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Research Article

Role of IoT and ML in Healthcare

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ABSTRACT

Internet of Things (IoT) is known as a network of various physical devices that are implanted with different sensors, software along with Internet connectivity to allow connected devices to communicate without human interference. Today, IoT has spread in almost all fields, such as agriculture, industries, supply chain management, sports, smart cities, traffic management, driverless vehicle technology, healthcare, etc. Devices can communicate any time at anywhere in all places, which makes the IoT called the Internet of Everything. Medical care is known as the progression of human health through the prevention of ailments, the diagnosis and treatment of illnesses, accidents and mental disabilities. With technological advancements, machine learning (ML) and deep learning (DL) are gaining popularity in many applications, such as natural language processing (NLP), disease prediction, bioinformatics, speech recognition, etc. The main data sources for the DL system are medical IoT, electronic health records, digitized images, and healthcare records. There are certain issues that can be encountered in DL, such as privacy, implementation, and optimization. This paper introduces ML applications for IoT in health systems and medical sciences by reviewing related work. Finally, this paper will discuss the challenges, opportunities, advantages, and disadvantages of each study.

1. INTRODUCTION

Now-a-days, the demand of linked devices is escalating across different industries. With the advancement of technology, IoT is finding applications in the domain of smart cities, healthcare, entertainment systems, smart homes etc [1-4]. There are numerous applications of IoT in healthcare such as patient's health monitoring, patient tracking in the hospitals, checking the availability of beds, tracking the medicine intake of the patients using smart pill dispensers along with generating alerts to the care givers etc. The primary components for the implementation of IoT are sensors, different medical equipment, artificial intelligence and advance devices used for imaging. These devices help to improve the efficiency as well as quality of life in industries. [5-6].With the use of IoT, certain health conditions can be detected at an early phase and it becomes possible to generate prompt responses to the health emergencies before even when patient is on the go [7]. Additionally, the IoT can enable the healthcare agencies to cut down the cost with the usage of equipment track systems [8]. Not only this, it is feasible to improvise the healthcare services quality by providing the personalized care to the patients.

Healthcare is considered to be the most crucial part of life. Health care involves the sustenance and improving the various health conditions by diagnosing various ailments and taking measures to prevent them. While checking the feasibility of healthcare solutions, there are three parameters that need to be considered [9-10]. Various diagnostic approaches such as CT Scan, MRI, X-rays are carried out in order to detect the abnormalities lying beneath the skin. The medical specialists and healthcare professionals focus on bringing the innovative methods to detect the diseases and deliver the targets.

Numerous health issues such as chronic artery disease and epilepsy can now-a-days be discovered even before their actual occurrence in the patient's body. As the consequence of population explosion, there is a huge demand for medical professionals and medical resources such as hospital beds, oxygen masks, smart pill dispensers etc. Sometimes, due to misdiagnosis, a huge amount of time as well as resources are mislaid in the healthcare systems. Therefore, there is a dire need to come up with the solutions that could considerably reduce the time, resource wastage and effort that are carried out on current human assisted healthcare systems. Not only this, solutions need to be generated for maintaining the effectiveness as well as quality of the health care offered. IoT facilitates the healthcare specialists to be more observant so as to connect proactively with the patients. The data gathered from IoT devices can assist the doctors recognize the best possible treatment for patients and reach the expected consequences.

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2. LITERATURE SURVEY

In [11] investigated the architecture used in the IoT especially the cloud integrated systems. In [12] reviewed various concepts with regard to sensor based wireless wearable devices in healthcare domain with the perception of whole IoT ecosystem. In [13] validated the different instances of the expertise associated with the policy reflections such as scalability, safety, pros and cons, competence of power and unobtrusiveness associated with the systems. In contribution towards the major positives, implanted body sensor domain networks and wearable domain looked into the main challenges and the vulnerabilities in the investigation that are explored beyond the resolution, demonstrated the in-body as well as out-body communication connection on the techniques of wireless communication along with embedded medical equipment with external observation equipment's on the body sensor networks employed in the health-care applications [14]. In [15] proposed an encryption protocol which was based on the identity and it was found to be suitable for body smart sensor systems. A well-formulated verification as well as validation architecture was presented in [16] for the healthcare systems based on IoT. The security of the proposed architecture was ensured by the DTLS handshake protocol that helps to authorize and authenticate the architecture. Further, in [17] demonstrated an implantable sensor which is wearable and flexible. In [18] offered a methodical as well as accurate model based on in-to-out human body path loss on the basis of a 3D heterogeneous human body prototypical below security limits.

3. INTRODUCTION TO IOT

The IoT is a network of physical devices, sometimes known as "things," that are equipped with sensors, software, and other technologies. These objects are able to connect to the internet and share data with other devices and systems. These "things" include a wide spectrum of objects, ranging from common domestic devices such as smart thermostats and refrigerators to intricate industrial gear. The objective of the IoT is to develop intelligent and highly efficient systems and procedures by using real-time data and networked devices [19]. The IoT is a network of linked physical objects that have the ability to interact and share data with one another over the internet. These devices, often outfitted with sensors, software, and other technologies, gather and exchange data to enhance efficiency, automation, and decision-making in many applications. In general, the IoT is revolutionizing our lifestyle and professional activities by facilitating the use of intelligent and highly effective systems via networked gadgets and insights derived from data analysis.

3.1 Key Aspects of IoT

Devices and Sensors: IoT devices range from everyday household items like smart thermostats and wearables to industrial equipment and smart city infrastructure. These devices often contain sensors to collect data on their environment or usage.

Connectivity: IoT devices communicate through various connectivity options, including Wi-Fi, Bluetooth, cellular networks, and specialized IoT protocols like Zigbee and LoRaWAN. This connectivity enables devices to send and receive data to and from other devices or central servers.

Data Processing and Analytics: The information gathered by IoT devices is often subjected to processing and analysis in order to extract important insights.. This can be done locally on the device or in centralized cloud servers.

Security and Privacy: The widespread use of IoT devices has raised significant issues about security and privacy. Ensuring that devices are secure from hacking and that the data they collect is protected is crucial.

Scalability: IoT solutions must possess scalability in order to handle the expanding quantity of interconnected devices and the rising magnitude of data they produce.

Automation and Control: IoT enables automation by allowing devices to be controlled remotely or to act autonomously based on the data they collect.

Interoperability: Devices from different manufacturers and with different functionalities can work together within an IoT ecosystem.

3.2 5 Layer Architecture of IoT

The 5-layer architecture of the IoT is a conceptual framework that outlines the different layers and their functions within an IoT system. These layers are: Perception, Network, Processing, Application, and Business. Figure 1 shows 5 Layer Architecture of IoT. This 5-layer architecture helps in organizing and understanding the different components and functions within an IoT system, facilitating better design, implementation, and management of IoT solutions. The function of 5-layer IoT architecture represented in Table 1.

