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Insights on the internet of things: past, present, and future directions

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ABSTRACT

The internet of things (IoT) is rapidly expanding and improving operations in a wide range of real-world applications, from consumer IoT and enterprise IoT to manufacturing and industrial IoT (IIoT). Consumer markets, wearable devices, healthcare, smart buildings, agriculture, and smart cities are just a few examples. This paper discusses the current state of the IoT ecosystem, its primary applications and benefits, important architectural stages, some of the problems and challenges it faces, and its future. This paper explains how an appropriate IoT architecture that saves data, analyzes it, and recommends corrective action improves the process's ground reality. The IoT system architecture is divided into three layers: device, gateway, and platform. This then cascades into the four stages of the IoT architectural layout: sensors and actuators; gateways and data acquisition systems; edge IT data processing; and datacenter and cloud, which use high-end apps to collect data, evaluate it, process it, and provide remedial solutions. This elegant combination provides excellent value in automatic action. In the future, IoT will continue to serve as the foundation for many technologies. Machine learning will become more popular in the coming years as IoT networks take center stage in a variety of industries.

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1. INTRODUCTION

Kevin Ashton, in a 1999 presentation to Proctor and Gamble, coined the phrase "internet of things" (IoT) to describe the company's plans to employ radio-frequency identification (RFID) tags across its supply chain [1]. This would give computers their own eyes, ears, and noses so they could observe the environment for themselves. It expanded upon prior concepts, most notably Mark Weiser's vision for ubiquitous computing, laid out in his 1991 article for Scientific American (The Computer for the 21st Century), in which he envisioned a future world populated by a vast network of interconnected computers that would become so intrinsic to daily life that they would be invisible to the naked eye [2]. However, the IoT did not really begin to take off on a worldwide scale until Gartner included it on its list of new emerging technologies in the year 2011. IoT devices accounted for more than 11.3 billion (or 52 percent of the 21.7 billion active connected devices in use globally) as of 2021, and it is anticipated that the number of linked IoT devices would rise by 16 percent to 13.1 billion in 2022 as shown in Figure 1 [3]. This suggests that there are more IoT devices than there are devices that are not connected to the internet all across the world.

The IoT is an interconnected network of computing devices, mechanical and digital equipment, objects, animals, or humans assigned unique identifiers (UIDs) [4], [5] and the capacity to transfer data via a network without the need for human-to-computer or human-to-human interaction [6]–[17]. The word "thing" refers to any natural or man-made object that can be given an internet protocol (IP) address and can send and receive data over a network, such as a person who has an implanted heart monitor, an animal on a farm that has a biochip transponder, a vehicle that has built-in sensors to alert the driver when the tire pressure is low, or any other similar thing [18]–[36]. IoT is being utilized more and more frequently by organizations across a wide variety of sectors to improve operational efficiencies, gain a deeper understanding of their clientele in order to deliver superior service, enhance decision-making capabilities, and add value to their operations [20], [25], [28], [36].

Figure 2 depicts an IoT ecosystem, which is made up of web-enabled smart devices that collect, send, and act on data collected from their surroundings using embedded systems such as processors, sensors, and communication equipment [37]–[65]. IoT devices exchange sensor data through a link to an IoT gateway or another edge device, after which the data is either transferred to the cloud for processing or examined locally [59]. These electronic gizmos will periodically communicate with other connected devices and will take action based on the information they receive from one another. The majority of the work is done without human intervention, but individuals must engage with the devices to set them up, offer instructions, or see the results. The IoT apps that are installed have a significant influence on the connection, networking, and communication protocols that these web-enabled devices utilize. Machine learning and artificial intelligence (AI) may also be used in IoT to simplify and dynamically acquire data [66]–[133].

The IoT enables individuals to live and work more effectively, as well as having total control over their life. IoT is critical for businesses, in addition to delivering smart gadgets for home automation [7], [58], [66], [73], [78], [122]. IoT provides organizations with a real-time perspective of how their systems are doing, providing insights into machine performance, supply chain, and logistical operations [71], [97]. The IoT allows businesses to automate operations and save labor costs. It also reduces waste and enhances service delivery by reducing the cost of making and transporting goods and by providing customers with more transaction-related information [68], [73], [90], [116], [134]. Due to the fact that more businesses are realizing the value of connected devices for their ability to compete, IoT has grown to become one of the most important technologies in modern life.

