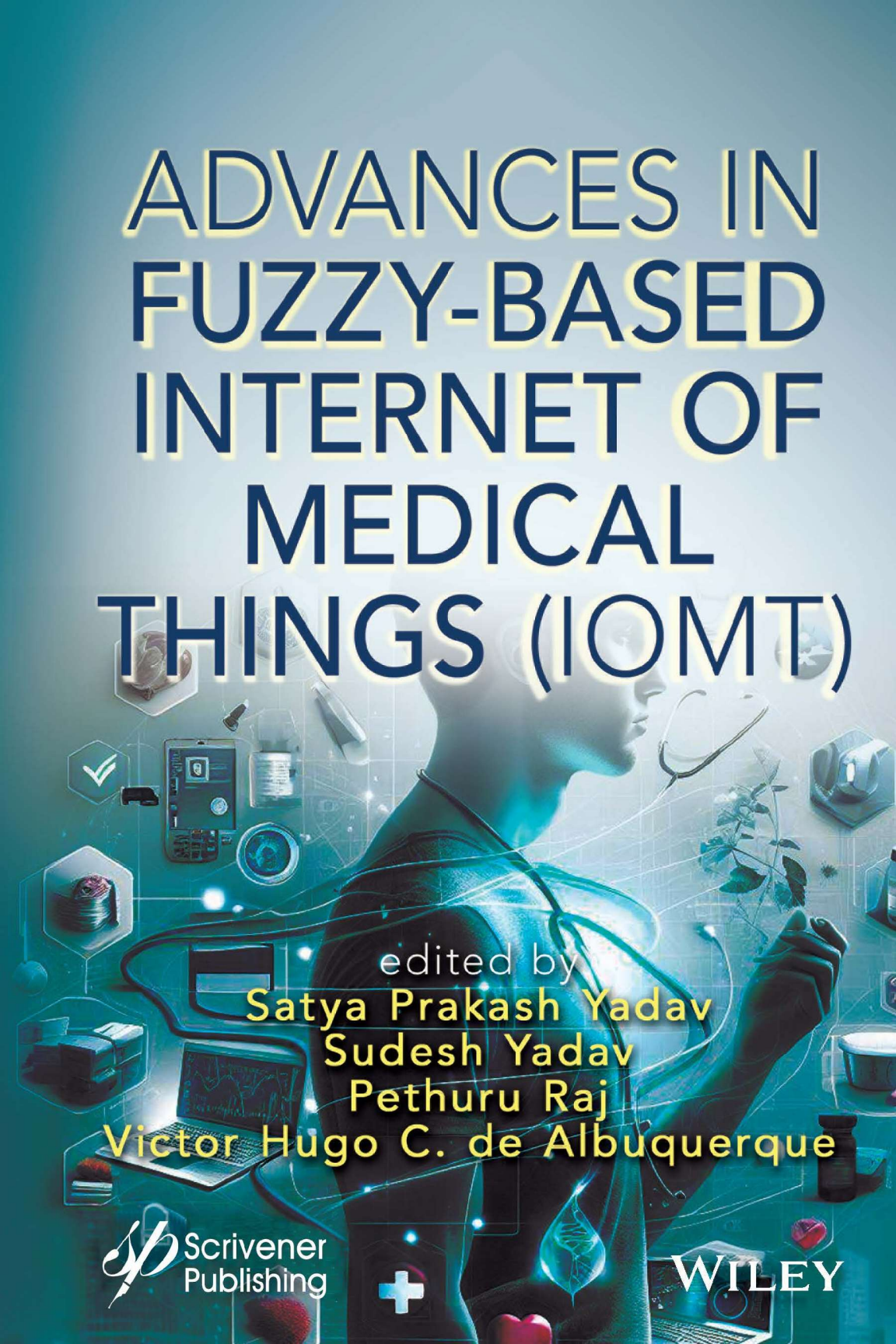
ADVANCES IN FUZZY-BASED INTERNET OF MEDICAL THINGS (IOMT)



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Preface

This book explores the latest trends and transitions concerning the Internet of Medical Things (IoMT). The emerging notion is that IoMT will play an important role in shaping the future of healthcare. Many medical instruments, equipment, scanners, robots, appliances, cameras, handhelds, wearables, and other devices are becoming integrated with cloud-hosted software applications, analytics platforms, digital twins, databases, AI models, etc. This integration adds the required intelligence necessary to exhibit intelligent behavior.

