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TOPICAL REVIEW

Blockchain-IoT Healthcare Applications and Trends: A Review

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ABSTRACT Despite the increasing reliance on the Internet of Things (IoT) as a basic infrastructure for future applications. Integrating blockchain technology with IoT extensively helps provide basic security requirements owing to the built-in security structure of the blockchain. Healthcare IoT applications are one of the industries that will be revolutionized by using IoT-blockchain technology. This review aims to provide an integrated understanding of blockchain IoT healthcare applications. The methodology of our paper is to review the literature from 2018 to 2023, paying more attention to research that intersects and integrates IoT, Blockchain, and healthcare applications. This review addresses IoT-based blockchain types and technologies, healthcare applications, sensors, hardware tools, application databases, programming languages, software tools, challenges and open issues, and solutions with their advantages and limitations. We then compared our work with existing works on common metrics. The study in this paper includes 14 blockchain IOT healthcare applications: remote patient monitoring, patient tracking, disease prediction, tracking COVID-19, image retrieval, security of medical records, smart telemedicine, securing the Internet of Medical Things, big data, blockchain and sensors, accurate medical decisions, health monitoring, tracking soldiers, and solar energy.

INDEX TERMS Internet of Things (IoT), blockchain, integrating blockchain and IoT, blockchain-IoT (BIoT), COVID-19, IoT healthcare applications, Internet of Medical Things (IoMT), healthcare sensors.

I. INTRODUCTION

Currently, healthcare is witnessing significant development as a result of the development of the Internet of Things (IoT), blockchain, and wearable sensor technologies, which has led to improvements in the health sector in many applications, such as patient tracking, disease prediction, infectious disease-fighting (COVID-19), electronic medical record management, remote patient monitoring, and drug traceability.

The increased use of IoT devices has led to increased amounts of data and, thus, the emergence of challenges related to confidentiality and privacy.

For this reason, the authors used blockchain with the Internet of Things to maintain the confidentiality and security of data. Blockchain is used with the Internet of Things to maintain confidentiality and trust data owing to the nature of blockchain operations such as decentralization, distribution, and encryption [1].

Healthcare is defined as mental, physical, and social well-being, not just the absence of disease or disability.

The healthcare sector is considered one of the most critical sectors. Humanity's demand in the modern era is to obtain good healthcare, as receiving appropriate healthcare and access to the best health facilities is of great importance in society and a primary goal through which sharing is achieved between digital devices that collect data and its production-advanced-formatted information shared by doctors, patients, and caregivers [2].

There have been many changes in healthcare in a short period owing to modern technologies; what used to be done in weeks can now be done in just one day [3].

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Advanced technologies have been used in the health field because of the importance of healthcare, as artificial intelligence algorithms and wearable sensors are used to detect pathological conditions and abnormalities and help diagnose diseases [4].

Communication with the outside world generates new challenges regarding data confidentiality and information technology, which require careful study to obtain the desired benefits in the medical field, as the medical aspect is considered essential, and there is no place for error in it [5].

The Internet of Medical Things (IoMT) is a framing structure for smart medical devices, as these devices are linked to health services, applications, and systems via the Internet. Many challenges associated with IoT must be considered regarding health data privacy and security, availability, ease of data access, and scalability [6].

IoMT devices are wearable devices that collect private and sensitive data about the human body, which enables healthcare service providers to make appropriate decisions at the right time. Because of the sensitivity and confidentiality of data, they must be treated securely and confidentially so that users can be assured of their safety [7].

Blockchain is a technology that stores data in a ledger so that the data are saved in blocks. Each block is linked to others so that a blockchain is formed, and the data are transferred through a peer-to-peer network.

Finance and banking were considered the first fields to use blockchain technology, and today, blockchain is used in energy, industry, insurance, healthcare, and others.

Many features of blockchain make it useful in all fields, as it is distributed, decentralized, and secured, so there is no need for a central authority, as a consensus algorithm is used to archive data and reach agreement between nodes, where the ledger is distributed and maintained by agreement among all nodes within the network [8].

Because the blockchain is duplicated throughout a network of nodes, and each node has a stake in it, it is also known as state machine replication.

The two categories of permission and permissionless blockchains are widely separated; in a permissionless blockchain, anyone can validate transactions, but only specific groups can. Although speedier and more scalable, permission systems are more centralized. By contrast, public access to permissionless blockchain systems is possible [9].

Ethereum and Hyperledger Fabric are two types of blockchain technologies that serve different purposes. Ethereum is a public blockchain, meaning that all information is accessible to the public, making it ideal for applications that require interactions with the global community. In contrast, Hyperledger Fabric is designed for private use cases, such as supply chains, to ensure confidentiality and control access to sensitive information [10].

By integrating the IoT with Blockchain in healthcare applications, we can control patient data in real-time while storing data more securely and collecting patient data from different nodes. Blockchain and big data technologies are growing. We can efficiently store data using big data tools, and the combination of these two technologies meets the requirements of security and efficiency, which are among the most essential requirements for extensive data analysis [4].

Integrating Blockchain with the healthcare IoT will bring about significant transformations. This integration will create new paradigms and force us to reevaluate current systems and processes. In addition to securing user data and protecting privacy, blockchains can boost IoT adoption by improving security and privacy [5].

Blockchain has revolutionized the sharing of medical and e-health information through secure applications [6].

Healthcare IoT applications are an industry that will be revolutionized using blockchain technology. This integration has emerged as a cutting-edge technology for the decentralized sharing of medical records, ensuring the privacy of patient records, and monitoring of patients. In general, blockchains can be utilized for data management, specifically to improve data security, which includes data integrity, access control, and privacy preservation.

Blockchain capabilities such as immutability, encryption, transparency, auditability, and operational resilience can help solve most shortcomings of the IoT architecture.

The methodology of our paper is to review the literature from 2018 to 2023, paying more attention to research that intersects and integrates IoT, Blockchain, and healthcare applications. This review addresses blockchain types, technology, healthcare applications, sensors, hardware tools, application databases, programming languages, software tools, challenges, open issues, and solutions with advantages and limitations. We then compared our work with existing works on standard metrics. To implement a BIOT healthcare application, blockchain types, technologies, sensors, hardware platforms, databases, software languages, software tools, challenges, and solutions should be known, and most survey papers have yet to focus on the software languages, databases, tools, and hardware platforms used in BIOT healthcare applications.

This paper reviews blockchain-IoT healthcare applications and analyzes them in terms of blockchain types, technologies, sensors, hardware platforms, database applications, software tools, programming languages used, challenges, solutions, and research trends. Figure 1 shows the structure of the BIOT healthcare applications.

We present the merging of these two technologies by providing examples of Blockchain IOT healthcare applications, namely remote patient monitoring, patient tracking, disease prediction, tracking the COVID-19 pandemic, image retrieval for medical IoT systems, security of medical records, smart telemedicine, securing the Internet of Medical Things, Big data, blockchain and sensors, accurate medical decisions, health monitoring, tracking systems for soldiers, blockchain, and solar energy.

Our contributions can be summarized as follows:

- Present different software languages, databases, and tools used in Blockchain IoT healthcare applications, which most researchers have not focused on, to facilitate the selection of appropriate software languages and tools for implementing Blockchain IoT healthcare applications.
- Present different hardware and sensors used in Blockchain BIOT healthcare applications, which most researchers have not focused on, to facilitate the implementation of Blockchain BIOT healthcare applications
- Current challenges and relevant solutions in blockchain IoT healthcare applications.
- Finally, we review the blockchain types, technologies, healthcare applications, hardware, and software used in articles that integrate blockchain with BIOT in healthcare applications.

In this paper, a review of BIOT healthcare applications is conducted, and it is organized as follows.

- Section II: Blockchain Types.
- Section III: Blockchain technology.
- Section IV: BIOT Healthcare Applications.
- Section V describes the sensors and hardware platforms of IOT devices.
- Section VI presents the various BIOT databases for healthcare applications.
- Section VII, BIOT healthcare programming languages and software tools.
- Section VIII, Challenges and Solutions.
- Section IX presents the trends in BIOT healthcare applications.
- Section X, discussion.
- Section XI presents the conclusions.

Our study answers the following questions:

1. What are the different types of blockchain?
2. How can blockchain impact healthcare? Names of successful healthcare applications of blockchain technology.
3. What are the most popular wearable IoT sensors and their applications?
4. Which hardware platforms are the most commonly used in healthcare blockchain IoT applications?
5. What are the most commonly used databases for blockchain IoT healthcare applications?
6. What are the most commonly used programming languages and tools for Blockchain IoT healthcare applications?
7. In IoT applications in healthcare, what are the most common challenges and their associated solutions?

II. BLOCKCHAIN TYPES

This section will address Question 1 in our study.

As shown in Table 1, blockchain is divided into two types (permission and permissionless). Blockchain types such as Bitcoin and Ethereum do not require approval to join and participate in the consensus process. Permission blockchain types such as Hyper-ledger and Quorum need prior authorization to join the network and participate in the consensus process. These are also referred to as private or consortium blockchains, respectively. Permission is helpful when we need to restrict participation and access to data, especially when dealing with sensitive information, as is the case in the medical and healthcare industries. Table 1 shows a comparison between permissionless and permissioned blockchains.

As shown in Table 1, a permissionless blockchain is public, meaning that anyone can participate in the data validation and access processes. By contrast, a permission blockchain is a private or consortium, meaning that only permission entities can participate in data validation and access.

A. PUBLIC BLOCKCHAIN

Anyone can join and participate in the consensus process on a public blockchain, such as Bitcoin or Ethereum, without permission [1].

B. PRIVATE BLOCKCHAIN

Because it is entirely under the control of one entity, this type of blockchain is considered a centralized network. A regulatory body certifies the addition of new members and provides write-and-read permission in a private blockchain. This power may be exercised solely or collaboratively by all the participants.

Therefore, only specific actors are allowed access to and use it, yet everyone may consult it. Companies such as banks are primary users of this type of blockchain. Hyperledger Fabric and Multichain can be used for private blockchains [4].

C. CONSORTIUM BLOCKCHAIN

The consortium blockchain is private, and a group, rather than a single organization, is responsible. A consortium between known businesses is formed to select those who have access to the blockchain ledger, whose transactions may remain public, and who must be restricted to a smaller group of members [5].

Health data are stored both on- and off-chains. On-chain data means On-chain data are data with identity features and with the hash of all health data, but off-chain data means data stored in the form of document-oriented databases [11]

The following is a collection of authors who used blockchain types in their research.

The application type in [2] is the security of medical records and remote patient monitoring by using a consortium blockchain. While the authors in [13] and [14] presented the application type of medical record deposits using only a private blockchain, the authors in [3], [4], [5], [8], and [12] presented the application type of medical record security and remote patient monitoring using a private blockchain. On the other hand, the application type in [17] is the security of medical records using a public blockchain, the application type in [18] is medical image retrieval with privacy protection

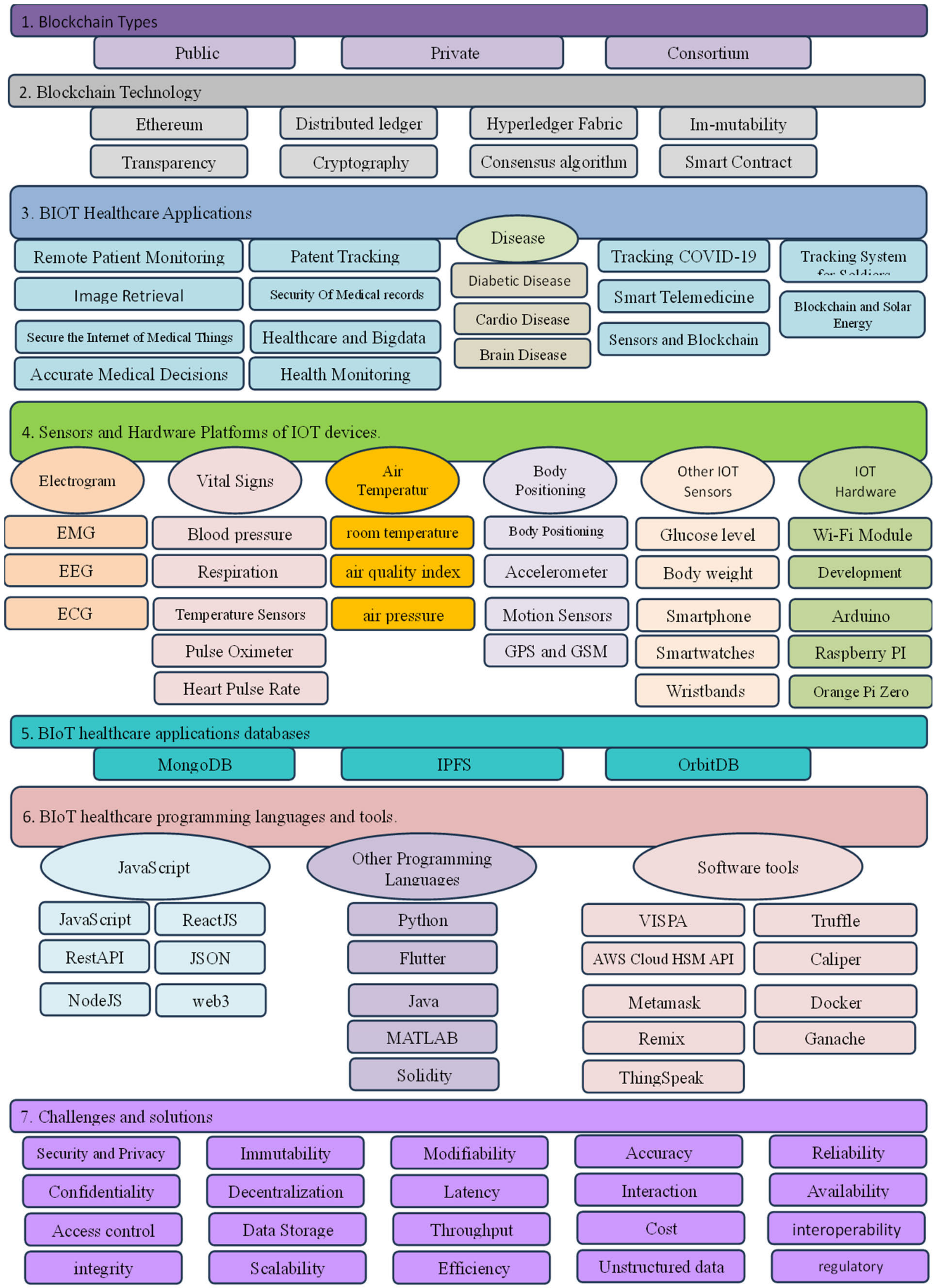

FIGURE 1. Structure of BIOT healthcare applications.

TABLE 1. Compare between permissionless and permissioned blockchains.

