiac healthcare monitoring systems are desirable, but can be difficult to implement in countries with inadequate infrastructure and resources, such as Pakistan [7] [8]. The lack of a comprehensive system that considers all of the essential and crucial cardiac metrics is a result of the limited scope of earlier research [15] [16] [17]. Additionally, the current study does not have a mechanism to continually monitor patients in real-time and notify family members of any abnormal patient conditions [20] [46] [18].

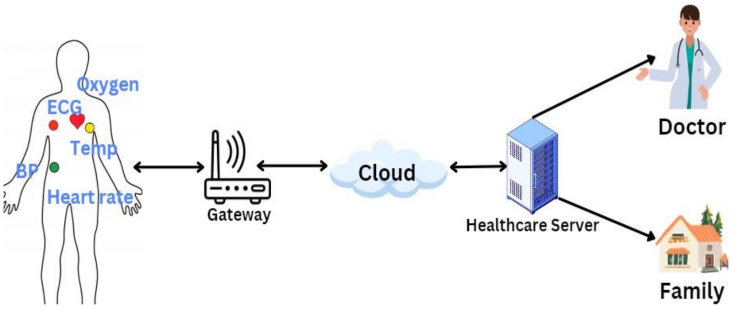

Figure 1. IoT-based Healthcare Architecture

In this paper, our objective is to propose a research idea based on AIoT aided cardiac healthcare monitoring system that must consist of the following:

- A single and integrated solution kit based on the IoT kit for cardiac healthcare monitoring.
- An integrated solution for cardiac patients with the combination of all the necessary vital cardiac parameters (HR, BP, Temperature, SpO2, ECG).
- An intelligent and integrated solution based on AI techniques for efficient monitoring and prediction of cardiovascular ailments.
- A cloud-based remote solution for continuous faraway patient monitoring with an added functionality of alarm generation or warnings if a patient's condition is found abnormal.
- The proposition of an all-in-one solution for heart patients in Pakistan has not been proposed before.

Section II elaborates on the literature review from 2016 to 2023. The suggested system as a proposed solution for the implementation of an AIoT-based cardiac system is discussed in Section III. The conclusion is mentioned in Section IV.

2. Literature Review

Our research on AIoT-based cardiac healthcare monitoring has been extensively studied from 2016 to 2023. Studies have been organized into three main categories: dis-integrated sensors, integrated sensor solutions, and AI-based approaches. Each approach has focused on distinct cardiac metrics. Following this literature survey is the critical review that follows:

2.1. Dis-integrated Cardiac Systems using IoT

The research study of 2016 suggested an IoT system for round-the-clock patient monitoring. Dis-integrated sensors, such as the MCP9700 heart rate and temperature sensor used to collect patient sensory data [7].

The research proposed in 2017 [9] was consisted of an IoT kit with a dependable alarm system for cardiac patients. The KY-039 heartbeat monitoring sensor and the 18DS20 body temperature sensor are two dis-integrated sensors that are used in this IoT kit. The Liquid Crystal Display (LCD) panel shows the data from the human body to a setup that contains a micro controller. This system's three-tier Wireless Body Sensor Network (WBSN) design was used to monitor cardiac patients' vitals in 2018 [10].

In the first level, data is composed of the patient's distributed sensors (heart rate, MAX30100, and temperature) using an Arduino Nano board. The sensor information is directed to a Tier 2 server using the Hyper Text Transfer Protocol (HTTP) protocol and a Wi-Fi ESP8266 module. Tier 2 also processes, stores, and interfaces with sensory data. The third tier of notifications is where medical crises are notified. This research published in 2019 [11] developed an IoT kit to detect heart strokes employing heart rate sensors. A temperature sensor (18DS20) and a distributed heart rate sensor collect data from the patient's body and feed it into the system. The Light Emitting Diode (LED) is used to perceive the patient's pulse rate when they place their finger on a pulse rate sensor. In the study 2020 [12], a method for detecting heart attacks was developed using sensory modules. Distributed sensors, such as temperature and blood pressure monitors, are used to build an Internet of Things (IoT) kit. Another study presented in 2020 [13] proposes a dis-integrated IoT kit for health monitoring. The AD8232 electrocardiogram module, temperature sensors from the LM35 series, pressure sensors from the MPX10 series, and a pulse sensor are all part of the recommended Internet of Things (IoT) package. According to research published in 2021 [14], some of the most crucial physical metrics' to track with distributed sensors are body temperature, BP, pulse rate, glucose level, and oxygen values. The goal of this study [48] is to enhance the quality of life of patients by using physiological parameter measures, such as body temperature and systolic and diastolic blood pressure, to provide real-time insight into their condition in 2021.