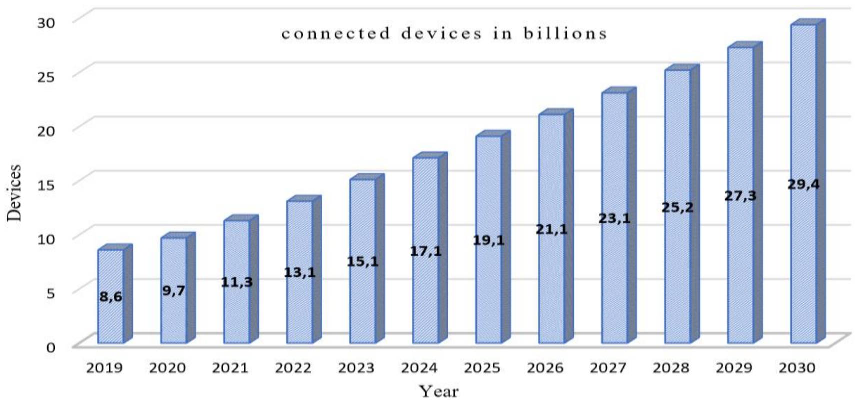

Figure 1. Global IoT connected device count from 2019 to 2021, with projections from 2022 to 2030 [3]

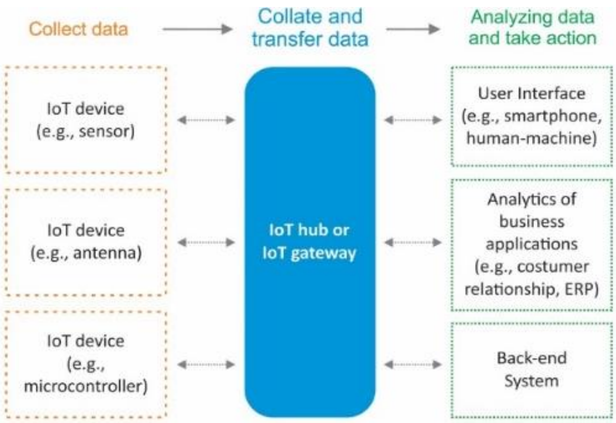

Figure 2. An IoT system example

2. APPLICATIONS AND BENEFITS

The IoT has various real-world applications, spanning from consumer, commercial, manufacturing as well as industrial IoT (IIoT) [59], [135]–[148]. IoT applications may be found in a variety of industries, including automotive, telecommunications, and energy [20], [122], [139], [140], [149]. Smart homes furnished with smart appliances, smart thermostats, and linked lighting, heating, and electrical devices, for example, may be handled remotely via computers and smartphones in the consumer market [150]–[155]. Wearable devices with sensors and software may gather and analyze user data, transmitting signals about the users to other technologies in order to make their lives simpler and more pleasant. Wearable tech is also used in public safety. For example, it can help first responders get to an emergency faster by showing them the best way to get there, or it can keep track of construction workers' or firefighters' vital signs in places that could be dangerous [120], [156]. In healthcare, IoT has several advantages, including the capacity to more closely monitor patients via data analysis. IoT systems are often employed in hospitals to control the supply of drugs and medical equipment [48], [55], [123], [125], [149]. By using sensors to determine the number of people present in a space, smart buildings, for instance, may reduce energy use. The temperature may be controlled automatically, for example by turning on the air conditioner if sensors detect that a conference room is full or by decreasing the temperature if everyone has left the office [47], [105], [157]–[161]. Linked sensors may be utilized by IoT-based smart farming systems to monitor the light, temperature, humidity, and soil moisture of agricultural areas. IoT may also be utilized to automate irrigation systems [4], [54], [162]–[165]. IoT sensors and installations such as smart lighting and smart meters might help decrease traffic, save energy, monitor and address environmental concerns, and make the city cleaner in a smart city [47], [80].

We can benefit from IoT in a number of ways. Some benefits are industry-specific, while others are applicable across several industries. Some of the most common IoT benefits enable businesses to: monitor their whole business operations; enhance customer experience (CX); save time and money; raise staff efficiency; integrate and adapt business models; make better business decisions; and generate more cash. IoT forces us to reconsider our business practices and offers us with the tools we need to improve our corporate strategy. IoT is especially common in industrial, transportation, and utility companies that use sensors and other IoT devices. It has, however, discovered application cases for firms in the home automation, agricultural and infrastructure sectors, driving some to digital evolution [66], [91], [98], [100], [166]–[170].

