Chapter 6
Novel Designs of Smart Healthcare Systems: Technologies, Architecture, and Applications

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6.1 Introduction

Today, the field of big data has promptly grown up in which a considerable volume of data is produced from numerous heterogeneous sources. Big data is receiving ever more acceptance by the industries for various form of applications; for instance, eHealth, mHealth, and the Internet of Medical Things [1]. More recently, the field of big data and healthcare has been strongly interconnected which is enabled by state-of-the-art modern technologies. Hence, the advances in healthcare services, for example, patient's electronic health records and amalgamation of eHealth, mHealth, smart health, and telehealth smart devices, have created ultramodern healthcare systems that facilitate the accuracy of medical treatment and tailored healthcare solutions.

The Internet of Things (IoT) is a set of devices, sensors, actuators, and moving objects that are networked and fixed with software, applications, and networks to gather data for real-time exchange among them [2]. The healthcare and IoT are widely studied as it has many values for human life that deal with the healthcare regulations [3]. The advancements in modern technologies in fog computing, edge

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computing, IoT, cloud computing, and big data have extended the prominence as a result of their strength and capability to offer various functionalities for healthcare systems [4, 5]. Big data has the capability of analytical power that deals with the huge dataset to mine unseen correlations, hidden links, insights, visuals, and various trends from healthcare data.

In general, healthcare data is complex in nature and is strongly intertwined. Hence, the necessity for an effective big data-based healthcare system is required to monitor and detect patient's disease symptoms and take clinical decisions by the healthcare officers on time. The increasing necessity of healthcare usage and the advancement in big data analytics entail the advanced tools that solve the challenges encountered by big data volume, variety, and velocity [3]. Big data analytics is well renowned for its unique capabilities as it has analytical power, design elements, superior methodological approach and viable solution, and flexibility [6]. Further, simplifying the complexity in data, exploring the interlinks among healthcare factors, and the selection of targeted features for healthcare analytics need to be considered for healthcare system development [7].

In the face of rising healthcare demand, conventional healthcare systems are rapidly becoming inadequate [8]. Big data in healthcare contains a variety of structured, semi-structured, and unstructured data that are produced from different bases that cannot be effectively processed by the traditional algorithms, frameworks, tools, and techniques [9]. Most of the present big data tools and techniques for storing, processing, extracting, and analyzing the heterogeneous large volume of big data are insufficient [10]. The traditional data processing tools, techniques, and frameworks were less capable of handling huge amount of big data [9]. Similarly, the IoT effect is yet in its early growth stage in the healthcare domain [11]. Hence, it required a big data-based framework that eases the process of gathering, storing, mining, sorting, modelling, and processing of huge heterogeneous data [9].

This chapter discusses the detailed outline of most general techniques, architectures, and models in big data analytics. Accordingly, Section 6.2 highlights the role of big data in healthcare, Section 6.3 discusses big data analytics tools and techniques, and the next section proceeds with novel design elements in smart healthcare using IoT. Section 6.5 elaborates on the big data techniques, tools, and frameworks. Section 6.6 discusses the challenges and future directions of healthcare systems. Section 6.7 discusses in detail the latest techniques and technologies that support healthcare 4.0. The next section proposes the conceptually designed healthcare systems using big data analytics. Finally, this chapter concludes with smart healthcare applications using real cases.

6.2 Role of Big Data in Smart Healthcare Systems

With the recent advancement and modern technologies in big data analytics, its effect in healthcare has made to detect several data sources, for instance, telematics, sensor and wearable devices, and social media platforms [7]. By integrating the IoT devices and big data, it creates a unique avenue for offering healthcare services to users by using machine learning, cloud computing, and data mining techniques [12]. When we take the healthcare industry, a huge amount of data is being kept by drug and pharmaceutical manufacturing companies. These data are extremely complex in nature, and sometimes, these cannot be connected with other information by the practitioners, but it has some potential insights for better decision-making. As a result, the latest state-of-the-art technologies can extract the unseen correlation, links, and pattern of the diseases from these complex healthcare datasets.

Nowadays, the big data analytics in the healthcare domain has received much attention. In this line of thinking, the issues such as security, privacy, legal procedures, and establishing standards to improve big data technologies will draw much more attention of the healthcare developers and users. Hence, the preparations such as more operational platforms for data processing, smarter technologies for collecting data, intelligent and accurate computational analysis, visualization, and storage techniques need to be established to extract the value from the data. The applications of big data in healthcare can offer noteworthy advantages, for instance, identifying diseases at an early stage that can be detected more quickly and efficiently. Pramanik [13] denote that big data analytics is the advanced *healthcare informatics and analytics* technologies that are employed in evaluating the large volume of heterogeneous datasets, mining the big data, and statistical analysis.

In healthcare, the data sources can be generally categorized into the followings. First, *structured data* refers to the data that follows well-defined data type, structure, and format, for instance, the classified terminologies of different diseases, information about disease symptoms and diagnosis, laboratory results, electronic health records, information about the patient like admission histories, and clinical and drug details. Second, *semi-structured data* refers to data having self-describing nature along with being organized in a minimal structure, for example, the IoT and sensor device-generated data for patient's health conditions, doctor-to-patient email, social media, and web. Third, unstructured data describes no natural structure such as medical prescriptions written by physicians/doctors using human languages, clinical records, biomedical description, discharge records, claims, and informal texts [14]. explored from popular databases and systematically reviewed the supporting technologies for fog computing in the context of healthcare IoT systems.

Scholars claimed that there is a massive volume of healthcare big data produced from smart IoT; hence, it would be a great fortune to explore many hidden insights [15]. The data that are stored in the cloud or healthcare repositories can be processed using big data analytics techniques; hence, the superior decision can be taken for diagnosis and medical treatment [16]. In the aspect of security, the blockchain permits data sharing while confirming the data origin, inspection, and governance for the stored and shared healthcare big data among the participating entities [17, 18].

Evolving advancements such as big data, IoT, and AI have sparked healthcare innovation all over the world. The purpose of healthcare innovation is to create smart healthcare systems and provide better healthcare services. Today, the patient's electronic health records are integrated with IT applications such as the Internet of Things, big data, cloud computing, sensor technologies, mobile applications, and artificial intelligence to create a range of innovative healthcare systems. Machine learning and blockchain technologies are currently being heavily considered for a variety of industrial applications. It has been found that healthcare systems and intelligent technology, as well as their amalgamation with blockchain, have a closer relationship. As a result, machine learning and blockchain technology's traceability, accountability, protection, and decentralization will allow the healthcare industry to enhance and uplift several areas, including patient healthcare management, medical insurance management, and patient record and file management, as well as increasing the effectiveness of various connected applications and systems.

6.3 Big Data Analytics Tools and Techniques

Big data analytics is defined as the approach of handling and exploring unseen patterns, unknown associations, and other valuable insights from a large amount of datasets containing various data types, generated from numerous sources [6]. The developments in the sphere of big data analytics are one of the greatest important factors to investigate big healthcare data. The software vendors across the globe have moved the traditional software development approach to new forms such as data analytics, data mining, big data, data visualization, and statistical modelling [19]. In recent years, big data analytics and healthcare systems are getting much more attention and more popular among both practitioners and researchers [13]. Especially, the data analytics software developers build and tailor healthcare tools that are linked to heterogeneous data sources to collect electronic health records (EHRs).

