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Research Article

Internet of Things (IoT) Its Applications and Enabling Technologies in Healthcare: A Review

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ABSTRACT

IoT technology has many uses in the healthcare industry, including integration of medical devices, smart sensor technologies, and remote monitoring. IoT unlocks the potential of modern technology and directs us toward the development of new and better medical device solutions. Medical devices gather a wide range of data from several real-world cases, which improves the amount and accuracy of the data. The Internet of Things (IoT) is a wireless, interrelated, and connected digital system that can collect, send, and store data over a network without requiring human-to-human or human-to-computer interaction. IoT devices can be used for remote health monitoring and emergency alerts. These health monitoring devices can range from blood pressure and heart rate monitors to sophisticated devices capable of monitoring specialized implants such as pacemakers, electronic armbands or advanced hearing aids. Many healthcare facilities have started using "smart beds" that can automatically identify when they are in use and when a patient is attempting to get up. These beds can also be self-adjusted to provide the necessary support and pressure to the patient without the need for manual intervention by nurses. Governments and policymakers around the world are implementing technology-based policies to improve health care, especially in response to the COVID-19 pandemic. It is increasingly important to understand how established and emerging IoT technologies can support healthcare systems in delivering safe and effective care.

I. INTRODUCTION

The Internet of Things (IoT) is characterized by devices with sensors, processing capabilities and software that connect and exchange data with other devices and systems via the Internet or other communication networks. The field of IoT includes electronics, communication and information technology[1].It has evolved through the convergence of multiple technologies such as ubiquitous computing, commodity sensors and powerful embedded systems, and machine learning. IoT technology is most often associated in the consumer market with "smart home" products, including appliances and devices such as lights, thermostats, home security systems, cameras, and other devices that support one or more general ecosystems and can be controlled by devices. related to this ecosystem, such as smartphones and smart speakers. However, IoT is also used in healthcare systems.

The COVID-19 pandemic loudly underscored the challenges of limited access to healthcare facilities. Millions of patients struggled to reach their healthcare providers and sought remote healthcare options. IoT healthcare devices played a significant role by empowering healthcare professionals to remotely monitor patients bridging the gap in healthcare accessibility [2].

The impact of IoT in the healthcare sector has expanded rapidly. IoT applications in healthcare are widespread globally, ranging from improved device operation to remote medical assistance. This advanced technology has the potential to save lives through rapid ailment diagnosis and the identification of suitable therapy options for patients [3]. We will investigate how IoT is transforming healthcare and discuss some of the applications and enabling technologies. The healthcare industry has drawn attention to several technologies, including artificial intelligence, machine learning and augmented reality. Among them, however, IoT is the most prosperous technology, and the applications of IoT in healthcare are more than gimmicks and very practical. Additionally, IoT developers are in significant demand not only in the healthcare industry, but also across various industries [4].

THE RATIONALE OF THE STUDY

The rationale for reviewing the Internet of Things (IoT) its applications and enabling technologies in healthcare is rooted in several key motivations:
1. Technological Advancements
The rapid evolution of IoT technology, including advancements in sensors, connectivity, data analytics, and artificial intelligence, has significantly transformed healthcare delivery. A comprehensive review helps capture the current state of these technologies, understand their integration into healthcare systems, and identify the potential benefits and challenges.
2. Enhanced Patient Care
IoT has the potential to improve patient outcomes through continuous monitoring, personalized treatment plans, and real-time data analysis. Reviewing existing applications can highlight successful implementations, demonstrating how IoT can lead to more effective and efficient patient care.
3. Operational Efficiency
Healthcare systems face constant pressure to optimize resources and reduce costs. IoT technologies can streamline operations, improve asset management, and enhance the efficiency of healthcare providers. A review can provide insights into how these technologies are being used to achieve operational excellence.
4. Data-Driven Decision Making
IoT generates vast amounts of data that can be leveraged for informed decision-making. Reviewing IoT applications in healthcare can shed light on how data analytics is being used to predict health trends, manage diseases, and improve clinical outcomes.
5. Addressing Healthcare Challenges
Healthcare faces numerous challenges, including aging populations, chronic diseases, and accessibility issues. IoT offers solutions to these problems through remote monitoring, telemedicine, and automated healthcare services. A review helps to identify which IoT applications are most effective in addressing these challenges.
6. Innovation and Future Trends
The healthcare sector is continually evolving, and staying abreast of new trends and innovations is crucial. Reviewing the current state of IoT in healthcare can identify emerging technologies and trends that could shape the future of healthcare.

2.HISTORY

In 1982, a modified Coca-Cola vending machine at Carnegie Mellon University became the first appliance connected to the ARPANET network. The temperature of newly loaded drinks could be reported by this machine. In 1991, Mark Weiser's paper on ubiquitous computing, "The Computer of the 21st Century," as well as academic conferences such as UbiComp and PerCom, helped shape the contemporary vision of the Internet of Things. Reza Raji described the concept as "moving small packets of data to a large set of nodes, so as to integrate and automate everything from home appliances to entire factories" in a 1994 article in IEEE Spectrum.