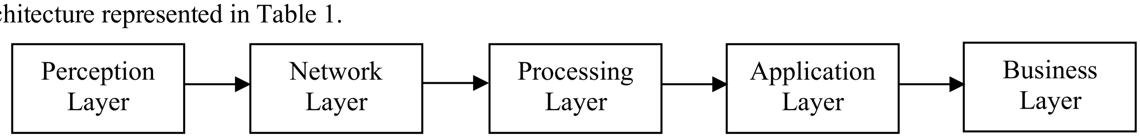

Fig. 1. 5 Layer IoT Architecture

TABLE I. 5 LAYER ARCHITECTURE

Layer	Function	Components
Perception Layer	This layer is responsible for sensing and collecting data from the physical environment. It includes sensors and actuators.	Sensors (temperature, humidity, motion, etc.), RFID tags, cameras.
Network Layer	This layer transfers the data collected by the perception layer to other devices or processing units. It includes various communication protocols and network infrastructure.	Routers, gateways, communication protocols (Wi-Fi, Bluetooth, Zigbee, LTE, etc.).
Processing Layer	The function of this layer is to handle the data that is received from the network layer. It includes data storage, data analytics, and decision-making mechanisms.	Cloud computing platforms, data analytics tools, databases, edge computing devices.
Application Layer	This layer defines various applications in which IoT can be deployed, delivering smart services to users.	Smart home applications, industrial automation systems, healthcare monitoring systems, etc.
Business Layer	The primary function of this layer is to oversee the whole IoT system, including aspects such as business models, security for users, handling of data, and business analytics.	Business models, data analysis reports, user privacy policies, management tools.

3.3 Various Applications of IoT

The IoT has a wide range of applications across various sectors, enhancing efficiency, automation, and convenience. These applications demonstrate how IoT can transform various industries by providing real-time data, improving operational efficiency, and enhancing user experiences. The various applications of IoT are shown in figure 2. Here are some key applications:

Smart Homes: IoT devices like smart thermostats, lighting systems, and security cameras help automate home management. They can be controlled remotely via smartphones, enhancing energy efficiency and security.

Wearables: Smartwatches, fitness trackers, and health monitors track physical activity, vital signs, and other health metrics, providing real-time data to users and healthcare providers.

Healthcare: IoT enables remote patient monitoring, telemedicine, and smart medical devices, improving patient care and operational efficiency in healthcare facilities.

Smart Cities: IoT is used for traffic management, waste management, and energy usage monitoring. It helps cities become more sustainable, efficient, and livable.

Industrial IoT (IIoT): IoT sensors in manufacturing monitor the operation of equipment, forecast maintenance requirements, and enhance production processes, resulting in improved efficiency and less downtime.

Agriculture: IoT devices help monitor soil moisture, weather conditions, and crop health, enabling precision farming. This leads to better crop yields and resource management.

Retail: IoT improves inventory management, customer experience, and supply chain operations. Smart shelves and RFID tags track product availability and movement.

Transportation and Logistics: IoT enhances fleet management, asset tracking, and route optimization. It helps reduce fuel consumption and improves delivery times.

Energy Management: Smart grids and meters enable real-time monitoring and management of energy consumption, helping utilities and consumers optimize energy usage and reduce costs.

Environmental Monitoring: IoT sensors monitor air quality, water quality, and other environmental parameters, providing valuable data for environmental protection and research.

Fig. 2. IoT Applications

3.4 Challenges and Open Research Issues for IoT

The development and deployment of IoT systems come with various challenges and open research issues. Addressing these challenges and research issues is crucial for the widespread adoption and success of IoT technologies, enabling them to realize their full potential in various applications. The various challenges and research issues of IoT are given in Table 2 and Table 3.

TABLE II. CHALLENGES FOR IOT

Challenges	Description
Security and Privacy	**Data Security**: Ensuring the confidentiality, integrity, and availability of data collected and transmitted by IoT devices is crucial. **Privacy Concerns**: Protecting user data from unauthorized access and misuse is a significant concern, especially with devices collecting sensitive information.
Interoperability	**Standards and Protocols**: The lack of standardized protocols and interfaces makes it difficult for devices from different manufacturers to communicate effectively. **Compatibility**: Ensuring compatibility between devices and platforms is necessary for seamless operation.
Scalability	**Network Congestion**: As the number of IoT devices grows, managing network traffic and ensuring efficient data transmission becomes challenging. **Data Management:** Handling the large volumes of data generated by IoT devices requires robust data storage and processing solutions.
Power Consumption	**Battery Life**: Many IoT devices are battery-powered, necessitating energy-efficient designs to prolong battery life. **Energy Harvesting**: Developing new methods for energy harvesting to power IoT devices is an ongoing research area.
Connectivity	**Network Coverage**: Ensuring reliable connectivity in remote or densely populated areas can be difficult. **Latency**: Reducing latency for real-time applications is critical for performance.
Data Management and Analytics	**Data Quality**: Ensuring the accuracy, completeness, and timeliness of data collected by IoT devices. **Real-Time Processing**: Developing algorithms and infrastructure capable of processing data in real time for immediate decision-making.

TABLE III. OPEN RESEARCH ISSUES FOR IOT

Research Issues	Description
Advanced Security Solutions	**Lightweight Cryptography**: Developing efficient cryptographic algorithms suitable for resource-constrained IoT devices. **Intrusion Detection Systems**: Enhancing intrusion detection and prevention systems tailored for IoT environments.
Edge and Fog Computing	**Distributed Processing**: Exploring the use of edge and fog computing to process data closer to the source, reducing latency and bandwidth usage. **Resource Management**: Optimizing resource allocation and task scheduling in edge and fog computing environments.
AI and ML	**Predictive Analytics**: Leveraging AI and ML for predictive maintenance, anomaly detection, and other applications. **Adaptive Algorithms**: Developing adaptive algorithms that can learn and evolve with changing conditions and data patterns.
Standardization Efforts	**Unified Protocols**: Creating standardized protocols and frameworks to ensure interoperability between different IoT devices and platforms. **Regulatory Compliance**: Addressing regulatory and compliance issues related to data security and privacy.
Energy-Efficient Design	**Low-Power Hardware**: Designing low-power hardware components for IoT devices. **Energy Harvesting Techniques**: Researching new methods for energy harvesting, such as solar, thermal, and kinetic energy.
Scalable Architectures	**Network Optimization**: Developing scalable network architectures to handle the growing number of IoT devices and data traffic. **Load Balancing**: Implementing effective load balancing techniques to ensure reliable and efficient network performance.
Human-IoT Interaction	**User Interfaces**: Creating intuitive user interfaces for interacting with IoT devices and systems. **Accessibility**: Ensuring that IoT solutions are accessible to a diverse range of users, including those with disabilities.