With the increased demand for healthcare-based analytical tools, several software developers are shifting their design, development, and manufacturing of the healthcare tools in the healthcare domain [19]. To extract insights and knowledge from big data, the healthcare system necessitates state-of-the-art and modern data storage capabilities, management, analytics, and visualization tools and techniques [13]. Hence, machine learning includes various types of techniques, tools, and frameworks which can be used to handle the difficulties created by complex data [20]. The big data analytical platforms are generally open source; for instance, Hadoop was originally established by Apache. Hadoop allows for handling a large volume of heterogeneous data in which the data is requested into diverse sub-unit and then scattered to diverse servers to calculate various units of a complex problem [13]. There are methods such as statistical modelling, text mining, data mining, machine learning, data visualization, web mining, simulation, optimization, forecasting, and social network analysis used to handle big data [20]. Figure 6.1 depicts about cloud computing-based healthcare platform that integrates different healthcare system components.

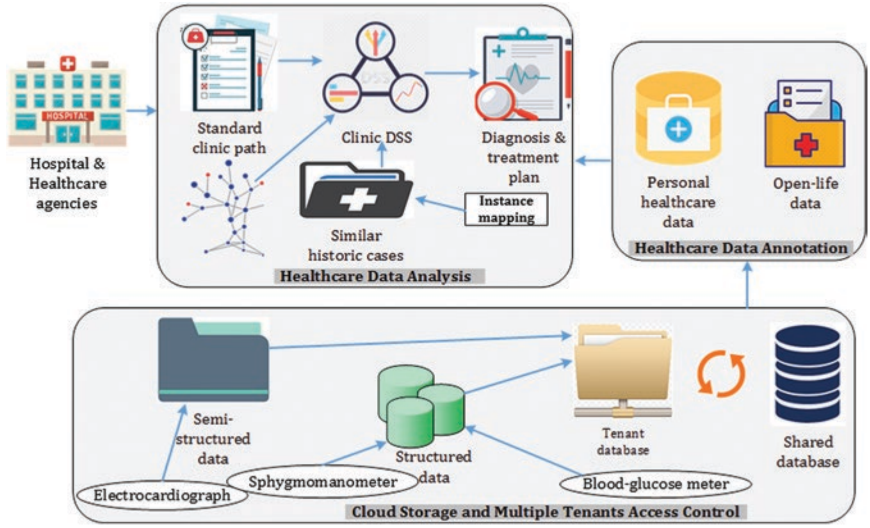

Fig. 6.1 Cloud computing-based healthcare platform

6.4 Novel Design and Smart Healthcare Using IoT

Scholars claimed that IoT is a novel Internet advent, in which the devices are systematized to create intelligent healthcare systems [11]. Today, the advancements in recent technologies and their integration are making the healthcare industry more modernized with the inclusion of smart healthcare services. The modern developments and advancements in the sphere of IoT create a distinctive method of using the healthcare systems [3]. The integration of IT and medicine renovate the healthcare sector to be more innovative such as precise and effective health services, IoT-enabled clinical services, and healthcare applications. The primary IoT-based healthcare system must provide efficient, easy-to-use application access to IoT data and devices that aid designers in creating visualization dashboards, analytics application, and healthcare-IoT application [11].

The IoT makes an atmosphere for smart house, smart healthcare, and smart business operation by transferring data through the Internet, whereas cloud computing instead powers the ability of IoT by offering computation power and storage capability to each smart artifact [21]. The healthcare solutions enabled by IoT linked devices anywhere, anytime, and with anybody seamlessly connected with any network and any applications, which brings to smart healthcare [11]. Researchers studied the medical applicability of nanotechnology, Internet of Nano Things, and nanobiosensors [22]. Similarly, [4] proposed a novel fog-based smart healthcare system called HealthFog to diagnosis heart diseases by using deep learning and IoT. This offers greater healthcare services and powerfully handing heart patient's data that is generated by various IoT devices. In the prior study, scholars have stated three paradigm shift trends in smart health and smart city study. Accordingly, (1) in healthcare, the traditional health to ubiquitous health, and smart health (2) in the city, the traditional city to digital city, and then to smart city (3) in data, database has shifted to data mining that is enabling big data [23].

Today, remote healthcare is becoming popular as it uses technology such as biosensors, efficient health records management, and computerized healthcare equipment to track a patient's health from a distance [24]. The rapid advancement in IoT, cloud computing, and a growing number of IoT and cloud computing-related applications in healthcare has received much more interest among researchers and healthcare stakeholders. As a result, the modern advances in nanotechnology drive the IoT toward it. The applications of nanotechnology in healthcare are, for instance, smart drug management, nanoscale surgeries, and epidemic spread detection and control. Nanomechanics can execute various functions inside the patient's body. Accordingly, it can build a nanonetwork inside the body and directly connect to the outside smart devices such as smart gadgets, smartphone, or access point [25].

6.5 Big Data Techniques, Tools, and Frameworks for Healthcare Systems

The ultimate success of the healthcare system merely rests on the primary architecture and the deployment of suitable techniques, tools, and frameworks that have been recognized as novel research areas in the big data domain [7]. There is literature evidence for many healthcare-supported big data frameworks to process a huge amount of heterogeneous data from different data sources to generate insightful patterns and trends that have been identified in recent times. The big data-related tools, techniques, and frameworks are classified based on the following aspects, for instance, (1) the programming model, (2) the programming languages that are supported, (3) type of available data sources, (4) the capability to allow for iterative data processing, (5) platform compatibility with existing master-learning libraries, and (6) the defect tolerance strategy [10]. In literature, there are prior studies that have tried to assess the big data tools, techniques, and frameworks [e.g., 7, 10, 12, 29]. The below division discusses novel design aspects from scholars around the world and their views for healthcare systems that have incorporated big data tools, techniques, and frameworks (see more in Table 6.1).