The basic idea is to keep an eye on patients' vital signs—blood pressure, heart rate, and body temperature—without making them move between institutions, ensuring that their health is always being observed. The data acquired by the temperature and blood pressure sensors is analyzed and then stored in the cloud so that the patient's caretakers may see it from any location and respond appropriately in the event of an alert. The research [55] suggested a dispersed Medical IoT kit equipped with all the necessary cardiac metrics. To minimize the frequency of catastrophic incidents, the system likewise comprises a mobile app for remote patient monitoring and an alarm notification that allows qualified medical professionals to intervene promptly without implementing any AI algorithm.

2.2. Integrated Cardiac Systems using IoT

In this study of 2016 [15] wearable combined band and Android phone app established the backbone of the IoT setup for heart patients. The patient's vitals are tracked using a band that resembles a wristwatch and records cardiac, pulmonary, and blood pressure readings. Once the human body supplies input values, the information is sent to a mobile via Wireless LAN (WLAN) or Bluetooth protocol. The objective of the research in 2018 [10] is to develop and organize a fitness- checking system for patients with cardiac problems. This system will make use of the MAX30100 integrated sensor to record vital signs, especially those associated with heart problems, such as heart rate and oxygen saturation. The goal of the study presented in 2018 [29] is to develop an IoT system that can foresee individual cardiac arrests, which is different from current eHealth-based IoT systems since it integrates its sensing and communication components inherently. Using GPS-guided navigation, the research in 2019 [33] created a smart handset app to assist heart patient in exercising securely and joyfully on scenic directions or ways in their area. They examined the effectiveness of the mobile app on 14 heart patients throughout a four-week field study. As per study, cardiac patients may reach the recommended weekly physical activity level, like cycling with the application, and are more likely to embark on longer motorbike outings.

2.3. AI/ML-based Cardiac Systems

The research study of 2016 [19] proposed a smooth IoT system to forecast cardiac ailment using a decision tree. While the research publication presented in 2019 established an IoT-based healthcare system using Neural Networks [34]. On the other hand, the research publications of 2019 [35] [36], and 2020 [37] [39] presented an IoT-based solution for cardiac patients using various ML techniques such as Pan Tompkins QRS detection, CNN, and SVM. Another research of 2020 [5] used the KNN algorithm for the classification of arrhythmia. The other article of 2020 [42] and the further studies of 2021 [46] [47] use AI techniques such as Deep Neural Networks, Long Short-Term Memory (LSTM), and Deep Belief Networks (DBN). The research published in 2022 [54] also used an AI technique Bi-LSTM (bidirectional long short-term memory for IoT-aided cardiac patient observation.

2.4. Critical Analysis

In 2016, only one system was determined to function as an integrated system; however, that research only dealt with two cardiac parameters (HR, BP). Similarly, only one research has worked on cardiac arrest using the ML technique in 2016. There is also a lack of research from 2017 and 2018 that utilizes AI or ML to address all five cardiac metrics. Except for two studies, all of the researchers who conducted their analyses in 2017 and 2018 used Dis-integrated IoT kits to monitor cardiac patients. Moreover, integrated kits were the focus of these two researches [10] [29]. Three researchers have used AI or ML approaches, such as CNN, PT-QRS, to apply cardiac solutions for patients with heart problems in 2019. However, 2019 has not produced a single research that covers every critical aspect of a cardiac patient's condition. However, in 2019, just one publication suggested an integrated solution. In 2020, four research were discovered that used AI or ML algorithms, such as TSVM, SVM, KNN, DHCAF, and MCHCNN, to construct an IoT-based cardiac solution. However, these studies did not address all the critical factors of cardiac patients with an integrated solution. Only one study focused on five essential cardiac parameters in 2020, and it did not provide a comprehensive solution using an AIoT algorithm. Two researches from 2021 used AI approaches, such as DNN and LTSM-DBN, for the monitoring and analysis of cardiac parameters; however, these investigations were dispersed and did not cover all cardio indications. One project was put into practice in 2022 to use AI to help cardiac patients. In 2022, there were only a few cardiac implementations that addressed a portion of heart patients' vital signs. There is only be one research conducted in 2023 that uses AI algorithms like Bi-LTSM to monitor cardiac patients' health via the Internet of Things. Every research found in 2023 focused on dispersed kit development. One study examines the five cardiac parameters of heart patients, however it does not provide an AIoT-based solution. Only 2 Pakistani studies provide IoT-based heart patient solutions. However, they do not cover all cardiovascular parametric values with AI aspect. In short, currently no AIoT-based solution for cardiac patients is present in Pakistan that can handle all of the critical parameters and provide an integrated solution.