Decision-making in the medical profession is imprecise and fuzzy logic handles the partial truth concept well. Fuzzy logic is advantageous in situations in which the truth-value ranges between completely false and completely true. The combination of the established fuzzy logic concepts with the IoMT systems is a game-changer.

The fuzzy logic theory is an important tool that deals with imprecise linguistic concepts, addresses the loss of precision in the decision-making power of a physician, and ultimately will improve medical science in the ensuing digital era.

Here the main goal is to strengthen medical professionals, caregivers, and surgeons by providing methods for achieving fuzzy logic-based health diagnosis and medication. The health condition and various physical parameters of humans, such as heartbeat rate, sugar level, blood pressure, temperature, and oxygen quality, are captured through a host of multifaceted sensors. Additionally, remote health monitoring, medication, and management are being facilitated through a host of ingestible sensors, 5G communication, networked embedded systems, AI models running on cloud servers and edge devices, etc. Furthermore, chronic disease management is another vital domain getting increased attention. The distinct advancements in the fuzzy logic field are useful in various advanced medical care functionalities and facilities.

The first chapter focuses on the IoMT paradigm, its healthcare applications, the challenges, how to surmount them, and the distinct benefits.

Chapter 2 illustrates various technical challenges in fuzzy-based IoMT system design and development. Chapter 3 conveys the design and implementation of a novel fuzzy logic-based IoMT framework.

Chapter 4 focuses exclusively on the different aspects of fuzzy logic-based medical image processing. It also deals with how fuzzy logic aids in efficient image processing. Chapter 5 explores the development of a fuzzy logic system for monitoring patients' health conditions and the articulation of solution approaches. Chapter 6 underscores the importance of establishing complete trust between patients and IoT systems using fuzzy logic theory.

Chapter 7 concentrates on articulating and accentuating the proven and potential methods for significantly improving the efficiency of IoMT using fuzzy logic techniques. Chapter 8 is predominantly about fuzzy interference system (FIS) for IoMT. Chapter 9 is a use-case chapter that primarily focuses on leveraging a fuzzy deep learning method to analyze Pap smear images to identify cervical cancer.

Chapter 10 deals with the classification and diagnosis of heart diseases using fuzzy logic-powered IoMT. Chapter 11 describes an implementation of a neuro-fuzzy-based classifier to find Type-1 and Type-2 diabetes. Chapter 12 discusses an efficient implementation of Type-2 fuzzy logic mechanisms in IoMT. Chapter 13 explains the ways and means of doing feature extraction and diagnosis of heart diseases using fuzzy logic-inspired IoMT.

Chapter 14 is dedicated to demystifying the unique capabilities of an intelligent heartbeat management system using fuzzy logic methods. Chapter 15 expounds on a fuzzy logic algorithm for effective monitoring of medical data management systems. Chapter 16 concerns the implementation of IoT's function in healthcare monitoring systems. The importance and value of IoT healthcare systems are discussed, along with the advantages of using such a system. Chapter 17 addresses the integration of edge computing and fuzzy logic to monitor novel coronavirus. Chapter 18 illustrates the aspect of IoT implementation in healthcare barriers and its future challenges.

We wish to express our gratitude to everyone involved in this project for their efforts, as well as Wiley and Scrivener Publishing for their cooperation and assistance in the timely publication of this book.

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IoMT—Applications, Benefits, and Future Challenges in the Healthcare Domain

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Abstract

In the healthcare sector, the Internet of Medical Things (IoMT) is significantly enhancing the accuracy, reliability, and efficiency of electronic devices. Interactions between machines and people or a combination of the two are made possible via the Internet of Things (IoT). The most recent advancements in the Internet of Things technology have helped human daily activities, including rapid service delivery and real-time information access. Our area of interest is the research benefits of the IoT in the healthcare sector though. By enabling the quick and efficient capture of diagnostic information and patient care, this technology has improved healthcare management and delivery, particularly inside medical facilities. The existing literature consists primarily of different investigations. The study focuses mostly on the evolution of the Internet of Things architecture, its accompanying challenges, and its benefits for the general public, with little to no attention paid to the IoT's potential applications in the healthcare industry. This study investigates the effects of utilizing the IoT to close the healthcare management gap.