Accordingly, Rahman and Bhuiyan [30] suggested an RFID framework resolves two privacy issues in RFID-centered healthcare system, namely, (1) authentication protocol for identification and monitoring purposes and (2) access control to control illegal access of protected data. Their research work exposes the security and privacy aspects in the technical design of RFID systems in this healthcare field. The privacy and sensitivity of healthcare data must be restricted with security measures and data quality requirements. Pramanik and Lau [23] proposed a big data-based smart healthcare framework with a three-dimensional structure of a paradigm shift

Table 6.1 Novel designs of IoT in smart healthcare systems in recent studies

Studies	Novel designs/ features	Key characteristics	Data sources	Big data tools/ systems	Analytical capability/ performance	Key highlights
Pramanik and Lau [13]	Proposed healthcare informatics and analytics (HCI&A) framework	Covers underlying technologies, system applications, system evaluations, and emerging research areas	–	HCI&A framework under the context of big data	HCI&A is conceptualized in three stages, such as HCI&A 1.0, HCI&A 2.0, and HCI&A 3.0	Bibliographic study is conducted on HCI and HC information systems
Tuli and Basumatary [4]	Proposed a framework by adding deep learning in edge computing devices for heart disease analysis	Framework offers healthcare as a fog service by IoT tools and powerfully handles the data of heart patient's requests	Heart patient's data from IoT devices (blood oxygen, heart rate, respiration rate, EEG, ECG, EMG, blood pressure, glucose level)	Fog-enabled cloud, FogBus framework	Deployed and test the performance considering power utilization, jitter, delay, bandwidth, correctness, and execution time	It offers greatest quality of prediction accuracy, in various fog computation states and for different user requests
Fang and Pouyanfar [26]	Health informatics processing pipeline	Machine learning techniques and algorithms compared	Electronic health records, public health, genomic, behavioral data	Feature selection machine learning (classification, regression clustering)	Decision support system via computational health informatics for practitioners	Data capturing, storing, sharing, analyzing, searching, and decision support through computational health informatics
Lin and Dou [27]	Cloud-based framework for self-caring service	Lucene-based distributed search cluster and Hadoop cluster are used	Patient profile, data, and clinical data	Hadoop cluster is used for highly concurrent and scalable medical record retrieval, data analysis, and privacy protection	Home diagnosis – Self-caring service	Home self-caring based on historical medical records and disease symptom

(continued)

Table 6.1 (continued)

Studies	Novel designs/ features	Key characteristics	Data sources	Big data tools/ systems	Analytical capability/ performance	Key highlights
del Carmen Legaz-García and Martínez-Costa [28]	Semantic web-based framework for interoperability and exploitation of clinical archetypes	Semantic web technologies for interoperability and exploitation of archetypes, EHR data, and ontologies	Electronic health records (EHR), ontologies	OWL-based ontology	Classification based on clinical criteria	Integration of semantic web resources with EHR
Mahmud and Iqbal [12]	Cloud-based data analytics and visualization framework – Health-shocks prediction	Amazon web services linked with geographical information systems and fuzzy rule summarization technique	Healthcare data focused on social, economic, cultural, and geographical conditions	Generated predictive model using fuzzy rule summarization	Public households to increase healthcare facilities	Cloud-enabled geographical information system
Sicari and Rizzardi [29]	Policy enforcement framework IoT-based smart health	Security and quality threats in dynamic large-scale smart hearth environments. Cross-domain policies have been defined using XML	RFID and instrument-generated data, patient and environmental data	Policy-based access control mechanism for availing healthcare resources	Smart health applications to prevent security threats in large-scale heterogeneous health environment	Implementing policy framework for smart healthcare
Rahman and Bhuiyan [30]	RFID-based framework to preserve two privacy issues in healthcare system	Authentication and access control are ensured for RFID tag application in healthcare domain	RFID tags	Techniques to preserve privacy in RFID	Protecting healthcare domain services	Better privacy mechanism to protect RFID applications in healthcare domain

Pramanik and Lau [23]	Big data-aided framework for smart healthcare system	State-of-the-art design and architecture of smart healthcare services	Electronic health record, patient diagnosis and biometric data, social media and surveillance data	Smart healthcare services at smart cities via advanced healthcare systems	Smart integration and technologies to provide state-of-the-art healthcare services	Combining big data and healthcare-designed smart services for the smart city
Forkan and Khalil [31]	Cloud-centric big data framework for personalized patient care through context-aware computing system	Knowledge discovery-based context-aware framework	Profile data, patient medical records, activity logs, vital signs and context cum environmental sensor data	Mine trends and patterns with associated probabilities that used to learn proper abnormal conditions	Classification to identify real abnormal conditions of patients having variations in blood pressure	Personalized healthcare services through context-aware decision-making approach
Hossain and Muhammad [9]	Voice pathology assessment big data framework	Machine learning algorithms	Speech signals	Classifiers such as support vector machine, an extreme learning machine, and a Gaussian mixture model	The audio features classified as normal or pathological	A framework to handle healthcare big data
Syed and Jabeen [32]	Smart healthcare framework using internet of medical things and big data analytics	Parallel process in Hadoop MapReduce used	Multiple wearable sensors	Multinomial naïve Bayes classifier that match with the MapReduce	Smart healthcare for ambient assisted living	Smart healthcare facilitates to remotely observe health status of elderly people
Raghupathi and Raghupathi [33]	Conceptual and architectural big data framework	Outlines methodological and architectural design of big data	Multiple location's physically dissimilar data sources in many formats	Analytical queries and generating reports	Healthcare design domain	Proposes a state-of-the-art model for designing healthcare big data framework

and three technical branches of big data healthcare systems that address the potential challenges and opportunities in executing this system to the healthcare business context. Likewise, Raghupathi and Raghupathi [33] suggested a big data framework that takes into account the theoretical and methodological facets in which the proposed conceptual architecture of big data analytics contains big data sources, the transformation of big data, existing platforms and tools, and the applications of big data analytics.

Furthermore, [29] have proposed a policy enforcement framework to address security threats that are expected during the development of IoT-based applications for smart health. Their modelling is suitable for heterogeneous IoT-based applications and their architecture in this smart healthcare context [32]. developed a smart healthcare framework that can monitor the physical health condition of aged people by using the Internet of Medical Things and analyzed by machine learning algorithms. Their proposed system applied the multinomial naïve Bayes classifier that supports the MapReduce paradigm, and the system consists of a faster analysis of data and better disease decision-making with better treatment recommendations in which the elderly people's health conditions could be remotely monitored. Similarly, Youssef [34] introduced big data analytics-based healthcare information systems framework in mobile cloud computing environments. Their proposed framework offers features such as interoperability, high integration level, and accessibility and data sharing among health workers, patients, and practitioners and enables them to find valuable insights for practitioners' effective decision-making at the right time.

6.6 Challenges and Future Directions of Healthcare Systems

There are various challenges in the aspects of design, development, implementation, and maintenance of IoT-based healthcare systems. For instance, the varied use of various IoT devices has challenges such as authorizing the IoT smart devices for the healthcare system, accumulation, and handling of real-time data [3]. Mutlag and Ghani [14] claimed that there are challenges for healthcare applications particularly in resource management and different requirement challenges such as adaptability, flexibility, consistency, privacy and security, low latency, and energy efficiency for intelligent global healthcare systems.

Though fog computing has various benefits in healthcare IoT systems, it is obvious that it also has some restrictions and challenges in resource management [14]. The fog computing latency and response time are identified as the key factors that make improving the quality of service in real-time healthcare applications difficult [14]. Similarly, IoT smart devices in healthcare system generate a large volume of big data that has challenges like processing and storage [21, 35]. The attack of patient privacy is identified as a serious concern using the healthcare big data analytics; moreover, big data security and privacy challenges, technical challenges, and skilled talents are also identified as challenges [36]. Similarly, the IOT's most puzzling problems include setting up system capabilities, safety, and reducing differences between individuals and sensors [11]. Din and Paul [3] identified several challenges for healthcare in big data in literature such as data aggregation, data format, incompleteness, timeliness, scaling, normalization, noise removal, and queuing.