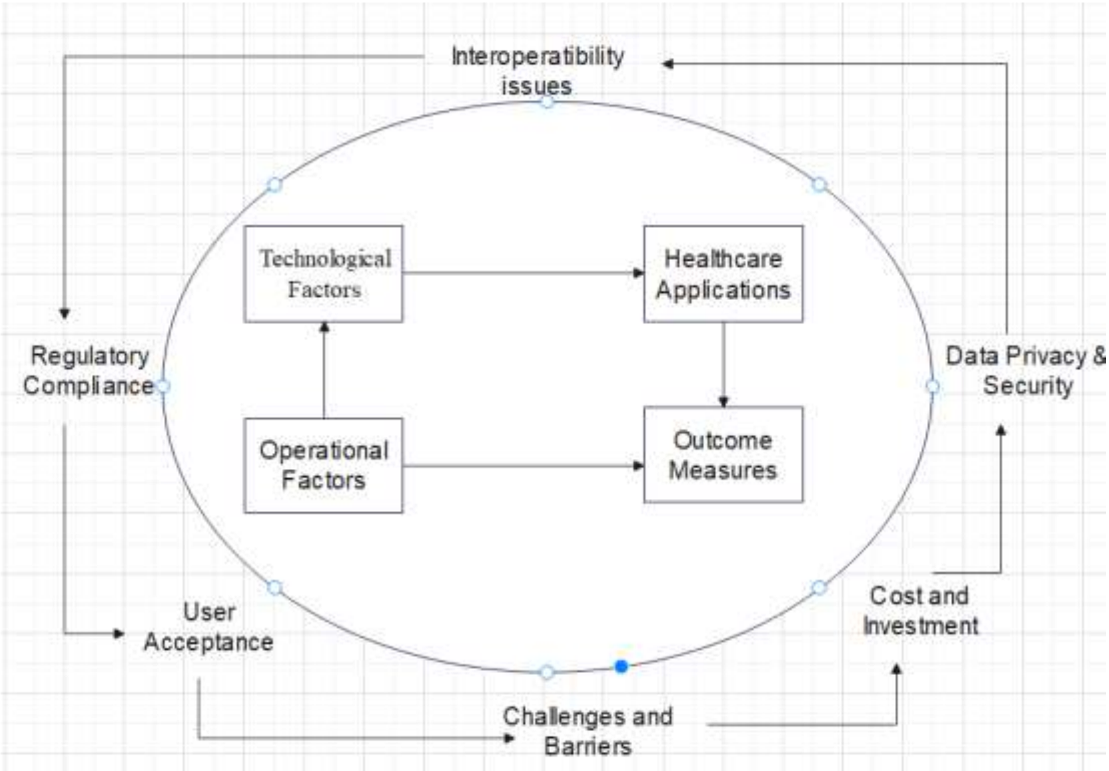
Several companies proposed IoT solutions in the late 1990s, including Microsoft's at Work and Novell's NEST. Bill Joy's "Six Webs" framework, presented at the World Economic Forum in Davos in 1999, helped to further momentum in the field. The term "Internet of Things" was first used in a speech by Peter T. Lewis to the Congressional Black Caucus Foundation 15th Annual Legislative Weekend in Washington, D.C., in 1985. Lewis defined the IoT as "the integration of people, processes, and technology with connectable devices and sensors to enable remote monitoring, status, manipulation, and evaluation of trends of such devices.".

The idea of the "Internet of things" was first proposed by Kevin Ashton of Procter & Gamble and later of MIT's Auto-ID Center in 1999, in context of supply chain management [5] K. Ashton, That “Internet of Things” thing, RFID Journal (2009). However, Ashton preferred the term "Internet for things." Ashton believed that radio-frequency identification was essential for the Internet of Things, which would allow computers to manage individual objects. Incorporating short-range mobile transceivers into everyday gadgets and necessities is the primary goal of the Internet of Things, enabling new forms of communication between people, things, and things themselves. [6].

The CEO of NetSilicon, Cornelius "Pete" Peterson, predicted in 2004 that the next phase of information technology would be dominated by IoT gadgets, and that networked gadgets would eventually outnumber networked computers and workstations. Peterson believed that medical devices and industrial controls would be the primary applications of the technology, according to Peterson [7,8,9,10,11,12].

Cisco Systems defined the Internet of Things as "the moment in time when more "things or things" are connected to the Internet than people" and estimated that the Internet of Things was "born" in 2008-2009 and things to people. ratio increases.

3. Hypothetical Model for IoT in Healthcare



This hypothetical IoT healthcare model leverages interconnected devices, advanced analytics, and real-time data to improve patient outcomes and operational efficiency in healthcare settings. By focusing on continuous monitoring, timely interventions, and secure data handling, this model addresses the critical needs of modern healthcare systems.

This model outlines a comprehensive framework for implementing IoT in healthcare, emphasizing the interplay between various factors and highlighting the challenges and barriers that need to be addressed. Here's a detailed explanation of each component and their interrelationships:

CORE COMPONENTS

1)Technological Factors:
Description: These include the hardware (wearable devices, medical sensors), software (data analytics, AI algorithms), communication protocols (Bluetooth, Wi-Fi, 5G), and data management systems (cloud platforms, edge computing).
Role: Provide the foundational infrastructure and tools necessary for IoT healthcare applications.
2) Healthcare Applications:
Description: Practical implementations of IoT technology in healthcare, such as remote patient monitoring, smart hospital beds, telemedicine platforms, and automated medication dispensers.
Role: Utilize the technological factors to deliver healthcare services, enhance patient care, and improve operational efficiency.
3) Outcome Measures:
Description: Metrics and indicators used to evaluate the effectiveness, efficiency, and impact of IoT healthcare applications. Examples include patient health outcomes, hospital readmission rates, and cost savings.
Role: Assess the success of healthcare applications and provide feedback for continuous improvement.
4) Operational Factors:
Description: Elements related to the implementation and day-to-day operation of IoT systems, including workforce training, device maintenance, workflow integration, and user support.
Role: Ensure smooth operation and integration of IoT solutions into existing healthcare practices.