4. IOT IN HEALTH CARE (H-IoT)

The IoT in healthcare, also known as the Internet of Medical Things (IoMT), consists of a network of networked devices that gather, analyze, and send health data. The incorporation of IoT in healthcare endeavors to increase patient care, optimize operational efficiency, and mitigate healthcare expenses. IoT in healthcare involves the use of smart devices, sensors, and software to create a connected environment where medical data can be seamlessly collected, analyzed, and acted upon. These devices range from wearable fitness trackers to sophisticated medical equipment that monitors vital signs and other health metrics. IoT in healthcare holds significant potential to transform the industry by enhancing patient care, improving operational efficiency, and reducing costs. As technology advances, addressing the challenges related to security, interoperability, and infrastructure will be crucial for realizing the full benefits of IoT in healthcare. The applications and benefits of H-IoT is given in Table 4.

4.1 Key Components of H-IoT

Wearable Devices: ***Fitness Trackers***: Track and analyze levels of physical activity, heart rate, and sleep patterns. ***Smartwatches***: Track vital signs and send alerts in case of abnormalities. ***Medical Wearables***: Devices like continuous glucose monitors for diabetes management.
Remote Patient Monitoring (RPM): Devices that allow healthcare providers to monitor patients' health data remotely, including blood pressure monitors, pulse oximeters, and ECG devices.
Smart Medical Devices: ***Connected Inhalers***: Track usage and help manage asthma. ***Smart Insulin Pens***: Monitor insulin doses and provide data for diabetes management. ***Implantable Devices***: Devices like pacemakers that transmit data to healthcare providers.
Telemedicine Platforms: Software and devices that facilitate remote consultations and care, allowing patients to connect with healthcare providers from anywhere.
Hospital IoT Systems: Smart beds, automated medication dispensers, and inventory management systems to improve hospital efficiency and patient care.

4.2 Challenges and Considerations

Data Security and Privacy: Protecting sensitive health data from cyber threats and ensuring compliance with regulations like HIPAA.
Interoperability: Facilitating easy communication and interoperability across various IoT devices and systems.
Reliability and Accuracy: Ensuring the accuracy of data gathered by IoT devices and the reliability of the systems that process and transmit this data.
Infrastructure: Developing the necessary infrastructure to support the widespread use of IoT in healthcare, including robust network connectivity and data storage solutions.
Regulatory Compliance: Navigating the complex regulatory landscape to ensure that IoT devices meet all necessary standards and requirements.

TABLE IV. APPLICATIONS AND BENEFITS

Applications and Benefits	
Enhanced Patient Care	• **Continuous Monitoring**: Real-time monitoring of patients' vital signs and health metrics enables early detection of potential issues and timely interventions. • **Personalized Treatment**: Data collected from IoT devices helps in tailoring treatment plans to individual patient needs.
Remote Healthcare	• **Telehealth Services**: IoT facilitates virtual consultations and remote monitoring, by minimizing the need for face-to-face appointments and broadening healthcare availability, particularly in remote regions.. • **Chronic Disease Management**: Patients with chronic conditions can be monitored remotely, improving disease management and reducing hospitalizations.
Operational Efficiency	• **Asset Management**: IoT helps in tracking and managing medical equipment, ensuring availability and proper maintenance. • **Workflow Optimization**: Automating routine tasks and improving resource allocation in healthcare facilities
Cost Reduction	• **Preventive Care**: Early detection and continuous monitoring help in preventing serious health issues, reducing the need for expensive treatments. • **Reduced Hospital Stays**: Remote monitoring and telemedicine reduce the need for prolonged hospital stays.
Improved Patient Experience	• **Convenience**: Patients can receive care and monitoring from the comfort of their homes. • **Engagement**: IoT devices empower patients to take an active role in managing their health.

4.3 H-IoT Technologies

The H-IoT technologies encompass a wide range of hardware and software solutions designed to improve healthcare delivery, patient monitoring, and overall wellness. These technologies collectively enable a comprehensive and integrated approach to healthcare, improving patient outcomes, efficiency of healthcare delivery, and reducing costs. Here are some key technologies in H-IoT:

Wearable Devices :

- ***Smartwatches and Fitness Trackers***: Devices like Apple Watch, Fitbit, and Garmin track physical activity, heart rate, sleep patterns, and more.
- ***Medical Wearables***: Devices such as continuous glucose monitors (CGMs) for diabetes management, ECG monitors, and blood pressure monitors.

Sensors :

- ***Biometric Sensors***: Measure physiological data such as heart rate, body temperature, and respiration rate.
- ***Environmental Sensors***: Monitor air quality, temperature, and humidity, which can impact health conditions like asthma.
- ***Implantable Sensors***: Devices implanted in the body to monitor critical health parameters, such as cardiac implants that track heart function.

Communication Technologies :

- ***Bluetooth and BLE (Bluetooth Low Energy)**:* Used for short-range communication between wearable devices and smartphones.
- ***Wi-Fi***: Enables devices to connect to the internet for data transmission to cloud services.
- ***Zigbee and Z-Wave***: Low-power, short-range wireless protocols used in home automation and medical devices.
- ***Cellular Networks (4G/5G*)**: Provide broader coverage and higher data transfer rates for remote monitoring and telemedicine.

Edge Computing :

- ***Edge Devices***: Localized processing units that perform initial data analysis close to the source, reducing latency and bandwidth usage.
- ***Fog Computing***: Extends cloud computing to the edge of the network, enabling data processing within the local network.

Cloud Computing :

- ***Data Storage***: Scalable storage solutions to handle vast amounts of health data.
- ***Big Data Analytics***: Tools for analyzing large datasets to identify trends, correlations, and patterns in health data.
- ***ML and AI***: Algorithms for predictive analytics, anomaly detection, personalized treatment plans, and decision support systems.

Telemedicine Platforms :

- ***Video Conferencing Tools***: Enable virtual consultations between patients and healthcare providers.
- ***Remote Monitoring Systems***: Collect and transmit patient data for continuous monitoring and management of chronic conditions.

Mobile Health Apps :

- ***Patient Portals***: Applications that allow patients to access their health records, schedule appointments, and communicate with healthcare providers.
- ***Wellness Apps***: Track fitness, diet, mental health, and provide personalized recommendations.

Integration Technologies :

- ***APIs (Application Programming Interfaces)**:* Facilitate data exchange between different systems and applications.
- ***Interoperability Standards***: Protocols like HL7 (Health Level 7), FHIR (Fast Healthcare Interoperability Resources), and DICOM (Digital Imaging and Communications in Medicine) ensure compatibility and seamless data exchange.

Security Technologies :

- ***Encryption***: Ensures data security during transmission and storage.
- ***Access Control***: Manages who can access data and ensures only authorized personnel can view or modify it.
- ***Blockchain***: Provides secure and tamper-proof records of health data transactions.

Data Analytics and AI :

- ***Predictive Analytics***: Uses historical data to predict future health events and outcomes.
- ***Natural Language Processing (NLP*)**: Extracts meaningful information from unstructured data like medical notes and patient records.
- ***Image Recognition***: AI algorithms analyze medical images for diagnostic purposes.

