ORIGINAL RESEARCH

Heart Vessels Transplant 2024; 8: 501-8
DOI: 10.24969/hvt.2024.536

Internet of Things technologies in cardiovascular diseases diagnostics: Literature review and proposal

J. Srinivasan Prasath*

Department of Computer Science and Engineering, Sapthagiri NPS University, Bengaluru, India

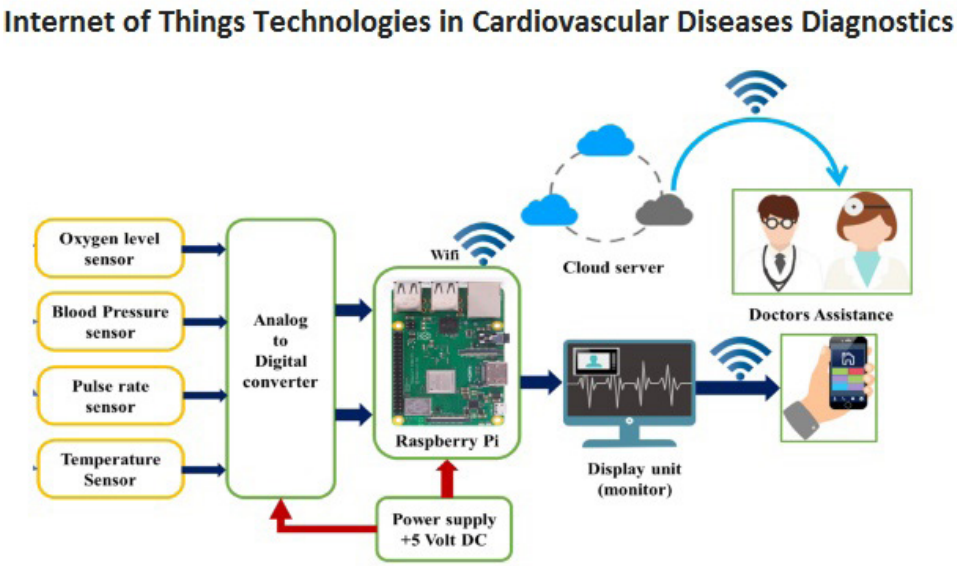
Abstract

Objective: Heart diseases occur for various age groups and the huge percentage of people lost their life due to the heart disease. Heart attack occurs regardless of age and it leads to the death. The aim of the study is to propose the Internet-of Things based electrocardiogram (ECG) monitoring system that can be used for detection of heart disease.

Methods: This proposed work is the detailed framework for monitoring of heart rate using ECG through internet. This work discusses Internet of Things (IoT) based ECG monitoring system through the ECG sensor and the embedded system utilized to process the heart related parameters and send the level of oxygen, blood pressure, pulse rate and temperature to the doctor for monitoring and further treatment. It detects the variation in the rate of heart beat using ECG and sends it to the doctor's mobile through Wi-Fi for diagnosis.

Results: Heart specialist has the provision of monitoring of patient heart conditions through his/her mobile. The scope of this work is to identify the heart problem through the ECG waveform. When the range of heartbeat becomes irregular, then the software send the information to the doctor about heartbeat is out of range. The indicator light and alarm signal is given as notification to the doctor to indicate the emergency. Based on this alarm signal, doctor will give suitable treatment by checking the conditions of the patient.

Conclusion: This work allows doctors to determine the severity of patient's condition very easy and allows administering the corresponding treatment.



Key words: Heart attack, electrocardiogram, Internet of Things, heart rate, embedded system

(Heart Vessels Transplant 2024; 8: 501-8. doi: 10.24969/hvt.2024.536)

Address for Correspondence: J. Srinivasan Prasath, Department of CSE, Sapthagiri NPS University, Bengaluru, India
E-mail: jsprasath@gmail.com
Citation: Prasath JS. Internet of Things technologies in cardiovascular diseases diagnostics: Literature review and proposal . Heart Vessels Transplant 2024; 8: 501-8. doi: 10.24969/hvt.2024.536
Received: 21.09.2024 **Revised:** 06.11.2024 and 07.112024 **Accepted:** 08.11.2024

Introduction

Nowadays, heart problems arise irrespective of age and majority of people are affected by the heart-related diseases. Heart diseases cause severe health issues and lead to death. The WHO reported that the death rate increases to several millions due to heart related issues. It is essential to eliminate the risk of heart related problems. The analysis towards coronary illness gives signs, manifestation, and physical testing of a long-suffering. The continuous monitoring and analysis of heart patient is essential and the proper treatment is required. The functioning of heart is determined by the electrocardiographic (ECG) signal. ECG can detect various cardiac diseases recoded at rest and during exercise. According to the American Heart Organization, an average beats of heart rate varies from 60 beats per minute and up to 100 beats per minute for human in the age of 15 years and older. They suggest person fitness corresponding to their particular limit of heart rate. The level of fitness cannot be maintained when the exercise goes below 50 percent whereas the heart attack causes due to exercising beyond 85 percent.