IoT can help farmers because it can make their jobs easier. Sensors can measure things like rainfall, temperature, humidity, and the amount of nutrients in the soil, among other things, to help automate farming. IoT may also help with being able to keep an eye on what's going on around infrastructure. For example, sensors could be used to keep an eye on what's going on inside buildings, bridges, and other infrastructure. This has benefits like saving money, saving time, changing the way work is done to improve quality of life, and getting rid of paper work. A home automation company could use the IoT to monitor and control the building's mechanical and electrical systems. On a larger scale, smart cities may assist inhabitants in reducing trash and energy use. The Internet of Things has an impact on every area, including healthcare, banking, retail, and manufacturing [150], [157], [162]–[165], [171]–[178].

3. ARCHITECTURE STAGES

The IoT refers to the widespread networking of various items, including consumer goods such as watches, wearable technologies, remote controls, tablets, household appliances, sensors, and more, with people who use them [179]–[183]. The solution is intended to collect data from devices and deliver it to data centers and servers for further analysis, which drives actions and automation. The IoT architecture is critical in directing data in the appropriate direction, establishing the format to use, and choosing what action to take. It is a network system made up of many components including sensors, actuators, cloud services, protocols, and IoT architectural layers [184]–[192]. Administrators may analyze, monitor, and maintain system consistency using several levels. For maximum effect, the system design strategy is thoroughly linked with the existing infrastructure systems. Organizations with strong IoT architecture have a higher chance of enhancing business processes and achieving better results. Such companies are known to maintain an IoT system architecture that is tailored to individual IoT initiatives, as well as other general-purpose IoT architectural formats. In addition, the system features IoT architectural layers that aid in system consistency monitoring. In reality, the layers must be in place long before the IoT architectural conceptualization process starts. A typical IoT architecture would consist of three layers: a) perception is the client layer that gathers data; b) network is the server-side operator that links devices to smart objects, servers, and network devices; and c) application is the final application that connects the operator and the client. These layers make certain that the IoT architecture is completely functional, scalable, available, and maintained [156], [193]–[203].

After that, we proceed to the four stages of the IoT architectural layout: sensors and actuators, gateways and data acquisition systems, edge IT data processing, and datacenter and cloud. A more in-depth examination of each of the four phases of IoT architecture:

1) Sensors and actuators [70], [84], [95], [102], [204]–[208]

Sensors and actuators are two types of linked devices that monitor and control physical processes. Sensors record process status data as well as external factors such as humidity, temperature, fluid movement in a pipeline, fluid level in a tank, and much more. Some condition data need an instantaneous reaction from the actuator in order to carry out real-time corrective activities. Adjusting the liquid flow rate to maintain a constant level is one example. It is critical to keep the latency between sensors and data processing as short as possible in order to trigger the actuator's action. To prevent delays in data relay to the server, its analysis, and the final signal to operate the 'thing,' data processing is performed near to the monitor and control system.

2) Gateways and data acquisition systems [43], [59], [66], [71], [113], [140], [158], [209]–[219]
A data acquisition system (DAS) collects the data given by the sensors and converts it to a digital-analog format. The DAS combines and prepares this data before sending it to the next level of processing through Internet gateways such as wireless wide area network (WANs), such as cellular or wireless fidelity (Wi-Fi), or wired WANs. In the case of industrial and manufacturing settings, the data at this level might be massive, with thousands of sensors collecting it at the same time. Before transmission, data must be filtered and compressed to an ideal size.

3) Edge IT data processing [67], [94], [100], [109], [122], [133], [140], [168]–[170], [216], [220]–[223]
Before reaching the cloud center, the digitized and aggregated IoT data is processed further. Edge devices do sophisticated analytics and preprocessing, which may include machine learning and visual representation. Machine learning helps to provide ever-improving input into the system and further improve the process without having to wait for instructions from the cloud data center. Such processing is often performed in a device adjacent to the sensor, such as an on-site wire closet. This step then allows data to be collected at local sensors and sent to faraway sites for analysis and processing.