CHALLENGES AND BARRIERS

1)Interoperability Issues:
Description: Challenges in ensuring different IoT devices and systems can communicate and work together seamlessly.
Impact: Affects the integration and efficiency of healthcare applications, potentially limiting the usefulness of IoT implementations.
2)Data Privacy & Security:

Description: Concerns about the protection of sensitive patient data and maintaining confidentiality.
Impact: Essential for compliance with regulations and maintaining patient trust, critical for the acceptance and success of IoT healthcare solutions.
3)Cost and Investment:
Description: The financial aspects of developing, deploying, and maintaining IoT systems.
Impact: Significant initial and ongoing investments are required, which can be a barrier, especially for smaller healthcare providers.
4)User Acceptance:
Description: The willingness of patients, healthcare providers, and other stakeholders to adopt and use IoT technologies.
Impact: Critical for the success of IoT healthcare applications, as low acceptance can hinder the adoption and effectiveness of these technologies.
5)Regulatory Compliance:
Description: Adherence to laws and regulations governing healthcare data, device standards, and patient privacy (e.g., HIPAA, GDPR).
Impact: Necessary to avoid legal repercussions and ensure ethical use of IoT in healthcare.

Interrelationships

Technological Factors and Healthcare Applications:

Flow: Technological factors directly influence the development and functionality of healthcare applications.
Feedback Loop: Insights from healthcare applications can drive further technological innovations and improvements.

Healthcare Applications and Outcome Measures:

Flow: The effectiveness of healthcare applications is assessed through outcome measures.
Feedback Loop: Outcome measures provide critical data that inform improvements and optimizations in healthcare applications.

Operational Factors and Outcome Measures:

Flow: Operational factors affect the implementation and efficacy of healthcare applications, impacting outcome measures.
Feedback Loop: Data from outcome measures can highlight operational inefficiencies and areas needing improvement.

Technological and Operational Factors:

Interplay: Technological advancements must be supported by operational readiness, including training and integration into workflows.
This model presents a holistic view of IoT in healthcare, showing how technological and operational factors work together to enable healthcare applications, which are then evaluated through outcome measures. It also highlights the major challenges—interoperability, data privacy, cost, user acceptance, and regulatory compliance—that must be addressed to successfully implement and sustain IoT solutions in the healthcare sector.

4. IOT APPLICATIONS IN DIFFERENT SECTORS

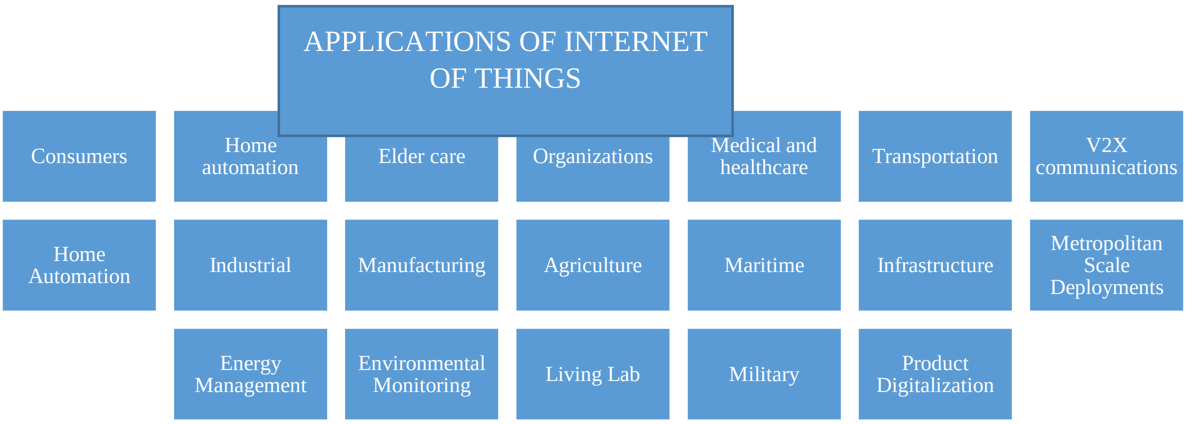


Figure 1

Consumers

The proliferation of consumer IoT devices has led to the development of many products, including connected vehicles, smart home systems, wearable technology, connected health solutions and devices with remote monitoring capabilities. [12,13,15,16,17]. At the business level, various IoT applications include retail, industrial IoT, smart services, and healthcare. Examples of IoT use cases include real-time supply chain monitoring, detection of power outages, and detection of empty parking spaces in a busy city center[18,19].