The aim of the study is to propose the Internet-of Things based electrocardiogram monitoring system that can be used for detection of heart disease.

Literature review

Many researchers analyzed and focused on diagnosis of heart diseases. The major concern related to the imbalanced data in predicting the heart problem is addressed (1). The machine learning technique is useful to enhance the data-driven decision-making. The efficient mechanism for detecting heart problem is examined with different techniques and the various factors through ECG signals (2). The various methodologies related to the cardiac abnormality detection issue is addressed (3). The integration of linear and logarithmic spectrogram-image characteristics is proposed. The heart sound was proposed to examine the exercised-induced cardiac fatigue based on its capacity to indicate variations in cardiac contractility (4). The various classes of heart failure is proposed in which the heart failure leads to an excess variation in the heart (5). The inherent cardiac dysfunction actuates the energizing of an array of neuro-hormonal techniques. The state between the vitamin D during pregnancy and the issues in heart rate is discussed (6). The chances of irregular and random functioning of heart in the vertebrate can increase due to the lack of vitamin D. The technique is proposed that rectifies the heart disease (7).

The strong factor for causes of non-functioning of heart is the high blood pressure (8). The extensive way to detect the cardiovascular disease of individual patients could help to personalize primary cardiovascular disease prevention (9). Most of the countries refer low dose aspirin particularly for high-risk heart affected people. A stochastic neuron framework is proposed to assist physical representation of heart rate variability (10). The Fuzzy-Long Short Term Memory framework is proposed to identify the heart problems (11). This approach is very much successful in determining the heart issues. The cognitive dysfunction related to heart failure in various forms is addressed (12). The various techniques related to heart monitoring as well as conventional cardiovascular monitoring equipment are discussed (13). The machine learning approach provides automatic identification of cardiac abnormalities in real-time. The various classes of heart beat are proposed using deep learning technique (14). The dynamic algorithm is proposed to obtain large signal amplitude (15). The framework is created for calculating the heart rate. The myocardial infarction is identified and controlled through the proposed hybrid method (16). The challenges, opportunities and the various levels in heart problems are addressed (17).

The various risk factors of cardiovascular disease are addressed (18). The prevention technique and setting of individualized therapeutic targets are essential to overcome the later stages of heart failure. The solution is suggested for preserving the stroke (19). The patent foramen ovale closure and oral antithrombotic treatment greatly decreased the occurrence of recurrent embolic stroke. The intruder targets the ECG signal of the patient and maps the ECG signals (20).

The deep learning approach is proposed for identifying the various heart parameters (21). This approach provides accurate calculation of heart beat. The human heart monitoring system is proposed which utilizes Internet of Things (22). The patient's heart functioning is monitored and the alert messages sent to the doctor when any heart problem occurs. A wearable tele-ECG and heart beat monitoring system is proposed (23). The function of variable medicine in preserving the abnormal functioning of heart is addressed (24). The framework is proposed for the identification of myocardial infarction (25). The huge less term memory is created to calibrate the heart rate (26). The sampling rate of the heartbeat is detected through the proposed heart rate monitoring (27).

When the level of heartbeat goes outside the range, the warning signal is generated and informs doctor. The wireless sensing system is proposed for monitoring and evaluating cardiac condition, which transmits the data to the doctor (28). The framework is proposed for identifying the abnormalities of heart functioning, and attacks, insertions, and alterations in the ECG (29). The requirement for power consumption is identified through various schemes (30).

The measure of energy consumption is an important criterion in continuous monitoring and analysis of ECG signals. The wireless monitoring of a heart rate using microcontroller is developed (31). The heartbeats and ECS signals are recorded, processed and sent to the personal computer for further diagnosis.

Related work

This proposed work is the detection of heart problems and heart attack through the continuous monitoring of patients through ECG signals. The heart rate sensor detects the heartbeat and sends them over the internet. Doctors can access

the pulse rate, temperature, oxygen level and blood pressure of the patients in his/her mobile and evaluate functioning of patients` heart. When the heart specialist reveals the abnormal heartbeat, he/she refers patient to hospital and provides required treatment. This work is very much useful for doctors to detect the heart problems of patients. Figure 1 provides normal electrocardiogram waveform: intervals and QRS complex.