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The study offers a thorough examination of how the IoT might be used to improve hospital management systems' operating capabilities. This study investigates prospective new innovations that might aid in development. Systems for managing hospitals are controlled by the IoT technology. Medical practitioners are able to treat patients anywhere and at any time. Patients, especially the elderly, are frequently offered medical care and monitoring. The goal of wearable sensor technology is to improve people's welfare in their homes. Multiple obstacles, such as the production of unnecessary and useless data, worries about the security and privacy of patient information, and the high cost of IoT adoption make it difficult to integrate IoT applications into the field of healthcare. Future research initiatives on the application of the IoT technology in the healthcare industry also include the prediction of stroke and epileptic convulsions as well as the use of prosthetic sensors to gather important information to speed up patient treatment.

***Keywords*:** IoMT, IoT, healthcare, management

1.1 Introduction

Scholars from all over the world have been investigating new methods to use technology to augment conventional healthcare services by utilizing the Internet of Medical Things (IoMT) [1]. This study demonstrates how the use of multi-homing dense networks enhances a hitherto unexplored component of the IoMT deployment, highlighting the significance of each contribution. The convergence process in the healthcare industry presents both new challenges and opportunities [2, 3]. The research aims to highlight cutting-edge research projects that advance the field. A major global challenge for civilization is preserving people's health. The healthcare industry has drawn a lot of scholarly attention in the last 10 years [4]. The current study examines the current applications of the Internet of Things (IoT) in healthcare and the possible benefits it might bring to the industry.

Figure 1.1 describes the IoMT's journey to improve the effectiveness and efficiency of healthcare applications. Researchers are also interested in spotting patterns in developing technologies [5]. An in-depth analysis of the multiple barriers preventing the widespread adoption of effective, reliable, and scalable IoT healthcare applications is provided in this study. New opportunities to raise the level of healthcare and, consequently, human life expectancy are urgently needed. It is envisaged that a reinforcement algorithm be developed and joined to the IoT-enabled healthcare infrastructure to address the issues brought on by duplicated sensory data acquired by wearable sensor devices [6–8]. This is anticipated to take place soon.

Figure 1.1 Journey of the IoMT system.

The Internet of Things refers to a collection of physical elements connected to one another via the Internet to facilitate the storage of shared and aggregated information [9]. These elements include sensor information, data processing, intelligence services, software, and intelligent applications. Potentially, medical institutions and potential patients may communicate via the Internet, opening up access to high-quality healthcare services at any time and from any location [10–13]. As a result, organizations or groups of healthcare experts can create a system that is open and effective. Additionally, the adoption of IoT technologies can make it easier to develop a real-time healthcare delivery paradigm. Additionally, IoT-based healthcare methods have improved the provision of healthcare services from a traditional healthcare standpoint, providing a cutting-edge real-time healthcare system [14]. Thus, the incorporation of bIoTechnology has aided in the modernization of traditional medicine and acted as a key catalyst for the creation of intelligent healthcare systems for hospital administration [15]. Because of its integration, Internet of Things technologies are establishing an innovative healthcare-based hospital management method for providing healthcare services.

Technology makes it possible to create an intelligent hospital management system with access to healthcare data that is frequently referred to as the IoMT [16, 17]. It entails employing wearable medical sensors and Internet-connected smart devices to monitor patient health, confirm medication compliance, predict cardiac events, and obtain the most recent diagnostic information. The healthcare sector is currently being affected by a surge of new trends and technological developments that are quickly gaining traction on a worldwide level. The latest innovations in the development of medical devices improve patient care. The immediate transmission of important data is made possible by emerging technical developments, which range from physical gadgets to intelligent systems. This makes it possible for specialists, medical professionals, and regular people to communicate and spot crucial situations that can jeopardize lives [18]. In order to meet patient needs, the paradigm of medical services being available always, everywhere, and spanning all facets of healthcare is changing. This change is causing the field to generate innovative innovations. At this time, smartphone framework developments have achieved a level of practicality

and utility that enables medical practitioners to offer consultations for medical support. A substantial problem is presented by the interconnectedness of IoT regions, which calls for the integration of frameworks related to enormous amounts of data, security, and privacy [19].