Table 1. Summary of Research Studies

Year	Metrics	Name of Cardiac Metrics	Solution Type	Use of AI/ML	Nation
2016 [7]	Two	Temp, PR	Dis-integrated	No	UAE
2016 [15]	Two	HR, BP	Integrated	No	India
2016 [16]	Only one	PR	Dis-integrated	No	India
2016 [19]	Only one	ECG	Dis-integrated	DT	Greece
2017 [8]	Four	ECG, BP, PR, SpO2	Dis-integrated	No	China
2017 [20]	Only one	PR	Dis-integrated	No	India
2017 [9]	Two	PR, Temp	Dis-integrated	No	India
2017 [21]	Two	BP, PR	Dis-integrated	No	India
2017 [22]	Four	ECG, BP, Temp, HR	Dis-integrated	No	India
2017 [23]	Only one	ECG	Dis-integrated	No	USA
2018 [10]	Two	SpO2, HR	Integrated	No	India
2018 [24]	Only one	PR	Dis-integrated	No	India
2018 [25]	Only one	PR	Dis-integrated	No	India
2018 [26]	Two	ECG, PR	Dis-integrated	No	India
2018 [27]	Three	ECG, PR, SpO2	Dis-integrated	No	India
2018 [28]	Three	Temp, BP, HR	Dis-integrated	No	India
2018 [29]	Three	ECG, BP, SpO2	Integrated	No	USA
2019 [11]	Two	Temp, HR	Dis-integrated	No	India
2019 [19]	Three	ECG, Temp, PR	Dis-integrated	No	USA
2019 [30]	Two	Temp, HR	Dis-integrated	No	India
2019 [31]	Only one	ECG	Dis-integrated	No	India
2019 [32]	Two	ECG, PR	Dis-integrated	No	USA
2019 [33]	Two	BP, HR	Integrated	No	India
2019 [34]	Three	ECG, BP, HR	Dis-integrated	NN	Bangla desh
2019 [35]	Only one	ECG	Dis-integrated	PTQRS	India
2019 [36]	Only one	ECG	Dis-integrated	CNN	Taiwan
2020 [37]	Only one	ECG	Dis-integrated	TSVM	India
2020 [12]	Three	Temp, BP, HR	Dis-integrated	No	India
2020 [38]	Only one	HR	Dis-integrated	No	India
2020 [13]	Five	ECG, Temp, BP, PR, SpO2	Dis-integrated	No	India
2020 [39]	Only one	ECG	Dis-integrated	No	India

2020 [40]	Two	ECG, HR	Dis-integrated	SVM	Malaysia
2020 [41]	Two	ECG, Temp	Dis-integrated	No	Romania
2020 [42]	Only one	ECG	Dis-integrated	DHCAF, MCHCNN	Australia
2020 [4]	Only one	ECG	Dis-integrated	No	Netherlands
2020 [5]	Two	ECG, HR	Dis-integrated	KNN	Iran
2021 [43]	Two	BP, Heart Rate	Dis-integrated	No	Iran
2021 [44]	Only eone	ECG	Dis-integrated	No	India
2021 [45]	Only one	ECG	Dis-integrated	No	Taiwan
2021 [46]	Only one	ECG	Dis-integrated	DNN	China
2021 [47]	Three	ECG, PR, SpO2	Dis-integrated	LTSM-DBN	Iran
2021 [48]	Only one	ECG	Dis-integrated	No	India
2022 [49]	Three	SPO2, Temp, PR	Dis-integrated	No	India
2022 [50]	Three	BP, HR, ECG	Dis-integrated	Bi-LTSM	India
2022 [51]	Only one	ECG	Dis-integrated	No	Italy
2023 [52]	Four	HR, ECG, BP, Temp	Dis-integrated	CNN	Pakistan
2023 [53]	Four	ECG, BP, HR SpO2	Dis-integrated	LTSM, RNN	India
2023 [54]	Two	HR, SpO2	Dis-integrated	No	Korea
2023 [55]	Five	ECG, BP, HR, SpO2, Temp	Dis-integrated	No	Pakistan