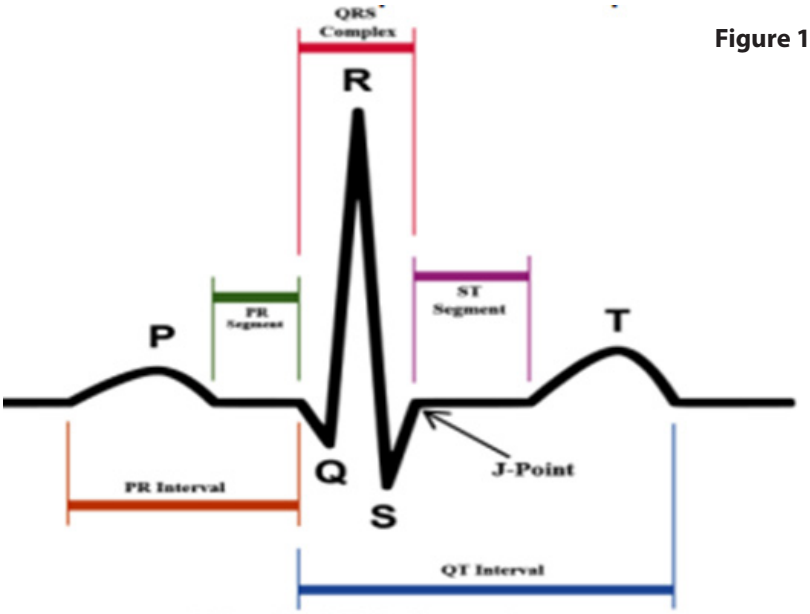


Figure 1. Electrocardiogram waveform

Proposed Internet-of-Things (IoT) based heart rate monitoring system

Figure 2 shows the proposed IoT based heart rate monitoring system.

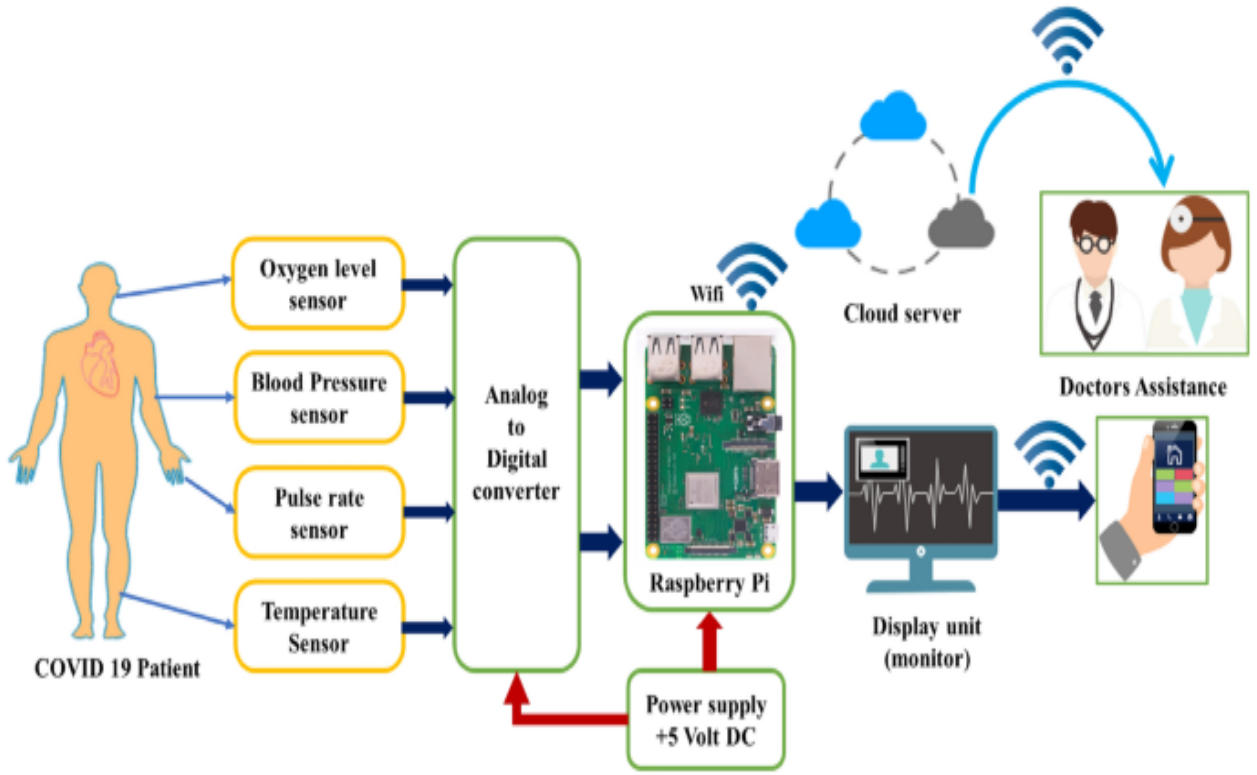


Figure 2. Proposed IoT based heart rate monitoring system

IoT - Internet-of-Things

Oxygen sensor

The oxygen level sensor is utilized to detect the amount of oxygen level in the admitted to the hospital patients.