Additionally, it gives users the ability to upload, access, archive, and aggregate data, which results in the creation of enormous databases. Transfer, retrieval, storage, and accumulation of data by persons are made easier by information technology (IT). The current study also investigates continuous considerable data streams to derive insightful conclusions in big data implementations across certain domains [20, 21]. Internet of Things technology's structures and automated systems, as well as healthcare systems that handle copious volumes of data to improve decision-making, are just a few examples of the potential digital solutions this study explores in the numerous facts of daily life. Technical developments have a substantial impact on the IoMT, and remote medical services are the main topic of this study.

The Internet of Medical Things makes it feasible for medical device performance to be improved, response times to be accelerated, and healthcare to be more widely accessible. The IoMT can collect health information from patients who are over a long distance to wearable sensors and gadgets connected to Internet health monitoring platforms. The processing of the IoMT is made easier by Wi-Fi-enabled medical devices by connecting to one another and transferring M to M. A cloud server receives data from connected medical devices and stores and analyzes them [22]. The method of continuously monitoring someone's health by tracking his or her activity levels and comparing them to expected future activity levels is known as "remote health monitoring" (RHM). Although RHM may ultimately lead to the provision of clinical services, there are other priorities. Physiological characteristics like heart rate may need to be monitored.

The idea of remote healthcare entails the methodical gathering and evaluation of health-related data to determine the efficacy of a certain program [23–25]. This strategy makes it easier to do fundamental analysis, which helps to get the desired results. Patients can conduct routine tests on their smartphones or wearable technology and submit the results to healthcare professionals in real time by integrating remote health monitoring with healthcare assistance. The use of remote health monitoring and healthcare services has enhanced doctors' ability to supervise and control patients in unusual healthcare settings [26]. RHM uses sophisticated methods to collect health information from people in a specific locality, like a patient's

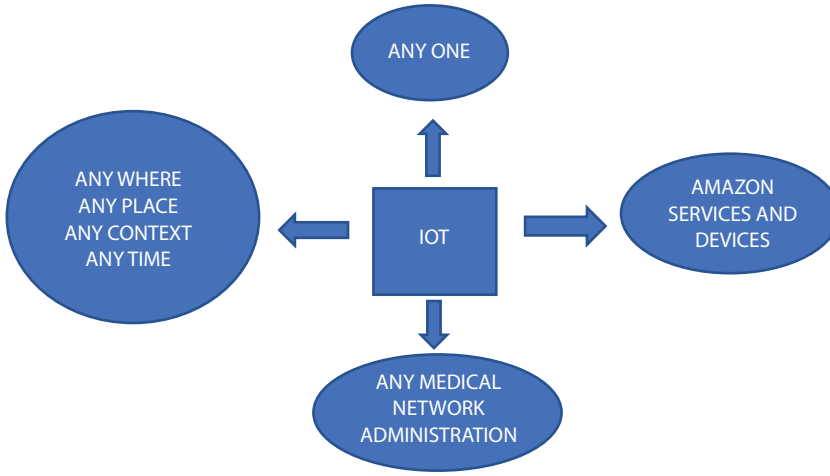

Figure 1.2 Various environments in the IoT.

home, and transfer the information to medical professionals in another location to access the patient and give directions to the nurses.

The concept of the IoMT refers to the Internet-based integration of computer networks and medical devices, allowing the collection of real-time data and enhancing patient participation. The IoMT refers to the concept of connecting animate and inanimate objects through the Internet. The term "things oriented" refers to everyday items that are connected to intelligent systems using cutting-edge interfaces like Zigbee, LAN Bluetooth, Wi-Fi, radio frequency identification (RFID), or other working devices to enable communication in social and client contexts. This concept is encompassed by the IoMT [27]. The object-oriented methodology used in the IoMT module relates to a physiological gadget with cutting-edge technology that permits virtual communication via Internet-based technologies [28]. A patient's physical measures concerning any element of his or her health can be collected and transmitted by the IoMT at any time and place [29, 30]. This is accomplished by utilizing the best services offered by different pathways and networks, as shown in Figure 1.2. People with chronic illnesses can connect remotely to the Internet of Medical Things. This is accomplished by using the physical locations of patients and hospitals, as well as by tracking medicine requests and wearable medical technology [31, 32]. The present study's noteworthy contributions are delineated as follows:

- The significance and rationale behind the creation of the IoT-enabled smart healthcare were emphasized and deliberated upon [33].
- This study presents a comprehensive examination of the implementation of Internet of Things technologies in the healthcare sector, with a particular focus on their utilization in medical hospitals.