Home automation

IoT devices play a significant role in home automation, which encompasses a wide range of systems, such as lighting, heating, air conditioning, media, security, and camera systems. Home automation has gained a lot of popularity in recent years as everyday life becomes easier with the rapid growth of technology [20,21]. Almost everything is digitized and automated. The long-term benefits of home automation include energy savings, as smart homes can automatically turn off lights and electronics or inform residents about energy usage.

A smart home can be based on a platform or hub that controls various smart devices and appliances. For example, Apple's HomeKit allows manufacturers to control home products and accessories via an app on iOS devices such as the iPhone and Apple Watch. This can be a dedicated app or a native app like Siri. Lenovo Smart Home Essentials is an example of devices that can be controlled with Apple's Home app or Siri without a Wi-Fi bridge. In addition, there are smart home hubs such as Amazon Echo, Google Home, Apple's HomePod and Samsung's SmartThings Hub that connect different smart home products. Additionally, there are open source ecosystems such as Home Assistant, OpenHAB, and Domoticz that provide custom and customizable solutions for home automation [22,23,24].

Elder care

One of the main applications of a smart home is to help the elderly and disabled. Smart home technology plays an important role in helping the elderly and disabled. By combining assistive devices, these systems can meet the specific needs of the user [25,26,27]. For example, voice control can be useful for people with limited mobility and visual impairments, while alarm systems can be integrated into cochlear implants to help the hearing impaired. In addition, smart homes can be equipped with safety features such as sensors that detect medical emergencies such as falls or seizures. Smart home technology, if used effectively, can improve the user's freedom and quality of life[28,29].

Organizations

The term "Enterprise IoT" refers to devices used in business and enterprise environments. By 2025, EIoT is estimated to have 75 billion devices. The Internet of Things (IoT) has ushered in a new industrial revolution, the Fourth Industrial Revolution (Industry 4.0), which has brought about radical changes in all industries. [30].

IoT has differentiated itself from other technologies by incorporating smart features that enable it to sense, collect, communicate, and analyze massive amounts of data from various internal and external sources across a global network [31]. These characteristics have attracted industries to adopt IoT, including healthcare, agriculture, transportation, oil and gas, manufacturing, supply chains and logistics. [32,33]. By 2025, the economic impact of the Internet of Things is expected to reach $3.9-$11.1 trillion; at that time, the value of such influence is around 11 percent of the world economy. [34]. Thus, IoT technology enables the transition from traditional business environments to smart ones in all industries.

Medical and healthcare

Internet of Medical Things (IoMT) is a medical and health-related application of the Internet of Things (IoT) that focuses on data collection and analysis for research and monitoring. It has been called "smart healthcare" for its ability to create a digitized healthcare system by connecting medical resources and services. IoT devices can be used for remote health monitoring and emergency notification systems, including devices such as blood pressure and heart rate monitors, pacemakers, Fitbit electronic wristbands and advanced hearing aids [35,36]. Some hospitals have even introduced "smart beds" that can detect when they are being used and adjust them to provide adequate pressure and support to patients without the need for manual intervention by nurses. According to a 2015 Goldman Sachs report, the use of healthcare IoT devices could save the United States more than $300 billion in annual healthcare costs through increased revenue and reduced costs. In addition, the use of mobile devices in medical monitoring has led to the development of "m-health", which involves the analysis of health statistics.

Special sensors can be integrated into living spaces that monitor the health and general well-being of the elderly, ensure proper care and help restore mobility lost through caregiving. These sensors form a network of intelligent devices that collect, process, transmit and analyze valuable information in different environments, connecting home monitoring devices to hospital-based systems[37,38,39]. The Internet of Things (IoT) also offers other consumer devices that promote healthy lifestyles, such as connected scales or wearable heart monitors. IoT platforms are available for end-to-end health monitoring, helping people manage vital signs and medication needs of chronic and prenatal patients.

Advances in plastic and fabric electronics manufacturing have led to the development of very cheap, disposable IoMT sensors that can be fabricated on paper or e-textiles, and the necessary RFID electronics for wireless high-performance sensing devices. These sensors have proven useful in medical diagnostics where portability and low system complexity are critical [40,41,42].

As of 2024, the Internet of Medical Things (IoMT) has been used not only in the clinical laboratory industry, but also in the healthcare and health insurance sectors. Healthcare IoMT allows doctors, patients, caregivers, nurses, families and others to be part of a system where patient information is stored in a database. This allows doctors and nurses to easily access patient information. In the insurance sector, IoMT provides access to better and new types of dynamic data, including sensor-based solutions such as biosensors, wearables, connected health devices and mobile applications to monitor customer behavior. This can lead to more accurate insurance contracts and new pricing models.

The application of IoT in healthcare is central to the treatment of chronic diseases and disease prevention and control. Remote monitoring is possible with efficient wireless solutions. It allows health professionals to collect patient data and apply complex algorithms to analyze health data [43].

Transportation

The Internet of Things (IoT) can aid in the seamless integration of communication, control, and information processing across numerous transportation systems. Its applications extend to all aspects of transportation systems, including vehicles, infrastructure, and drivers or users. Communication between vehicles using IoT is a new era of communication, leading to ITS (Intelligent Transport System). IoT is a combination of sensor data storage and processing and data processing with data analytics to achieve and contribute to the efficient management of the traffic system. IoT-based Intelligent Transport System (IoT-ITS) helps automate rail, road, air and shipping, improving the customer experience of transporting, tracking and delivering goods [44,45,46]. IoT enables dynamic interaction between these transportation system components, facilitating inter- and in-vehicle communication, intelligent traffic management, intelligent parking, electronic toll systems, logistics and fleet management, vehicle tracking, safety and roadside assistance [47,48,49,50,51].