HR- Heart Rate, PR- Pulse Rate, Temp- Body Temperature, DT- Decision Tree, NN- Neural Network, PTQRS-Pan Tompkins QRS, CNN- Convolutional Neural Network, TSVM- Tuned Twin Support Vector machines, DHCAF- Dynamic Heartbeat Classification with Adjusted Features, MCHCNN Multi-channel Heartbeat Convolution Neural Network, KNN- k-Nearest Neighbor, DNN- Deep Neural Network, LSTM- Long Short-Term Memory, DBN- Deep Belief Network, RNN- Recurrent Neural Network

3. Proposed System

Drawn The primary objectives of the Artificial Intelligence of Things-based cardiac care unit planned in this study are the examination of real-time ECG data and the monitoring of all the factors essential for a cardiac care system by using intelligent techniques. Among these include BP, oxygen saturation level, body temperature, heartbeat, and ECG exploration. The AIoT device addresses the greatest number of cardiac factors and may be likened to a tiny cardiac critical care unit (CCU) with universal access. Based on these factors, this research would significantly aid in lowering the risks of arrhythmias, myocardial infarction, and cardiovascular disorders. The proposed idea for this research is composed of seven modules that are illustrated in Figures 2 and 3. Our suggested modules are discussed below:

3.1. Sensory Module

The hardware sensors make up the sensory module for our system. The temperature monitoring sensor, BP sensor, heart rate sensor, SPO2 sensor, and removable ECG examination device are some of these sensors. The sensors must be integrated into a single component or device. A unique communication interface is used to connect each sensing device to the microcontroller.

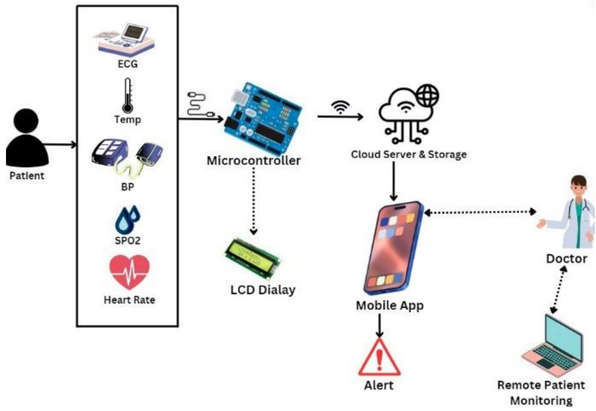

Figure 2. Proposed System Module

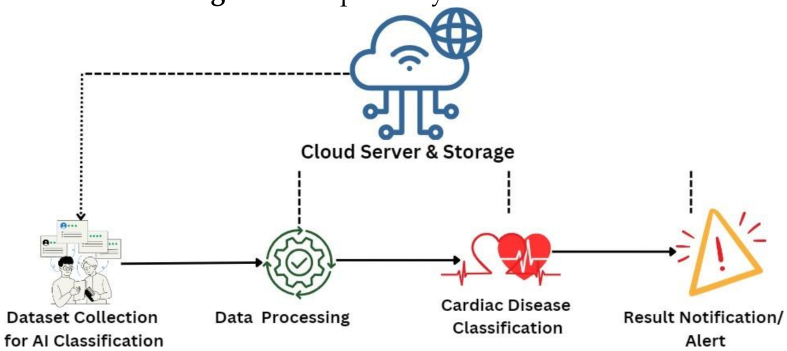

Figure 3. AI Module

3.2. Controller Module

This module has a microcontroller that controls peripherals and processes data. The microcontroller may communicate sensory data via Bluetooth, WiFi, or Zigbee protocols. Common controllers include Arduino and Raspberry Node MCU.