The identified challenges pertaining to security and privacy were thoroughly discussed, thereby laying the groundwork for potential research in future avenues in this domain [34].

A major goal is to give academic scholars a thorough assessment of the present state of IoT technologies in the field of healthcare-enabled hospital administration and key issues for future attention. The goal of the essay is to give a critical critique that helps to guide academic discussion on the topic.

1.2 Literature Review

For monitoring epileptic seizures, a dependable and low-power alert system has been created. Conceptual learning and fuzzy categorization form the basis of this system, guaranteeing its efficacy and precision. In addition, a selective data transfer technique has been designed to pick the optimal data transmission mode according to the recognized patient's individual needs.

A mobile app has been developed to facilitate the transfer of health information between individuals, their healthcare providers, and their insurance companies. To ensure a thorough data gathering, this software gathers information from various sources, including wearables, manual input, and medical equipment. Every medical file is kept safely on the cloud, where its authenticity and accuracy can be independently verified. In addition, the blockchain links these documents for even greater security and transparency.

An IoMT healthcare system architecture framework has been suggested for use in the medical profession. The patient's health is tracked in real time through a network of sensors infused into the patient's body. The system's ability to recognize trends and insights on patients' health and offer possible preventative measures directly results from its use of ensemble tree-based learning algorithms. When a patient's health state changes, medical staff receives real-time instructions and alerts to respond quickly to keep

the patient alive. Integrating an IoMT-based wearable body sensor network has shown potential for improving patient health outcomes.

Various machine learning (ML) algorithms are applied to enhance the reliability of diagnostic tools in healthcare. The effectiveness of different courses of action is compared, ensuring informed decision-making in medical settings. Moreover, the report addresses open issues and explores possibilities arising from the convergence of the IoMT in the healthcare sector, paving the way for future advancements.

The emerging healthcare applications and specific technological requirements for delivering end-to-end solutions are thoroughly discussed. The focus is on both short- and long-range communication, and a comprehensive analysis of present and future technologies and standards is presented. These discussions provide valuable insights into the potential of technological advancements in healthcare.

In the coming years, artificial intelligence (AI) and machine learning will play vital roles in medical professionals' ability to diagnose diseases accurately, suggest treatment options, and offer recommendations. Additionally, AI is expected to assist in providing cues for image interpretation in medical imaging, further enhancing diagnostic capabilities.

The comprehensive analysis of the IoMT examines various methodologies employed in smart healthcare systems (SHSs). This includes the utilization of radio frequency identification, artificial intelligence, and blockchain technologies. Multiple architectural frameworks proposed by scholars in the field are compared, aiding in the development of robust IoMT solutions.

Ensuring data security in the Internet of Things is of utmost importance. The method that employs an improved version of the Crowd search algorithm has been introduced to detect data manipulation and infiltration in IoT environments. Deep convolutional neural networks are utilized to conduct a comparative analysis, enhancing coordinated data security.

The research efforts dedicated to enhancing the IoMT are comprehensively analyzed, exploring data collected from various sensors that monitor a wide range of aspects, from heart rate to emotional well-being. These efforts contribute to the continuous improvement of healthcare systems and pave the way for personalized patient care.

The increasing frequency of cyberattacks on the healthcare sector is a pressing concern. This analysis seeks to identify the most critical challenges in cybersecurity, examine the solutions implemented by the health sector, and explore areas that require further development to ensure robust security measures.

The Internet of Things has the potential to improve healthcare in a number of ways, one of which is the ability to monitor breathing via noncontact wireless technologies. In this research, the accuracy of ultrasound (US) and Internet of Things-based methods of measuring respiration rate is assessed. The effectiveness and viability of the suggested method are investigated via simulation utilizing a programmable moving surface platform to model chest movement during breathing.

Significant difficulties exist in optimizing IoMT cybersecurity and establishing resilience against cyberattacks. Physical layer risks and the necessity for collaborative efforts to combat crime-as-a-service (CaaS) in the healthcare ecosystem are two examples of the difficulties that must be overcome.

The effective deployment of the IoT technology in healthcare depends on the ability to understand customers' concerns about privacy and security. Understanding the hazards involved with using the IoT technology is important; thus, it is important to have open and safe processes in place.