The oxygen level of the patient is detected through sensors and produces the equivalent signal. The embedded ARM cortex microcontroller is used in this work to read the oxygen level of the patient. The threshold level of these parameters is programmed in the microcontroller and detected value is displayed in the computer. These parameters also transmitted to the cloud server for the purpose of storage and analysis. These health related parameters sent to the doctor's mobile for immediate diagnosis.

Blood pressure sensor

The high blood pressure leads to obesity, whereas low blood pressure causes fatigue, dizziness, fading vision, weak and rapid pulse. MPS-2000 silicon pressure sensor is utilized to detect the blood pressure. MPS-2000 is the 6-pin dual in-line package chip that generates a output voltage proportional to the input pressure. MPS-2000 is perfect for applications need low hysteresis, high reliability and stability.

Temperature sensor

The normal human body temperature range is typically stated as 36.5–37.5 °C (97.7–99.5 °F). Body temperature higher than 37.8 °C is considered as fever. The variety of techniques is available for measuring the human body temperature. The MAX30205 sensor is used in this work to measure human body temperature. It is a digital thermometer for measuring the temperature in the range 0°C to 50°C, with an accuracy of about 0.1°C. The operating voltage in the range 2.7 V to 3.3 V and operating current is 600 micro-amperes.

Heartbeat sensor

Heartbeat device comes in various models and it is used to measure the heartbeat. The finger type heartbeat sensor is available used to differentiate the beats.

The range of heartbeat gradually reduces when the age increases from birth till 12 years. The normal rate of heartbeat is between 60 and 100 when the age is above 12 years.

Heart rate sensors, also known as pulse sensors, measure heart rate by identifying the variations in blood vessel volume, or pulse waves, caused by the heart pumping blood. The SEN-11574 Pulse Sensor is utilized to detect the rate of heart beat. The heart rate can be detected by placing a human finger in front of this pulse sensor. When a finger is placed in front of this pulse sensor, then the reflection of LED light is varied based on the volume of blood change inside capillary vessels. This means during the heartbeat the volume of blood in capillary vessels will be high and then will be low after each heartbeat. So, by changing this volume the LED light is changed. This variation of LED light measures the heartbeat rate.

The output of oxygen sensor, blood pressure sensor, pulse rate sensor, and temperature sensor is a continuous analog signal. The sensor data is lower in amplitude. The signal conditioning circuit is used to convert the low level signal to higher in amplitude to make it suitable for analysis and display. The signal conditioning circuit includes amplifier and filter. Amplifier increases the signal strength of the sensor output. Filter is used to remove the noise and unwanted ripples present in the sensor output. This signal conditioning circuit is inbuilt with the Analog to Digital Converter (ADC). Raspberry Pi board contains in-built ARM cortex processor which works only on digital signal. The analog voltage signals generated by the sensors need to be converted into digital signal in order to process it in the raspberry pi. The analog to digital converter (ADC) is used to convert the analog signals from various sensors into its equivalent digital signal.

The python code is used in Raspberry Pi which compares the patient's blood pressure, heart rate, temperature, and oxygen level with the standard values and sends the information as normal or abnormal to the doctor's mobile through the Internet of Things (IoT).

Computational Power

Raspberry Pi is a 64-bit quad core ARM Cortex processor and the computational power is 1.2 GHz clock speed.

Data Storage

Raspberry Pi ARM Cortex processor storage capacity is 1 GB (Giga Byte) RAM (Randam Access Memory).

Network Technologies

The Raspberry Pi 3 uses the following network technologies:

1. WiFi : 2.4 GHz and 5 GHz IEEE 802.11b/g/n/ac wireless LAN
2. Bluetooth: Bluetooth 4.1
3. Ethernet: 10/100 Mbit/s Ethernet port

Analysis of heart disease

The variety of tests are utilized to examine the heart disease. The basic technique is used to diagnose the heart disease are blood tests and a chest X-ray. The other tests used to identify the heart problems are electrocardiography, echocardiography, computed tomography and cardiac magnetic resonance imaging.

Electrocardiogram (ECG or EKG)

The various heart diseases that can be identified through ECG test are congenital heart defects, heart enlargement, fast, slow or random heart beats, heart damage due to the block of arteries, abnormal positioning of heart, heart inflammation, poor blood supply to the heart, cardiac arrest during intensive care monitoring, and early heart attacks. The ECG tests can be taken in different ways and various tests are available to identify the heart diseases.