Robotics and Automation :

- ***Surgical Robots***: Assist surgeons in performing precise and minimally invasive procedures.
- ***Automated Medication Dispensers***: Ensure timely and accurate medication administration.

Network Infrastructure :

- ***IoT Gateways***: Act as intermediaries between IoT devices and the cloud, facilitating data aggregation and transmission.
- ***Network Management Systems***: Monitor and manage the health IoT network, ensuring reliability and performance.

4.4 Role and Significance of IoT in Healthcare

The role and significance of the IoT in healthcare are profound, as IoT technologies enhance patient care, streamline healthcare operations, and improve overall health outcomes. The role and significance of IoT in healthcare are transformative, offering numerous benefits such as improved patient outcomes, enhanced operational efficiency, and the potential for groundbreaking medical research. As IoT technology continues to evolve, its integration into healthcare systems is likely to expand, further revolutionizing the way healthcare is delivered and experienced. IoT healthcare trends are represented in figure 3. Table 5 indicates role and significance of IoT in Healthcare. Here are the key roles and their significance:

TABLE V. ROLE AND SIGNIFICANCE OF IOT IN HEALTHCARE

Parameter	Role	Significance
Enhanced Patient Monitoring and Care	IoT devices provide uninterrupted, instantaneous monitoring of patients' vital signs and health issues.	• Timely identification of health problems and prompt management may avert complications and enhance patient outcomes.y • Chronic disease management becomes more effective with continuous monitoring, reducing hospital readmissions.
Remote Patient Monitoring (RPM) and Telemedicine	IoT facilitates remote monitoring of patients and enables virtual consultations with healthcare providers.	• Enhances healthcare accessibility, particularly in remote and underprivileged regions. • Minimizes the need for frequent face-to-face appointments, therefore conserving time and money for both patients and healthcare professionals. • Helps manage patients with chronic conditions at home, improving their quality of life.
Operational Efficiency in Healthcare Facilities	IoT systems automate various processes in hospitals and clinics, such as patient flow management, asset tracking, and inventory management.	• Increases efficiency in healthcare delivery, allowing staff to focus more on patient care. • Reduces waste and optimizes the use of medical resources and equipment. • Enhances the overall patient experience by reducing wait times and improving service quality.
Data-Driven Decision Making	IoT devices gather vast quantities of health data that may be examined to acquire valuable knowledge and guide therapeutic judgments.	• Enables personalized medicine by tailoring treatments to individual patients based on their specific health data. • Supports predictive analytics, helping healthcare providers anticipate and mitigate potential health issues. • Improves the accuracy of diagnoses and the effectiveness of treatments.
Preventive Care and Wellness Management	IoT devices such as fitness trackers and smartwatches monitor lifestyle parameters like physical activity, sleep, and nutrition.	• Encourages individuals to adopt healthier lifestyles by providing real-time feedback and personalized recommendations. • Helps in early detection of potential health problems, allowing for preventive measures. • Reduces the overall burden on healthcare systems by promoting wellness and preventing disease.
Emergency Response and Management	IoT systems can detect emergencies such as falls, heart attacks, or other critical health events and alert healthcare providers or emergency services.	• Ensures rapid response to emergencies, potentially saving lives and reducing the severity of outcomes. • Provides peace of mind to patients and their families, especially for elderly or high-risk individuals.
Medication Management	IoT-enabled smart medication dispensers and trackers help patients adhere to their prescribed medication regimens.	• Ensures patients take their medications correctly and on time, improving treatment effectiveness. • Reduces the risk of medication errors and adverse drug interactions. • Provides healthcare providers with data on patient adherence, allowing for better management of treatment plans.
Research and Development	IoT-generated health data can be used for medical research and the development of new treatments and therapies.	• Accelerates the pace of medical research by providing large datasets for analysis. • Helps in identifying patterns and correlations that can lead to breakthroughs in understanding and treating various health conditions. • Supports clinical trials and drug development by providing real-time monitoring and data collection.

4.5 Limitation of IoT in Healthcare

While the IoT offers numerous benefits to healthcare, there are several limitations and challenges that need to be addressed for its full potential to be realized. Despite the significant potential of IoT in healthcare, addressing these limitations is crucial for its successful implementation and widespread adoption. Overcoming challenges related to security, interoperability, cost, data management, reliability, technical complexity, regulatory compliance, and ethical concerns will require concerted efforts from healthcare providers, technology developers, policymakers, and other stakeholders. Here are the key limitations:

Data Security and Privacy Concerns : IoT devices collect and transmit sensitive health data, making them attractive targets for cyberattacks.

Interoperability Issues : The lack of standardized protocols and data formats across different IoT devices and systems.

High Implementation and Maintenance Costs : The costs associated with implementing IoT systems in healthcare can be substantial.

Data Overload and Management : The sheer volume of data generated by IoT devices can be overwhelming.

Reliability and Accuracy of Devices : Ensuring the reliability and accuracy of data collected by IoT devices is critical.

Technical Complexity and Integration Challenges : Integrating IoT solutions into existing healthcare systems and workflows can be complex.
Regulatory and Compliance Issues : Navigating the regulatory landscape for IoT devices in healthcare can be difficult.
Ethical and Social Concerns : The use of IoT in healthcare raises ethical and social issues.

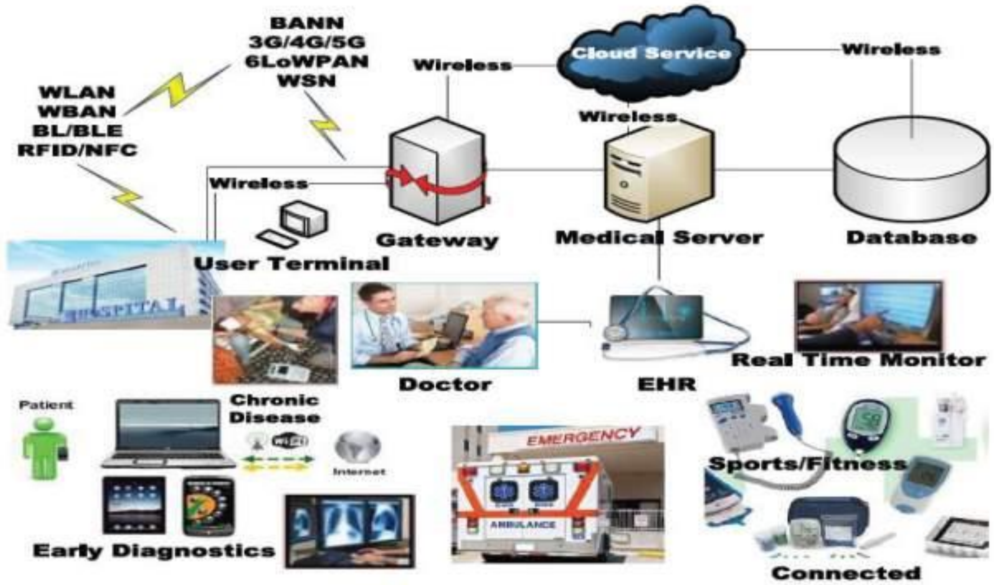

Fig. 3. IoT healthcare trends

5. INTRODUCTION TO ML

ML is a branch of AI focused on creating statistical models and algorithms that allow computers to carry out certain tasks without relying on explicit instructions [20]. Instead, ML systems learn from data to make predictions or decisions. ML is a potent technique that allows computers to acquire knowledge from data and enhance their performance without requiring explicit programming for certain tasks. Its applications span numerous industries, making it a cornerstone of modern AI. Understanding the basics of ML is essential for leveraging its capabilities to solve complex problems and make data-driven decisions.