	Permissionless	Permissioned
Blockchain type	Public	Private/Consortium
Data validation	Anyone can participate in the validation process	Permissioned entities
Data access	Anyone can have access to data	Permissioned entities
Examples	Bitcoin/Ethereum	Hyperledger/Quorum

using a public blockchain, and the application type in [19] is remote patient monitoring and diabetic disease prediction using a public blockchain. In [20], authors conducted the authors applied an Accurate Medical Decision using a private blockchain.

Authors in [15] introduced the application type of diabetic-cardio disease prediction in fog computing using a consortium blockchain. In contrast, the authors in [16] introduced the application type of diabetic-cardio disease prediction in fog computing using a public blockchain.

The authors in [20] and [21] introduced an application for tracking the COVID-19 pandemic, securing medical records, and remote patient monitoring using a private blockchain. The authors in [22] presented an application for healthcare monitoring using a public blockchain. The authors in [23] addressed the application type of healthcare monitoring, securing the Internet of Medical Things, and security of medical records using a private blockchain. These studies are summarized according to blockchain and application types in Table 2.

Most healthcare applications use private blockchains and only authorized entities can participate in access and processing.

III. BLOCKCHAIN TECHNOLOGY

With the creation of Bitcoin in 2008, blockchain technology has become increasingly popular [3].

The system enables transaction transmission and storage by relying on a peer-to-peer network. Without centralized authority, transactions are organized into blocks and kept in a distributed ledger.

Technically stated, blockchain is a system that incorporates many other concepts and technologies, including Ethereum, a Distributed Ledger system, Hyperledger Fabric, Immutability, Transparency, Cryptography, Consensus Algorithm, and Smart Contract [1]. Figure 2 illustrates blockchain technologies.

A. ETHEREUM

To provide generalized blockchain technology in which all transaction-based state-machine concepts may be constructed, the project Ethereum was released as a platform in 2013. The goal is to provide end developers with access to a tightly integrated end-to-end system.

This enables software development using a trustworthy object messaging computing architecture, a hitherto unexplored computing paradigm. Ethereum is an example of a blockchain with integrated decentralized transactions and a complete execution environment that allows the system to carry out calculations. However, every node in the blockchain must have access to all records [2].

B. DISTRIBUTED LEDGER

The ledger is shared among all blockchain participants in a distributed ledger blockchain, which can span numerous businesses. Records are kept in a distributed ledger continuously rather than in sorted blocks, and can be either private or public [24].

C. HYPERLEDGER FABRIC

Developed by consensus, the hyperledger is a distributed peer-to-peer ledger.

A new generation of transactional applications that establish trust, accountability, and transparency at their core while streamlining business processes and legal restraints can be built using Hyperledger, a blockchain combined with a system for "smart contracts" and other supporting technologies.

By protecting intellectual property rights and implementing necessary standards, hyperledgers promote the community-based development of blockchain technologies [2].

D. IMMUTABILITY

Blockchain immutability occurs because their transaction data are tamper-proof, which means they cannot be altered or withdrawn [25].

E. TRANSPARENCY

The primary benefit of blockchain is transparency, which allows the creation of an unchangeable public record of transactions and the ability to trace them from their origin to their destination [26].

Additionally, transparency provides financiers, policymakers, and investors with the knowledge they need to be

TABLE 2. Blockchain types used in recent research.

Blockchain types	Application types	Articles
Public	Diabetic-Cardio Disease Prediction in Fog Computing using (SCA_WKNN) algorithm	[16]
Public	Security of medical records	[17]
Public	medical image retrieval with privacy protection	[18]
Public	remote patient monitoring and Diabetic Disease Prediction	[19]
Public	Healthcare monitoring	[22]
Private	Security of medical records and remote patient monitoring	[3] [4] [5] [8] [12]
private	Accurate Medical Decision	[20]
private	Tracking COVID-19 Pandemic, Security of medical records, remote patient monitoring, and Security of medical records	[21]
private	Security of medical records	[13] [14]
private	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Consortium	Security of medical records and remote patient monitoring	[2]
Consortium	Diabetic-Cardio Disease Prediction in Fog Computing	[15]

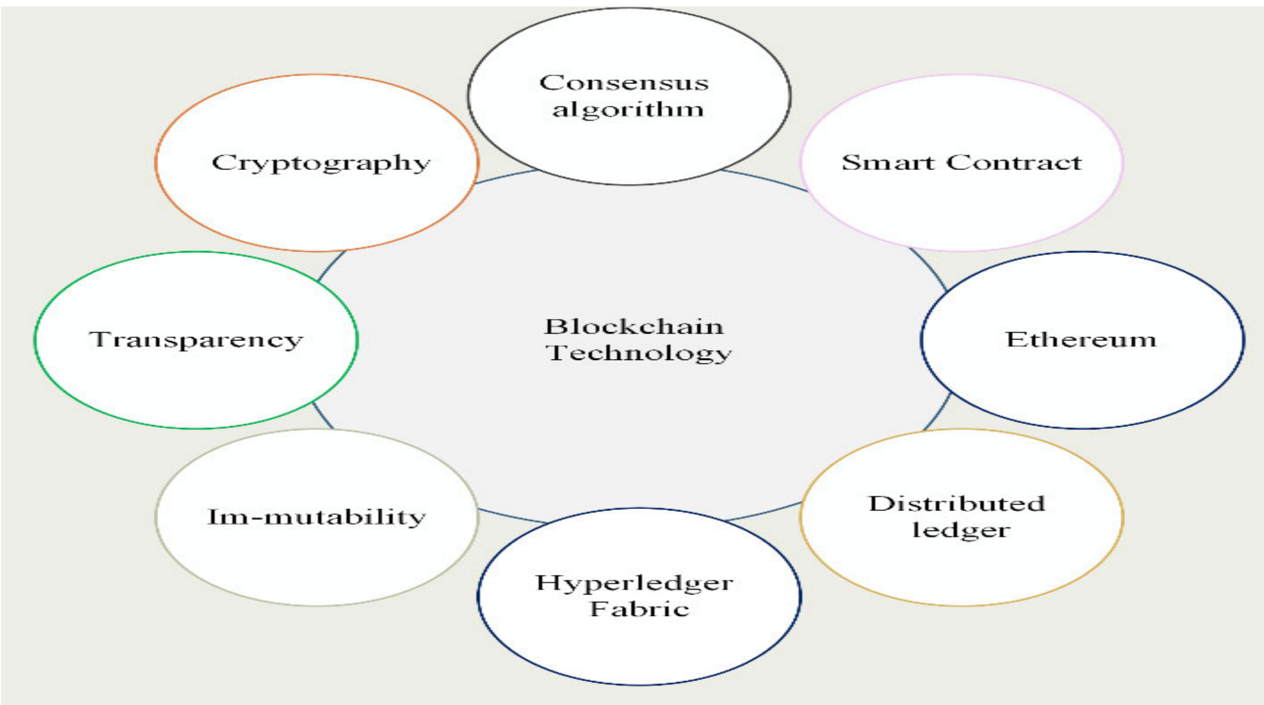

FIGURE 2. Blockchain technologies.

accountable for and make responsible decisions about the sustainability of supply chains [27].

F. CRYPTOGRAPHY

The conversion of data and files from a well-known formula to other types of files is a component of encryption in terms of information technology. There are various encryption algorithms with different characteristics. Depending on the application, the correct algorithm can be selected [28].

Finding new cryptographic strategies to enhance blockchain solutions is always possible because cryptography is a large area of study [29].

G. CONSENSUS ALGORITHM

Owing to its decentralized nature, the blockchain has scattered nodes throughout the network. The Byzantine Generals (BG) problem is analogous to the problem in which all network nodes establish consensus (i.e., general agreement).

The BG dilemma arises when the generals in charge of the Byzantine army disagree with one another during the assault. Failure results from certain generals preferring assault, while others do not. Owing to the absence of a central node that maintains the ledger of all nodes, it is difficult for nodes in a dispersed network to reach a consensus.

Blockchain can use different methods to reach consensus; further, consensus algorithms are classified as proof-based and voting-based consensus algorithms [30].

H. SMART CONTRACT

A set of computer programs, called smart contracts, is used to simplify the exchange of money, assets, or data. It becomes autonomous and impossible for a third party to stop or interfere with it once it is connected to the blockchain. In healthcare, smart contracts and blockchain technology are regarded as a secure way to transfer data from remote patient monitoring devices or to share the patient's record electronically. This is because smart contracts are distinguished by allowing only authorized devices or people to access the patient's history and attachments.

Additionally, they support interoperability through cooperative version control to keep the record consistent. [3]. Below is a collection of authors who have used blockchain technologies in their research. In [2], the application type was secure data management and remote patient monitoring, using Ethereum and Hyperledger Fabric blockchain technologies. In [3], the application type was the security of medical records and remote patient monitoring, using Ethereum and Smart Contract blockchain technologies. In [4], the application type was the security of medical records and remote patient monitoring using Ethereum blockchain technology. In [5], the application type was Security of medical records and remote patient monitoring, using Hyperledger Fabric blockchain technology. In [6], the application type was the security of medical records using Distributed ledger blockchain technology. In [7], the Internet of Medical Things application type was secure using Elliptic Curve Cryptography (ECC) blockchain technology. In [8], the application type was Security of medical records and remote patient monitoring, using Cryptography, Smart Contract, and Consensus algorithm blockchain technologies. In [9], the application type was the Security of medical records, using a cryptographic hash of the papers. In [12], the application type was the security of medical records and remote patient monitoring, using Ethereum, Immutable, Transparency, and smart contract blockchain technologies. In [13], the application type was the security of medical records, using Ethereum and Smart Contract blockchain technologies. In [14], the application type was the security of medical records using Ethereum, distributed ledgers, and innovative contract blockchain technologies. In [15], the application type was Diabetic-Cardio Disease Prediction in Fog Computing, using Distributed ledger, Transparency, and Consensus algorithm blockchain technologies. In [16], the application type was Diabetic-Cardio Disease Prediction in Fog Computing, using Ethereum blockchain technology. In [17], the application type was the Security of medical records, using Distributed ledger blockchain technology. In [18], the application type was medical image retrieval with privacy protection, using Ethereum and Smart Contract blockchain technologies. In [19], the application type was remote patient monitoring and diabetic disease prediction, using Ethereum, Distributed ledger, Transparency, and Smart Contract blockchain technologies. In [21], the application type was TrackingCOVID-19Pandemic, Security of medical records and remote patient monitoring, using Hyperledger Fabric, Distributed ledger, and Smart Contract blockchain technologies.

In [22], the application type was healthcare monitoring, using distributed ledger blockchain technologies. In [23], the application type was healthcare monitoring, securing the Internet of Medical Things, and securing medical records using Hyperledger Fabric, consensus algorithms, and smart contract blockchain technologies. In [31], the application type addressed the COVID-19 crisis and telemedicine, using distributed ledger, immutability, Consensus algorithm, and smart contract blockchain technologies. In [32], using Smart Contract blockchain technology, the application type was secure medical data management, telemedicine, and disease prediction. In [33], the application type was fast Internet of Things (IoT) and remote patient monitoring systems; authors used lightweight cryptographic techniques. They used ARX and double encryption to enhance symmetric critical security across the network. Moreover, they used Diffie-Hellman key exchange technology for the blockchain-based network, which protects the public key from unauthorized access and smart contracts. In [34], the application type was Smart Telemedicine, remote patient monitoring, and prediction of diseases using transparent blockchain technology.

In [35], the application type was healthcare data security, using Consensus algorithm blockchain technology.

In [36], the application type was a healthcare monitoring and tracking system for soldiers, using Distributed Ledger, Cryptography, hashing, and Immutable blockchain technologies.

In [37], the application type was the security of medical records and remote patient monitoring, using Ethereum, RSA, and DES Cryptography algorithms, Immutable, and smart contact blockchain technologies.

In [38], the application type was healthcare monitoring, solar energy, and blockchain, using smart contract blockchain technologies. In [39], the application type was the security of medical records and smart telemedicine, using a Hyperledger fabric blockchain platform, transparency, and smart contract blockchain technologies. In [40], the application type was Security, high-speed medical records, and brain disease prediction, using smart contracts and distributed ledger blockchain technologies. In [41], the application type was healthcare monitoring, using Ethereum, distributed ledger, and smart contract blockchain technologies.

These studies are summarized according to blockchain technology and application type, as shown in Table 3.

Many blockchain technologies are used in blockchain IOT healthcare applications like Ethereum, Distributed ledger, Hyperledger Fabric, immutability, Transparency, Consensus algorithm, Smart Contract, and cryptography.

Furthermore, many algorithms are used in cryptography technologies like Elliptic Curve Cryptography (ECC), lightweight ARX encryption, double encryption, Diffie-Hellman key exchange technology, RSA and DES Cryptography algorithms, and cryptographic hash of the records.

IV. BIOT HEALTHCARE APPLICATIONS

This section will solve Question 2 of our paper; there has been a growing interest in healthcare issues recently due to the search for safer and faster ways to serve patients and monitor patients remotely using Internet of Things technology. As the number of IoT devices increases, security and privacy issues arise. To solve these problems, many studies have presented using blockchain technology to ensure the security of device data and patient information [3]. In this section, we have tried to collect most of the healthcare applications of Blockchain IOT technology; Figure 3 shows the Blockchain IOT healthcare applications we will discuss.

A. REMOTE PATIENT MONITORING (RPM)

A subtype of telemedicine called remote patient monitoring (RPM) enables people to use portable medical equipment to gather and transmit patient-generated health data (PGHD) to healthcare professionals.

These devices include typical physiological data that can be gathered utilizing a remote patient monitoring system, such as weight, blood pressure, and heart rate.

Once patient information has been gathered, it is delivered to the doctor's office using a software program that can be downloaded and installed on desktops or mobile devices. [3].

B. PATIENT TRACKING

Inside a hospital or healthcare facility, a system for keeping track of patients is an integrated system with a base station (coordinator), tracking routers (placed at critical locations inside the facility), sensor pendants for patients and caregiver units, and other peripheral devices [74]. Aids caregivers in recognizing specific behaviors or areas as risky so they can get alarm messages when these behaviors are found [1].

C. DISEASE PREDICTION

The system used to Predict Disease Prediction utilizing machine learning models is a method that uses symptoms provided by patients or other users to forecast diseases. The system analyzes the user's signs as input and returns the likelihood that the disease will occur as the output [69].

D. FIGHTING COVID-19 PANDEMIC

An IoT and AI-based method for remotely detecting the COVID-19 disease so that it can be stopped early [1].

E. IMAGE RETRIEVAL FOR MEDICAL IOT SYSTEMS

The variety and quantity of medical images have greatly expanded with the introduction of IoT devices for the medical industry.

Medical image retrieval facilitates disease diagnosis and enhances medical image processing. However, as medical photos contain patients' private and sensitive information, it can cause them to worry about their privacy [18].

F. SECURITY OF MEDICAL RECORDS

Healthcare is one of the most sensitive industries since it deals with sensitive data, and privacy, security, access control, and the accessibility of medical records are significant concerns. Transmission, storage, and manipulation are three main stages where security in this industry must be guaranteed. There are numerous studies using blockchain to secure medical records [8].