Results and Discussion

Figure 3 shows the ECG waveform during normal functioning of human heart. The functioning of atria of the heart is

described by the P-wave, while the functioning ventricle is indicated by the T-wave, and QRS complex. The QRS complex wave plays a critical role in diagnosing the issues related to functioning of heart. This QRS complex wave may become shorter, wider or lengthier, when the patients are affected by the heart problems.

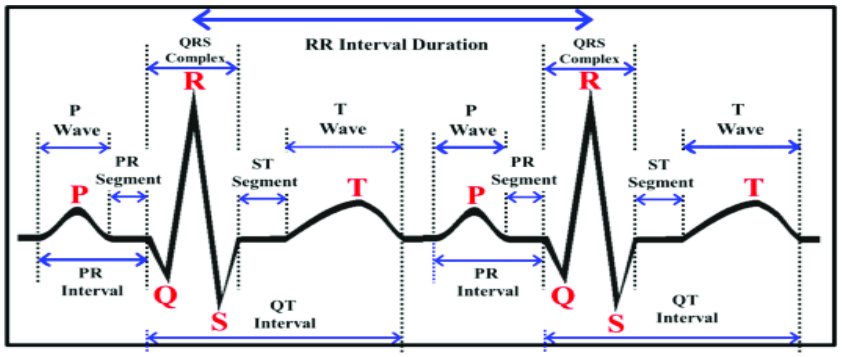


Figure 3. Normal ECG Waveform

The measurement of R-peak is essential in ECG signal and it is used to find out the abnormal functioning of heart. The average value of heartbeat for normal person is 72 beats per minute. The range of heartbeat for a healthy person is from 70 to 80 beats per minute.

The functioning of heart is indicated in the ECG waveform. In ECG, The normal amplitude of a P wave on an electrocardiogram (ECG) is 0.25 millivolts (mV) or less than two and a half small squares. The amplitude of the QRS complex is greater than 0.5 mV in at least one standard lead and greater than 1.0 mV in at least one precordial lead. The upper range limit of normal amplitude for the QRS complex is 2.5 to 3.0 mV.

The normal heart beat can be detected using ECG waveform and the ECG values for P wave interval is 80 milliseconds, PR interval is 120-200 milliseconds, QRS wave is 80 to 100 milliseconds, and the T wave is 160 milliseconds.

ECG recording device is portable, consists of 12 lead wires, which is long and flexible, with the electrodes attached. The ECG electrodes are inserted on selected areas around the heart, placed on the arms and legs. These electrodes detect the electrical signals produced from various directions. The advantage of ECG device is its simple procedure, detection of heart rate without pain, it does not produce electricity, and it takes less time of about five minutes to generate the ECG waveform.

Figure 4 indicates the ECG waveforms during the abnormal functioning of heart. The ECG signal becomes abnormal when the patient experiences the chest pain, increase in pulse rate, weakness, fatigue, dizziness, a heart defect, coronary artery disease, shortness of breath, and heart valve disease. The irregular heart rate and high blood pressure are also lead to abnormal ECG signals. Normal ECG range for RR interval is 0.6-1.2 seconds, PR segment is 50-120 milliseconds, ST segment is 80-120 milliseconds, and QT interval is 420 milliseconds.

The raw data is imported in python language using pandas, and plotting a data. In python, the electrocardiogram (ECG) waveform can be produced using scipy.misc. electrocardiogram (32).

The steps to generate ECG waveformare:

1. Import NumPy and SciPy modules.
2. Create an ECG model.
3. Calculate time data with frequency.
4. Display the graph.

   The X-axis and Y-axis limit can be varied while plotting the ECG waveform.

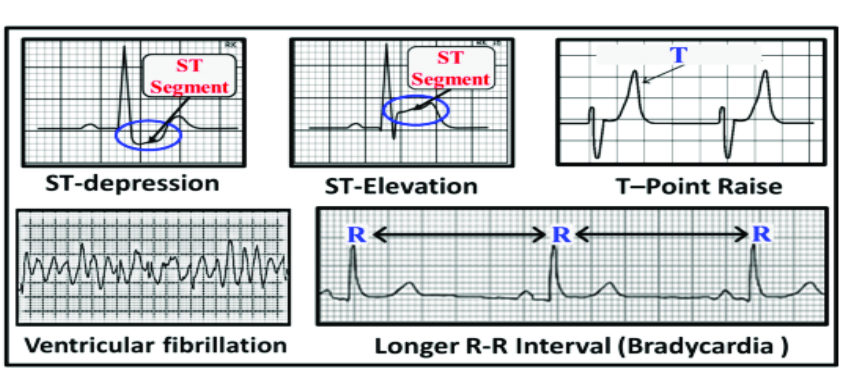


Figure 4. Abnormal ECG waveform

The normal heart beat range is programmed using python code. The program compares the normal heart beat in terms of PQRST intervals with the heart beat of the patient indicated in the ECG wave. If any intervals or amplitude value goes low or exceeds the threshold value, it sends the status of patient heart rate to the doctor's mobile through the internet along with the patient name and ward number. This abnormal value of ECG indicates the occurrence of heart attack. If the intervals or amplitude of ECG wave for a patient is within the range, then it indicates that there is no chance of occurrence of heart attack.