3.3. Display Module

After essential processing data is transferred to the screen to display the sensor values getting from the human body. The display module can be an LCD or monitor screen.

3.4. Cloud Server and Storage Module

This module allows the system to upload patient health reports or parametric data to a cloud server. The data can be stored to the cloud. Doctors and family members can access patient histories on the cloud.

3.5. Mobile Application Module

The mobile app module lets doctors and family members remotely monitor cardiac patients. Any crucial statistic may trigger an alert or notice. Using the mobile app, the doctor can review patient history at any time.

3.6. AI Algorithmic Module

Five cardiac parameters are under consideration. An AI method is needed to predict the most common heart problems. This AI approach requires ECG analysis and hybrid CCU parameter integration. Therefore, by using the other crucial metrics, this unique combination will allow for the prediction of various types of arrhythmias and the maximum number of cardiovascular illnesses (CVD). The categorization using AI will be carried out on a cloud server. It would be more difficult to classify different cardiovascular diseases (CVD) and arrhythmias using many IoT-based data and ECG analyses. We now suggest an intelligent deep learning (DL) approach for this all-inclusive programmed cardiac investigative analyzer. Several deep-learning models have been published for arrhythmia identification and ECG interpretation. These days, a broad variety of medical industries apply deep learning techniques to handle numerous critical challenges. Furthermore, the machine learning paradigm's success in ECG classification is heavily reliant on QRS detectors. Due to its methodology, the DNN paradigm is best for this diagnostic engine. Because of its accuracy and performance, the deep learning-based programmed diagnostic system is more effective.

3.7. Alarm Generation Module

The alarm module alerts when crises or the CCU variables exceed or fall below a threshold. After that, an instant decision needs to be made

4. Conclusion and Future Work

This study proposes an AIoT-based system for monitoring, detecting, and analyzing cardiac disorders using intelligent approaches. The maximum number of CCU parameters should be used in combination with integrated technology and ECG analysis. Patients in areas without access to medical facilities, cardiologists, and hospitals might all benefit from its remote monitoring system. Patients in areas without access to medical facilities, cardiologists, and hospitals might all benefit from its remote monitoring system. The purpose of uploading data to a cloud server is to make it globally accessible. Additionally, using the proper AI approach, cloud-based categorization and prediction of the maximum number of cardiovascular ailments will be carried out. This AIoT-based classification helps Cardiologists focus more of their time on treating patients rather than diagnosing them. This system's capabilities are increased by smart warning or alert features. Rapid, lifesaving reactions to a patient's critical situation concerns can made possible by this alert system.

5. **Abbreviations**

Table 2. Abbreviations

Full Name	Abbreviation
Artificial Neural Network	ANN
Long Short-Term Memory	LSTM
Amreli Steel Limited	ASTL
Meezan Bank Limited	MEZL
United Bank Limited	UBL
Oil & Gas Development Company	OGDC
Open High Low Close	OHLC
Support Vector Machine	SVM
Convolutional Neural Network	CNN
Principal Component Analysis	PCA
K-Nearest Neighbors	KNN
Pakistan Stock Exchange	PSX
Autoregressive Integrated Moving Average	ARIMA
Gross Domestic Product	GDP
Recurrent Neural Network	RNN
Multi-layer Perceptron	MLP
Root Mean Square Error	RMSE
Mean Absolute Percentage Error	MAPE
Mean Bias Error	MBE
Standard & Poor's 500 Index	SP500
National Stock Exchange (of India)	NSE
One-Against-One	OAO
One-Against-All	OAA
Discounted Cumulative Gain	DCG
Journal of Econometric and Statistics	JEKS