5.1 Key Concepts

Learning from Data: In training data a set of examples used to train the model. The model learns patterns and relationships within this data. In testing data a separate set of examples used to evaluate the model's performance and generalization to new, unseen data.
Supervised Learning (SL): The model is trained on labeled data, where the input comes with the corresponding correct output. Examples are Classification (e.g., spam detection) and regression (e.g., predicting house prices).
Unsupervised Learning(USL): The model is trained on unlabeled data and must find patterns and relationships within the data. Examples are Clustering (e.g., customer segmentation) and dimensionality reduction (e.g., principal component analysis).
Reinforcement Learning (RL): The model learns by interacting with an environment and receiving feedback in the form of rewards or penalties. Examples are Game playing (e.g., AlphaGo) and robotics [21].
Semi-Supervised Learning (SSL): Combines labeled and unlabeled data for training, which can improve learning accuracy when labeled data is scarce.

5.2 Components of a ML System

Data Collection: Gathering relevant data from various sources to train and evaluate the model.
Data Preparation: Cleaning and preprocessing the data, including handling missing values, normalizing features, and splitting the data into training and testing sets.
Model Selection: Choosing an appropriate algorithm or model based on the problem type.
Training: Feeding the training data to the model and adjusting the model parameters to minimize errors using optimization techniques.

Evaluation: Assessing the model's performance using metrics such as accuracy, precision, recall, F1 score, and mean squared error on the testing data.
Hyperparameter Tuning: Adjusting model hyperparameters (settings not learned from data) to optimize performance.
Deployment: Integrating the trained model into a production environment to make predictions or decisions on new data.
Monitoring and Maintenance: Continuously monitoring the model's performance in the real world and updating it as needed to maintain accuracy and relevance.

5.3 Applications of ML

Healthcare: Disease diagnosis, personalized medicine, and predictive analytics.
Finance: Fraud detection, risk assessment, and algorithmic trading.
Retail: Customer segmentation, recommendation systems, and inventory management.
Automotive: Autonomous driving, predictive maintenance, and vehicle recognition.
Natural Language Processing: Speech recognition, language translation, and sentiment analysis.

5.4 ML Algorithms in IoT

ML algorithms are essential for improving the capabilities of IoT systems. They enable these systems to evaluate large volumes of data, generate predictions, and automate decision-making processes. ML algorithms greatly boost the functionality of IoT systems by allowing them to acquire knowledge from data, make informed choices, and automate intricate procedures. From basic linear models to advanced neural networks, these algorithms are essential for fully harnessing the potential of IoT in many applications and sectors. Various ML algorithms are shown in figure 4 and given in Table 6.