For the future direction of healthcare systems, there are specific techniques needed in communication and IoT mobile applications to aggregate, store, and handle big data [3]. In the near future, the advanced technologies and standards will be addressing the privacy and security aspects of users, data, applications, and network [11].

6.7 Overview of Latest Technologies and Methods Supporting for Healthcare 4.0

In recent times, industry 4.0 has enabled healthcare 4.0 that includes IoT, industrial IoT, AI, cognitive computing, edge computing, and cloud and fog computing in the healthcare domain [5, 37]. Healthcare 4.0 integrates smart devices and advanced technologies in the healthcare sector. Hence, healthcare 4.0 aims to integrate with big data, AI, blockchain, cloud computing, IoT, and fog and edge computing analytics to offer better healthcare support [38]. Big data analytics, cloud computing, IoT, and blockchain technologies have involved healthcare 4.0 to process, store, analyze, and respond to medical records [39]. Moreover, in recent time, the remote healthcare services in which the patients are not moving for the medical treatment or clinics have become a new trend in smart healthcare [40]. The below section discusses in detail various techniques in healthcare.

6.7.1 Cloud Computing and Architecture

Cloud computing is a computing architecture in which all computing resources including storage capacity, memory allocation, and computing power are used collectively in the cloud-based environment on the Internet. With the arrival of modern technologies, the world is encircled by numerous intelligent mobile smart devices that are used to connect the world in which the data is stored and retrieved from the cloud. The features in cloud computing such as storing capacity, managing server, benefits in bandwidth, and network efficiencies that enable to coordinate with connected devices have made cloud computing as one of the foremost reasons big data becomes so popular [26]. Mainly, the web applications are used in the cloud computing platform to access the resources, and it can be flexible in a way that scales up and scales down the resources based on the computing requirement [21]. The figure shows the architecture of IoT-based cloud computing in healthcare in which the connected devices are interacting to share data and information (Fig. 6.2).

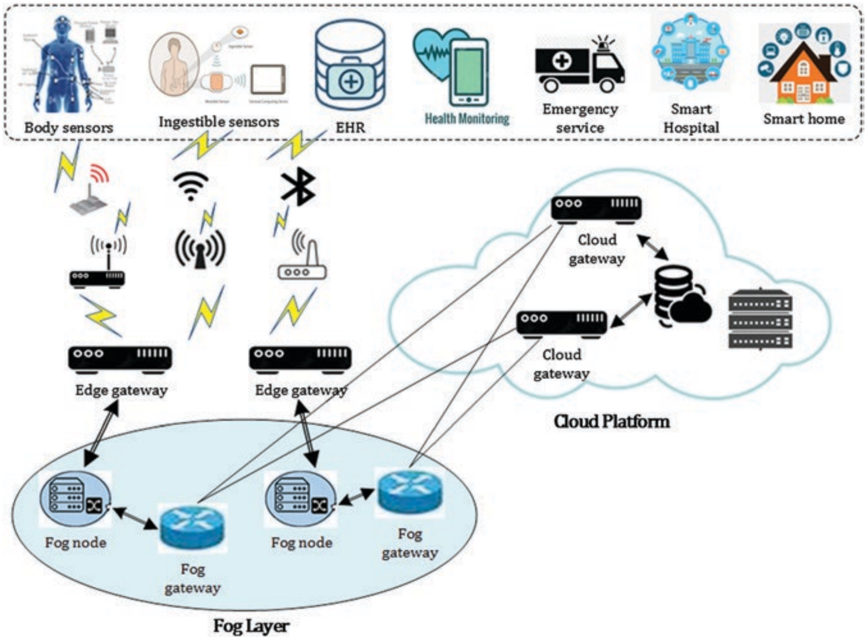

Fig. 6.2 IoT and cloud computing in healthcare architecture

Cloud computing has been identified as the most widely adopted architecture by healthcare application developers being a key big data client for deploying the application on the cloud environment [12]. The IoT-supported cloud computing can be adaptable to extend the development of innovative applications services in the healthcare sector over the smart platform [41]. Cloud computing offers data analytics, exploring new insights, and mining critical results; thus, it can speed up many analytical decision in healthcare systems [12]. As a result, healthcare systems commonly use cloud storage platforms to save information between the data originator layer/sensor device and the data analyzer layer/end-user applications for real-time disease analysis [42].

6.7.2 Fog Computing and Architecture

In recent years, the paradigm shift is from cloud computing to fog computing in healthcare [43]; that reduces many drawbacks in cloud computing such as storage shortage, computing power, and network delays [44]. Fog computing is defined as the physically isolated heterogeneous devices that are connected with the network to share computing resources and to offer storing capability, flexible connection, and calculating power [14]. Fog computing employs nodes, gateways, and routers to deliver services with the lowest network latency, response time, and energy utilization [14]. For healthcare system development, the fog computing has been identified as appropriate as it has the abilities that the application needs for greater availability, superior response, minimum latency, and real-time availability [14]. Fog computing is an improved layer in addition to cloud computing that has developed as an emerging paradigm with shorter delay and improved network efficiency for healthcare systems [45]. The significant benefits of fog computing are to increase the scalability and storage capacity and improve efficiency for collecting data, storing, processing, and analyzing [45]. In fog computing, the well-networked device, capacity to store, computing power, and geographically distributed nodes are facilitating the real-time, low-latency, and increased responses for healthcare systems [39]. On other hand, fog computing supports surmounting drawbacks in big data processing [44].

Figure 6.3 illustrates the design-layered architecture of fog computing for a healthcare network. It contains three layers such as the smart terminal layer, the fog computing layer, and the cloud computing layer. The smart terminal layer contains various