G. SMART TELEMEDICINE

Modern telemedicine technology uses communication to help doctors virtually visit their patients by using recorded video, email, or live video and obtaining patient information about their illnesses.

A way to instantly exchange resources with any hospital or doctor worldwide is through telemedicine [34].

H. SECURE THE INTERNET OF MEDICAL THINGS

Beyond 50 billion devices across a wide range of application domains are expected to be connected through the Internet of Things.

However, user security and privacy remain significant IoMT concerns [7].

I. HEALTHCARE AND BIG DATA

Generating enormous amounts of medical big data by intelligent Internet of Things (IoT) devices makes this another massive industry to investigate [70]

J. SENSORS AND BLOCKCHAIN

A sensor is a piece of equipment that receives a signal or stimulus and reacts to it by producing an electrical signal. The output signals represent various electrical signals, such as current or voltage. A sensor is a tool that receives multiple signals, such as physical, chemical, or biological signals and transforms them into an electric signal. Based on the uses, input signal, conversion method, and material properties of the sensor, such as price, accuracy, or range, the sensors are divided into many types [51].

K. ACCURATE MEDICAL DECISION

Non-communicable illness diagnoses are sometimes incomplete, undesired, or unnecessary. Therefore, we need accurate medical decisions to lessen the burden of sickness, promote public health, and effectively treat any disease.

TABLE 3. Research in blockchain technologies.

Blockchain Technology	Application types	Articles
Ethereum	Security of medical records and remote patient monitoring	[2] [3] [4] [8] [72] [37]
Ethereum	Diabetic-Cardio Disease Prediction in Fog Computing	[16]
Ethereum	medical image retrieval with privacy protection	[18]
Ethereum	remote patient monitoring and Diabetic Disease Prediction	[19]
Ethereum	Accurate Medical Decision	[20]
Ethereum	Security of medical records	[13] [14]
Ethereum	Health care monitoring	[41]
Distributed ledger	Security of medical records	[6] [17] [14]
Distributed ledger	Diabetic-Cardio Disease Prediction in Fog Computing	[15]
Distributed ledger	addressing the COVID-19 crisis and telemedicine	[31]
Distributed ledger	addressing the COVID-19 crisis, Security of medical records, and remote patient monitoring	[21]
Distributed ledger	remote patient monitoring and Diabetic Disease Prediction	[19]
Distributed ledger	Accurate Medical Decision	[20]
Distributed ledger	healthcare monitoring and tracking system for soldiers	[36]
Distributed ledger	Security and high-speed medical records and brain disease prediction	[40]
Distributed ledger	Health care monitoring	[41] [22]
Hyperledger Fabric	Security of medical records and remote patient monitoring	[2] [5]
Hyperledger Fabric	addressing the COVID-19 crisis, Security of medical records, and remote patient monitoring	[21]
Hyperledger Fabric	Security of medical records and Smart Telemedicine	[39]
immutability	addressing the COVID-19 crisis and telemedicine	[31]
immutability	Accurate Medical Decision	[20]
immutability	healthcare monitoring and tracking system for soldiers	[36]
immutability	Security of medical records and remote patient monitoring	[37] [12]
Transparency	Diabetic-Cardio Disease Prediction in Fog Computing	[15]
Transparency	Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]
Transparency	remote patient monitoring and Diabetic Disease Prediction	[19]
Transparency	Security of medical records and remote patient monitoring	[8] [33] [12]
Transparency	Accurate Medical Decision	[20]
Transparency	Security of medical records and Smart Telemedicine	[39]
Cryptography	Security of medical records and remote patient monitoring using lightweight ARX encryption and double encryption and Diffie-Hellman key exchange technology	[33]
Cryptography	healthcare monitoring and tracking system for soldiers using cryptography and hashing	[36]
Cryptography	Security of medical records and remote patient monitoring using RSA and DES Cryptography algorithms	[37]
Cryptography	Security of medical records using a cryptographic hash of the records	[9]
Consensus algorithm	Security of medical records and remote patient monitoring application	[8][72]
Consensus algorithm	Diabetic-Cardio Disease Prediction in Fog Computing	[15]
Consensus algorithm	addressing the COVID-19 crisis	[31]
Consensus algorithm	Security of medical records	[35]

TABLE 3. *(Continued.)* **Research in blockchain technologies.**

Consensus algorithm	Accurate Medical Decision	[20]
Smart Contract	Security of medical records and remote patient monitoring	[3] [8] [33] [37] [12]
Smart Contract	addressing the COVID-19 crisis and telemedicine	[31]
Smart Contract	addressing the COVID-19 crisis, Security of medical records, and remote patient monitoring	[21]
Smart Contract	medical image retrieval	[18]
Smart Contract	Security of medical records, telemedicine, and disease prediction	[32]
Smart Contract	remote patient monitoring and Diabetic Disease Prediction	[19]
Smart Contract	Accurate Medical Decision	[20]
Smart Contract	Healthcare monitoring, solar energy, and blockchain	[38]
Smart Contract	Security of medical records and Smart Telemedicine	[39]
Smart Contract	Security of medical records	[13] [14]
Smart Contract	Security and high-speed medical records and brain disease prediction	[40]
Smart Contract	Health care monitoring	[41]

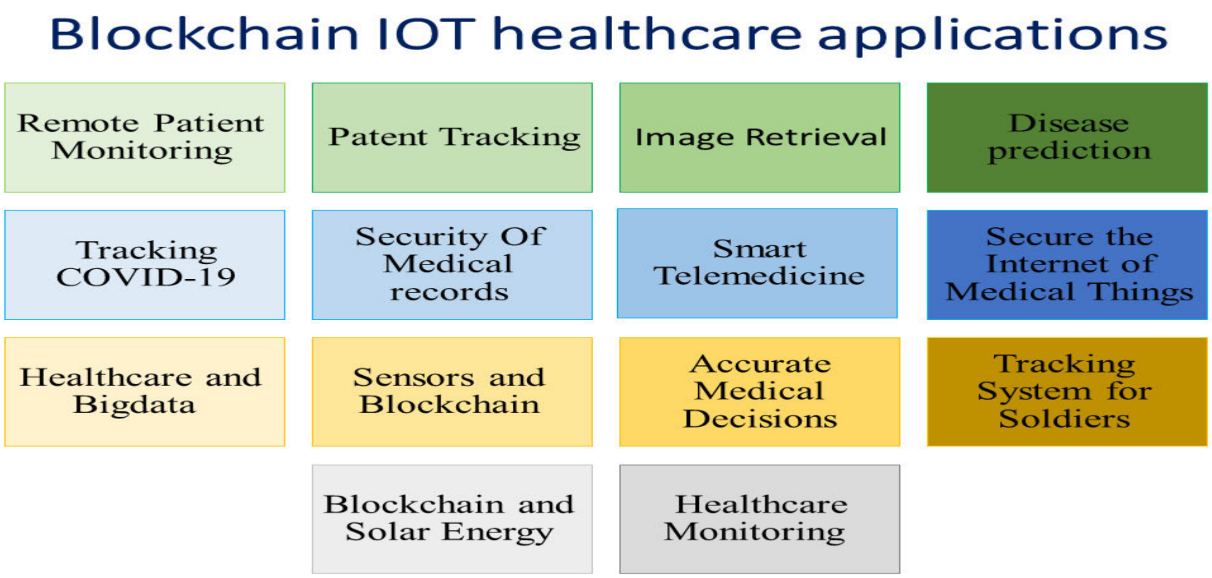

FIGURE 3. **Blockchain IoT healthcare applications.**

Many problems that electronic health records (EHR) or health information exchange (HIE) have yet to be able to solve will be resolved by accurate medical decisions [20]

L. HEALTHCARE MONITORING

A system for monitoring healthcare that would deliver the greatest possible medical care to everyone, everywhere, at all times. Many contemporary technologies are combined to address the growing need for solutions to health-related issues. There are numerous current studies in this area [38].

M. TRACKING SYSTEM FOR SOLDIERS

Various studies have been done on military tracking systems. The application can be installed on the soldier's body using GPS and other sensors to monitor their condition and current location [36].

N. BLOCKCHAIN AND SOLAR ENERGY

Solar energy is used to provide a power supply to the sensors. Many applications use blockchain technology with solar energy to ensure the accuracy of data blockchain can be

TABLE 4. Research in BIOT healthcare applications.

BIOT healthcare Application type	Articles
Remote Patient Monitoring	[2] [3] [4] [5] [6] [8] [76] [33] [34] [49] [19] [72] [21] [37]
Patient Tracking	[4] [76] [74]
Disease Prediction	[32] [34] [15] [16] [45] [46] [75]
Diabetic-Cardio Disease Prediction	[15] [16]
Diabetic Disease Prediction	[19]
Cardio Disease Prediction	[45] [46]
Brain Diseases prediction	[40]
Tracking Covid-19 Pandemic	[31] [21] [75]
Smart Telemedicine	[31] [32] [34] [39]
Image Retrieval for Medical IoT systems	[18]
Security of Medical Records	[2] [5] [8] [13] [17] [32] [73] [35] [72] [21] [37] [12] [39] [14][40] [23] [11]
Secure the Internet of Medical Things	[7] [23]
Healthcare and Big data	[70]
Sensors and Blockchain	[50]
Accurate Medical Decision	[20] [40]
Healthcare Monitoring	[36] [38] [41] [22] [23]
Tracking system for Soldiers	[36]
Blockchain and Solar energy	[38]
High-speed medical record	[40]

used [38]. Table 4 displays a group of articles and BIOT healthcare applications.

Based on Table 4, the primary blockchain IoT healthcare applications are securing medical records, remote patient monitoring, disease prediction, and others. Additionally, Figure 4 displays various healthcare applications.

V. SENSORS AND IOT HARDWARE PLATFORM DEVICES

This section will solve Question 4 of our paper.

IoT enables incorporating sensors into real-world objects to gather health information like vital signs. Due to their Internet connectivity, these gadgets may exchange data and give the medical staff a real-time update on a patient's health. Sensors and IoT devices make it possible to gather patient data and share it with healthcare professionals so they can analyze it [1].

Figure 5 shows the sensors and IOT hardware platforms we will discuss.

A. ELECTROGRAM SENSORS

An Electrogram sensor records the electrical activity of many organs, including the heart and brain, by keeping track of variations in electric potential [42]. Electroencephalogram (EEG), electrocardiogram (ECG), and Electromyography (EMG) are the three electrogram sensors that are typically used.

1) ELECTROENCEPHALOGRAM (EEG)

Monitoring and storing data regarding the electrical activity of the human brain is done via an EEG.

EEG signals comprise the rhythmic and spontaneous firing of brain cells. It has been hypothesized in neuroscience and psychology that EEG signals can characterize human behavior and affective brain states and aberrant brain conditions and cognitive impairments like epilepsy, Parkinson's disease, and Alzheimer's [4].

2) ELECTROCARDIOGRAM (ECG)

The transmission of impulses via the heart, which ultimately spreads throughout the body, generates electric currents. An electrocardiograph can be used to record these impulses and detect them on the body's surface. The electrical changes during the cardiac cycle are depicted visually on an electrocardiogram (ECG or EKG) (Figure 6). Three different waves, known as deflection waves, comprise the typical EKG; for instance, the tiny P wave shows that the atria depolarized right before atrial contraction—figure 6. Electrocardiogram [43]

The massive QRS complex resulting from ventricular depolarization has a convoluted form because of the differences in size between the two ventricles and the time delays necessary for both chambers to depolarize. Before ventricular contraction, it happens. The T wave is produced by currents that spread during ventricular repolarization. The massive QRS complex hides the atria's repolarization, which takes place during the QRS gap.

Understanding what an EKG does and does not reveal is essential. An EKG is just a time and voltage log.

Although we can and often do infer it, muscle contraction does not always occur after excitement. Second, nodal tissue activity, which can only be assumed as a muscular contraction, is not captured by an EKG; instead, it only records electrical events in relatively considerable volumes of muscle tissue (i.e., the majority of the heart muscle).

However, variations in the EKG's time intervals and anomalies in the deflection help identify problems with the hepatic conduction system [43].

3) ELECTROMYOGRAPHY (EMG)

EMG is a medical procedure that analyzes and tracks skeletal muscle electrical impulses. A diagnostic tool called an electromyogram is used to perform electromyography, and it produces an electromyogram report [44].

Below is a group of authors who used electrogram sensors in their research. In [4], the application type was the