References

1. M. Creager and S. Henkin, eds., Vascular Medicine, An Issue of Cardiology Clinics, E-Book, vol. 39, no. 4. Elsevier Health Sciences, 2021.
2. Y.-J. Lin, C.-W. Chuang, C.-Y. Yen, and S.-H. Huang, "Artificial intelligence of things wearable system for cardiac disease detection," in 2019 IEEE International Conference on Artificial Intelligence Circuits and Systems (AICAS), pp. 67–70. IEEE.
3. WHO,"The top 10 causes of death," 2024. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of- death.
4. J. Moreira, L. F. Pires, M. van Sinderen, L. Daniele, and M. Girod-Genet, SAREF4health: Towards IoT standard-based ontology-driven cardiac e- health systems, Applied Ontology, vol. 15, no. 3, pp. 385–410, 2020.
5. E. Moghadas, J. Rezazadeh and R. Farahbakhsh, "An iot patient mon- itoring based on fog computing and data mining: Cardiac arrhythmia usecase.
6. Malche, T., Tharewal, S., Tiwari, P. K., Jabarulla, M. Y., Alnuaim, A. A., Hatamleh, W. A., Ullah, M. A. (2022). Research Article Artificial Intelligence of Things-(AIoT-) Based Patient Activity Tracking System for Remote Patient Monitoring.
7. K. Aziz, S. Tarapiah, S. H. Ismail, and S. Atalla, "Smart real-time health- care monitoring and tracking system using GSM/GPS technologies," in 2016 3rd MEC International Conference on Big Data and Smart City (ICBDSC), pp. 1–7. IEEE.
8. C. Li, X. Hu, and L. Zhang, The IoT-based heart disease monitoring system for pervasive healthcare service, Procedia Computer Science, vol. 112, pp. 2328–2334, 2017.
9. A. R. Rao, H. Ajay, M. Balavanan, R. Lalit, and J. Anand, A novel cardiac arrest alerting system using IoT, International Journal of Science Technology Engineering, vol. 3, no. 10, pp. 78–83, 2017.
10. U. Gogate and J. Bakal, Healthcare monitoring system based on wireless sensor network for cardiac patients, Biomedical Pharmacology Journal, vol. 11, no. 3, p. 1681, 2018.
11. M. N. H. M. S. E1, "A study on heart attack detection by heartbeat monitoring using iot," 2019.
12. S. Lokesh, S. P. Nandhakumar, and R. Ranjith, Remote health and monitoring, heart attack detection and location tracking system with IoT, Hindusthan J. Inf. Commun. Mod. Comput., vol. 1, pp. 1–5, 2020.
13. R. R. S. Lokesh, "Remote health and monitoring, heart attack detection and location tracking system with iot,"," Hindusthan Journal of Infor- mation Communication and Modern Computing, Vols. 1, no.1, 2020.
14. M. P. Savaridass, N. Ikram, R. Deepika, and R. A. Savaridass, Devel- opment of smart health monitoring system using Internet of Things, Materials Today: Proceedings, vol. 45, no. 1, pp. 986–989, 2021.
15. K. N. V. S. a. P. R. M. Manisha, "Iot on heart attack detection and heart rate monitoring," International Journal of Innovation in Engineering and Technology (IJIET), 2016.
16. H. Ajay, A. Rao, M. Balavanan and R. Lalit, " A novel cardiac arrest alerting system using iot," p. 78–83, 2017.
17. Umar, U., Khan, M. A., Irfan, R., Ahmad, J. (2021, July). IoT- based cardiac healthcare system for ubiquitous healthcare service. In 2021 International Congress of Advanced Technology and Engineering (ICOTEN) (pp. 1-6). IEEE.
18. Umar, U., Nayab, S., Irfan, R., Khan, M. A., Umer, A. (2022). E- Cardiac care: A comprehensive systematic literature review. Sensors, 22(20), 8073.
19. Y. A. E. R. Y. a. D. R. U. A. Majumder, "Advances in Human-Computer Interaction," An energy efficient wearable smart iot system to predict cardiac arrest, vol. 2019, 2019
20. A. Sidheeque, A. Kumar, R. Balamurugan, K. Deepak and K. Sathish,"Heartbeat sensing and heart attack detection using internet of things: Iot.," p. 6662–6666, 2017.
21. M. Manimaraboopathy, S. Vijayalakshmi, D. Hemavathy, and A. Priya, A wearable multiparameter medical monitoring and alert system with first aid, International Journal on Smart Sensing and Intelligent Systems, 2017.
22. M. Mathivanan, M. Balamurugan, Nandini and M. Reddy," Iot based- continuous monitoring of cardiac patients using raspberry pi.," AIP Conf. Proc., 2018.
23. M. Yasin, T. Tekeste, H. Saleh, B. Mohammad, O. Sinanoglu and M. Ismail,"Ultra-low power, secure iot platform for predicting cardiovas- cular diseases.," IEEE Trans. Circuits Syst. Regul. Pap., p. 2624 2637, 2017.
24. V. Hemalatha, K. Poykasi, P. Sangeetha and P. Gomathi, "Detection of cardiac arrest using internet of things.," Int. J. Sci. Res. Comput. Sci.,p. 793–801, 2018.