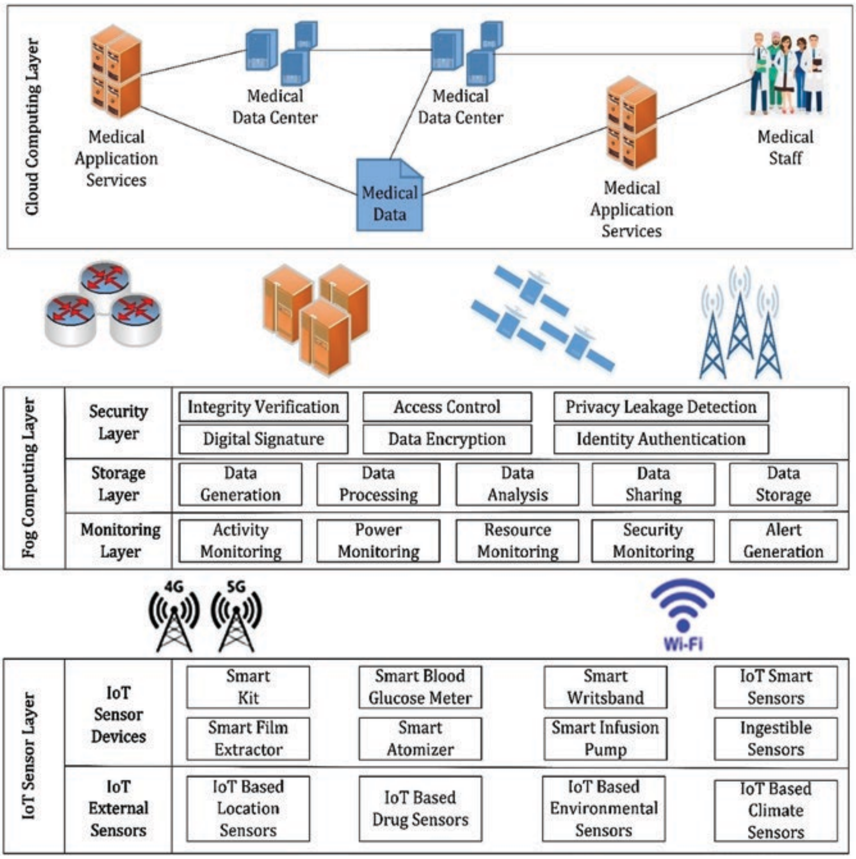

Fig. 6.3 Fog computing architecture for healthcare network

smart intelligent devices and tools that are used to gather healthcare data from the patient. Then, the gathered data are transmitted to the fog computing layer for additional data processing. This fog computing layer functions as a middle layer between the smart terminal and cloud computing layer. This layer contains actions to preprocess, handle, analyze, distribute, store, control, encrypt, and distribute the data. Finally, the cloud computing layer is responsible for the data processing and transmission and supplying the healthcare data to relevant entities and healthcare users. Accordingly, fog computing offers computation, networking, storage, and management services among the end-user applications or edges and the cloud data centers [44].

Due to the bottlenecks such as latency and inadequate scalability in cloud computing, modern healthcare and surveillance systems necessitate greater computing power to handle huge amounts of big data that are transmitted between centralized database to cloud data centers. Hence, the new models of fog and edge computing offer state-of-the-art solutions by providing low-latency and energy-efficient solutions for data handling than cloud domains [4]. Fog computing has several benefits, for instance, reduced latency, improved bandwidth, reliability, energy-efficient operation, safety, and flexibility [46]. It can offer instant outcomes and offer sophisticated healthcare, well-improved diagnostics, and treatments [42]. The foremost notion of fog computing is to improve the effectiveness and flexibility and reduce the volume of the data that can be transferred to the cloud-based components for analyzing, managing, and processing big data.

6.7.3 Internet of Things (IoT) and Its Architecture

The future will be the era that connects the physical things with the Internet in which the things include sensors, machine, and appliances; even the humans also become the part and partial of it. The IoT is the future technology to renovate an artifact into smart things by linking them to the Internet. IoT plays a noteworthy function in smart healthcare system development. The IoT contains various tools and technologies such as sensors, controllers, and wired and wireless connectivity services that allow links among physical things and virtual connections [47]. The reason for joining healthcare with IoT into smart medical devices advances the quality and efficiency of healthcare service, offering high value for elderly patients with chronic conditions and need for regular observation [25]. The IoT architecture involves various tools that enable the IoT to incorporate technologies to make the IoT system for modularity and extensibility for diverse situations [11].

The IoT system architecture consists of layers for various functionalities such as sensor, gateways and networks, management service, and application layer [11]. The IoT and cloud computing have emerged as a combined platform that offers a vital role in healthcare services to the connected users by minimizing the cost and time related to the data collection. In the context of healthcare, IoT-based applications can be applied to monitor patient health conditions, ubiquitous healthcare management, and telemedicine and identify clinical issues and diseases, maintenance, and logistics arrangement in the healthcare systems [29]. Scholars suggest that for the smart healthcare system development, experts from information and communication technology, electronics, and healthcare professionals must work seriously [48]. The efficient implementation of IoT for gathering, processing, and supplying data produced by medical devices, sensors, wearables, and humans is important for modern healthcare systems.

6.7.4 Internet of Medical Things (IoMT)

It's a radical shift for the healthcare industry with the Internet of Things. The growing applications of IoT and the Internet of Medical Things electronic devices have made medical treatment more systematic, and the healthcare records can be handled and well organized [49]. The recent emerging advancements in healthcare equipment, usage of IoT devices, and state-of-the-art wireless and computing power have enabled the extensive applications of the Internet of Medical Things [50]. Therefore, the practice of data handling in healthcare is improved particularly by employing techniques like machine and deep learning, data mining, artificial intelligence, and algorithmic modelling. The Internet of Medical Things connects with diverse objects such as end users, sensor devices, and network nodes that operate on a simultaneous basis for supreme disease analysis and diagnosis; as a result, it increases to have reduced cost, finest analysis, superior supervision of clinical procedures, and more precise cures [51]. Equally, the Internet of Medical Things devices have been extensively employed for detecting symptoms, predicting weather and the climate, virtual observation, and superior connection of healthcare devices.

6.7.5 Wireless Body Sensor Network

The wireless body sensor network is an emerging healthcare technology that requires modern micropower bases with great energy density, extensive lifetime, and worthy biocompatibility [52]. It assimilates the technology of detecting nodes, smart data handling, computing power, and communication [53]. The wireless body area network is a system of interconnected sensor devices, digital objects, and people that are offered distinctive identifiers and the capacity to transmit data over a network [54]. The wireless body sensor network is a set of smart and intelligent medical sensor devices implanted or on the surface of patients' body, which is employed to constantly monitor sign, symptoms, and patient's condition and for remote health tracking on a real-time basis to share them with a doctor or patient [e.g., 55–58]. Its healthcare monitoring includes blood pressure, pulse rate, heartbeat rate, pressure, oxygen level, temperature, and respiration rate [59, 60].

The applications of wearable IoT healthcare devices especially for patient's remote monitoring and the design of wireless body area network have facilitated the modern healthcare system. The wireless body sensor network is important and vital for elders who require continuous monitoring without others' support or being hospitalized. Further, as the aged people require more medical services health monitoring, the wireless body area network supports to remotely control and monitor various diseases [61]. The body sensor network contains similar and/or various detecting nodes including wearable and biocompatible sensors [53]. The wireless body area network has made continuous health monitoring possible; thus, the users can get unlimited medical services on space and time [62]. The wireless body area network has been not only used to prevent and cure different diseases but also employed in elders and disabled people's healthcare [62]. Similarly, it has various advantages such as reducing medical cost and human mistakes, increasing the patient's comfort, and no longer need to wake for physical checkup [60].

The intelligent biosensor-enabled body sensor network facilitates for healthcare monitoring, remote health tracing, and even offering alerts to physician or doctor through the Internet and mobile devices that are beneficial in terms of accuracy, cost, and reply time [58]. Based on the patient's symptoms, continuous treatments for emergency conditions are done with the help of body sensor devices. Body sensors are widely used for diagnosis and continuous monitoring of patients undergoing emergency care [63].