The input values for PQRST wave is imported using pandas in python, and plotting the ECG waveform. The intervals and amplitude of PQRST wave is sent to the doctor for further analysis and to detect the occurrence of heart attack.

Python is widely used with Raspberry Pi in IoT. Python is a cross-platform language and it can run on multiple platforms, such as Windows, and Linux.

Python libraries including PyUSB, PySerial, and PyBluez gives access to hardware interfaces, communication protocols, and other IoT-related features that make it suitable and easy to develop IoT applications. Python can be easily integrated with other languages and platforms.

Python provides support for several IoT protocols and standards, such as HTTP (Hyper Text Transfer Protocol), MQTT (Message Queuing Telemetry Transport), and CoAP (Constrained Application Protocol), making it easy to develop applications that can communicate with other smart devices and platforms.

Integrating Python with IoT platform

Python is commonly used with Raspberry Pi in IoT. Python is a cross-platform language and it can run on multiple platforms, such as Windows, and Linux. Python libraries including PyUSB, PySerial, and PyBluez gives access to hardware interfaces, communication protocols, and other IoT-related features that make it suitable and easy to develop IoT applications. Python can be easily integrated with other languages and platforms. Python provides support for several IoT protocols and standards, such as HTTP (Hyper Text Transfer Protocol), MQTT (Message Queuing Telemetry Transport), and CoAP (Constrained Application Protocol), making it easy to develop applications that can communicate with other smart devices and platforms. Python includes libraries such as Pandas, NumPy, and Matplotlib, which make it easy to process and visualize data from IoT sensors and devices.

Integrating Python with Cloud Computing

Python can be used efficiently for cloud computing. Data in various forms such as image, video, audio, document are used in Cloud that are supported by the python. Python can be used to perform the following tasks in Google cloud:

1. Cloud logging
2. Monitoring of cloud
3. Tracing cloud
4. Reporting errors in cloud
5. Help in diagnosing setbacks in performance

Python libraries play a significant role in AWS (Amazon Web Services), cloud computing, and DevOps, enabling developers to harness the full potential of these domains.

AWS CLI: The AWS Command Line Interface (CLI) is a unified tool that provides a command-line interface for managing AWS services. AWS CLI commands using Python to automate and organize AWS resources.

Paramiko: Paramiko is a Python implementation of the SSH (Secure Shell) protocol, allowing to securely automate and interact with remote servers and devices.

Integrating Python with Edge Computing

Python has established itself as a leading programming language for developing edge applications and solutions due to its flexibility, powerful tools and large community support. Many key edge computing deployments utilize Python for its powerful data processing, machine learning and integration capabilities. Industrial IoT systems in environments like factories utilize Python at the edge. This involves using Python on local devices to monitor sensors on machinery, gathering real-time data. OpenCV, an open-source library, allows real-time video analysis via Python. Many python tools are available for edge development which includes:

MicroPython - A lean implementation of Python-3 for microcontrollers and embedded systems, enabling edge intelligence on small, low-power devices.

TensorFlow Lite - Google's framework for machine learning inference at the edge, optimizing models for low-resource embedded devices using Python APIs.

PyTorch - Facebook's machine learning framework that supports model optimization, conversion and deployment to edge systems via Python.

Dash - An open-source Python framework for building interactive web interface dashboards to remotely monitor and control edge deployments.

AsyncIO - Python's standard asynchronous I/O library for building high-performance edge services that handle concurrent connections efficiently.

Flask/Django - Popular web application frameworks utilized for edge APIs, gateways, and user interfaces to collect, process and visualize edge data.

This proposed heart rate monitoring system reads the medical data from oxygen sensor, blood pressure sensor, heart rate sensor, and temperature sensor. These sensor data are in analog signal and are converted into digital signal by using Analog to Digital Converter (ADC). The converted digital signal is processed using embedded processor and programmed using python language. It compares the patient medical

information such as temperature, heart rate, Blood pressure, and oxygen level with the standard values and sends the normal or abnormal level to the doctors through Internet of Things (IoT).