Consideration of the public's part in the creation and deployment of IoT applications in healthcare is crucial. Acceptance and adoption of IoT solutions in healthcare might be facilitated through public outreach and the resolution of public concerns.

In conclusion, innovations like conceptual learning, wearable sensors, ML algorithms, and IoT integration have the possibility to change the healthcare system. Accurate diagnoses, individualized treatment plans, strengthened data security, and better health outcomes are all made possible by these innovations. Research and analysis of this scale show a persistent dedication to improving healthcare via technology.

1.3 Healthcare System and IoT Overview

The Internet of Things has revolutionized the way intelligent devices interact with the environment. With the IoT, devices like mobile phones, sensors, and Raspberry Pi can connect to the Internet, allowing enhanced connectivity and communication. Thanks to this network, machines can talk to one another, and people can talk to devices. This network is used to conduct operations, keep tabs on patients at home, and keep an eye on the physical facilities of hospitals in real time, among other applications in the healthcare sector.

Interactions between humans and machines let people perform their healthcare duties more efficiently. These duties might include everything from operating on patients to checking on their well-being at home.

In addition, computers may exchange data with one another for convenient access. Sensors may send information to a cloudlet system for short-term storage to make data administration easier.

The scenario above is representative of a typical IoT-enabled healthcare platform. This infrastructure exemplifies how the Internet of Things might transform the medical industry by facilitating seamless information sharing across smart devices.

Figure 1.3 shows the four main parts of a typical IoT-enabled healthcare system. The hospital is the hub where medical staff coordinates and provides inpatient and outpatient treatment. Hospitals may keep tabs on patients' well-being and recovery after being discharged from the facility by using the Internet of Things (IoT) apps. Wearable or implanted medical body sensors may be used to get this information.

Machine learning algorithms and application software are used to process and interpret the obtained sensor data. The sensor data give the hospital staff a visual representation of the outpatient's health at home. If a patient's health suddenly worsens or becomes life-threatening, steps are made to get him or her to the emergency department, such as calling an ambulance.

For patients who are no longer hospitalized or have fully recovered, ambient assisted living devices powered by the Internet of Things come into play. These devices enable individuals to monitor their health in real time from the comfort of their own homes. They can track various parameters like calorie expenditure, blood sugar levels, and heart rate. With the data obtained from these ambient assistive IoT devices, patients can proactively manage any unforeseen health issues that may arise.

By equipping healthcare professionals with timely and accurate data, a competent IoT-enabled healthcare system enhances patient outcomes. It empowers medical professionals to deliver high-quality treatment and care

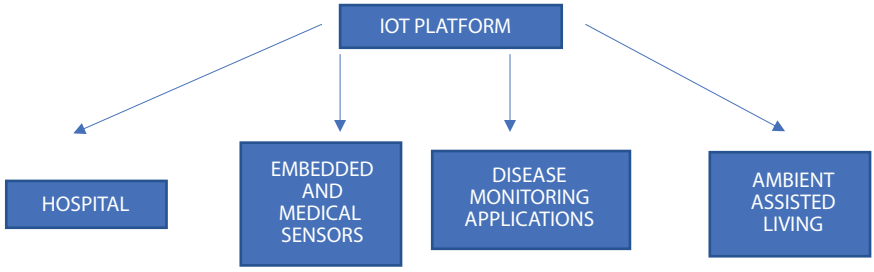

Figure 1.3 Healthcare and the IoT system.

when needed, ultimately improving the overall healthcare experience for patients.

1.4 IoT-Based Healthcare System

The concept of a "Smart Planet" forms the basis of "Smart Healthcare," which is an intelligent infrastructure driven by sensor-based information retrieval. The data collected from various sources are transmitted to a cloud data center, where it is processed into actionable information. This information is then made accessible to healthcare practitioners and authorized patients through the Internet of Things. The demand for excellent and fast healthcare services anytime, anywhere has been a key motivator in the development of efficient healthcare systems.

Innovative healthcare has been defined in various ways, but it generally refers to patient-centric facilities connected within an ecosystem that extends beyond traditional hospital settings. These facilities can include patients' homes, hospital wards, and other healthcare settings. Innovative healthcare aims to improve patient–provider interaction by facilitating the exchange of emotional information, enabling informed decision-making, optimizing resource allocation, and ensuring high-quality treatment. The term "smart healthcare" encompasses advanced interpretation and utilization of medical data.