V2X communications

In vehicle communication systems, V2X (vehicle-to-everything) communication is a key component, which consists of three main elements: V2V (vehicle-to-vehicle), V2I (vehicle-to-infrastructure) and V2P (vehicle-to-pedestrian) . V2X is the first step towards autonomous driving and a connected road infrastructure [52,53,54].

Home Automation

IoT devices can be used to monitor and control mechanical, electrical and electronic systems in different types of buildings, such as public and private, industrial, institutional or residential, home and building automation systems. Three main areas have been identified in the literature:

1. Integrating the Internet into building energy management systems to create energy-efficient and IoT-based smart buildings.
2. Potential real-time monitoring tools to reduce energy consumption and monitor passenger behavior.
3. Integration of smart devices into the built environment and their possible use in future applications.

People have become increasingly dependent on technology in various fields of work, including human supervision. Many smart home system architectures consisting of sensors, home servers and web platforms have been presented in the literature [55]. With this technology, remote monitoring and control is possible without constant physical presence. However, some components can consume significant amounts of energy if not managed properly, increasing electricity costs. To solve this problem, a home automation system based on text messages or the Internet is proposed, which allows users to remotely control home appliances from anywhere. [56].

Industrial

Industry 4.0 is a promising field of the industrial revolution characterized by a rapidly growing network of intelligent, interconnected devices, equipment and physical objects. This is facilitated by the use of the Industrial Internet of Things (IIoT) in industry. Industrialists and manufacturers are actively participating in this transformation, combining new and existing information and work technologies (IT and OT). IIoT is still a relatively new concept in the industry, but it offers a significant opportunity for businesses to operate more safely and efficiently while reducing costs and improving productivity[57,58].

Industrial IoT (IIoT) devices are known for collecting and analyzing data from connected devices, operational technology (OT), places and people. Combined with OT monitoring devices, IIoT can effectively regulate and monitor industrial systems. In addition, the same implementation can improve capital investment in industrial warehouses, since assets can vary in size from small screws to entire engine spare parts. The misplacement of such assets can result in wasted time and money, underscoring the need for effective asset management in industrial environments[59,60].

Manufacturing

The Internet of Things (IoT) enables the connection of various industrial devices with sensing, identification, processing, communication, actuation and networking capabilities. IoT devices enable management and control of manufacturing equipment, asset and situation management, and intelligent manufacturing processes. In addition, intelligent IoT systems enable rapid production and product optimization, as well as rapid response to changing product requirements[61,62].
On the other hand, the Industrial Internet of Things (IIoT) focuses on digital control systems to automate process control, user tools and service information systems to optimize plant safety.[63,64] Predictive maintenance, statistical evaluation and measurements. can be used for asset management to maximize reliability. In addition, industrial control systems can be integrated into smart grids to optimize energy use. Networked sensors provide various functions such as measurements, automated controls, plant optimization, health and safety management and more[65].

Agriculture

IoT has many applications in agriculture, such as collecting data on temperature, rainfall, humidity, wind speed, pest infestation and soil content. This information can be used to automate farming techniques and make informed decisions to improve yield quality and quantity, while minimizing risk and waste and reducing the effort required to manage them. For example, IoT technology allows farmers to remotely monitor soil temperature and moisture and apply the data to precise fertilization programs. The ultimate goal is to increase farm productivity and reduce costs by combining sensor data with the farmer's knowledge and intuition about his own farm [66].
In August 2018, Toyota Tsusho collaborated with Microsoft to develop fish farming tools that use the Microsoft Azure application for IoT water management technologies. Developed in part by Kindai University researchers, the water pump mechanisms use artificial intelligence to count fish on a conveyor belt and analyze the data to determine the efficiency of water flow. In addition, Microsoft Research's FarmBeats project, which uses an empty TV room to connect farms, is now available on the Azure Marketplace [67,68,69].

Maritime

IoT devices are used to monitor the environments and systems of boats and yachts. Many yachts are left unattended for long periods in summer and winter, and such devices provide invaluable early warning of floods, fires and deep battery discharges. Using global internet data networks such as Sigfox, together with long-life batteries and microelectronics, engine rooms, imaging areas and batteries can be continuously monitored and transmitted to connected Android and Apple applications[70].

Infrastructure

Monitoring and managing the performance of sustainable urban and rural infrastructure such as bridges, railways and offshore wind farms is a key application of the Internet of Things (IoT). IoT infrastructure can be used to monitor events or changes in structural conditions that may compromise security and increase risk. IoT can benefit the construction industry by reducing costs, saving time, improving work quality, facilitating a paperless workflow and increasing productivity. It can also help you make faster decisions and save money through real-time data analysis [71,72]. In addition, IoT can be used to effectively schedule repair and maintenance activities by coordinating tasks between different service providers and users of their facilities. IoT devices can also be used to monitor critical infrastructure such as bridges to ensure access to ships. The use of IoT devices to monitor and operate infrastructure is likely to improve incident management and emergency coordination, as well as service quality, availability and cost savings in all areas related to infrastructure. Areas such as waste management will also benefit from the automation and optimization provided by IoT [73].