In the existing ECG monitoring system, doctors should be available near the patients, connecting the ECG electrodes with the patient's heart, and to analyze the ECG waveform. Based on the PQRST waveform, doctors has to decide the further treatment.

In this proposed ECG monitoring system, doctors do not need to be available near the patients. This proposed work allows automatic monitoring of ECG, heart rate, blood pressure, temperature, and oxygen level through the sensors, programmed using embedded system and send this medical report of the patient to the doctor's mobile through IoT. The patient medical information can be stored in cloud storage for further analysis.

This proposed work utilizes low cost sensors for monitoring and it reduces the doctor's time in checking the patient's health conditions manually. This work is suitable for hospital with large number of patients admitted especially in the emergency ward. Data security is achieved through encryption algorithms. Symmetric AES (Advanced Encryption Standard) algorithms are used to convert the readable text into unreadable cipher text. It uses single key for both encryption and decryption. It ensures confidentiality of medical data. The sensor data can be encrypted using python code and generate cipher text. This unreadable cipher text is transmitted across internet to ensure confidentiality of medical data.

The benefits of this proposed heart attack detection and prevention are that it may achieve high accuracy for efficient diagnosis of heart condition, reduce the time consumption of doctors to check and to test the heart patients, cost-effective device for identifying the ECG, oxygen level, pulse rate, blood pressure level and the temperature.

Study limitations

The system has to be validated in clinical setting.

Conclusion

The heart diseases are common and most of the patients are admitted to the hospital due to heart problems. It is essential to monitor the heart rate continuously for those who are suffered from the cardiovascular diseases and especially for elderly people. This proposed work is the continuous monitoring of rate of heartbeat using ECG through internet. It utilizes the software that detects the signal and converts it into data for further analysis. The heart related issues can be identified by analyzing the ECG waveform.

This proposed work becomes useful for doctor to identify and analyze the heart problems of the patient. It provides a cost-effective approach in analyzing the heart related issues and the occurrence of heart attack. It can be widely used to identify and diagnose the elderly people with heart problems.

Ethics: No human or animal research is applied

Peer-review: Internal

Conflict of interest: None to declare

Authorship: J.S.P

Acknowledgements and funding: None to declare

Statement on A.I.-assisted technologies use: We declare that we did not use AI-assisted technologies in preparation of this manuscript

Data Availability Statement

No data is associated with this research work.

References

1. Manjurul A, Siddique Z. Machine learning-based heart disease diagnosis: A systematic literature review. Artif Intell Med 2022; 128.
2. Goyal S, Waghmare JM, Ranjanikar MA. Heart disease classification models from optical device-based electrocardiogram signals using machine learning algorithms. Optik 2022; 271.
3. Azam FB, Ansari I, Nuhash SISK, McLane I, Taufiq H. Cardiac anomaly detection considering an additive noise and convolutional distortion model of heart sound recordings. Artif Intell Med 2022; 133.
4. Yin C, Zhou X, Zhao Y, Zheng Y, Shi Y, Yan X, Guo X. Diagnosis of exercise-induced cardiac fatigue based on deep learning and heart sounds. Appl Acoustics 2022; 197.
5. McBeath K, Cowie MR. Heart failure: classification and pathophysiology. Medicine 2022; 50: 471-8.
6. Rastegar M, Fateh M, Rahnama A, Sheybani-Arani MH, Asi AS, Rajaei S. Evaluation of the relationship between vitamin D level during pregnancy and the rate of fetal heart problems: a cross-sectional study. Clinical Nutrition ESPEN 2022; 51: 22-266.
7. Sigamani A, Gupta R. Revisiting secondary prevention in coronary heart disease. Indian Heart J 2022; 74: 431- 40.
8. Di Palo ke, Barone NJ. Hypertension and heart failure: prevention, targets, and treatment. Cardiol Clin 2022; 40: 237-44.
9. Li XY, Li L, Na SH, Santilli F, Shi Z, Blaha M. Implications of the heterogeneity between guideline recommendations for the use of low dose aspirin in primary prevention of cardiovascular disease. Am J Prev Cardiol 2022; 11.
10. Buzas A, Horvath T, Der A. A novel approach in heart-rate-variability analysis based on modified Poincare plots. IEEE 2022; 10: 36606-15.
11. Munagala K, Langoju LRR, Rani D, Reddy RK. A smart IoT-enabled heart disease monitoring system using meta-heuristic-based Fuzzy-LSTM model. Biocybernetics Biomed 2022; 42: 1183-204.