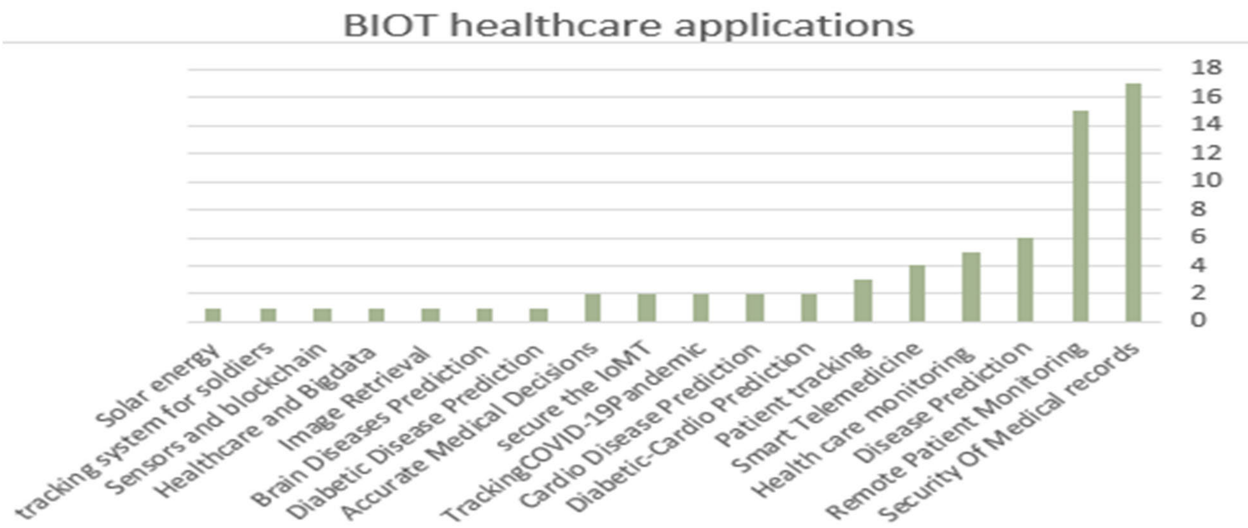

FIGURE 4. **BIOT healthcare applications.**

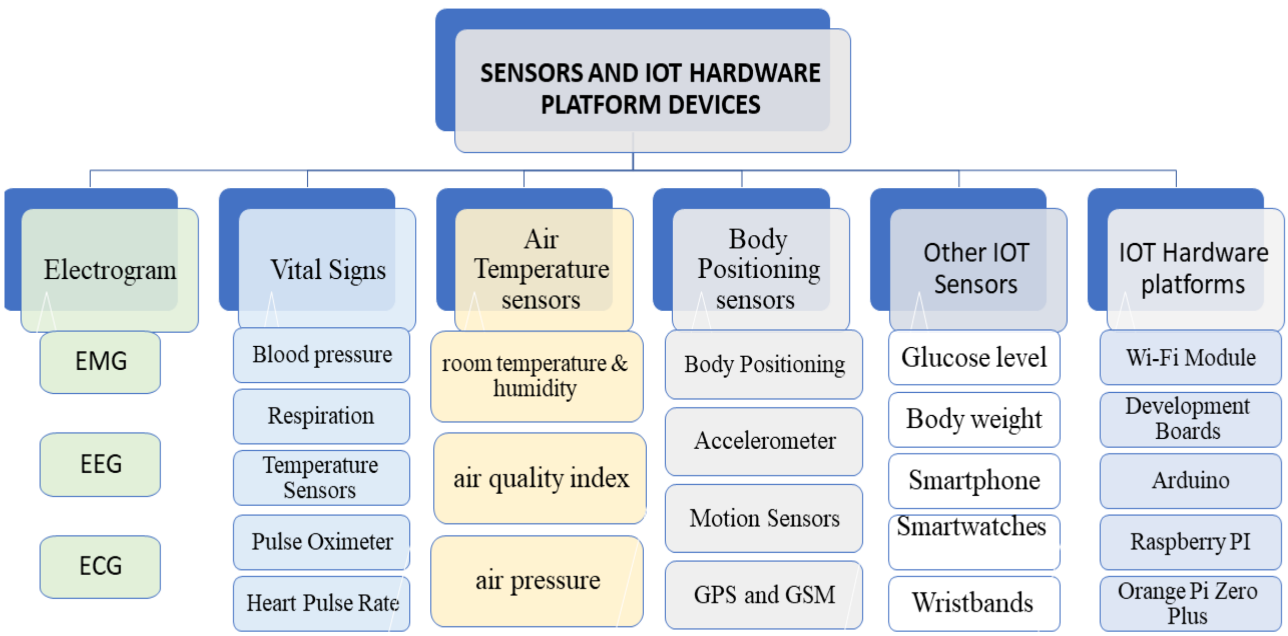

FIGURE 5. **Sensors and IoT hardware platform devices.**

security of medical records and remote patient monitoring, using EEG, ECG, and EMG electrogram IOT sensors.In [5], the application type was the security of medical records and remote patient monitoring, using EEG and ECG electrogram IOT sensors.

In [7], the application type was secured to the Internet of Medical Things using EEG electrogram IOT sensors. In [8], the application type was the security of medical records and remote patient monitoring using EEG electrogram IOT sensors. In [13], the application type was the security of medical records using ECG electrogram IOT sensors.

In [17], the application type was the security of medical records using ECG IOT sensors. In [23], the application type was healthcare monitoring, securing the Internet of Medical Things, and securing medical records using EEG, ECG, and EMG electrogram IOT sensors.In [35], the application type was the security of medical records using EEG, ECG, and EMG electrogram IOT sensors.In [45], the application type

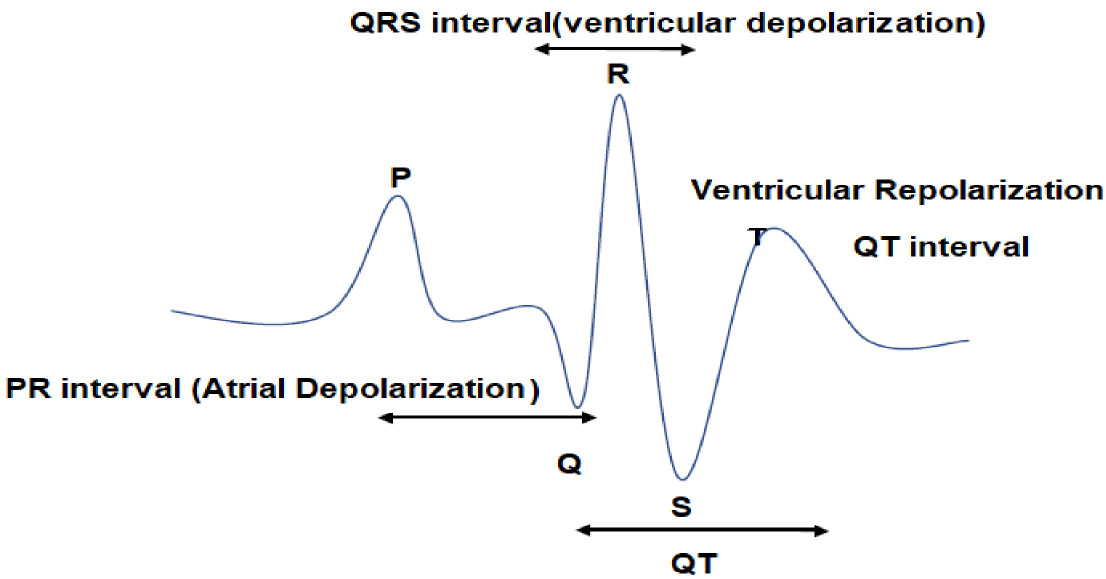

FIGURE 6. Electrocardiogram.

was cardio disease prediction, using EEG, ECG, and EMG electrogram IOT sensors. In [46], the application type was cardio disease prediction, using the ECG IOT sensors. These studies are summarized according to electrogram sensors and blockchain IOT application type, as shown in Table 5.

According to Table 5, most healthcare applications use electrocardiogram (ECG), electroencephalogram (EEG), and electromyogram (EMG) sensors to record the electrical activity of various organs, including the heart and brain.

B. VITAL SIGNS

The body's most calculated functions, which are of utmost importance, are vital signs. Body temperature, pulse, respiration rate, blood pressure, and oxygen saturation level are the four main signs that doctors and other healthcare professionals frequently monitor [38].

1) BLOOD PRESSURE

A blood pressure sensor provides accurate blood pressure readings in the veins [34].

2) RESPIRATION RATE

The rate of respiration can be observed using standard pulse oximeters. It detects flow rates of several hundred l/min and measures minute flow rates near the respiratory flow's zero point. [45].

3) TEMPERATURE SENSORS

Human body temperature sensor.

4) PLUS OXIMETER

It is a medical instrument that subtly checks a patient's blood's oxygen saturation [45].

TABLE 5. Research used electrogram IoT devices.

Electrogram sensors	BIOT healthcare Application types	Articles
EEG	Security of medical records and remote patient monitoring	[4] [5] [8]
EEG	secure the Internet of Medical Things	[7]
EEG	Cardio Disease Prediction	[45]
EEG	Security of medical records	[35]
EEG	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
ECG	Security of medical records and remote patient monitoring	[4][5]
ECG	Security of medical records	[13] [17] [35]
ECG	Cardio Disease Prediction	[45] [46]
ECG	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
EMG	Security of medical records and remote patient monitoring	[4]
EMG	Cardio Disease Prediction	[45]
EMG	Security of medical records	[35]
EMG	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]

5) HEART PULSE RATE

A sensor that measures the heart rate.

Below is a group of authors who used vital sign sensors in their research. In [4], the application type was the security of medical records and remote patient monitoring, using a blood pressure vital sign sensor. In [5], the application type was the security of medical records and remote patient monitoring, using blood pressure, Temperature sensors, and pulse oximeter vital sign sensors. In [8], the application type was the security of medical records and remote patient monitoring, using a blood pressure vital sign sensor. In [16], the application type was diabetic-cardio disease prediction, using blood pressure vital sign sensors. In [22], the application type was healthcare monitoring, using heat rate, temperature, and blood pressure vital sign sensors. In [23], the application type was healthcare monitoring, security of the Internet of Medical Things, and security of medical records, using temperature and vital sign sensors.

In [31], the application type addressed the COVID-19 crisis and telemedicine, using blood pressure and temperature vital sign sensors. In [32], the application type was the security of medical records, telemedicine, and prediction of diseases using blood pressure and heart pulse rate vital sign sensors. In [33], the application type was the security of medical records and remote patient monitoring using blood pressure vital sign sensors. In [34], the application type was smart telemedicine, remote patient monitoring, and prediction of diseases. I used IoT, the Neural Network (NN), blood pressure, temperature sensors, pulse oximeter, and heart pulse rate vital sign sensors. In [35], the application type was the security of medical records, using blood pressure, Temperature sensors, pulse oximeters, and heart pulse rate vital sign sensors. In [36], the application type was a healthcare monitoring and tracking system for soldiers, using temperature, heartbeat, oxygen level, and vital sign sensors.

In [37], the application type was the security of medical records and remote patient monitoring, using temperature, heartbeat, blood pressure, and vital sign sensors. In [39], the application type was the security of medical records and intelligent telemedicine, using oxygen and blood pressure vital sign sensors. In [41], the application type was healthcare monitoring, using Temperature and pulse vital sign sensors. In [45], the application type was cardio disease Prediction, using blood pressure, Respiratory rate, Temperature sensors, and pulse oximeter vital sign sensors. In [49], the application type was security of medical records and remote patient monitoring, using Temperature sensors and heart pulse rate vital sign sensors. These studies are summarized in Table 6 according to vital sign sensors and BIOT application type.

Table 6 shows that vital sign sensors, including body temperature, pulse, respiration rate, blood pressure, and oxygen saturation level, are commonly used in healthcare applications to measure key signs frequently monitored by healthcare professionals.

C. AIR TEMPERATURE SENSORS

Devices that measure the air, such as room temperature and humidity sensors, air quality index sensors, and air pressure sensors, are called air and temperature sensors.

1) ROOM TEMPERATURE AND HUMIDITY SENSORS

It is an Internet of Things (IoT) gadget that gives data for regulating the humidity and temperature in the server room; this device can be used to monitor the temperature and humidity of a space or other area [47].

2) AIR QUALITY INDEX SENSOR

The air quality index (MQ135) Gas Sensors are used to identify dangerous gases and smoke, including ammonia (NH3), sulphur (S), benzene (C6H6), and CO2. This MQ series gas sensor includes a digital and analog output pin. The digital pin swings high when the amount of these gases in the air reaches a specific limit. [41].

3) AIR PRESSURE

Pressure is an external force applied in a single direction to a surface. The pressure of liquid, air, and other gases is frequently measured. This pressure is monitored by a pressure sensor, also known as a pressure transmitter, since it transforms the pressure into an electrical signal [48].

Below is a collection of authors who have used air and temperature sensors in their research. In [23], the application type was Healthcare monitoring, security of the Internet of Medical Things, and Security of medical records, using air pressure, room temperature, and humidity sensors. In [36], the application type was a healthcare monitoring and tracking system for soldiers, using GPS, GSM, room temperature, and humidity sensors.

In [41], the application type was healthcare monitoring, using quality index (MQ135), room temperature, and humidity sensors. In [50], the application type was sensors and Blockchain, using room temperature and humidity sensors. These studies are viewed in Table 7.

Table 7 shows Air temperature sensors used in blockchain IOT healthcare applications: room temperature, air quality, and air pressure sensors.

D. BODY POSITIONING SENSORS

The body positioning sensors consist of Body positioning (MEMS), GPS and GSM sensors, Accelerometer sensors, and Motion sensors.

1) BODY POSITIONING (MEMS)

The sensor changes the patient's position ratio, allowing for easy evaluation of the patient's stand-by and felt-down positions [49].

2) ACCELEROMETER

This sensor senses the acceleration of gravity and determines the direction of the object to detect the acceleration of an object. These sensors use piezoelectric, piezo-resistive, and capacitive components to transform the mechanical motion generated by an accelerometer into an electrical signal [51].

TABLE 6. The research used vital sign sensor IoT devices.

Vital sign sensors	BIOT healthcare Application type	Articles
blood pressure	Security of medical records and remote patient monitoring	[4][5][8] [33] [12]
blood pressure	Diabetic-Cardio Disease Prediction	[16]
blood pressure	Cardio Disease Prediction	[45]
blood pressure	addressing the COVID-19 crisis and telemedicine	[31]
blood pressure	Security of medical records, telemedicine, and disease prediction	[32]
blood pressure	Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]
blood pressure	Security of medical records	[35]
blood pressure	Security of medical records and Smart Telemedicine	[39]
blood pressure	Health care monitoring	[22]
blood pressure	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Respiration rate	Cardio Disease Prediction	[45]
Temperature sensors	Security of medical records and remote patient monitoring	[5][49] [12]
Temperature sensors	Cardio Disease Prediction	[45]
Temperature sensors	addressing the COVID-19 crisis and telemedicine	[31]
Temperature sensors	Smart Telemedicine and prediction of diseases	[34]
Temperature sensors	Security of medical records	[35]
Temperature sensors	healthcare monitoring and tracking system for soldiers	[36]
Temperature sensors	Healthcare monitoring, solar energy, and blockchain	[38]
Temperature sensors	Security of medical records and Smart Telemedicine	[39]
Temperature sensors	Health care monitoring	[41] [22]
Temperature sensors	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
pulse oximeter	Security of medical records and remote patient monitoring	[5] [12]
pulse oximeter	Cardio Disease Prediction	[45]
pulse oximeter	Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]
pulse oximeter	Security of medical records	[35]
pulse oximeter	healthcare monitoring and tracking system for soldiers	[36]
Heart Pulse rate	Security of medical records and remote patient monitoring	[49]
Heart Pulse rate	Security of medical records, telemedicine, and prediction of diseases	[32]
Heart Pulse rate	Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]
Heart Pulse rate	Security of medical records	[35]
Heart Pulse rate	healthcare monitoring and tracking system for soldiers	[36]
Heart Pulse rate	Healthcare monitoring, solar energy, and blockchain	[38]
Heart Pulse rate	Security of medical records and Smart Telemedicine	[39]
Heart Pulse rate	Health care monitoring	[41] [22]

3) MOTION SENSOR

Motion sensors, also known as motion tracking sensors, are used to track various motions, such as walking, standing, and sitting.

4) GPS AND GSM

Serves as a wireless communications system. For tracking location and observing health indicators [36]. In [23], the application type was Healthcare monitoring, security of the Internet of Medical Things, and Security of medical records using motion and Accelerometer sensors. In [35], the application type was the security of medical records of accelerometer sensors. In [36], the application type was a healthcare monitoring and tracking system for soldiers using GPS and GSM sensors. In [49], the application type was Security of medical records and remote patient monitoring using Body

Positioning Identification (MEMS) sensors. These studies are summarized according to body positioning sensors and BIOT application type, as shown in Table 8.

Table 8 shows body positioning sensors used in blockchain IOT healthcare applications: body positioning identification, accelerometer, GPS, GSM, and motion sensors.

E. GLUCOSE LEVEL

An instrument for blood tests that measure blood glucose levels.

F. BODY WEIGHT

A scale that measures body weight.

G. SMARTPHONE

a laptop that resembles a phone and combines the capabilities of both a computer and a mobile device.