6.7.6 Blockchain in Healthcare

Today, the modern technologies, innovative applications, privacy, and security of healthcare data have become the utmost importance. The applications of blockchain technology are in many sectors, for instance, finance, healthcare, big data, cybersecurity, supply chain management, and law [64]. The blockchain, initially introduced from bitcoin, that has modernized and was applied in various industries in the past now has become one of the state-of-the-art technology in today's world [65]. The blockchain-centered architecture provides a new model focusing the data in the aspect of safety, integrity, standardization, and compatibility for accessing and sharing data [15, 37]. Healthcare records, laboratory tests, physician prescription, and exact healthcare details can all be decentralized using blocks and transactions in healthcare [66]. The big data in healthcare can optimize the blockchain by exploiting big data-driven business intelligence for various supportive services like insurance policy [15]. Currently, the blockchain has developed as an appropriate way to advance the privacy and security of healthcare data and its participating entities [16]. Further, the blockchain has been identified as a means to elucidate challenges encountered by healthcare, such as the secure transmission of healthcare records and data privacy compliances [67].

The blockchain with other state-of-the-art recent technologies has the ability to renovate the present intelligent healthcare systems from an integrated and susceptible system to a distributed, decentralized, and highly safe system for enlightening the quality of healthcare services [16]. Similarly, researchers highlighted that the blockchain enables decentralization as it has distributed ledger technology, improved safety, authentication, stability, computing infrastructure, and compatibility [e.g., 17, 67–69]. In healthcare, the foremost characteristics of blockchain are interoperability with data sharing, various systems, and participating entities. The blockchain has various benefits in healthcare such as clear data for all participating entities while keeping the privacy and preventing malicious attacks and data thefts and offers cheap and secure healthcare and supportive services for related entities (e.g., suppliers, insurance, healthcare researchers, pharmaceutical and drug companies) [16]. Though the blockchain has several benefits, still, there are concerns and vulnerabilities such as data mining attacks and mining incentives, anonymity, data privacy, and authentication issues [17].

6.7.7 Machine Learning

There are well-known healthcare analytical techniques to be applied for healthcare data such as machine learning, modelling, visualization, statistical analysis, and data mining. Above all, machine learning is the highly used technique that gives massive potential in the domain of healthcare predictive analytics to advance the results [20]. The Internet of Medical Things and cloud server frequently gather and share data that can be handled and analyzed by using the machine learning and big data analytics techniques [32]. Scholars claimed that further development should be taken on the machine learning decision support systems that will offer clarifications and healthcare officers' interactive visualization tools to study the consequences of potential effects [20]. Supervised, semi-supervised, and unsupervised classifications are the major types of machine learning algorithms [70].

Machine learning is the perfect method to exploit the unseen insights and pattern from the large volume of the dataset with the least support from the human direction [6]. Machine learning contains a range of techniques such as predictive analytics, data mining, pattern recognition, and various modelling. The healthcare industry is powerful in utilizing the applications of machine learning techniques into actionable knowledge bases by executing predictive and prescriptive analytics to support intelligent clinical services. Scholars define machine learning as a kind of artificial intelligence that enables the machine to learn without being programmed and is used to increase future outcome based on past results [47]. In healthcare, machine learning techniques are being used for predicting disease severity and reasoning, decision support for medical surgery or therapy, extracting healthcare knowledge, analyzing various health data, and drug discovery [23]. Different machine learning techniques are executed for mining from large-volume datasets, for instance, decision trees, support vector machines, neural networks, and dimensionality reduction [6].

6.7.8 Deep Learning

Deep learning is a subset of machine learning that involves extracting high-level, complex abstractions as data representations with the support of a hierarchical learning process [6]. Deep learning aims to predict and classify extremely high accuracy of healthcare data. Deep learning's main feature is its ability to analyze a huge volume of unsupervised data, which is critical in big data analytics because the data is unlabeled and unclassified [6].

6.7.9 Intelligent Computational Techniques and Data Mining

The traditional methods for handling health data have reached limited success because they are incapable of treating a large volume of complex data [26]. Big data is used for the sole reason of analytics in which knowledge and significant insights are mined from big data. There are various data sources such as media, cloud, web, IoT sensors, and database which can be used to collect a large volume of big data [71].

Pramanik and Lau [23] identified three comprehensive technical branches such as intelligent agents, text mining, and machine learning as the modern healthcare technologies in their smart health in smart city study. Intelligent agents in healthcare are defined as the entities that gather instructions and interrelate with environments in which they recognize the physical and virtual settings by using various sensing devices to perform the given tasks [23]. The application of intelligent agent in the healthcare domain is retrieving health information from big data; disease diagnostic decision support systems; planning and scheduling task for doctors, nurses, and patient; medical information sharing; medical image processing; automation; simulations; bioinformatics; medical data management; and health decision support systems [23].

In healthcare, text mining enables to mine important knowledge insights from textual data in which some analytical models can spontaneously code unstructured information with text mining grouping, research activities on the biomedical field, and knowledge management and discovery [23]. In healthcare, various data mining procedures can be used such classification, association rule mining, regression, clustering, detection, analysis, decision trees, and visualization to extract effective details [12, 71]. Data mining is the technique that extracts patterns and connection that can generate knowledge or insights from databases or large datasets [71]. The powerful amalgamation of healthcare informatics and data mining by employing big data analytics techniques will increase the quality of healthcare services with effective decision-making [72].

The machine learning technique is applied to extract pattern and model, whereas data mining is a mixture of statistics and machine learning that are mostly involved with large datasets and analyze huge, complex, and unstructured/structured data [26]. Researchers have identified the fuzzy logic systems as a perfect option to design healthcare systems as they can handle uncertainties, inaccuracies, complications, and comprehensiveness of the data. Further, fuzzy systems offer apparent and convenient rule-oriented models that can be a methodology for designing predictive models and cataloguing by employing imprecise cognitive of uncertain data and information [12].

6.7.10 Hadoop Architecture

In healthcare, several techniques, tools, and frameworks have been established to process the big data in which Hadoop is the distributed data processing framework that is used to store and process a large set of data by employing the MapReduce programming paradigm. Hadoop is the famous open-source distributed processing platform for big data analytics that can function as the data analytics and data organizer in the Apache environment [23]. Hadoop and MapReduce have the ability such as flexible and computational powerful cloud computing environment to execute healthcare ontology quality assurance [20]. Apache Hadoop is the most frequently used computing platform for big data analytics tools in healthcare.

The Hadoop contains two key components, namely, *Hadoop Distributed File System* (HDFS) for data storage and *Hadoop MapReduce*, aimed to deal with parallel processing of huge datasets. The application depends on Hadoop for processing big data issues, and the users can request only smaller amounts of data to the statistical software [20]. To solve the key drawbacks in Hadoop, a new architecture was established, namely, YARN, which has the resource management infrastructure and gives many scheduling functions [20].

6.8 Proposed Novel Conceptual Design of Healthcare Systems Using Big Data Analytics

Sensor and wearable devices are regularly generating a large volume of data that contains structured and unstructured data. Table 6.1 lists a comparison of big data-related healthcare system features in prior and present studies. Following a comprehensive review, a big data-based conceptual framework is proposed in healthcare systems that contain IoT sensors, data sources, big data types, big data analytical platform and tools, analytics data output, patient health monitoring, and recommender system, which are presented in Fig. 6.4.