25. N. Patel, P. Patel and N. Patel, ”Heart attack detection and heart rate monitoring using iot.,” Int. J. Innov. Adv. Comput. Sci. (IJIACS) , p. 611–615, 2018.
26. M. Mathivanan, M. Balamurugan, Nandini and M. Reddy, ” Iot based- continuous monitoring of cardiac patients using raspberry pi.,” AIP Conf. Proc., 2018.
27. U. Gogate and J. Bakal, ”Healthcare monitoring system based on wireless sensor network for cardiac patients.,” Biomed. Pharmacol, 2018.
28. A. Gurjar and N. Sarnaik, ”Heart attack detection by heartbeat sensing using Internet of Things: IoT.,” Int. Res. J. Eng. Technol. 2018, p. 3332–3335, 2018.
29. A. Majumder, Y. ElSaadany, R. Young and D. Ucci, ”An energy efficient wearable smart iot system to predict cardiac arrest.,” Adv.-Hum. Interact., 2019.
30. A. Vaishnave, S. Jenisha and S. Tamil Selvi, ”IoT Based Heart Attack Detection, Heart Rate and Temperature Monitor. I,” nt. Res. J. Multi- discip. Technovat., pp. 61-70, 2019.
31. A. Sharma and L. Saini, ”Iot based diagnosing myocardial infarction through firebase web application.,” In Proceedings of the 2019 3rd International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India, pp. 12-14, 2019.
32. A. Majumder, M. Elsaadany, J. Izaguirre and D. Ucci, ”A realtime car- diac monitoring using a multisensory smart iot system.,” In Proceedings of the 2019 IEEE 43rd Annual Computer Software and Applications Conference (COMPSAC), Milwaukee, WI, USA,, pp. 15-19.
33. D. H. P. D. a. K. C. E. Geurts, ”Impact of a mobile cycling application on cardiac patients’ cycling behavior and enjoyment,” In Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference, p. 257–26, 2018
34. S. Tabassum, M. Zaman, M. Ullah, A. Rahaman, S. Nahar and A. Islam, ”The cardiac disease predictor: Iot and ml driven healthcare system,” In Proceedings of the 2019 4th International Conference on Electrical Information and Communication Technology, 2019.
35. R. Devi and V. Kalaivani, ”Machine learning and iot-based cardiac arrhythmia diagnosis using statistical and dynamic features of ecg.,”J. Supercomput, p. 6533–6544, 2020.
36. Y.-J. Lin, C.-W. Chuang, C.-Y. Yen, S.-H. Huang, P.-W. Huang, J.Y. Chen and S.-Y. Lee, ” Artificial intelligence of things wearable system for cardiac disease detection.,” In Proceedings of the 2019 IEEE International Conference on Artificial Intelligence, 2019.
37. S. Raj, ” An efficient iot-based platform for remote real-time cardiac activity monitoring.,” IEEE Trans. Consum. Electron., p. 106–114, 2020.
38. K. Kumari and G. Sarma, ” Iot Based Heart Attack and Alcohol Detection in Smart Transportation and Accident Prevention for Vehicle Drivers.,” Int. J. Recent Dev. Sci. Technol. , p. 179–185, 2020.
39. E. Prabhakararao and S. Dandapat, ”Automated detection of posterior myocardial infarction from vcg signals using stationary wavelet trans- form based features.,” IEEE Sens. Lett., p. 1–4, 2020.
40. H.] Yew, M. Ng, S. Ping, S. Chung, A. Chekima and J. Dargham, ” Iot based real-time remote patient monitoring system.,” In Proceedings of the 2020 16th IEEE International Colloquium on Signal Processing Its Applications (CSPA).
41. I. Zagan, V. Gaitan, A.-I. Petrariu, N. Iuga and A. Brezulianu, ”Design, fabrication, and testing of an iot healthcare cardiac monitoring device.,” Computers, 2020.
42. J. He, J. Rong, L. Sun, H. Wang, Y. Zhang and J. Ma, ”A framework for cardiac arrhythmia detection from iot-based ecgs.,” World Wide Web, vol. 23, p. 2835–2850, 2020.
43. F. Akhoondan, H. Hamidi and A. J. Broumandnia, ” Monitoring patients to prevent myocardial infarction using internet of things technology,” p. 52–59, 2021.
44. S. Selvaraj, P. Ramya, R. Priya and C. Ramya, ”Filtering the ecg signal towards heart attack detection using motion artifact removal technique.,” In Proceedings of the Third International Conference on Intelligent Communication Technologies and Virtual, 2021.
45. W.-L. Chen, Y.-B. Lin, T.-Y. Chang and Y.-R. Lin,”Ambtalk: A cardiovascular iot device for ambulance applications,” Sensors, 2021.
46. Z. Fu, S. Hong, R. Zhang and S. Du,”Artificial-intelligence-enhanced mobile system for cardiovascular health management,” Sensors, p. 773, 2021.
47. S. Dami and M. Yahaghizadeh,”Predicting cardiovascular events with deep learning approach in the context of the internet of things.,” Neural Comput Appl., p. 7979–7996, 2021.