4) Data center and cloud [88], [152], [224]–[231]
In this last stage, data centers do extensive processing with the assistance of high-end programs built and managed by expert analytics specialists. IT systems that are powerful assess, handle, and store data in the cloud or corporate data centers. Multiple site sensors are combined here to provide a more comprehensive view of the complete IoT system and its deliverable actions. When activities are dispersed over many regions, these cloud data centers monitor and detect critical trends, patterns, or anomalies to aid in the optimization of operations. This is the stage at which a firm or industry-specific application conducts an in-depth analysis with unique or bespoke business rules in mind to decide the next step. Incoming data may indicate that device settings should be changed or recommend other remedial steps to enhance operations. It is a component of a continuous development loop that also saves data for future study.

4. OBSTACLES AND CHALLENGES

The expected exponential rise of smart devices, as well as the merging of low-cost infrastructure, connectivity, and data, will propel IoT from lofty idea to reality. Reduced device prices, extensive and pervasive connection, and a growing emphasis on operational efficiency and productivity are driving the mainstream use of IoT solutions. The IoT offers a concept in which the Internet expands into the physical world, including ordinary things. Physical objects are no longer cut off from the virtual world; they may now be operated remotely and serve as physical access points to Internet services. This progress is creating enormous potential for the economy as well as for people [20], [63], [78], [115], [116], [134], [146], [188], [189], [196], [197], [232]–[234].

The IoT concept is based on the premise that the recent continuous developments in microelectronics, communications, and information technology will continue in the near future. Processors, communications modules, and other electronic components are progressively being incorporated into ordinary things owing to their shrinking size, consistently lowering costs, and decreasing energy usage. "smart" things are important in the IoT concept because embedded communication and information technology has the ability to transform the usefulness of these products. They can sense their surroundings via sensors, and they can talk with one another, access Internet services, and interact with people thanks to built-in networking capabilities. "Digitally upgrading" traditional items in this manner improves their physical function by incorporating the capabilities of digital objects, resulting in significant additional value. Sewing machines, exercise cycles, electronic toothbrushes, washing machines, energy meters, and photocopiers are already being "computerized" and outfitted with network ports as forerunners of this evolution [235]–[248].

Despite IoT's enormous promise, enterprises must overcome various obstacles and challenges that are impeding IoT development. It is fraught with danger and, without a doubt, offers a massive technological and societal challenge. To learn about IoT and master it in the long run, businesses will need to work closely with mature providers to overcome significant obstacles such as:

1) A lack of standards and interoperable technologies [249]–[264]

Interoperability refers to the capacity to exchange data between various IoT devices and platforms. This information interchange is independent of the software and hardware in use. The issue of interoperability arises owing to the diverse nature of various technologies and solutions employed in IoT development. Technical, semantic, syntactic, and organizational interoperability are the four layers of interoperability. IoT systems provide a variety of features to increase interoperability, which facilitates communication between diverse items in a heterogeneous environment. Furthermore, multiple IoT platforms may be combined based on their characteristics to give a variety of solutions to IoT consumers. Given the importance of interoperability, researchers authorized many methods known as interoperability handling methodologies. These solutions might be based on adapters/gateways, virtual networks/overlays, service-oriented architectures, and so on. Although interoperability management mechanisms alleviate some of the load on IoT systems, there are still certain difficulties with interoperability that might be the subject of future research.

2) Data and information management issues [265]–[268]
Traditional infrastructures struggle to route, capture, analyze, and apply the insights created by massive amounts of IoT data in timely and appropriate ways. The sheer volume of data gathered will need advanced algorithms capable of sifting, analyzing, and extracting value from the data. As more devices are introduced to the market, more data silos emerge, resulting in a complicated network of links between isolated data sources. Organizations will find it considerably more difficult to eliminate data silos if uniform standards and protocols do not exist.