6.8.1 Proposed System Functionalities

6.8.1.1 Data Sources

This section describes the functionalities of the proposed system. The healthcare-related data will be collected from embedded sensor devices that are placed on the patient's body. The heterogeneous data resources in healthcare, namely, clinical, patient, pharmacological, and drug-related data, must be correctly handled and examined to develop the latest healthcare systems. Similarly, there are a variety of healthcare data available on social media and websites that can also be collected for this healthcare system. The generated data will be transferred to the cloud data storage server. In the meantime, the data-handling portion will migrate the patient's symptoms and body condition-related data to the fog computing environment. Once the transferred data has been compared with the existing data in the database, a report describing the current state of the patient's health will be produced, along with the necessary tentative care/medical therapy to be taken. The healthcare data

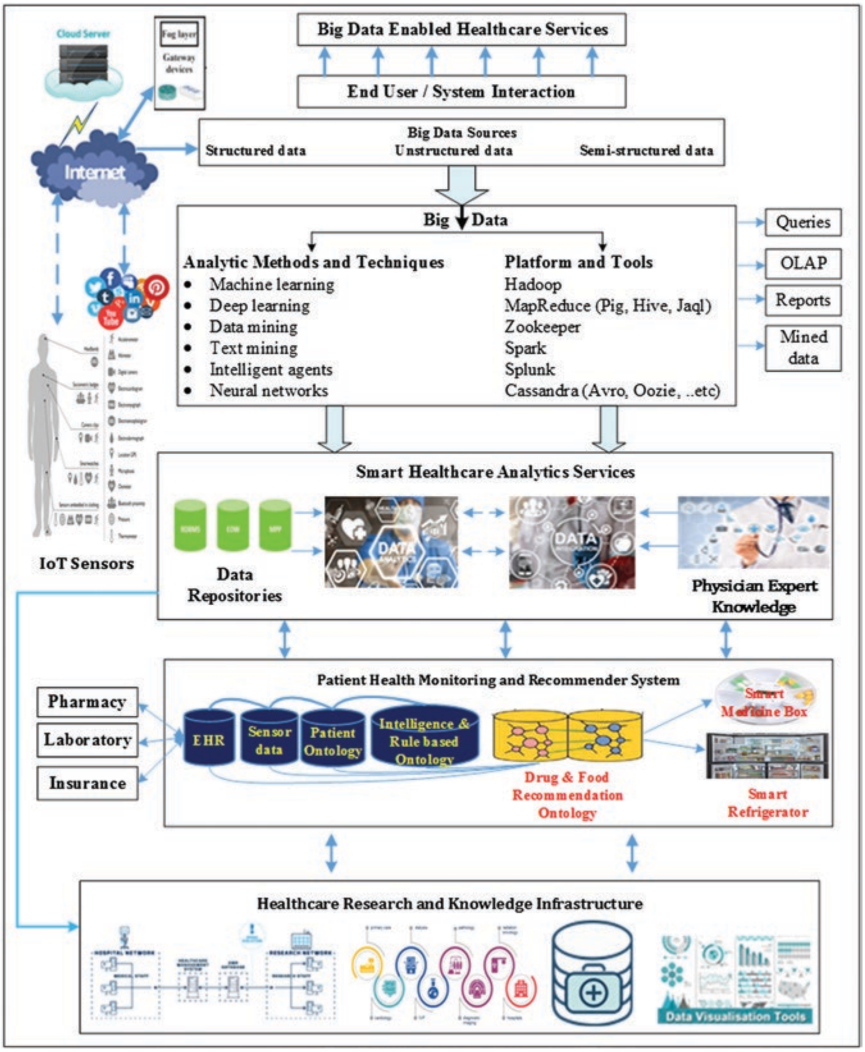

Fig. 6.4 Proposed big data-based conceptual framework in the healthcare system

collected from the patient's body/social media can be in any format, including structured, unstructured, and semi-structured data. To handle these kinds of data, there are several big data analytics methods, techniques, and platform tools that exist. These techniques and tools will be used for analyzation based on the data types. The output of these analyses will be in any form such as queries, reports, Online Analytical Processing (OLAP), and extracted data mining.

6.8.1.2 Patient Healthcare-Related Data

The modern developments especially in IoT and sensor devices have made patient's monitoring more advanced, and that aims to offer superior healthcare service delivery to sick persons. Healthcare records may include a variety of symptoms and patient health issue data. For instance, it may include body symptoms such as fever, headache, pain in the bones and joints, skin eruption, body pain, red eyes, nausea, vomiting, and myalgia. To collect these symptoms, IoT sensor devices or physical test will be used. If it is an IoT device, it will be embedded in the victim's body to identify or detect the conditions. The symptoms detected by the IoT sensors will be transmitted to the fog computing environment which is linked through cloud computing to store in single or multiple data storage components.

6.8.1.3 Cloud and Fog Computing Components

In this proposed system, cloud and fog computing environments have been employed. As the healthcare data seems to be highly sensitive and private, there is a need for the protected transfer of these medical records, hence, to make sure the data security of the data encryption mechanism will be employed. The cloud layer saves data from the Internet for the concurrent retrieval of data by the devices linked with this ecosystem. The data which require further sorting or handling will be transmitted to the cloud layer. The cloud layer is responsible for storing, managing, and processing records as the fog computing layer cannot manage. The fog computing component gathers data from the Internet for further analysis. This fog computing component is responsible for data storage, data processing, data transmission, and communication-related activities. Therefore, the patient's health condition associated with symptoms and sign will be collected, transferred, handled, and analyzed at this fog component. Further, this fog computing component is used for the real-time data handling and processing of data from the IoT devices. The sophisticated cloud and fog computing applications have received greater attention in the recent healthcare system development.

6.8.1.4 Big Data Analytics Methods, Techniques, and Platform Tools

The output from the big data analytics techniques and platform will be transferred to smart healthcare analytics services that include data repositories, data analytics, data integration, and physician expert knowledge. The healthcare-related big data will be systematically analyzed with modern state-of-the-art techniques, and each component in this category will collaborate effectively. The component will offer updated valuable insights, disease analysis, medical therapies, drug suggestion, healthcare clinical management, healthcare scheduling, and many other services. Applying the machine learning techniques and inference algorithms in IoT-based healthcare system can properly learn from sensor devices and patient medical history to alert the status of the present and future health status of the patient and even