Metropolitan scale deployments

Several large-scale Internet of Things (IoT) deployments are underway or in the planning stages to improve city management and system efficiency. For example, Songdo in South Korea is being built as a fully equipped and wired smart city, with approximately 70 percent of the business district completed by June 2018. The city is designed to be highly automated with minimal human intervention.
Another IoT deployment application using two approaches was implemented in Santander, Spain. The city of 180,000 already has 18,000 downloaded city smart apps connected to 10,000 sensors that enable things like parking search and environmental monitoring. Santander's outreach leverages urban contextual data for marketers through a "spark deal" mechanism based on urban behavior designed to maximize the impact of each notification [74].

Energy management

The growing number of Internet-enabled devices such as lamps, appliances, and motors has led to the integration of Internet connectivity into a large number of energy-consuming devices. This connectivity allows communication with utilities to balance energy production and optimize total energy consumption. These devices provide users with remote control capabilities or centralized management through a cloud-based user interface, including features such as device scheduling and remote management. A smart grid is an Internet of Things application on the power side that uses systems to collect and operate energy and power-related information that improves power generation and distribution. Advanced Metering Infrastructure (AMI) and networked devices enable utilities to collect data from end users and manage distribution automation equipment such as transformers.

Rising energy costs and demand have prompted many organizations to find smart ways to monitor, control and conserve energy. An intelligent energy management system (EMS) can help reduce costs while meeting energy demand. The emerging technologies of the Internet of Things (IoT) and Big Data can be used to better manage energy consumption in the residential, commercial and industrial sectors. A smart grid is an electricity-side IoT application that uses systems to collect and influence energy and electricity-related information that improves electricity generation and distribution. Advanced Metering Infrastructure (AMI) and networked devices allow utilities to collect data from end users and manage distribution automation devices such as transformers [75].

Environmental monitoring

Internet of Things (IoT) environmental monitoring applications often use sensors to protect the environment by monitoring air or water quality, soil conditions, and even the movement of wildlife and their habitats. In addition to these uses, IoT devices can be connected to the Internet to develop resource-limited early warning systems for disasters such as earthquakes or tsunamis, enabling emergency services to provide more effective assistance. These IoT devices can cover a wide geographic area and even be mobile, making them very versatile. The standardization of wireless identification brought about by the IoT has been called a potential revolution in the field. Effective change management is widely regarded as one of the world's most daunting challenges. Governments, Semi government organizations and public institutions are working to solve this problem, both socially and environmentally, with the aim of making the world a better place for us all. Several sophisticated systems have been developed to keep up with the rapidly changing reality, including home automation [76,77], traffic and accident monitoring [78,79], smart city solutions [80,81], automatic irrigation systems [82], smart grids [83], problem-solving robots for solving real problems [84], wireless sensor network systems [85], and web-based services [86].

Living Lab

Integrating the Internet of Things (IoT) in public-private-people partnerships is demonstrated through the Living Lab concept, which combines research and innovation processes to create collaborative efforts between stakeholders. Since 2006, over 440 Living Labs have been established, although not all remain active, to share knowledge and co-create technological products using the IoT[87,88]. Governments play a crucial role in implementing and developing IoT services for smart cities, as policy changes can promote the use of the IoT, leading to increased efficiency, accuracy, and resource utilization. For example, governments can provide tax breaks, cheap rents, improved public transport and an environment that encourages collaboration between start-ups, creative industries and multinationals. This environment enables shared infrastructure, labor market division and access to locally embedded technologies, production processes and transaction costs [89].

Military

Military Internet of Things (IoMT) represents the integration of Internet of Things (IoT) technologies into military operations for intelligence, surveillance and combat missions. This concept is strongly influenced by the anticipated future of urban warfare and includes the use of sensors, munitions, vehicles, robots, wearable biometrics and other advanced technologies connected to the battlefield[90.91,92].

One example of an IoT device used by the military is the Xaver 1000 system, created by Israel's Camero Tech. This device is the latest in the company's series of "through wall imaging systems" and uses millimeter wave (MMW) radar with a frequency range of 30-300 gigahertz. Device specifications include an AI-based life goal tracking system and a 3D wall tour feature.

Internet of Battlefield Things

The Internet of Battlefield Things (IoBT) is a project initiated and implemented by the US Army Research Laboratory (ARL) that focuses on the fundamental science of the Internet of Things (IoT) to improve the skills of Army Soldiers. In 2017, ARL established the Internet of Battlefield Things Collaborative Research Alliance (IoBT-CRA), which facilitated collaboration between industry, academia and military researchers to advance the theoretical foundation of IoT technologies and their applications in military operations[93,94].