H. SMARTWATCHES

An electronic device that can be worn, like a watch.

I. WRISTBANDS

It is a medical instrument that counts the number of pulses and steps [4].

Below is a collection of authors who have used IOT sensors in their research. In [4], the application type was the security of medical records and remote patient monitoring, using wristbands, smartwatches (SPO2), and smartphone sensors. In [6], the application type was the security of medical records, using smartwatches (SPO2) and smartphone sensors. In [7], the application type was to secure the Internet of medical things using Smartphone sensors. In [8], the application type was the security of medical records and remote patient monitoring, using glucose level sensors and body weight. In [19], the application type was remote patient monitoring and diabetic disease prediction using glucose level sensors. In [21], the application type addressed the COVID-19 crisis, security of medical records, and remote patient monitoring using wristband sensors. In [22], the application type was healthcare monitoring, using glucose and weight sensors. In [31], the application type addresses the COVID-19 crisis and telemedicine using glucose level and wristband sensors. In [33], the application type was the security of medical records and remote patient monitoring, using glucose level and smartphone sensors. In [34], the application type was smart telemedicine, remote patient monitoring, and prediction of diseases using Glucose level sensors. In [35], the application type was the security of medical records using glucose level sensors. In [39], the application type was the security of medical records and smart telemedicine using Glucose sensors. In [45], the application type was cardio disease Prediction, using Glucose level sensors. In [50], the application type was sensors and blockchain, using Glucose level sensors, wristbands, and Smartwatches.

These studies are summarized according to sensors, IOT devices, and BIOT application type, as shown in Table 9.

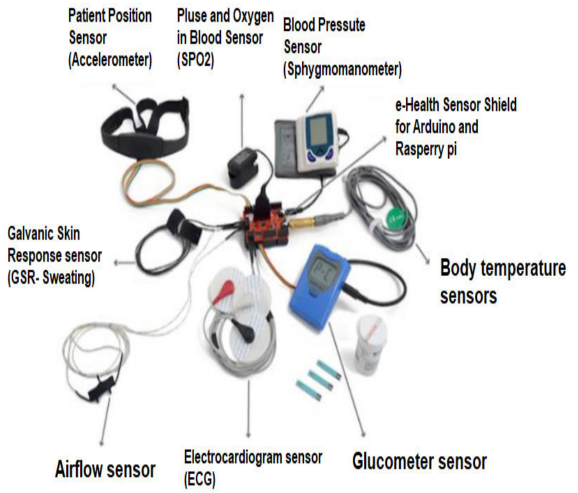

FIGURE 7. IoT sensors [52].

Table 9 displays the IoT sensor devices used in blockchain IOT healthcare applications, including glucose monitors, wristbands, smartwatches, smartphones, and body weight. An array of IoT sensors is shown in Figure 7.

J. IoT HARDWARE PLATFORMS

Platforms are defined very differently in both broad and specific contexts. Media are referred to more generally as ''technological building blocks that serve as the foundation upon which other businesses can develop complementary products, technologies, or services.'' A platform can also refer to any other common entity that runs related components or services, such as a hardware configuration, operating system, software framework, or any combination [53].

1) ESP-01 WI-FI MODULE

The ESP-01 is a Wi-Fi service that makes it simple for an Arduino to connect to a Wi-Fi network. It is one of the market's most often utilized Wi-Fi chips since it includes an antennae switch, a radiofrequency balun, a power amplifier, a low noise reception amplifier, and a power executive [41].

A microcontroller-based design can provide wireless internet access by acting as a Wi-Fi adapter, with straightforward communication through the UART interface or the CPU AHB bridge interface [54]. Doctors may view the patient at any time and location by entering their login information using this microcontroller and a Wi-Fi module, which we're utilizing to broadcast sensor data to the Thing Speak web server [41].

Figure 8 shows the ESP-01 Photon device [54].

K. ARDUINO

Arduino is a company that provides open-source hardware and software to create the project's microprocessor and controller and a community-based service for producing intelligent digital gadgets [55].

TABLE 7. The research used air temperature sensor IoT devices.

Air temperature sensors	BIOT healthcare Application type	Articles
Room temperature and humidity sensor	Health care monitoring	[41]
Room temperature and humidity sensor	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Room temperature and humidity sensor	Sensors and Blockchain	[50]
Room temperature and humidity sensor	healthcare monitoring and tracking system for soldiers	[36]
Air quality index sensor	Health care monitoring	[41]
Air pressure sensor	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]

TABLE 8. The research used body positioning sensor IoT devices.

Body positioning sensors	BIOT healthcare Application types	Articles
Body Positioning Identification (MEMS)	Security of medical records and remote patient monitoring	[49]
Accelerometer	Security of medical records	[35]
Accelerometer	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
GPS and GSM	healthcare monitoring and tracking system for soldiers	[36]
Motion sensor	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]

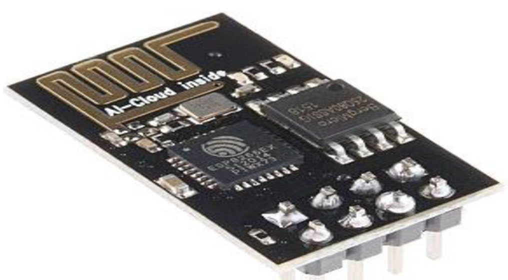

FIGURE 8. ESP -01 module.

The Arduino platform, first introduced in 2005, was created to give professionals, students, and amateurs a simple and affordable way to build gadgets that use sensors and actuators to interact with their surroundings. It is an open-source computer platform based on basic microcontroller boards for building and programming electronic devices.

Like other microcontrollers, it may also function as a tiny computer by accepting inputs and directing the outputs of various electronic devices.

Arduino uses hardware called the Arduino development board and software called the Arduino IDE (Integrated Development Environment) to create its code.

Contrary to other microcontroller boards in India, the Arduino boards were only allowed for small-scale projects when they first debuted on the electronic market a few years ago.

Electronics-related individuals are already emerging and accepting the role of Arduino for their initiatives.

Built with an Atmel 32-bit ARM or an 8-bit AVR microcontroller, these devices are easily programmable using the Arduino IDE's C or C++ programming languages [56]. Figure 9 shows the Arduino shield – ethernet, wireless, and motor driver.

L. RASPBERRY PI

The Raspberry Pi is a small computer capable of carrying out tasks well.

The module uses various processors; hence, it can only run open-source operating systems and applications.

TABLE 9. Research used sensors IoT devices.

Sensors IOT devices	BIOT healthcare Application types	Articles
glucose level	Security of medical records and remote patient monitoring	[8] [33]
glucose level	Cardio Disease Prediction	[45]
glucose level	addressing the COVID-19 crisis and telemedicine	[31]
glucose level	Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]
glucose level	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
glucose level	Security of medical records	[35]
glucose level	Sensors and Blockchain	[50]
glucose level	Health care monitoring	[22]
wristbands	Security of medical records and remote patient monitoring	[4]
wristbands	addressing the COVID-19 crisis and Security of medical records and remote patient monitoring	[21]
wristbands	addressing the COVID-19 crisis and telemedicine	[31]
wristbands	Sensors and Blockchain	[50]
Smartwatches (SPO2)	Security of medical records and remote patient monitoring	[4]
Smartwatches	Sensors and Blockchain	[50]
Smartwatches (SPO2)	Security of medical records	[6]
Smartphone	Security of medical records and remote patient monitoring	[4] [8] [33]
Smartphone	Security of medical records	[6]
Smartphone	secure the Internet of Medical Things	[7]
body weight	Security of medical records and remote patient monitoring	[8]
body weight	Health care monitoring	[22]

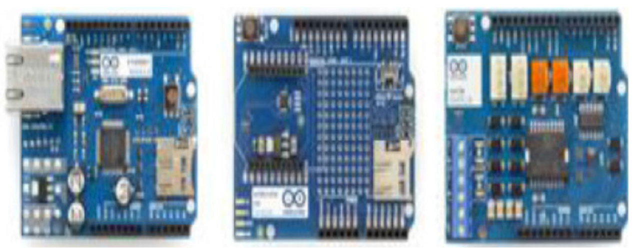

FIGURE 9. Arduino shields – ethernet, wireless and motor driver [56].

Pi also allows users to send emails, utilize word processors to create papers, and much more.

The Raspberry Pi supports Python, C, C++, BASIC, Perl, and Ruby.

Eben Upton, Jack Lang, Rob Mullins, and Alan Mycroft were the researchers who created the first model of Raspberry Pi.

The goal of Raspberry Pi, founded in 2009, is to produce an affordable computer that young people may use to learn the fundamentals of computer programming.

The United Kingdom Raspberry Pi Foundation introduced the original Raspberry Pi, model B, in 2012. It was initially equipped with a Broadcom BCM2835 Soc with 512 MB memory storage capacity, a 700 MHz ARM ARM1176JZF-S

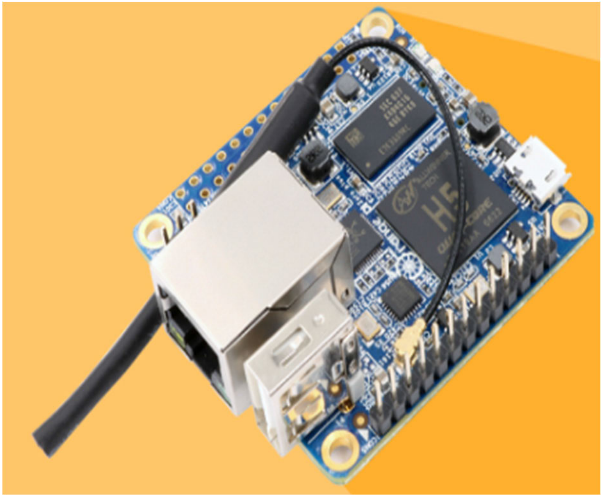

FIGURE 10. Orange PI zero plus [58].

FIGURE 11. Raspberry PI [47].

processor, and a Video Core IV graphics processing unit (GPU).

Later, the foundation released a less expensive edition with less memory storage, a single USB port, and no Ethernet controller. The firm has sold over 19 million units as of 2019, ranking it the third best-selling ''general-purpose computer'' [57]. Figure 10 shows Raspberry Pi.

M. ORANGE PI ZERO PLUS

An open-source single-board computer with Gigabit Ethernet is the Orange Pi Zero Plus. It is tiny, measuring 45 × 48 mm.

The All Winner H2 SoC, featuring Quad-core 32-bit Cortex-A7 and 256 MB/512 MB DDR3 (shared with GPU), is used by Orange Pi Zero Plus.

It includes 26 pin headers, a TF card slot, a USB 2.0 connector, and more. It receives electricity via USB OTG.

Furthermore, it offers a nice balance between price and value (presently available for less than $20) [19]. Figure 11 shows orange pi zero. plus.

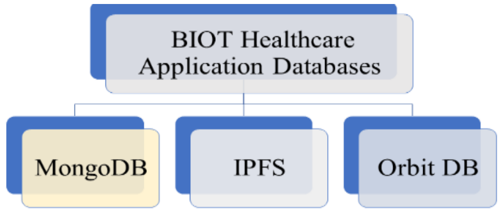

FIGURE 12. BIOT healthcare databases.

Below is a collection of authors who have used hardware platforms in their research.

In [4], the application type was the security of medical records and remote patient monitoring using the Raspberry Pihardware platform. In [8], the application type was the security of medical records and remote patient monitoring using the Raspberry Pihardware platform. In [19], the application type was remote patient monitoring and diabetic disease Prediction, using the orange Pi Zero Plus Platform. In [21], the application type tracked the COVID-19 Pandemic, secured medical records, and enabled remote patient monitoring using the Raspberry Pihardware platform. In [22] and [41], the application type was healthcare monitoring, using the Arduino hardware platform.

In [23], the application type was Healthcare monitoring, security of the Internet of Medical Things, and security of medical records, usingtheRaspberry Pihardware platform.In [34], the application type was smart telemedicine, remote patient monitoring, and prediction of diseases using the Arduino hardware platform. In [36], the application type was a healthcare monitoring and tracking system for soldiers using the Raspberry Pihardware platform. In [37], the application type was the security of medical records and remote patient monitoring using the Raspberry Pihardware platform. In [38], the application type was healthcare monitoring, solar energy, and blockchain, using the Arduino hardware platform. In [39], the application type was the security of medical records and smart telemedicine using the Raspberry Pihardware platform.

These studies are summarized according to hardware platforms and BIOT application type, as shown in Table 10.

Table 10 shows Hardware Platforms used in blockchain healthcare applications, including Wi-Fi Module, Arduino, Raspberry Pi, and Orange Pi Zero Plus.

VI. BIOT HEALTHCARE DATABASES APPLICATIONS

This section will solve Question 5 of our paper; in this section, we have tried to collect database software used in BIOT healthcare applications.

Figure 12 shows the BIOT healthcare application databases we will discuss.

A. MONGODB

A leading NoSQL database and open-source document store is MongoDB. C++ is used to write MongoDB.

TABLE 10. Research in hardware platform.

Hardware Platforms	BIOT healthcare Application types	Articles
Wi-Fi Module	Health care monitoring	[41]
Arduino	Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]
Arduino	Healthcare monitoring, solar energy, and blockchain	[38]
Arduino	Health care monitoring	[41] [22]
Raspberry Pi	Security of medical records and remote patient monitoring	[4][8] [37]
Raspberry Pi	Tracking the COVID-19 Pandemic, Security of medical records, and remote patient monitoring	[21]
Raspberry Pi	Health care monitoring and tracking system for soldiers	[36]
Raspberry Pi	Security of medical records and Smart Telemedicine	[39]
Raspberry Pi	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Orange Pi Zero Plus	Remote Patient Monitoring and Diabetic Disease Prediction	[19]

TABLE 11. Database applications used in BIOT healthcare applications.

Database applications	BIOT healthcare Application types	Articles
MongoDB	Security of medical records and remote patient monitoring	[4]
Orbit DB	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
IPFS	Security of medical records and remote patient monitoring	[8]
IPFS	Security of medical records	[17]
IPFS	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
IPFS	Security of medical records and Smart Telemedicine	[39]

A document-oriented, cross-platform database called MongoDB offers excellent performance, high availability, and simple scalability. MongoDB utilizes the collection and document concepts.

B. IPFS

Extension data is stored using the Interplanetary File System (IPFS) [39].

C. ORBITDB

A distributed, serverless, peer-to-peer database is called OrbitDB. OrbitDB stores data on IPFS and automatically syncs databases with peers using Libp2p Pubsub.

Below is a collection of authors who have used database software applications in their research. In [4], the application type was the security of medical records and remote patient monitoring using MongoDB. In [8], the application type was the security of medical records and remote patient monitoring using IPFS. In [17], the application type was the security of medical records using IPFS. In [19], the application type was remote patient monitoring and diabetic disease prediction using OrbitDB. In [39], the application type was the security of medical records and smart telemedicine using IPFS. These studies are summarized according to database applications and BIOT application type, as shown in Table 11.