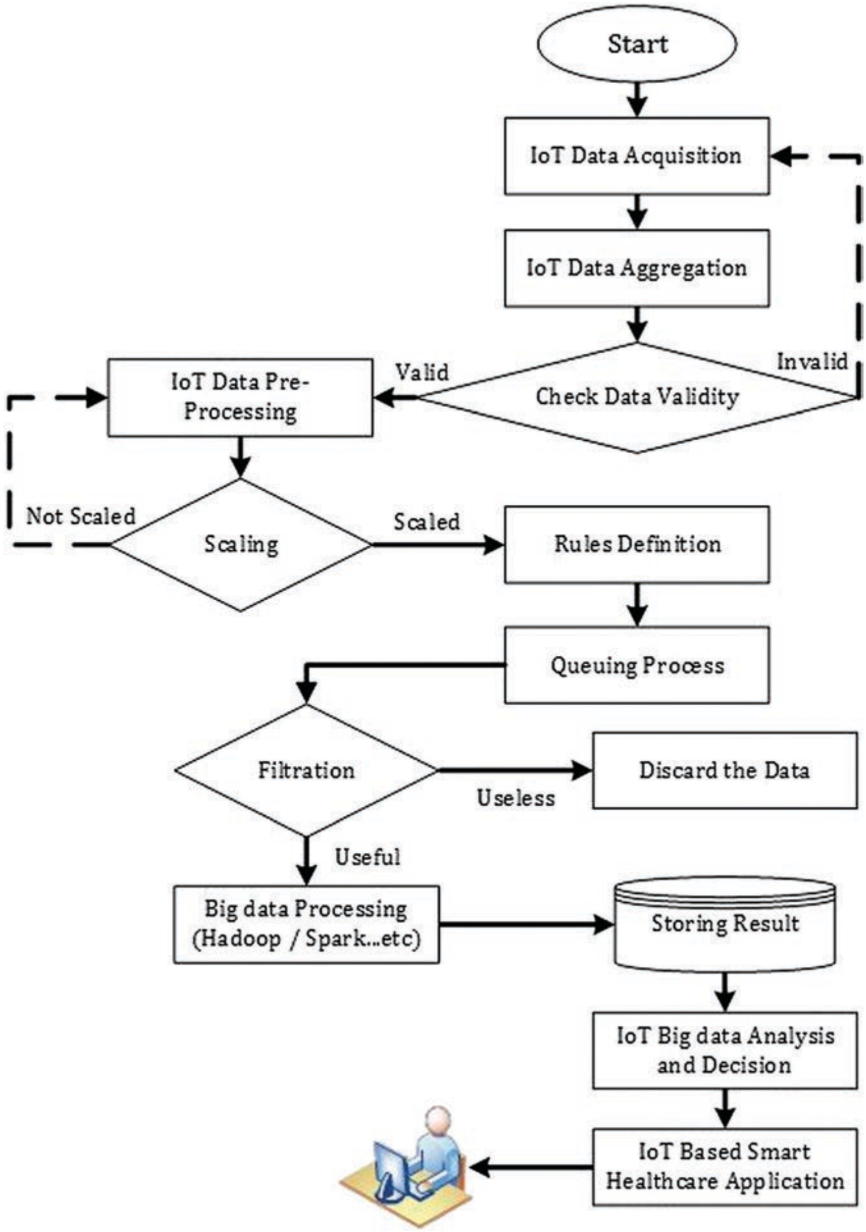

Fig. 6.5 IoT data acquisition and data processing flow chart

make alarms to the healthcare officers and to the patient if needed [1]. Accordingly, the data collected by the IoT devices can be processed and analyzed via the MapReduce platform that can handle the large volume of data by employing machine learning techniques to decide subjects' actions over time. Figure 6.5 demonstrates the process of IoT data acquisition and processing flow chart.

6.8.1.5 Patient Healthcare Monitoring and Recommender System

This component database includes electronic health record (EHR), sensor data, patient ontology, and intelligence rule-based ontology. The data will be gathered for these databases from various healthcare units/departments that are located across the country, for instance, clinical and administrative departments such as pharmacy, radiology, medical laboratory, billing, and insurance. The above departments are linked via the EHR unit in the cloud that allows data sharing and interoperability. Further, the EHR consists of patient records that are linked from different units (pharmacy, lab, insurance, etc.) such as city, state, or region and stored in the cloud.

The second component is the food and drug recommendation ontology. The recent developments in Internet-based technologies have made greater alternatives for a recommender system to support patients for their routine lifestyle [73]. There are a sophisticated collection of smart devices, agents, techniques, and linking components that are supporting to make this recommender system. Further, the needed data for patient drug and food will be gathered and preprocessed to recommend by looking at the patient status. This contains a collection of data for drugs, for instance, its dose, chemical structure, and properties. With regard to meals, the data, for example, its nutrition values and ingredients, will be considered for the recommendation. Furthermore, this recommender system is paired with specifics such as the spice level and choices such as vegetarian or nonvegetarian for the patient's diet favorites.

6.8.1.6 Healthcare Research and Knowledge Infrastructure

This layer includes healthcare-related various research, innovation, and knowledge infrastructure components. The purpose of these components is to build a system that offers state-of-the-art healthcare services and support for patients, researchers, hospital management, medical professionals, healthcare agencies, government organizations, and policymakers. The databases and knowledge repositories in this layer keep the symptoms, diseases, drugs, drug composition and dose level, clinical records, clinical procedures, disease prediction, prevention mechanisms, medical practices, etc. to explore new insights and trend for future usage and knowledge discoveries. Researchers and data scientist will use advanced simulations, data visualization, data mining, classification, and modelling to support the knowledge demand of medical professionals and policymakers.

6.9 Smart Healthcare Applications Using Big Data: Real Cases

The need for smart healthcare systems is necessitated for the patient's accurate health monitoring in various circumstances. Accordingly, there are several practical applications or development of smart healthcare system in the practice. This section describes such real practices or system development in detail. Nayyar and Puri [58] proposed an Internet of Medical Things-based monitoring system to measure patient heartbeat, temperature, and oxygen level and to notify these details to the doctors. This system was tested with more than 50 patients, and the results proved 90% accuracy compared to the available health monitoring system. Mahapatra and Krishnamurthi [74] discussed different models and algorithms for the security and privacy of healthcare records. Their focus is on the recent development of various security and privacy aspects in developing healthcare applications. Similarly, Kumar and Krishnamurthi [37] worked on the novel designing, modelling, and implementation of healthcare systems in the aspects of integration and compatible blockchain 3.0 and healthcare 4.0. The simulation and test of the system showed good performance overall [63]. proposed a cloud-based healthcare test case selection and prioritizing framework to identify the fault recognition rate, in which their experimental results of this framework reveal a better fault detection rate compared to earlier fault detection methods.

6.10 Conclusion

The role of big data analytics in the healthcare domain contains the approaches of evaluating the large volume of healthcare records associated with patient healthcare and symptoms. The IoT will be the future revolution that will be heavily integrated with big data in the healthcare domain. The size of big data has increased exponential, and the process involved to gather, store, extract, analyze, and optimize these data that also become very much important in healthcare systems. Hence, the mixture of big data and healthcare systems can accelerate the potentials benefits in the healthcare sector. This chapter discusses various big data-related techniques, platforms, architectures, and challenges in the field of big data analytics in healthcare systems. In addition, this chapter proposed a conceptually developed big data analytics that illustrate various aspects of big data for a healthcare system. The key contributions of this chapter include a systematic review of big data analytics in the healthcare system context and various big data- and analytics-based methods, techniques, and platforms and proposed a modern conceptually designed healthcare system framework.

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