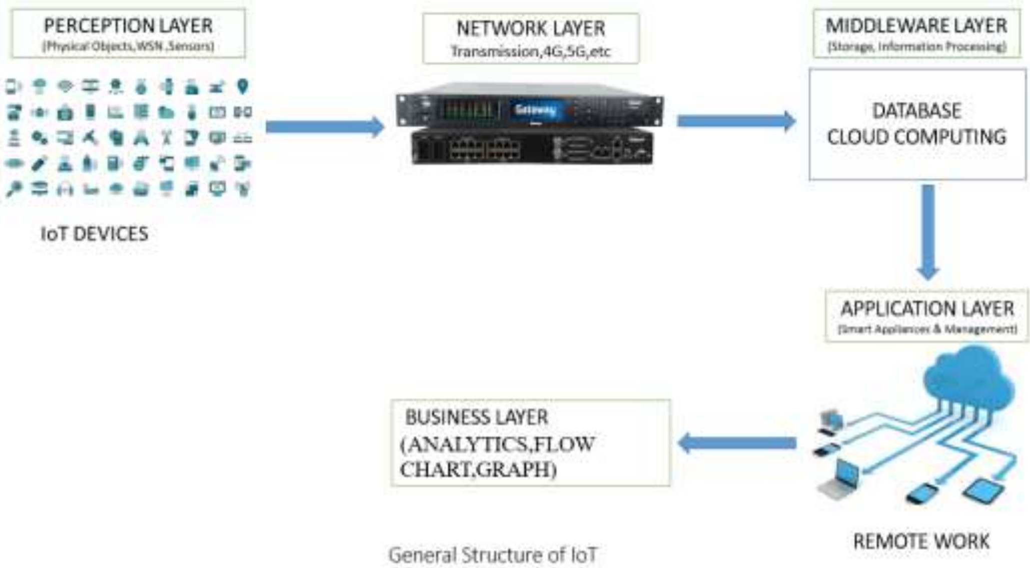
Ocean of Things

The Ocean of Things Project is a DARPA-led program that aims to create an Internet of Things across large ocean areas to collect, monitor and analyze environmental and shipping activity data. The project uses about 50,000 floats equipped with an array of passive sensors that independently detect and track military and cargo ships as part of a cloud-based network [95,96].

Product digitalization

Smart or active packaging is a technology where a QR code or NFC tag is attached to the product or its packaging, which provides digital information about the product. This technology has several applications and uses unique identifiers to facilitate digital communication. Although technically not part of the Internet of Things, this technology has been called the "Internet of Packaging". By scanning a QR code or NFC tag, unique identifiers can be authenticated and encrypted communication can be enabled. This technology has the potential to revolutionize supply chains and enable consumers to access digital content at scale [97,98].

5. GENRAL ARCHITECTURE OF IOT



General Structure of IoT
Figure.2

The IoT architecture consists of five important layers that defines all the functionalities of IoT systems. The various layers are :
1.Perception layer
2.Network layer,
3.Middleware layer,
4.Application layer,
5.Business layer.
Perception layer exists at the bottom of IoT architecture that consists of various types of physical devices i.e. sensors, RFID chips, barcodes etc. and other physical objects connected in IoT network. These devices collects information in order to deliver it to the network layer. Network layer works as a transmission medium to deliver the information from perception layer to the information processing system [99]. This transmission of information may use any wired/wireless medium along with 3G/4G, Wi-Fi, Bluetooth etc. Next level layer is known as middleware layer. This layer's primary responsibility is to process data from the network layer and make judgments based on ubiquitous computing's output.. The business layer is responsible for managing the IoT system, its applications, and services, in addition to its architecture. The business layer visualized information and statistics from the application layer and used this information to plan further goals and strategies. In addition, the IoT architecture can be modified according to the need and application field. [100,101]. In addition to the layered framework, an IoT system consists of several functional blocks that support various IoT functions such as sensing mechanism, authentication and identification, control and management [103]. Figure 2 illustrates such functional blocks of IoT architecture. Several key functional blocks are responsible for I/O, connectivity, processing, audio/video monitoring and storage management. Together, all these functional blocks form a powerful IoT system that is essential for optimal performance. Although several reference architectures with technical specifications have been proposed, they are still far from a standard architecture suitable for the global Internet of Things [104]. Therefore, an appropriate architecture to meet the needs of the global Internet of Things has yet to be designed. The general working structure of an IoT system is shown in Figure 2. Figure 2 shows the dependence of IoT on certain application parameters. IoT gateways play an important role in IoT communication because they enable communication between IoT servers and IoT devices connected to different applications[105].

5. IOT(INTERNET OF THINGS) ENABLING TECHNOLOGIES

1. Wireless Sensor Network
2. Cloud Computing
3. Big Data Analytics

4. Communications Protocols
5. Embedded System

1. Wireless Sensor Network(WSN) :
A wireless sensor network (WSN) includes a number of devices equipped with sensors to monitor physical and environmental variables. WSN includes coordinators, routers and end nodes. Multiple sensors at the end nodes collect data and then transmit it through routers to the coordinator, which acts as a gateway between the Internet and the WSN.
Example -
• Weather Monitoring System
• Indoor Air Quality Monitoring System
• Soil Moisture Monitoring System
• Surveillance System
• Health Monitoring System

2. Cloud Computing :
Cloud technology allows us to use applications over the Internet as utilities. The term "cloud" refers to resources located remotely. Cloud computing allows users to access various resources such as databases, web servers, storage, hardware and software from anywhere via the Internet.Characteristics –
Broad network access
On demand self-services
Rapid scalability
Measured service
Pay-per-use
IaaS (Infrastructure as a service)
Infrastructure as a Service (IaaS) provides network services such as physical machines, virtual machines, servers, networks, storage and data center space on a per-use basis. Prominent IaaS providers include Google Compute Engine, Amazon Web Services, and Microsoft Azure.
Examples
- Web Hosting
- Virtual Machine etc.