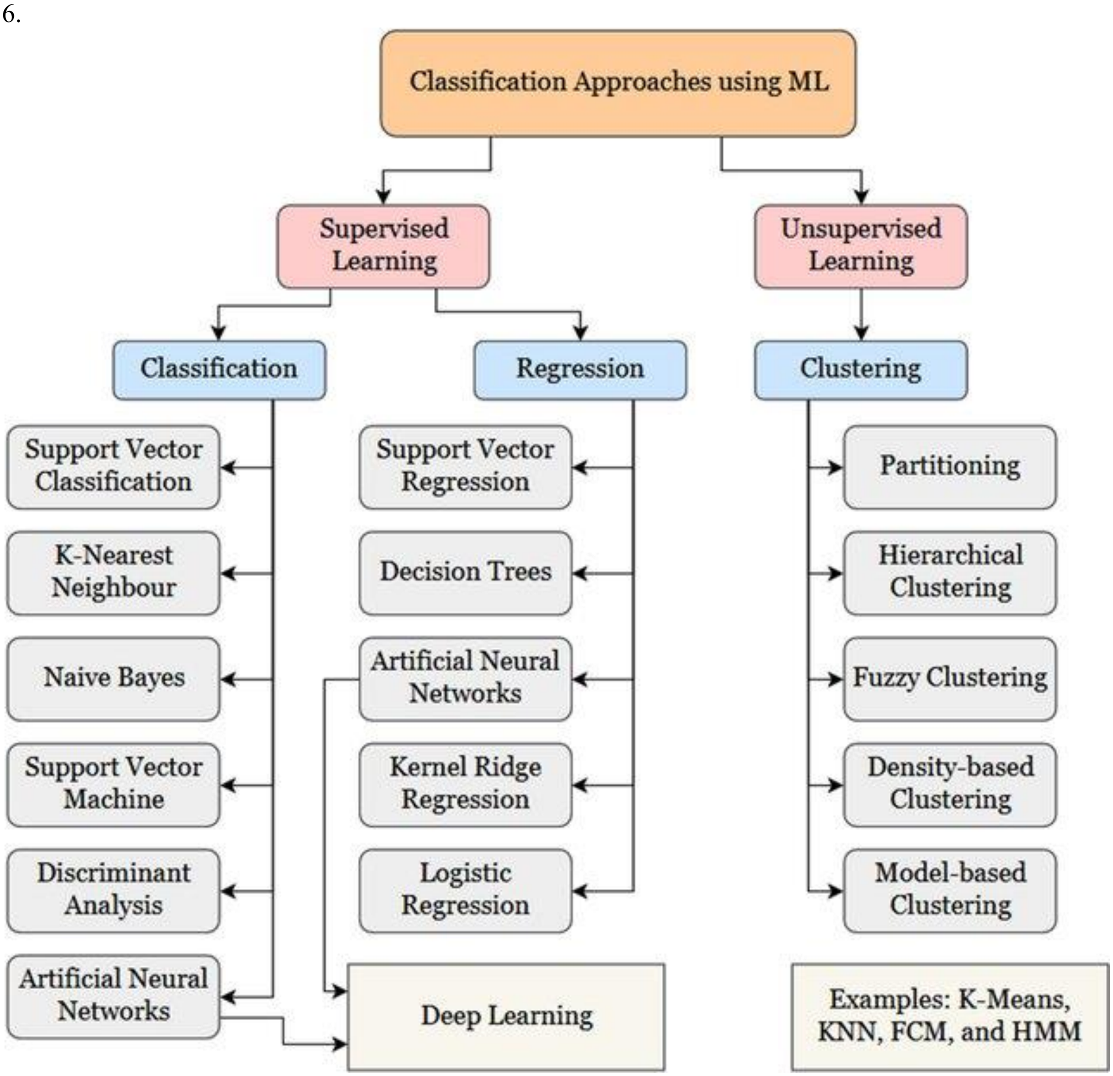

Fig. 4. Classification approaches using ML

TABLE VI. ML ALGORITHMS IN IOT

Algorithm	Explanation	Applications in IoT
Linear Regression	It is a straightforward and extensively used approach for predictive analysis. It represents the correlation between a variable that is influenced by other factors by using a linear equation to analyze collected data.	• Predicting energy consumption based on historical usage data. • Forecasting environmental parameters like temperature or humidity in smart homes.
Logistic Regression	It is used for binary classification problems. It calculates the likelihood that an instance is a member of a certain category.	• Detecting anomalies or faults in industrial equipment. • Classifying whether a patient's health metrics indicate a normal or abnormal condition in healthcare monitoring systems.
Decision Trees (DTs)	Used for the purpose of categorizing and predicting numerical values. The data is divided into subsets according to the input feature values, resulting in the creation of a decision tree-like model.	• Diagnosing faults in machinery by analyzing sensor data. • Classifying types of human activities (e.g., walking, running) based on wearable sensor data.
Random Forest (RF)	It is an ensemble learning technique that builds many DTs during training and produces the average forecast of the individual trees. It enhances precision and mitigates overfitting.	• Predicting equipment failure by analyzing patterns in sensor data from industrial machines. • Enhancing precision in agricultural monitoring systems by combining data from various sensors.
Support Vector Machines (SVM)	It is a kind of SL technique that is often used for both classification and regression applications. The algorithm identifies the hyperplane that achieves the highest possible margin between distinct classes.	• Intrusion detection in smart home networks. • Health condition monitoring by classifying normal and abnormal patterns in physiological data.
K-Nearest Neighbors (KNN)	It is a straightforward technique for classification and regression that relies on instances. The algorithm determines the label of a new instance by considering the majority vote of its KNN.	• Detecting anomalies in sensor data by comparing it with historical data. • Classifying activity types in wearable fitness trackers.
K-Means Clustering	It is an USL algorithm used for clustering. It partitions the data into k clusters based on feature similarity.	• Grouping similar devices or sensors in a smart city infrastructure for better management. • Segmenting customers based on usage patterns in smart utility grids.
Neural Networks (NNs)	A set of algorithms modeled after the human brain, capable of learning from data and recognizing patterns. They are used for complex tasks that require high-level abstraction.	• Image recognition in smart surveillance systems. • Predictive maintenance in industrial IoT by analyzing complex sensor data patterns.
Convolutional Neural Networks (CNNs)	Specialized NNs designed for processing structured grid data like images. They are highly effective in recognizing spatial hierarchies.	• Object detection and recognition in smart cameras. • Analyzing medical images for diagnostic purposes in healthcare IoT.
Recurrent Neural Networks (RNNs)	Specifically designed to handle the processing of input that occurs in a consecutive manner. Loops in these systems enable the retention of information, making them well-suited for jobs that involve time series data.	• Predicting future values of sensor data in environmental monitoring. • Analyzing sequences of events in industrial automation systems for fault detection.
Long Short-Term Memory Networks (LSTMs)	It is a specific sort of RNN that excels at learning and capturing long-term relationships, making it particularly well-suited for tasks involving sequence prediction.	• Forecasting energy usage patterns over time in smart grids. • Monitoring and predicting patient health trends in wearable healthcare devices.

5.5 Benefits of ML Analytics in IoT

Enhanced Decision Making: Provides data-driven insights for better and faster decision-making.
Improved Efficiency: Optimizes operations and reduces downtime through predictive maintenance.
Cost Savings: Identifies inefficiencies and areas for cost reduction, such as energy usage optimization.
Personalization: Enables tailored services and solutions, such as personalized healthcare treatments or customer experiences.
Scalability: Can handle vast amounts of data from numerous IoT devices, ensuring scalability in large deployments.

5.6 Challenges and Considerations

Data Privacy and Security: Ensuring the protection of sensitive data collected from IoT devices.
Interoperability: Integrating different IoT devices and systems to work seamlessly together.
Data Quality: Ensuring the accuracy and reliability of data used for training ML models.
Resource Constraints: Managing the computational and energy constraints of IoT devices, especially in edge computing scenarios.
Model Maintenance: Keeping ML models up-to-date with new data and changing conditions.

6. ML IN HEALTHCARE

ML is increasingly becoming a pivotal technology in healthcare, revolutionizing how medical professionals diagnose, treat, and manage diseases. By leveraging data-driven approaches, ML enhances decision-making, improves patient outcomes, and optimizes healthcare processes. Machine learning refers to the use of algorithms and statistical models that enable computers to learn from and make predictions based on data. In healthcare, ML can analyze vast amounts of clinical and non-clinical data, uncover patterns, and support clinical decision-making. ML is transforming healthcare by providing powerful tools for diagnosis, treatment, and management of diseases [22]. As healthcare organizations continue to adopt ML technologies, the potential for improved patient outcomes, operational efficiencies, and cost savings will grow. Addressing the challenges associated with data quality, interoperability, privacy, and ethical concerns will be crucial in realizing the full potential of ML in healthcare. With ongoing advancements in ML techniques and a focus on patient-centric care, the future of healthcare looks promising.

6.1 Key Areas of Application

Disease Diagnosis and Prediction : ML algorithms can analyze patient data, medical images, and laboratory results to assist in diagnosing diseases and predicting outcomes. The techniques used are classification algorithms, ML models. ML models can analyze X-rays, MRIs, and CT scans to detect conditions like tumors, fractures, and other abnormalities. For example, CNNs are widely used in radiology for image classification. ML can predict disease outbreaks or patient deterioration by analyzing historical health data, demographics, and environmental factors. For instance, predicting the likelihood of readmission for heart failure patients.

Personalized Medicine : ML can help tailor treatments based on individual patient profiles, including genetic information, lifestyle, and treatment history. The techniques used are Supervised learning for classification, clustering for identifying similar patient groups. ML algorithms analyze genomic data to identify mutations and predict responses to targeted therapies. Algorithms can suggest personalized treatment plans based on past treatment outcomes and patient characteristics.

Drug Discovery and Development : ML accelerates the drug discovery process by predicting the efficacy and safety of new compounds. The techniques used are Regression analysis, clustering, reinforcement learning for optimizing drug combinations. ML models can predict which chemical compounds are likely to be effective against specific diseases, reducing the time and cost of drug development. ML helps identify suitable patient populations for clinical trials, increasing the chances of successful outcomes.

Clinical Decision Support Systems (CDSS) : ML can enhance decision-making in clinical settings by providing evidence-based recommendations. The techniques used are Predictive modeling, natural language processing for analyzing clinical notes. CDSS can notify healthcare providers of potential adverse drug interactions or suggest alternative therapies based on patient history. ML models assess patient risk levels for various conditions, allowing for proactive management.