In Table 11, you can see the database applications utilized in blockchain IoT healthcare applications, which include MongoDB and Orbit DB.

VII. PROGRAMMING LANGUAGES AND SOFTWARE TOOLS

This section will solve Question 6 of our paper. In this section, we have tried to collect programming languages used in BIOT healthcare applications.

Figure 13 shows the BIOT healthcare programming languages and tools we will discuss.

A. JAVASCRIPT

JavaScript is a popular object-oriented programming language for building interactive web browser effects, including creating dynamically updated content and managing multimedia.

JavaScript can be divided into several categories: JavaScript, REST API, Node.js, ReactJS, JSON, and Web3.

1) JAVASCRIPT

A computer programming language with object-oriented syntax that's frequently used to produce interactive effects in web browsers.

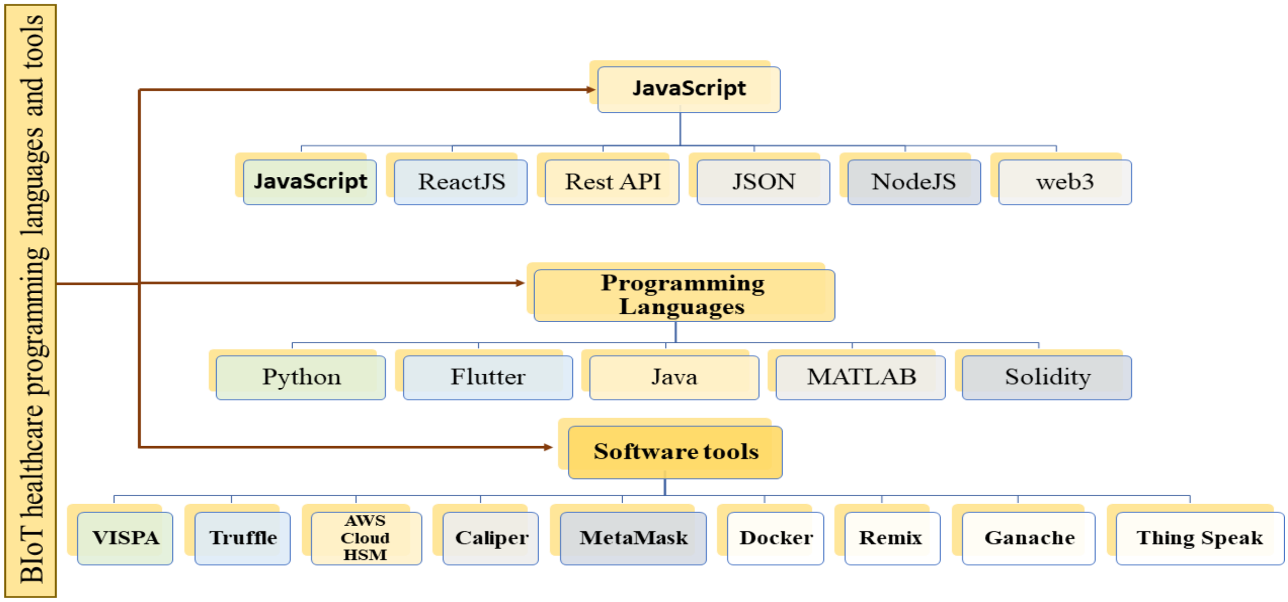

FIGURE 13. BIOT healthcare programming languages and tools.

2) REACTJS

React is a free and open-source JavaScript package for creating user interfaces (UI) for online applications.

A straightforward, feature-rich, component-based JavaScript UI library is ReactJS. Both tiny and large, complicated applications can be created with it; it offers a minimum and reliable feature set to get a web application off the ground. The React community supports the React library by offering a sizable collection of pre-made components to construct web applications quickly,

Facebook creates and distributes React By addressing issues and adding new features, Facebook is constantly improving the React library.

On top of the React library, the React community offers advanced concepts like state management, routing, etc. [59].

3) NODE.JS

Built on Google Chrome's JavaScript V8 Engine, Node.js is a JavaScript-based framework and platform.

It is used to create online applications that require a lot of I/O, such as single-page programs and websites that stream video. Numerous developers use the open-source, cost-free Node.js platform worldwide [60].

4) REST API

The number of web services offered by different businesses in the form of other APIs (Application Programming Interfaces) has dramatically expanded recently.

Message exchange protocols like SOAP (Simple Object Access Protocol) and service-oriented architectures (SOA) have gained popularity to facilitate the data-sharing process for web services.

Resources are the system's entities in the resource-oriented architecture known as REST. These resources provide the basis of the API implementation.

The REST architecture is also stateless because neither the client nor the server stores data. RESTful services return resources in a representation format. REST is a means by which a business offers a way to use its services. Many SOAP-oriented websites switched to REST implementation to streamline and update their workflows. It was discovered that APIs lacked headers and used straightforward HTTP verbs. The HTTP protocol is used in the development of REST web APIs. As a result, it utilizes all the HTTP features, including HTTP verbs, HTTP replies, and header data [61].

5) JSON

An open standard file called JSON, or JavaScript Object Notation, employs human-readable language to store and transfer data objects of attribute-value pairs and arrays (or other serializable values).

It is a widely used data format for electronic data exchange, notably between servers and online applications.

JSON is a data format that is not language-specific; although many contemporary computer languages have code to generate and parse JSON-format data, it was initially derived from JavaScript.

The extension is used in JSON filenames. JSON.

6) WEB3

Web3 is used as a JavaScript API [19].

Below is a collection of authors who have used JavaScript in their research.

TABLE 12. Javascript software applications used in BIOT healthcare applications.

JavaScript applications	BIOT healthcare Application types	Articles
JavaScript	Health care monitoring	[41]
API	Security of medical records and remote patient monitoring	[2] [8]
API	Diabetic-Cardio Disease Prediction	[15][16]
API	Cardio Disease Prediction	[45]
API	addressing the COVID-19 crisis and telemedicine	[31]
API	TrackingCOVID-19Pandemic, Security of medical records, and remote patient monitoring	[21]
API	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
API	Health care monitoring	[41]
Node.js	Security of medical records and remote patient monitoring	[4] [5]
Node.js	TrackingCOVID-19Pandemic, Security of medical records, and remote patient monitoring	[21]
Node.js	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
Node.js	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Web3	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
Web3	Security of medical records and remote patient monitoring	[8]
Web3	Security of medical records	[13]
Web3	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
Web3	Health care monitoring	[41]
JSON	Security of medical records and remote patient monitoring	[8]
JSON	Accurate Medical Decision	[20]

In [2], the application type was Secure Data Management for Remote Patient Monitoring, using API JavaScript. In [4] and [5], the application type was Secure Data Management for Remote Patient Monitoring, using Node.js JavaScript. In [8], the application type was Secure Data Management for Remote Patient Monitoring, using API, JSON, and web3 JavaScript. In [13], the application type was Security of medical records, using web3 JavaScript. In [15], the application type was diabetic-cardio disease Prediction, using API JavaScript. In [16], the application type was diabetic-cardio disease Prediction using API JavaScript. In [19], the application type was remote patient monitoring and diabetic disease Prediction, using OrbitDB, IPFS, web3, and Node.js. In [20], the application type was an accurate medical decision using JSON JavaScript.

In [23], the application type was Healthcare monitoring, security of the Internet of Medical Things, and Security of medical records, using Node.js JavaScript. In [31], the application type addressed the COVID-19 crisis and telemedicine using API JavaScript. In [39], the application type was the security of medical records and smart telemedicine, using REST API JavaScript. In [41], the application type was healthcare monitoring, using Solidity, JavaScript, web3, and API software. In [45], the application type was cardio disease prediction, using API JavaScript. These studies are summarized according to JavaScript Software applications and BIOT application type, as shown in Table 12.

Table 12 shows JavaScript software applications used in blockchain IOT healthcare applications, which include JavaScript, API, Node.js, Web3, and JSON.

B. PYTHON

Python is a general-purpose, interpreted programming language. The Python design philosophy, which Guido van Rossum developed and initially released in 1991, strongly emphasizes code readability. Its language constructs and object-oriented methodology are designed to aid programmers in creating clean, understandable code for small and big projects [62].

C. FLUTTER

Flutter is an open-source framework for developing top-notch, fast mobile applications for Android and iOS devices. It offers a straightforward, strong, practical, and simple SDK that makes it simple to create mobile applications in Dart, Google's programming language.

The Dart-based Flutter framework is easy to use. It performs impressively by drawing the user interface (UI) directly on the operating system's canvas rather than using a native framework [63].

D. JAVA

Provides a mechanism for creating application software and delivering it in a cross-platform computing environment. James Gosling made it at Sun Microsystems.

E. MATLAB

Matlab, a programming language created by Math Works, can be used to analyze and handle Internet of Things (IoT) services [44].

TABLE 13. Programming languages us ed in BIOT healthcare applications.

Programming Languages	BIOT healthcare Application types	Articles
Python	Security of medical records and remote patient monitoring	[3]
Python	Security of medical records	[9]
Python	Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]
Python	Security and high-speed medical records and brain disease prediction	[40]
Flutter	Security of medical records and remote patient monitoring	[4]
Java	Security of medical records	[35]
Java	Security of medical records and remote patient monitoring	[8]
MATLAB	Cardio Disease Prediction	[45]
MATLAB	Security of medical records	[35]
MATLAB	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Solidity	Security of medical records and remote patient monitoring	[2][3][4][8] [37] [12]
Solidity	Diabetic-Cardio Disease Prediction	[16]
Solidity	Security of medical records	[13][14]
Solidity	Health care monitoring	[41]

F. SOLIDITY

The programming language Solidity is used to create highly secure smart contracts that manage operation communications between nodes on the one side and IoT devices and conventional PC devices on the other [14].

Below is a collection of authors who have used software languages in their research. In [3], the application type was the security of medical records and remote patient monitoring using Python and Solidity software languages. In [4], the application type was the security of medical records and remote patient monitoring, using flutter and solidity software languages. In [8], the application type was the security of medical records and remote patient monitoring, using Java and Solidity software languages. In [9], the application type was the security of medical records using the Python software language. In [12] and [37], the application type was the security of medical records and remote patient monitoring using solidity software languages. In [13] and [14], the application type was the security of medical records using solidity software languages. In [16], the application type was diabetic-cardio disease prediction, using solidity software languages. In [23], the application type was Healthcare monitoring, security of the Internet of Medical Things, and Security of medical records, using Matlab software languages. In [34], the application type was smart telemedicine, remote patient monitoring, and prediction of diseases using Python software languages.

In [35], the application type was the Security of medical records, using Java and Matlab software languages. In [40], the application type was Security and high-speed medical records and brain disease prediction, using Python software languages. In [41], the application type was Healthcare monitoring, using solidity software languages. In [45], the application type was Cardio Disease Prediction, using Matlab software languages. These studies are summarized according to programming languages in Table 13.

Table 13 shows the programming languages used in blockchain IOT healthcare applications: Python, Flutter, Java, Matlab, and Solidity.

G. SOFTWARE TOOLS

There are several software tools used in BIOT healthcare applications.

1) VISPA

VISPA is a robust physics analysis development environment that enables scientists to blend graphical and textual work. The analysis is prototyped, carried out, and verified in a cycle in physics. The centerpiece of VISPA is a multifunctional window for the visual analysis step steering, analysis template building, and browsing physics event data at various analysis stages. VISPA adopts an experiment-independent methodology, including some steering and controlling tools necessary for a typical study. It is possible to connect to many high-energetics experiment frameworks using various interfaces [64].

2) AWS CLOUD HSM API

It gives the module seclusion by establishing a distinct Virtual Private Network and makes it simple to generate and use necessary encryption keys on the AWS cloud. FIPS 140-2 Level 3 approved HSMs can manage keys. It allows users to be created and HSM policies to be specified while controlling encryption keys over a secure channel. AWS manages the HSM appliance but does not have access to the data—keys—that are kept inside. AWS also offers role-based access to the

HSM. This demonstrates that it is a safe method of crucial storage [37].

3) METAMASK

The Metamask Chrome extension is a crypto-wallet for Ethereum that enables you to manage your Ethereum accounts; it is a crucial tool for creating and testing smart contracts [65].

4) REMIX

Remix lets you concentrate on the user interface and move backward through web standards to offer a quick and reliable user experience. People will adore using your products [66].

5) THINGSPEAK

ThingSpeak is an open-source HTTP-based IoT application and API for storing and retrieving data from devices via the Internet or a local area network. Additionally, it offers status updates, the ability to create apps for sensor tracking, and monitoring of application locations. Furthermore, it promotes the mathematical computer program MATLAB, which enables academics to examine and analyze the uploaded data without purchasing a licensed copy of MATLAB [38].

6) TRUFFLE SUITE

The ecosystem known as the Truffle Suite is used to create DApps. A truffle suite has the subcategories Ganache, Truffle, and Drizzle. The techniques and resources that must be used before deploying smart contracts with the Truffle suite are divided into two groups:

1. Smart contracts: solidity, meta mask, ganache, and truffle.
2. Front end: Web3.js and a live server [67].

7) CALIPER

Caliper is a free benchmarking tool; Users can assess the effectiveness of various blockchain platforms and consensus algorithms using the Linux Foundation's Caliper platform in a uniform setting [23]

8) DOCKER

A software platform called Docker makes developing, testing, and deploying applications simple. Docker packages software into standardized units called containers that contain all the necessary code, libraries, system tools, and runtime. You can swiftly deploy and scale applications with Docker into any environment while being confident that your code will work [68].

9) GANACHE

Ganache is used to create the personal Ethereum Blockchain and test Solidity contracts [4].

Below is a collection of authors who have used software tools in their research

In [4], the application type was the security of medical records and remote patient monitoring, using Metamask, Truffle, and Ganache software tools.

In [7], the application type was secured on the Internet of Medical Things using VISPA software tools.

In [8], the application type was the security of medical records and remote patient monitoring using Remix software tools. In [12], the application type was the security of medical records and remote patient monitoring, using Remix and Metamask software tools. In [14], the application type was the security of medical records using AWS and Solidity software applications. In [19], the application type was remote patient Monitoring and Diabetic Disease Prediction, using Truffle software tools.

In [21], the application type was TrackingCOVID-19 Pandemic, security of medical records, and remote patient monitoring, using Docker platform tools. In [23], the application type was Healthcare monitoring, protection of the Internet of Medical Things, and Security of medical records, using docker and caliper software tools. In [37], the application type was the security of medical records and remote patient monitoring using cloud HSM tools. In [38], the application type was healthcare monitoring, solar energy, and blockchain, using ThingSpeak software tools. In [41], the application type was healthcare monitoring, using Remix, Metamask, ThingSpeak, truffle, and Ganache software tools.

These studies are summarized according to Software tools and BIOT application type, as shown in Table 14.