➢ PaaS (Platform as a service)
It provides a cloud-based environment with everything you need to support the entire lifecycle of building and delivering web (cloud) applications. This eliminates the cost and complexity of purchasing and managing hardware, software delivery and hosting. This includes computer platforms such as hardware, operating systems and libraries. Basically, it provides a platform for application development.

Examples :
- App Cloud
- Google app engine

➢ SaaS (Software as a service)
It is a way of delivering applications over the Internet as a service. Instead of installing and maintaining software, you can run it online, eliminating the need for complex software and hardware management. SaaS applications, also known as web-based software, on-demand software, or hosted software, run on the servers of a SaaS provider, where the service provider manages security, availability, and performance.

Examples:
- Google Docs
- Gmail
- office etc.

3. Big Data Analytics :
It involves the process of analyzing large **amounts** of data, often called big data. This type of data is **difficult** to store, **manage** and process with traditional databases due to its **large** volume, high **speed** or complexity. Big data is collected from a **variety** of sources, including social media videos, digital images, sensor **readings** and sales **transactions.** There are several steps involved in the analysis of big data. –
Data cleaning
Munging
Processing
Visualization
Examples –

- Bank transactions
- Data generated by IoT systems for location and tracking of vehicles
- E-commerce and in Big-Basket
- Health and fitness data generated by IoT system such as a fitness bands

4. Communications Protocols :
Communication protocols are the backbone of IoT systems, enabling network connectivity and integration with applications. These protocols allow devices to exchange data over the network. Often, multiple protocols describe various aspects of a single communication. A collection of protocols designed to function together is known as a protocol suite, and when implemented in software, they form a protocol stack. They are used in

Data encoding
Addressing schemes
5. Embedded Systems :
A combination of hardware and software is designed for specific tasks and includes components such as microcontrollers, microprocessor memory, network devices such as Ethernet and Wi-Fi adapters, input/output devices such as screen keys, and storage devices such as flash memory. It collects data and transmits it to the internet. Embedded systems used in
Examples –

- Digital camera
- DVD player, music player
- Industrial robots
- Wireless Routers etc.

6. CONCLUSION AND DISCUSSION

The Internet of Things (IoT) has shown significant potential to revolutionize healthcare through its various applications and enabling technologies. This review has highlighted the continued advancement and integration of IoT technologies hold great promise for transforming healthcare delivery, making it more efficient, personalized, and accessible. Successful deployment of IoT in healthcare requires collaboration among technologists, healthcare professionals, policymakers, and other stakeholders to overcome existing barriers and maximize its potential benefits.
IoT facilitates remote monitoring, improves patient outcomes, and optimizes healthcare resources. By leveraging IoT devices, healthcare providers can collect and analyze vast amounts of data, enhancing diagnostic accuracy and enabling personalized treatments.
The integration of IoT in healthcare also supports the development of smart medical devices, such as wearables and implantable sensors, which continuously monitor patient health metrics and provide real-time feedback. These advancements not only improve patient care but also contribute to more efficient healthcare systems by reducing the need for frequent hospital visits and enabling timely interventions.
IoT has a transformative impact across multiple domains. In home automation, IoT enhances convenience, energy savings, and security through smart systems that allow remote control and monitoring. In the industrial sector, IoT, integral to Industry 4.0, optimizes asset management, predictive maintenance, and overall efficiency, leading to safer and more productive operations. In agriculture, IoT improves farming practices by providing real-time data on environmental conditions, thereby increasing yield quality and reducing waste. Energy management benefits from IoT through optimized energy use and cost savings enabled by smart grids and advanced metering infrastructure. Environmental monitoring applications use IoT sensors to track air and water quality, aiding in disaster management and environmental protection. In healthcare, the Internet of Medical Things (IoMT) enhances patient care by enabling continuous health monitoring and data analysis.

7. LIMITATIONS OF THE STUDY

The paper might have a limited scope, focusing on certain aspects of IoT in healthcare while neglecting others.The review cover a broad range of topics without delving deeply into any specific application or technology. Given the fast pace of advancements in IoT and healthcare technologies, some of the data or technologies discussed may quickly become outdated.The paper might not include the very latest research, developments, or innovations as it relies heavily on older sources. There may be a bias toward published studies, potentially overlooking relevant but unpublished work or studies in languages other than English. The authors have selectively chosen studies that support a particular viewpoint or technological approach. Findings from the review might not be generalizable across different healthcare settings, regions, or patient populations. The applicability of certain IoT technologies may vary depending on the technological infrastructure and readiness of the healthcare system in different regions.
Future research should focus on developing secure and interoperable IoT systems that can seamlessly integrate with existing healthcare infrastructures. Additionally, efforts should be made to standardize data formats and

communication protocols to facilitate widespread adoption and ensure the reliability of IoT applications in healthcare.

In conclusion, the continued advancement and integration of IoT technologies hold great promise for transforming healthcare delivery, making it more efficient, personalized, and accessible. The successful deployment of IoT in healthcare requires collaboration among technologists, healthcare professionals, policymakers, and other stakeholders to overcome existing barriers and maximize its potential benefits.

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