48. P. Kora, A. Rajani, M. Chinnaiah, K. Swaraja and K. I. Meenakshi, ”iot based wearable monitoring structure for detecting abnormal heart,” In Proceedings of the International Conference on Sustainable Energy and Future Electric Transportation (SEFET, 2021.
49. Sharma, A. K., & Mandot, M. (2021). Diagnosis of the Feature Extraction For Brain Tumor In Matlab. Turkish Online Journal of Qualitative Inquiry, 12(7).
50. Saravanan, S., Kalaiyarasi, M., Karunanithi, K., Karthi, S., Pragaspathy, S., Kadali, K. S. (2022). IoT based healthcare system for patient monitoring. In IoT and Analytics for Sensor Networks: Proceedings of ICWSNUCA 2021 (pp. 445-453). Springer Singapore.
51. Nancy, A. A., Ravindran, D., Raj Vincent, P. D., Srinivasan, K., Gutierrez Reina, D. (2022). Iot-cloud-based smart healthcare monitoring system for heart disease prediction via deep learning. Electronics, 11(15), 2292.
52. Morello, R., Ruffa, F., Jablonski, I., Fabbiano, L., De Capua, C. (2022). An IoT based ECG system to diagnose cardiac pathologies for healthcare applications in smart cities. Measurement, 190, 110685.
53. Umer, M., Aljrees, T., Karamti, H., Ishaq, A., Alsubai, S., Omar, M. Ashraf, I. (2023). Heart failure patients monitoring using IoT-based remote monitoring system. Scientific Reports, 13(1), 19213.
54. Ramkumar, G., Seetha, J., Priyadarshini, R., Gopila, M., Saranya, G. (2023). IoT-based patient monitoring system for predicting heart disease using deep learning. Measurement, 218, 113235.
55. Armand, T. P. T., Mozumder, M. A. I., Ali, S., Amaechi, A. O., Kim, H. C. (2023, January). Developing a Low-Cost IoT-Based Remote Cardiovascular Patient Monitoring System in Cameroon. In Healthcare (Vol. 11, No. 2, p. 199). MDPI.
56. Iftikhar, A., Elmagzoub, M. A., Shah, A. M., Al Salem, H. A., ul Hassan, M., Alqahtani, J., & Shaikh, A. (2023). Efficient Energy and Delay Reduction Model for Wireless Sensor Networks. Comput. Syst. Sci. Eng., 46(1), 1153-1168.
57. Nayab, S., Irfan, R., Umar, U. (2023, December). MIoT-based Smart Cardiac Healthcare Monitoring System for Ubiquitous Healthcare Ser- vices. In 2023 17th International Conference on Open Source Systems and Technologies (ICOSST) (pp. 1-6). IEEE.