Table 14 shows software platforms and tools used in blockchain IOT healthcare applications, which include VISPA, AWS cloud, HSM, Remix, Metamask, ThingSpeak, Truffle suite, Docker, Caliper, and Ganache.

VIII. BIoT HEALTHCARE APPLICATIONS CHALLENGES AND SOLUTIONS

This section will solve Question 7 of our paper; in this section, we have tried to present the most prominent challenges and solutions facing the use of blockchain technology with the Internet of Things in healthcare applications [1] and [3].

Figure 14 shows the BIOT healthcare challenges and solutions we will discuss.

A. SECURITY AND PRIVACY

The most crucial problem with the information system is security. The security model is a formal approach to verifying and describing complex information. It is critical to secure privacy and message integrity from unauthorized users [71]; a tamper-proof audit log makes identifying fraudulent data and users and managing data access simple [70].

B. CONFIDENTIALITY

Data confidentiality is a significant issue on the Internet of Things, as it means that data can be modified or accessed only by parties authorized to access and modify it [77].

TABLE 14. Software tools used in BIOT healthcare applications.

Software Tools	BIOT healthcare Application types	Articles
VISPA	secure the Internet of Medical Things	[7]
AWS cloud HSM	Security of medical records and remote patient monitoring	[37]
AWS cloud HSM	Security of medical records	[14]
Remix	Security of medical records and remote patient monitoring	[8] [12]
Remix	Health care monitoring	[41]
MetaMask	Security of medical records and remote patient monitoring	[4] [12]
MetaMask	Health care monitoring	[41]
Thing Speak	Healthcare monitoring, solar energy, and blockchain	[38]
Thing Speak	Health care monitoring	[41]
Truffle suite	Security of medical records and remote patient monitoring	[4]
Truffle suite	Remote Patient Monitoring and Diabetic Disease Prediction	[19]
Truffle	Health care monitoring	[41]
Docker	TrackingCOVID-19Pandemic, Security of medical records, and remote patient monitoring	[21]
Docker	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Caliper	Security of medical records	[14]
Caliper	Health care monitoring, security of the Internet of Medical Things, and Security of medical records	[23]
Ganache	Security of medical records and remote patient monitoring	[4]
Ganache	Health care monitoring	[41]

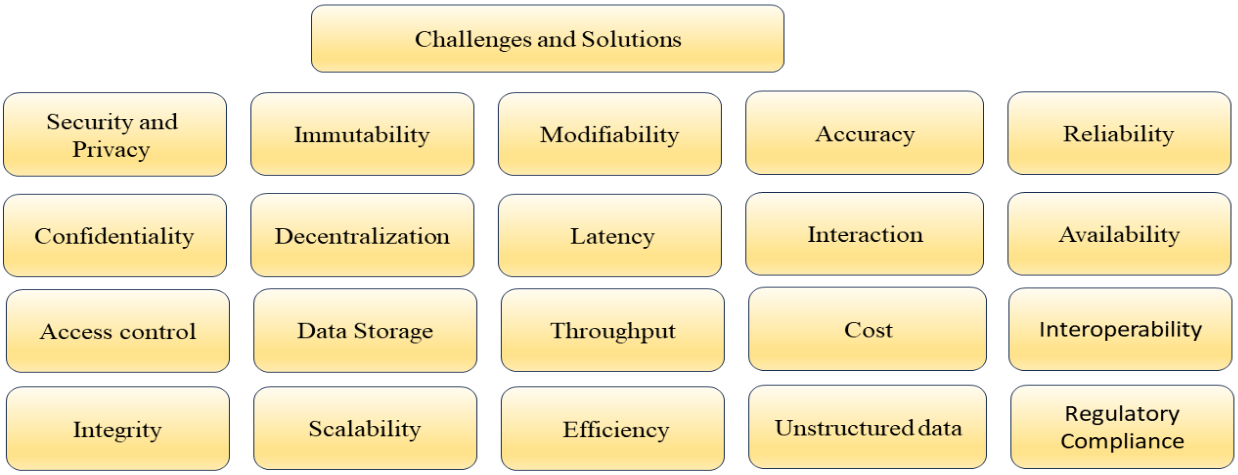

FIGURE 14. BIOT healthcare applications challenges and solutions.

C. ACCESS CONTROL

Multiple sources are handled by computers, including memory, disk, network interface, and printer (object access). The user (subject of access) has access to the computer system's resources [71].

Access control can be used to detect unauthorized access and control people's entrance to restricted areas [78]

Controlling access to IoT devices is complex because IoT devices have limited battery life, processing power, storage, and network capacity [79].

D. INTEGRITY

Integrity is the promise that the data is reliable and correct [29].

E. IMMUTABILITY

The immutability property protects data from being altered or tampered with, ensuring security and privacy features [1].

F. DECENTRALIZATION

Decentralization is a reality that enables parties to conduct transactions without using intermediaries. Compared to using intermediaries or centralized systems, this increases the transparency of commerce [26]; higher levels of security, parallel data processing, and cooperative version control are available to everyone [70].

G. DATA STORAGE

Data is kept locally in local storage or in the cloud, where it can be accessed by clients or service providers located elsewhere. To allow the stowage procedure and for the stent to be preserved in the block, the device must authenticate with the stand in the event of local storage. Personal information authentication should be performed before submitting the data to a cloud storage service [7].

H. SCALABILITY
Scalability is becoming a significant issue in the blockchain space due to the constant growth in blockchain size. The architecture, underlying consensus, and network synchronization all affect scalability. Each blockchain node should have high processing and bandwidth capabilities to scale the network [29].

I. MODIFIABILITY
Data modification: On the one hand, the immutability of data provided by blockchain technology secures the system, but on the other, it eliminates the option of data deletion and makes data modification and modifications inevitable.

As a result, the creation of blockchain applications must be done to minimize the need for data alteration [70].

J. LATENCY
The time elapsed between the start of a transaction and its commitment is known as latency [23].

K. THROUGHPUT
It measures the number of blocks added to the blockchain each second, essentially the number of transactions carried out each second. Throughput is influenced by several variables, including the underlying consensus process, the number of participating nodes, the network architecture, node behavior, block parameters, and the complexity of the contract (in the case of blockchains supporting smart contracts) [29].

L. EFFICIENCY
Through theoretical study and tests, the scheme's accuracy and effectiveness are demonstrated [23].

The advanced certified tool "Caliper" is used to assess the effectiveness and performance of smart contracts by evaluating their fundamental operations: Query, Open, and Transfer [14].

M. ACCURACY
Accuracy is defined as the ability to forecast events correctly [16].

The most common categorization performance parameter is accuracy. It indicated the quantity of positive instances and displayed the proportion of these instances.

The classification accuracy should be near 100% for improved performance [34].

N. INTERACTION
Recent patterns show that developers are concentrating on Blockchain model test attributes. It implies that interaction needs to be defined for an open standard for the Blockchain to be communicated and accepted in a functioning healthcare environment. Open standards guarantee communication between multiple Blockchain components [72].

O. COST
Making blockchain more affordable in terms of processing power, computational cost, memory needs, and security is the focus of academic and industrial research [29].

P. UNSTRUCTURED DATA
Unstructured data that cannot be processed by a computer, such as clinical notes or discharge summaries [20].

Q. RELIABILITY
The system should be able to prevent potential threats from deleting or altering shared data. It should also store data replicas to provide dependable services in the event of a single point of failure [18].

R. AVAILABILITY
An assurance of dependable access to the information by authorized individuals is available [29].

S. INTEROPERABILITY
Interoperability refers to the ability of different information systems, software, or hardware to link data frameworks between stakeholders across organizational boundaries in a synchronized manner, improving individual safety [15].

T. REGULATORY COMPLIANCE
Refers to the commitment of service provider entities, organizations, and institutions to a complex framework of laws and regulations to provide safe, high-quality health services, protect patient confidentiality, support the overall safety of healthcare, and prevent fraud.

Below is a group of authors who discussed BIOT challenges and solutions in their research.

Authors in [2] discussed how Blockchain technology is crucial due to its immutable nature, which could result in reduced regulatory compliance costs, greater transparency, improved traceability, increased speed, and efficiency.

Authors in [8] discussed various security and confidentiality issues that they were able to resolve by utilizing the proxy encryption technique and the security characteristics of the Blockchain.

Authors in [14] discussed some difficulties related to scalability, performance, network processing speed, data management on remote nodes, security breaches, and attacks. The authors also displayed some blockchain-based solutions, including support for granular-level access mechanisms, permission-based blockchain networks, supported intelligent contracts, distributed blockchain consensus, and immutable blocks, which maintain data integrity. These solutions allow data to be shared and controlled in a transparent, patient-centric manner.

Authors in [18] explored several issues relating to the efficiency and accuracy of picture retrieval for medical IoT systems and several potential solutions to enhance security in image retrieval on cloud platforms. They provide users convenient data storage and query services with great scalability and large storage capacities. The primary method for safe picture retrieval in the cloud is to encrypt the extracted image characteristics to protect the privacy of the original image. Authors used blockchain techniques for privacy-preserving image retrieval over photos obtained from many data owners to increase the efficiency and accuracy of image retrieval. Each data owner can encrypt image characteristics with their private using a method they developed for encryption.

Authors in [20] discussed challenges and solutions related to anonymity and peer-to-peer communication. In response, the Office of the National Coordinator for Health Information Technology (ONC) of the US Department of Health and Human Services (HHS) announced the "Use of Blockchain in Health IT and Health-Related Research" challenge in July 2016. From more than 70 entries, 15 were selected as the best ones. The authors also explored the difficulty with using medical or clinical data, including unstructured data like clinical notes or discharge summaries that could be more computer-understandable. Natural language processing system (NLP)-assisted evidence-based medicine is needed to promote this and analytics on massive data actively.

Authors in [21] discussed a set of challenges related to detecting the prevalence of COVID-19 before symptoms manifest, security vulnerability challenges, scalability challenges, and interoperability challenges. The authors also discussed a set of solutions, The Web of Things (Wot) paradigm, as an attempt to solve the scalability and interoperability challenges of IoT by using the Web as an application layer for IoT, using blockchain technologies as a mechanism to monitor the traffic generated by wearables while providing tools to preserve privacy within smart homes.

Authors in [22] discussed Some difficulties with IoT systems, such as Big Data, energy consumption, security, dependability, and availability. Additionally, the authors covered a few options that employed blockchain technology and solar or wind power.

Authors in [31] discussed several issues and potential solutions about the TrackingCOVID-19Pandemic applications; they discussed several possible solutions to improve the scalability of blockchains, including

1) designing more scalable consensus algorithms like Delegated Proof of Stake (DPoS), Practical Byzantine Fault Tolerance (PBFT), and Proof-of-Authority (PoA).

2) looking into off-chain solutions

3) turning to new blockchain structures.

They also discussed some challenges, such as the issue of poor scalability, exhibiting low transactional throughput, and high latency.

Authors in [35] examined various blockchain-related difficulties, including processing power, storage, and scalability. Authors suggested blockchain and keyless signatures to ease the safe movement of information utilizing a series of cryptographically secure keys throughout a healthcare system.

Authors in [36] examined the difficulties of reducing network security performance. The authors also discussed the blockchain as a possible tool to address issues with IoT security. Authors in [37] proposed a centralized, decentralized structure that provides complete integrity and security of medical data.

Blockchain technology provides indistinguishable availability of information when and where it is needed, balancing server load during high traffic periods. Increased data security is provided by double encryption in medical data and the publication of produced keys. Because blockchain transactions typically involve massive amounts of data and large dollar amounts, the authors published only a modest amount of the chain, resulting in a low cost.

Authors in [38] explained the issue of patient data's compassionate nature and the sensors' short battery life. To solve these problems, a system combining solar energy and blockchain technology was developed in the study.

Authors in [39] proposed a blockchain system to address data security, privacy, sharing, and storage issues. In addition, the proposed solution uses blockchain technology to ensure the highest level of transparency in medical data security within the healthcare system.

Authors in [50] discussed several issues and potential solutions for ensuring sample and sensor performance. Sensors that continuously generate large data sets would call for a quick blockchain that is not only computationally cheap to reach consensus but also able to store large amounts of data.

According to the authors, vast amounts of "raw" data will probably require secured off-chain storage in the cloud, where only metadata or "fingerprints" are stored onto a blockchain.

Investigating energy harvesting for self-powered sensors like biofuel cells (converting glucose in sweat using enzymes or utilizing microbial fuel cells) and human motion could help address the problem of continuous monitoring using wearables. Instead of Bluetooth, Lora WAN technology may be used to build a low-power, high-coverage wireless digital infrastructure enabling remote sensors to communicate with the blockchain network.

Additionally, near-field communication and other low-cost, high-security wireless and battery-free technologies can be integrated with blockchain and sensors to expand capabilities and gather data over extended periods from regions that would otherwise be inaccessible.

New technologies can further reduce the carbon footprint of blockchain networks and IoT-enabled sensors by significantly lowering their energy consumption.

Authors in [70] discussed several issues and potential solutions relating to the Internet of Things and blockchain applications in big data for health applications. They highlighted many benefits of using blockchain technology, including immutability, non-intermediation, cost reduction, decentralization, security, system interoperability, scalability, transparency, secure distribution, and decentralization. They also talked about various difficulties, including the issues of storage, scalability, modifiability, privacy, and rules.

Authors in [72] examined numerous issues with and solutions for Latency, Scalability, Interaction, Security, and Privacy. Latency: The validation procedure, which takes longer than typical in shared Blockchains, involves the nodes. A few Blockchain nodes must participate in the validation process to solve the delay issue. Time is saved, and the system's processing speed and effectiveness are improved. Scalability is an issue that pertains to the limiting power of the Bitcoin organization to manage enormous information exchange on its foundation in a constrained amount of time.

Various solutions, including a hard fork (Bitcoin currency), a soft fork (Segwit), a lighting organization network, and plasma currency, are available and have been used to address issues. Interaction: Current patterns show that engineers are concentrating on testing Blockchain model properties. It implies that interaction needs to be defined for an open standard for the Blockchain to be communicated and accepted in a functioning healthcare environment. In these circumstances, open standards ensure communication between multiple Blockchain components. Security and privacy: An outsider can attack a company and cause serious issues if any unauthorized activity occurs within a Blockchain. A permission blockchain, such as a consortium or private Blockchain, should be used to overcome these difficulties.

These studies are summarized according to BIOT application type, Challenges, and solutions, as shown in Table 15.

IX. RESEARCH TREND IN BIOT HEALTHCARE APPLICATION

Several types of research in BIOT healthcare applications are shown in Table 16 with publishers.

Publishers like IEEE, ScienceDirect, Hindawi, MDPI, Scopus-Elsevier, Springer, and others.

Figure 15 shows BIOT healthcare applications, and according to the figure, the most popular BIOT healthcare applications are the security of medical records, remote patient monitoring, disease prediction, and healthcare monitoring, among others.

Figure 16 shows that most BIOT healthcare publishers like IEEE, ScienceDirect, Hindawi, MDPI, Scopus-Elsevier, and Springer.