12. Maroofi AB, Moro T, Agrimi J, Safari F. Cognitive decline in heart failure: Biomolecular mechanisms and benefits of exercise, Biochim Biophys Acta 2022; 1868.
13. Kwon SH, Dong L. Flexible sensors and machine learning for heart monitoring. Nano Energy 2022; 102.
14. Sun l, Wang Y, Qu Z, Xiong NN. Beat Class: A sustainable ecg classification system in IoT-based eHealth. IEEE Internet of Things J 2022; 9: 7178-95.
15. Ngoc-Thang B, Nguyen TMT, Truong TT, Nguyen BLH, Nguyen TT. dynamic reconfigurable wearable device to acquire high quality PPG signal and robust heart rate estimate based on deep learning algorithm for smart healthcare system. Biosensors and Bioelectronics 2022; 12: X.
16. Sheida Jabbedari Khiabani SJ, Atefeh Batani A, Ehsan Khanmohammadi E. A hybrid decision support system for heart failure diagnosis using neural networks and statistical process control. Health Analyt 2022.; 2.
17. Jone PN, Gearhart A, Lei H, Xing F, Nahar J, Lopez-Jimenez F, et al. Artificial intelligence in congenital heart disease: current state and prospects. JACC: Advances 2022; 1.
18. Faggiano P, Bernard N, Calvi E, Bonelli A, Faggiano A, Bursi F, et al. Stage a heart failure: modern strategies for an effective prevention. Heart Fail Clin 2021; 17: 167-77.
19. Morino Y, Nakajima Y. Structural heart intervention for prevention of embolic and hemorrhagic stroke: The new field of neurocardiology. J Cardiol 2020; 76: 227-35.
20. Karimian N, Woodard D, Forte D. ECG biometric: spoofing and countermeasures. IEEE Transact Biometr Behav, Ident Sci 2020; 2: 257-70.
21. Panwar M, Gautam A, Biswas D, Acharyya A. PP-Net: A deep learning framework for ppg-based blood pressure and heart rate estimation. IEEE Sens J 2020; 20: 10000-11.
22. Sarmah SS. An Efficient IoT-based patient monitoring and heart disease prediction system using deep learning modified neural network. IEEE Access 2020; 8: 135784-97.
23. Ozkan H, Ozhan O, Karadana Y, Gulcu M, Macit S, Husain F. A portable wearable tele-ecg monitoring system," IEEE Transact Instrum Measur 2020; 69: 173-82.
24. Upadhya B, Lovato LC, Rocco M, Lewis CE, Oparil S, Cushman WC, et al. Heart failure prevention in older patients using intensive blood pressure reduction: potential role of diuretics. JACC: Heart Fail 2019; 7: 1032-41.
25. Tripathy RK, Bhattacharyya A, Pachori RB. A novel approach for detection of myocardial infarction from ecg signals of multiple electrodes. IEEE Sens J 2019; 19: 4509-17.
26. Jin X, Gu F, Niu J, Yu S, Ouyang Z. HRCal: An effective calibration system for heart rate detection during exercising. J Network Comp Appl 2019; 136: 1-10.
27. Joseph S, Shahila FD, Patnaik S. IoT based remote heartbeat monitoring. International Conference on Advances in Computing, Communication and Control. Mumbai. 2019.
28. Ren H, Jin H, Chen C, Ghayvat H, Chen W. A novel cardiac auscultation monitoring system based on wireless sensing for healthcare. IEEE J Translat Engin Health and Med 2018; 6.
29. Khan FA, Haldar NAH, Ali A, Iftikhar M, Zia TA, Zo AY. A continuous change detection mechanism to identify anomalies in ecg signals for wban-based healthcare environments. IEEE Access 2017; 5: 13531-44.
30. Kim JY, Chao-Hsien Chu CH. Analysis and Modeling of Selected Energy Consumption Factors for Embedded ECG Devices," IEEE Sens J 2016; 16: 1795-905..
31. Prasath JS. Wireless monitoring of heart rate using microcontroller. Int J Adv Res Comp Sci Electr Engin 2013; 2: 209-14.
32. www.scipy.misc.electrocardiogram

Author profile

J.S.Prasath received Master of Engineering degree in Process Control and Instrumentation Engineering from Annamalai University, Chidambaram and Doctor of Philosophy degree in Wireless Sensor Networks for Industrial Security from Hindustan Institute of Technology and Science, Chennai, India. Currently he is working as an Associate Professor in the Department of Computer Science and Engineering at Sapthagiri NPS University, Bengaluru, India. He is an interdisciplinary and guiding many Research projects at Under graduate and Post graduate level. Earlier he served in SRM University, Hindustan University, KCG College of Technology and Narayana Engineering College. His research interests are Embedded Systems, Wireless Sensor Networks, Internet of Things, Process Control and Industrial Automation. He has published eighteen articles in international journals, presented sixteen papers in International Conference, published two patents, one book and one book chapter. He received the best teacher award and the two innovation awards for his research work.