Remote Patient Monitoring and Telemedicine : ML can analyze data from wearable devices and remote monitoring tools to manage chronic conditions and enhance telemedicine services. The techniques used are Time-series analysis, anomaly detection. ML algorithms analyze data from devices like glucose monitors or heart rate monitors to provide real-time insights into patient health. ML-driven chatbots and virtual assistants can assist in patient triage and provide preliminary health assessments.

Operational Efficiency and Resource Management : ML can optimize healthcare operations by predicting patient flow, resource utilization, and operational bottlenecks. The techniques used are Time-series forecasting, clustering. Predictive models can forecast patient volume, allowing healthcare facilities to allocate staff effectively. ML algorithms can optimize inventory levels for medical supplies based on usage patterns.

6.2 Future Trends in ML and Healthcare

Integration of AI with Telehealth: Enhanced remote monitoring capabilities and AI-driven diagnostics through telehealth platforms.

Wearable Technology: Increased use of wearable devices for real-time health monitoring and data collection.

Natural Language Processing (NLP): Improved extraction of insights from unstructured clinical data (e.g., physician notes) to enhance decision-making.

Federated Learning: Collaborative ML approaches that allow training models on decentralized data without compromising privacy.

TABLE VII. CHALLENGES IN IMPLEMENTING ML IN HEALTHCARE

Parameter	Challenge	Solution
Data Quality and Availability	The effectiveness of ML algorithms relies on high-quality, representative data. Inconsistent, incomplete, or biased data can lead to inaccurate predictions and conclusions.	Implementing robust data governance practices and ensuring data standardization and normalization.
Interoperability	Healthcare systems often use divergent data formats and standards, posing difficulties in the integration of data from many sources.	Adopting standardized data formats (e.g., FHIR for health data) and interoperable systems.
Privacy and Security Concerns	Patient data is sensitive and subject to strict regulations. Ensuring data privacy and security is paramount.	Employing encryption, access controls, and anonymization techniques to protect patient data.
Regulatory and Ethical Issues	ML applications in healthcare must comply with regulatory standards and ethical considerations, including transparency, accountability, and informed consent.	Collaborating with regulatory bodies to ensure compliance and developing guidelines for ethical AI use.
Resistance to Change	Healthcare providers may be resistant to adopting new technologies due to concerns about reliability, training, and workflow disruptions.	Providing adequate training and demonstrating the value of ML applications in improving patient care and operational efficiency.

6.3 Role and Significance of ML in Healthcare

ML plays a transformative role in healthcare by enhancing diagnostics, treatment personalization, and operational efficiency. Overall, ML enhances the ability to deliver high-quality, efficient, and personalized healthcare, ultimately improving patient outcomes and reducing costs. Here are some key aspects of its significance:

Predictive Analytics: ML algorithms analyze patient data to predict disease outbreaks, patient deterioration, and treatment responses, enabling proactive care.

Diagnostic Accuracy: ML models can assist in diagnosing diseases by analyzing medical images and lab results, often achieving accuracy levels comparable to or better than human experts.

Personalized Medicine: Through the analysis of genetic information and patient histories, ML may assist in customizing medicines for specific patients, leading to enhanced results and reduced adverse effects.

Drug Discovery: ML accelerates drug discovery by predicting how different compounds will interact with targets, potentially reducing the time and cost of bringing new drugs to market.

Operational Efficiency: ML optimizes hospital operations by predicting patient admissions, optimizing staff allocation, and streamlining supply chain management.

Remote Monitoring: ML algorithms process data from wearable devices to monitor patients' health in real-time, allowing for timely interventions.

NLP: NLP, a subset of ML, is used to extract valuable insights from unstructured data in electronic health records, enabling better clinical decision-making.

Health Equity: ML can identify disparities in healthcare access and outcomes, helping to address inequities in treatment and care.

6.4 Benefits of ML in Healthcare

The benefits contribute to a more efficient, effective, and personalized healthcare system, ultimately improving patient outcomes and satisfaction. The benefits of ML in healthcare include:

Enhanced Diagnostic Accuracy: ML algorithms can analyze complex medical data, leading to more accurate and timely diagnoses, especially in medical imaging and pathology.

Personalized Treatment Plans: ML helps tailor treatments to individual patients by considering their unique genetic makeup, medical history, and response to previous therapies.

Predictive Analytics: ML can forecast disease outbreaks, patient deterioration, and treatment outcomes, allowing for proactive interventions and improved patient management.

Efficient Drug Discovery: ML accelerates the drug development process by identifying potential drug candidates and predicting their effectiveness, reducing time and costs associated with research.

Improved Patient Monitoring: ML algorithms analyze data from wearable devices and remote monitoring tools, enabling real-time health assessments and timely interventions.

Operational Efficiency: ML optimizes hospital operations by predicting patient flow, managing resources, and streamlining administrative tasks, leading to cost savings.

Data-Driven Decision Making: ML empowers healthcare providers with data insights, improving clinical decision-making and enhancing overall care quality.

Reduction of Human Error: Automated systems powered by ML reduce the likelihood of human errors in diagnosis and treatment, leading to safer patient care.

Identification of Health Disparities: ML can analyze large datasets to identify disparities in healthcare access and outcomes, informing policies to improve health equity.
Continuous Learning: ML systems can continually learn from new data, improving their performance and adaptability over time.

7. CONCLUSION AND FUTURE DIRECTION

The emergence of IoT has caused a fundamental change in the way healthcare facilities are designed and provided. The use of IoT-based technologies has not only enhanced the performance of products, but also closed the divide between healthcare delivery and the capabilities of equipment. The integration of IoT devices has initiated a significant transformation in the healthcare industry, particularly with the use of HIoT, which allows for the remote monitoring and tracking of patients. Incorporating cloud computing and virtual infrastructures enables caregivers to access real-time information, which in turn supports evidence-based therapy. This chapter has presented a comprehensive analysis of the advantages, obstacles, technology, and many uses of HIoT. An encouraging approach involves combining AI and ML algorithms with HIoT systems. Healthcare practitioners may use AI and ML to extract more profound understandings from the extensive data gathered by IoT devices. This allows for more precise diagnosis, tailored treatments, and preventive healthcare interventions. Moreover, the proliferation of HIoT in telemedicine and telehealth services is anticipated to fundamentally transform the healthcare industry. The use of HIoT enables the remote monitoring of patients and the provision of virtual consultations, hence enhancing healthcare accessible, particularly in rural or underserved regions. Another potential ways for development is the establishment of strong security and privacy protocols for HIoT systems. With the growing interconnectivity and reliance on IoT devices in the healthcare business, it is vital to prioritize the protection of sensitive patient data by maintaining its confidentiality, integrity, and availability. The development of standardized protocols, encryption techniques, and secure data transmission methods will be crucial in fostering confidence and facilitating the broad use of HIoT technology. In summary, the future of HIoT has significant potential to revolutionize healthcare delivery, enhance patient outcomes, and propel medical research forward. To fully harness the potential of the IoT in the healthcare ecosystem, it is crucial to continue doing research, fostering cooperation between industry and academics, and establishing regulatory frameworks.