X. DISCUSSION

This paper presents a review of BIOT healthcare applications. Blockchain types are shown in Table 2, which are public, private, and consortium, and the most common blockchain type used was a private blockchain. Blockchain technologies shown in Table 3 were Ethereum, Distributed ledger, Hyperledger Fabric, Immutability, Transparency, Cryptography, Consensus algorithm, and Smart Contract, and the most blockchain technologies used were Ethereum, Distributed ledger and Smart Contract. BIOT healthcare applications are shown in Table 4, which include Remote Patient Monitoring, Patent Tracking, Disease prediction (Diabetic Disease, Cardio Disease, Bain Disease), COVID-19 pandemic, image retrieval for Medical IoT Systems, Security of medical records, Smart Telemedicine, Secure the Internet of Medical Things, Healthcare and Big data, Sensors and Blockchain, Accurate Medical Decisions, Health Monitoring, Tracking System for Soldiers, Blockchain and Solar Energy. Electrogram sensors are shown in Table 5, consisting of EMG, EEG, and ECG. Vital sign sensors are shown in Table 6, consisting of Blood pressure, Respiration, Temperature Sensors, Pulse Oximeter, and Heart Pulse Rate.

Air and Temperature sensors are shown in Table 7, which consist of room temperature and humidity, air quality index, and air pressure. Body Positioning sensors are shown in Table 8 consisting of Body Positioning (MEMS), Accelerometer, Motion Sensors, GPS, and GSM. Other Sensors' IOT devices are Glucose levels,

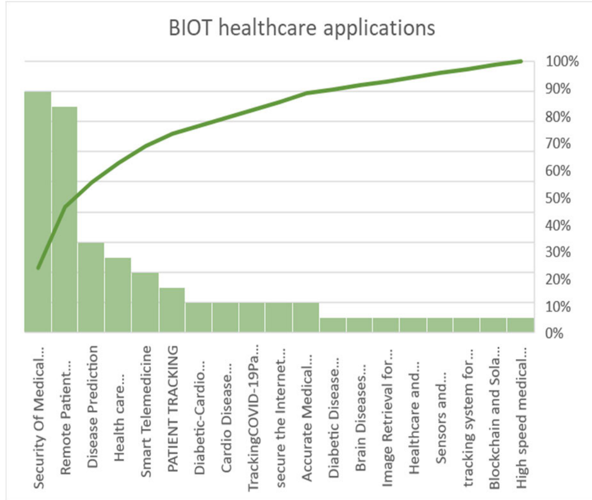

FIGURE 15. BIOT healthcare applications.

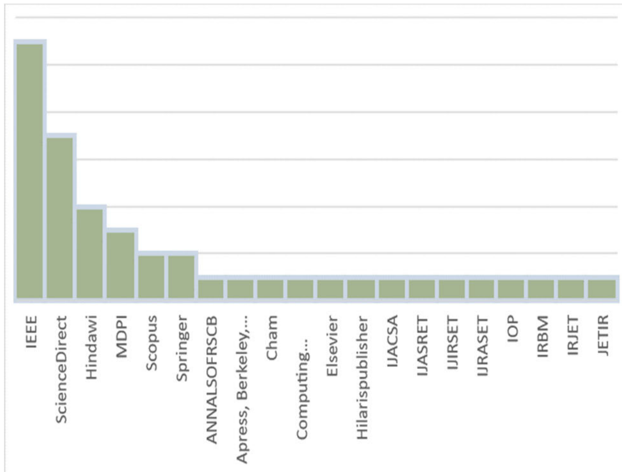

FIGURE 16. BIOT healthcare publisher.

TABLE 15. Some research in BIOT healthcare applications challenges and solutions.

BIOT healthcare Application types	Challenges	Solutions	Articles
Security of medical records and remote patient monitoring	Monitor and address the health Records of patients, removing the need to trust any third-party servers.	Blockchain technology could result in reduced regulatory compliance costs, transparency, traceability, increased speed, immutable, and efficiency.	[2]
Security Of Medical Records and Remote Patient Monitoring	Security and privacy	utilizing the security characteristics of the Blockchain and the proxy encryption system	[8]
Security of medical records	scalability, performance, processing speed over the network, data management on distributed nodes, and security breaches and attacks	Granular-level access mechanisms can be supported by permission-based blockchain networks to enable granular access control for medical records. Smart contracts supported by blockchains also enable patient-centric and transparent data sharing and control, the blockchain's distributed consensus mechanism overcomes the centralization restriction, and the immutable block maintains the integrity of data, making a blockchain verifiable and provable.	[14]
Image Retrieval for Medical IoT Systems	Efficiency, security, and accuracy of image retrieval	Large storage, high scalability, encryption of extracted images, use of blockchain techniques for privacy-preserving retrieval over images gathered from multiple data owners, design of an encryption method that enables each data owner to encrypt image features with their private key, and creation of a unique transaction structure.	[18]
Accurate Medical Decision	To provide anonymity and peer-to-peer communication, medical or clinical data, is that they are unstructured data like clinical notes or discharge summaries that are not computer-understandable.	Use Blockchain distributed ledger systems, natural language processing (NLP), and big-data analytics.	[20]
TrackingCOVID-19Pandemic, Security of medical records, and remote patient monitoring	Security, scalability, interoperability, and Asymptomatic SARS-CoV-2 patients pose huge challenges as they can infect others unknowingly	using Blockchain technology and the paradigm of the Web of Things	[21]
Healthcare monitoring	There is a lot of data involved, which is Big Data, as well as power energy, security, reliability, and availability.	Solar or wind energy and blockchain technology	[22]
TrackingCOVID-19Pandemic and telemedicine	poor scalability, low transactional throughput, high latency	designing more scalable consensus algorithms like Delegated Proof of Stake (DPoS), Practical Byzantine Fault Tolerance (PBFT), and Proof-of-Authority (PoA), looking into off-chain solutions, turning to new blockchain structures	[31]
Security Of Medical Records	Processing power, storage, scalability	Using a series of cryptographically secure keys, proposed blockchain, and keyless signatures permits the secure flow of information across a healthcare system.	[35]

TABLE 15. ***(Continued.)*** **Some research in BIOT healthcare applications challenges and solutions.**

healthcare monitoring and tracking system for soldiers	network security performance	Blockchain is an appropriate solution	[36]
Security of medical records and Remote Patient Monitoring	security	Uses blockchain technology	[37]
Healthcare monitoring, solar energy, and blockchain	Sensitive patient data, e limited battery lifespan sensors	Solar power and blockchain technology are both viable options.	[38]
Security Of Medical records and Smart Telemedicine	data security, privacy, sharing, and storage	Uses blockchain technology to provide complete transparency in the security of medical data within the healthcare system.	[39]
healthcare monitoring and tracking system for soldiers	network security performance	Blockchain is an appropriate solution	[36]
Blockchain and sensors	sample and sensor performance, Digital data, users, cost, storage	Significant reductions in energy consumption of both IoT-enabled sensors and blockchain networks with new technologies can further lower their carbon footprint. Examples of these new technologies include encrypted off-chain storage on the cloud, research into energy harvesting for self-powered sensors like biofuel cells (converting glucose in sweat using enzymes or using microbial fuel cells), human motion, and LoRaWAN® (long-range wide-area network) technology.	[50]
Healthcare and Big data	storage, scalability, modifiability, Privacy and regulations	immutability, non-intermediation, cost reduction, decentralization, security, system interoperability, scalability, transparency, secure distribution, decentralization	[70]
Security Of Medical records and Remote Patient Monitoring	Latency, Scalability, Interaction, Security and Privacy	There are several options available, including a hard fork (Bitcoin Cash), a soft fork (Segwit), a lighting organization network, and plasma cash, which have been implemented to address scalability issues. Few nodes are required to be involved in the validation process to solve the latency problem. Open standards guarantee that interactions between the various Blockchain components may address interface problems in these circumstances. To safeguard the patients' security and privacy, permissioned blockchain should be used.	[72]

Body weight, Smartphones, Smartwatches, and Wristbands, as shown in Table 9. The IOT hardware platforms shown in Table 10 consist of the Wi-Fi module, development boards, Arduino, Raspberry Pi, and Orange Pi Zero Plus. The IOT hardware platforms most used were Raspberry Pi and Arduino.

BIOT healthcare database applications are shown in Table 11, which consists of MongoDB, IPFS, and Orbit DB; the most used BIOT healthcare Database is IPFS. JavaScript's software technologies used in BIOT healthcare applications are shown in Table 12, which consists of JavaScript, Rest API, Node.js, ReactJS, JSON, and web3.

Programming Languages used in BIOT healthcare applications are shown in Table 13, such as Python, Flutter, Java, MATLAB, and Solidity; according to Table 13, the most common software language applications used in BIOT healthcare applications is Solidity. Software tools used in

TABLE 16. Researches in BIOT healthcare applications and publishers.

BIOT healthcare Application types	Articles	Publishers
Blockchain and IOT healthcare applications	[1]	IRBM
Security of medical records and remote patient monitoring	[2] [5] [33] [72]	IEEE
Security of medical records and remote patient monitoring	[3]	TOP
Security of medical records and remote patient monitoring	[4] [11]	MDPI
Security of medical records	[6]	Springer
Secure the Internet of Medical Things	[7]	IEEE
Security of medical records and Remote Patient Monitoring	[8]	ScienceDirect
Security of medical records	[9]	ScienceDirect
Remote Patient Monitoring and patient tracking	[76]	ScienceDirect
Blockchain and Mutability	[25]	IEEE
Blockchain and Cryptography	[29]	IEEE
Smart Telemedicine, remote patient monitoring, and prediction of diseases	[34]	Hindawi
Healthcare and Big data	[70]	ScienceDirect
Security of medical records	[13]	IEEE
Diabetic-Cardio Disease Prediction	[15]	IEEE
Diabetic-Cardio Disease Prediction	[16]	ScienceDirect
Security of medical records	[17]	ScienceDirect
Cardio Disease Prediction	[45]	Hindawi
TrackingCOVID-19Pandemic and telemedicine	[31]	IEEE
Cardio Disease Prediction	[46]	IJRASET
medical image retrieval with privacy protection	[18]	IEEE
Security of medical records, telemedicine, and prediction of diseases	[32]	Computing Machinery
Security of medical records and remote patient monitoring	[49]	ANNALSOFRSCB
Security of medical records	[73]	Hindawi
Security of medical records	[35]	IEEE
Remote Patient Monitoring and Diabetic Disease Prediction	[19]	MDPI
Blockchain and sensors	[50]	ScienceDirect
Accurate Medical Decision	[20]	IEEE
TrackingCOVID-19, Security of medical records, and remote patient monitoring	[21]	Scopus
health care monitoring and tracking system for soldiers	[36]	IJASRET
Security of medical records and Remote Patient Monitoring	[37]	Hilarispublisher
Security of medical records and Remote Patient Monitoring	[12]	Springer, Cham
Blockchain and MetaMask	[66]	A press, Berkeley, CA
Healthcare monitoring, solar energy, and blockchain	[38]	IRJET
Security of medical records and Smart Telemedicine	[39]	IEEE
Security of medical records	[14]	IJACSA
Security and high-speed medical records and brain disease prediction	[40]	Hindawi
Health care monitoring	[41]	JETIR
Health care monitoring	[22]	IJIRSET
Health care monitoring, security of the IoMT, and Security of medical records	[23]	MDPI
Truffle Suite in a Blockchain	[67]	Scopus - Elsevier
TrackingCOVID-19Pandemic, and prediction of diseases	[75]	Springer

BIOT healthcare applications are shown in Table 14, which are VISPA, AWS Cloud HSM API, MetaMask, Remix, ThingSpeak, Truffle, Caliper, Docker, and Ganache.

Challenges and solutions in BIOT healthcare applications are shown in Table 14, which are Security and Privacy, Confidentiality, Access control, integrity, Immutability,

TABLE 17. Components covered compared with other review papers.

Article	Blockchain types	Blockchain technologies	healthcare applications	Programming languages, tools, and databases	sensors	Hardware platforms	Challenges	solutions
[1]	√	√	√	×	√	×	√	√
[80]	√	×	√	×	√	×	√	×
[81]	√	√	×	×	×	×	×	×
[82]	√	√	√	×	×	×	√	√
Our study	√	√	√	√	√	√	√	√

Decentralization, Data Storage, Scalability, Modifiability, Throughput, Latency, Efficiency, Accuracy, Interaction, Cost, Unstructured data, Reliability, and Availability.

We have been compared between our review paper and reviews in [1], [80], [81], and [82] regarding components covered in the reviews.

Table 16 presents our review structure compared with other review papers [1], [80], [81], [82].

As shown in Table 17, Our paper comprehensively analyzes software languages, databases, and tools used in Blockchain IoT healthcare applications. This information can help choose the most appropriate software language and tools for implementing Blockchain IoT healthcare applications, an area that most researchers still need to explore thoroughly.

Our paper presents various hardware and sensors used in Blockchain IoT healthcare applications that have yet to be focused on by most researchers, aimed at facilitating the choice of appropriate hardware platforms to implement Blockchain IoT healthcare applications.

Our paper presents different challenges and relevant solutions in blockchain IoT healthcare applications.

Furthermore, we review the blockchain types, technologies, healthcare applications, hardware, and software used in articles that integrate blockchain with IoT.

XI. CONCLUSION

This paper reviews and analyzes blockchain-IoT healthcare applications regarding blockchain types, technologies, sensors, hardware platforms, database application programming languages, hardware platforms, challenges, and solutions.

Using blockchain technology with IoT greatly helps provide basic security requirements due to the built-in security structure of blockchain.

The decentralized architecture of blockchain can provide secure and scalable, low-cost, and fast transactions for IoT devices.

In this review, we present the merging of these two technologies by providing examples of Blockchain IOT healthcare applications, namely remote patient monitoring, patient tracking, disease prediction, tracking the COVID-19 pandemic, image retrieval for medical IoT systems, security of medical records, smart telemedicine, securing the Internet of Medical Things, Big data, blockchain and sensors, accurate medical decisions, health monitoring, tracking systems for soldiers, blockchain, and solar energy.

Furthermore, we focused on determining the software language databases and tools used with blockchain IOT healthcare applications. This information can help choose the most appropriate software language and tools for implementing Blockchain IoT healthcare applications, an area that most researchers still need to explore thoroughly.

We also focused on presenting the challenges associated with Blockchain IOT healthcare applications and existing solutions to create a complete understanding that facilitates the design and implementation of Blockchain healthcare applications and provides an extensive state-of-the-art for further research. We believe that the review presented in this paper will be helpful for developers and researchers as a reference guide to fully understand the structure of BIOT healthcare applications and facilitate the choosing of appropriate software language, tools, and hardware for the design and implementation of blockchain IOT healthcare applications.

Future work is to leverage this review to build a healthcare BIOT application model using best-in-class technologies, platforms, sensors, and a combination of databases and software tools and leverage most of the features of this review.

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