A healthcare management service enabled by the IoT can be classified as a form of heterogeneous computing. The wireless communication system employed by IoT applications and devices serves as a means of connectivity between patients and healthcare professionals. This enables a wide range of services, including identification, monitoring, observation, and storage of crucial medical and statistical data. Numerous potential applications of innovative healthcare involve devices such as brainwave-measuring headsets, sensor-embedded clothing, blood pressure monitors, glucose monitors, electrocardiogram (ECG) monitors, and pulse oximeters. Additionally, medical sensors integrated into equipment, drug-dispensing systems, surgical robots, implantable devices, and various wearable technologies fall within the scope of innovative healthcare.

A notable example of intelligent healthcare implementation is demonstrated by Ably Medical Centre in Norway, where a smart bed has been deployed. Equipped with sensors, the smart bed can measure essential physiological parameters such as weight, blood pressure, heart rate,

and vital signs. This technology enables healthcare professionals to stay updated on the patient's current health status, indicating whether his or her condition is improving or deteriorating in response to medical interventions. Additionally, the smart bed helps prevent falls and allows patients to reposition themselves autonomously, reducing the occurrence of pressure ulcers.

1.5 Smart Healthcare System—Benefits

Figure 1.4 illustrates the benefits of integrating the IoT technology into healthcare systems. These benefits include improved treatment outcomes, enhanced disease management, and increased safety and maintenance of medical facilities.

The use of IoT devices in capturing and processing diagnostic information has led to more accurate and error-free diagnoses, ultimately improving treatment outcomes. Patients receiving improved or high-quality treatment are likely to have increased confidence and trust in the healthcare providers and institutions associated with the hospital.

The Internet enables the general public to access medical advice in real time from anywhere and at a reasonable cost. This accessibility to medical guidance contributes to better healthcare outcomes and empowers individuals to make informed decisions about their health.

Intelligent healthcare systems, enabled by the IoT, play a crucial role in the maintenance and security of healthcare facilities. Continuous surveillance through embedded camera sensors ensures the upkeep and safety of medical establishments.

Furthermore, the IoT technology assists the elderly in effectively managing significant health concerns without the need for frequent hospital visits. Remote monitoring and healthcare applications allow healthcare professionals to evaluate and monitor patients' conditions remotely, reducing the burden on elderly individuals and promoting better health management.

Figure 1.4 Benefits of healthcare and the IoT system.

Overall, incorporating the IoT technology in healthcare systems brings forth a range of advantages, including improved treatment outcomes, enhanced disease management, increased accessibility to medical advice, and the ability to maintain and secure medical facilities.

1.6 Smart Healthcare System—Applications

The organizational structure of companies has undergone significant changes, driven by the development and widespread use of modern technology. However, the e-healthcare industry has been relatively slow in adapting to these transformations, which recently started to experience the reorganization that other sectors have skilled. Similar to other commercial fields, the healthcare industry is witnessing a trend toward technology division and standardization, leading to improved quality and cost-effectiveness in healthcare delivery.

Within the IoMT framework, various types of e-health data are generated and shared among relevant parties. The increasing prevalence of the IoT devices has attracted attention from different industries, including healthcare. The healthcare industry is actively investigating the potential of technologies like ingestible sensors, wearables, moodables, and intelligent video pills to improve medication administration, monitor patients, and support paramedical personnel. The Internet of Things is revolutionizing the delivery of healthcare.

By implementing self-correcting capabilities based on feedback, IoMT devices may further increase the accuracy of their decisions. Doctors may use virtual assistants to research recent developments in the healthcare industry and academic literature and publications. Using virtual assistants in this way has the potential to improve healthcare.

Multiple hashes should be stored on sensor data to guarantee data integrity and patient ownership. By taking this precaution, vital medical records are protected from prying eyes and kept private.

In conclusion, the online healthcare industry is reorganizing to keep up with the rest of the business world. The proliferation of IoT devices offers diverse applications, including improved drug management, patient tracking, and assistance for healthcare professionals. Implementing the IoT technology in healthcare can lead to enhanced decision accuracy and improved patient care. Safeguarding data integrity and patient ownership is crucial to maintain the privacy and security of e-health data.