Conflicts Of Interest

The authors declare no conflicts of interest.

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References

[1] M. Nasajpour, S. Pouriyeh, R. M. Parizi, M. Dorodchi, M. Valero, and H. R. Arabnia, "Internet of Things for current COVID-19 and future pandemics: An exploratory study," J. Healthc. Informatics Res., vol. 4, no. 4, pp. 325-364, 2020.
[2] D. Shin and Y. Hwang, "Integrated acceptance and sustainability evaluation of Internet of Medical Things: A dual-level analysis," Internet Research, 2017.
[3] Y. Liu, B. Dong, B. Guo, J. Yang, and W. Peng, "Combination of cloud computing and internet of things (IOT) in medical monitoring systems," Int. J. Hybrid Inf. Technol., vol. 8, no. 12, pp. 367-376, 2015.
[4] K. K. Vaigandla, M. K. Vanteru, and M. Siluveru, "An Extensive Examination of the IoT and Blockchain Technologies in Relation to their Applications in the Healthcare Industry," Mesopotamian J. Comput. Sci., vol. 2024, pp. 1–14, 2024. [Online]. Available: https://doi.org/10.58496/MJCSC/2024/001
[5] M. S. Rahman, N. C. Peeri, N. Shrestha, R. Zaki, U. Haque, and S. H. Ab Hamid, "Defending against the Novel Coronavirus (COVID-19) outbreak: How can the Internet of Things (IoT) help to save the world?," Health Policy Technol., vol. 9, no. 2, p. 136, 2020.
[6] M. Javaid, A. Haleem, R. Vaishya, S. Bahl, R. Suman, and A. Vaish, "Industry 4.0 technologies and their applications in fighting COVID-19 pandemic," Diabetes Metab. Syndr. Clin. Res. Rev., vol. 14, no. 4, pp. 419-422, 2020.
[7] B. Almadani, M. Bin-Yahya, and E. M. Shakshuki, "E-AMBULANCE: real-time integration platform for heterogeneous medical telemetry system," Procedia Comput. Sci., vol. 63, pp. 400-407, 2015.

[8] M. Nasajpour, S. Pouriyeh, R. M. Parizi, M. Dorodchi, M. Valero, and H. R. Arabnia, "Internet of Things for current COVID-19 and future pandemics: An exploratory study," J. Healthc. Informatics Res., vol. 4, no. 4, pp. 325-364, 2020.
[9] K. K. Vaigandla, R. Karne, M. Siluveru, and M. Kesoju, "Review on Blockchain Technology: Architecture, Characteristics, Benefits, Algorithms, Challenges and Applications," Mesopotamian J. CyberSecurity, vol. 2023, pp. 73–85, 2023. [Online]. Available: https://doi.org/10.58496/MJCS/2023/012
[10] R. Yadav, Ritambhara, K. K. Vaigandla, G. S. P. Ghantasala, R. Singh, and D. Gangodkar, "The Block Chain Technology to protect Data Access using Intelligent Contracts Mechanism Security Framework for 5G Networks," in Proc. 5th Int. Conf. Contemporary Computing and Informatics (IC3I), Uttar Pradesh, India, 2022, pp. 108-112, doi: 10.1109/IC3I56241.2022.10072740.
[11] S. Selvaraj and S. Sundaravaradhan, "Challenges and opportunities in IoT healthcare systems: a systematic review," SN Appl. Sci., vol. 2, no. 1, pp. 1-8, 2020.
[12] A. Rathee, T. Poongodi, M. Yadav, and B. Balusamy, "Internet of things in healthcare wearable and implantable body sensor network (WIBSNs)," in Soft Computing in Wireless Sensor Networks, pp. 193-224, Chapman and Hall/CRC, 2018.
[13] A. Darwish and A. E. Hassanien, "Wearable and implantable wireless sensor network solutions for healthcare monitoring," Sensors, vol. 11, no. 6, pp. 5561-5595, 2011.
[14] S. K. V, M. K. V, C. N. Azmea, and K. K. Vaigandla, "BCSDNCC: A Secure Blockchain SDN framework for IoT and Cloud Computing," Int. Res. J. Multidiscip. Technovation, vol. 6, no. 3, pp. 26–44, Apr. 2024, doi: 10.54392/irjmt2433.
[15] M. Hamdi, N. Boudriga, H. Abie, and M. Denko, "Secure wearable and implantable body sensor networks in hazardous environments," in Proc. 2010 Int. Conf. Data Communication Networking (DCNET), 2010, pp. 1-8, IEEE.
[16] S. R. Moosavi, T. N. Gia, A. M. Rahmani, E. Nigussie, S. Virtanen, J. Isoaho, and H. Tenhunen, "SEA: a secure and efficient authentication and authorization architecture for IoT-based healthcare using smart gateways," Procedia Comput. Sci., vol. 52, pp. 452-459, 2015.
[17] N. M. C. Hurtado, M. H. Zarifi, M. Daneshmand, and J. A. Llobet, "Flexible microdisplacement sensor for wearable/implantable biomedical applications," IEEE Sensors J., vol. 17, no. 12, pp. 3873-3883, 2017.
[18] Y. Liao, M. S. Leeson, M. D. Higgins, and C. Bai, "Analysis of in-to-out wireless body area network systems: Towards QoS-aware health internet of things applications," Electronics, vol. 5, no. 3, p. 38, 2016.
[19] K. K. Vaigandla, "Communication Technologies and Challenges on 6G Networks for the Internet: Internet of Things (IoT) Based Analysis," in Proc. 2nd Int. Conf. Innovative Practices in Technology and Management (ICIPTM), 2022, pp. 27-31, doi: 10.1109/ICIPTM54933.2022.9753990.
[20] N. Sivapriya, R. Mohandas, and K. K. Vaigandla, "A QoS Perception Routing Protocol for MANETs Based on Machine Learning," Int. J. Intell. Syst. Appl. Eng., vol. 12, no. 1, pp. 733–745, 2023. [Online]. Available: https://ijisae.org/index.php/IJISAE/article/view/4171
[21] K. K. Vaigandla, T. Mounika, N. Azmi, U. Urooj, K. Chenigaram, and R. K. Karne, "Investigation on machine learning towards future generation communications," in AIP Conf. Proc., vol. 2965, no. 1, AIP Publishing, 2024.
[22] C. Banapuram, A. C. Naik, M. K. Vanteru, V. S. Kumar, K. K. Vaigandla, "A Comprehensive Survey of Machine Learning in Healthcare: Predicting Heart and Liver Disease, Tuberculosis Detection in Chest X-Ray Images," SSRG Int. J. Electr. Commun. Eng., vol. 11, no. 5, pp. 155-169, 2024.