3) Privacy and security concerns [20], [41], [196], [221]
One of the most essential and difficult concerns in IoT is privacy and security owing to a variety of threats such as cyber-attacks, dangers, and vulnerabilities. Insufficient authorization and authentication, insecure software, firmware, web interface, and inadequate transport layer encryption are the challenges that give birth to device level privacy. Security and privacy concerns are critical factors in instilling trust in IoT devices in a variety of ways. To avoid security risks and assaults, security methods must be included in every tier of the IoT architecture. To secure the security and privacy of IoT-based systems, several protocols have been designed and efficiently applied on every tier of the communication channel. Datagram transport layer security (DTLS) is one of the cryptographic protocols used to provide security solutions in various IoT systems. It is implemented between the transport and application levels. However, various solutions are required for specific IoT applications to ensure the security of communication between IoT devices. Furthermore, communication inside the IoT system via wireless technology makes it more exposed to security vulnerabilities. As a result, certain approaches should be used to identify harmful behaviors as well as for self-healing or recovery. On the other hand, privacy is a crucial consideration that allows consumers to feel secure and comfortable when utilizing IoT solutions. As a result, maintaining authorization and authentication via a secure network is essential to facilitate communication between trusted parties. Another difficulty is that various items interacting inside the IoT system have varying privacy rules. As a result, before transferring data, each device in an IoT system should be able to validate the privacy policies of other objects.

4) Organizational inability to manage IoT complexities [269]–[283]
While the IoT provides immense value, using it will need a whole new level of systems and skills capable of harnessing the ecosystem and unlocking value for enterprises. For example, making sense of the deluge of data created by sensors every millisecond would need excellent data management, storage, and analytics skills. Similarly, policymakers will need to handle data security and privacy issues. Organizations will also need to build abilities to anticipate probable component failures and replacements via preventative service and maintenance methods to guarantee company operations function smoothly and efficiently.

5) Ethics, law and regulatory rights [284]–[286]
Another concern for IoT developers is ethics, the rule of law, and regulatory rights. Certain laws and regulations are in place to protect standards and moral values and to keep people from breaching them. The sole difference between ethics and law is that ethics are principles that individuals believe in, whereas laws are limits imposed by the government. However, both ethics and legislation are intended to maintain a high level of quality while discouraging unlawful usage. Several real-world issues have been solved as a result of the development of IoT, but it has also given birth to major ethical and legal difficulties. Some of these problems are data security, privacy protection, trust and safety, and data usability. Because of their lack of faith in IoT devices, the majority of IoT consumers favor government standards and laws regarding data protection, privacy, and safety. As a result, this issue must be addressed in order to retain and strengthen public trust in IoT devices and systems.

6) Scalability, availability and reliability [287]–[301]
A system is scalable if it can add more services, equipment, and devices without affecting how well it works. Supporting a huge number of devices with different amounts of memory, processing power,

storage space, and bandwidth is the main problem with IoT. Availability is another important thing to think about. In the IoT's layered structure, scalability and availability should be set up at the same time. Cloud-based IoT solutions are a great example of scalability because they let you add more devices, storage, and processing power to the IoT network as needed. On the other hand, this IoT network that is spread out all over the world leads to a new research paradigm for building a seamless IoT framework that can meet global needs. Another big problem is that it is hard to find resources for real artifacts, no matter where or when they are needed. Several local IoT networks are connected to global IoT platforms in a disorganized way to use their resources and services. Because of this, availability is a very big problem. Some services and resources might not be available because of the use of other ways to send data, like satellite communication. Because of this, it is important to have an independent and reliable data transmission route to make sure that resources and services are always available.

7) Quality of service (QoS) [254], [301]–[311]
Another critical aspect of IoT is QoS. QoS is a metric used to assess the performance, quality, and efficiency of IoT devices, systems, and architecture. Reliability, security, availability, cost, energy consumption, and service time are critical and essential QoS criteria for IoT systems. A more intelligent IoT ecosystem must meet QoS criteria. Furthermore, in order to assure the dependability of any IoT service or device, its QoS metrics must first be specified. Furthermore, consumers may be able to indicate their demands and expectations. A variety of ways may be used to analyze QoS, however there is a trade-off between quality parameters and methodologies. To address this trade-off, high-quality models must be used. Certain high-quality models, such as ISO/IEC25010 and OASIS-web services quality model (WSQM), are accessible in the literature and may be used to evaluate the methodologies employed for QoS assessment. These models include a wide variety of quality parameters that are more than enough for assessing QoS for IoT services.

The IoT has the potential to significantly improve both human quality of life and company efficiency. Through a widely dispersed and locally intelligent network of smart devices, the IoT has the potential to enable extensions and enhancements to fundamental services in a variety of domains, including transportation, logistics, security, utilities, education, healthcare, and other fields. Additionally, it has the potential to provide a new ecosystem for the development of software applications. A concerted effort, motivated by a common understanding of the distinctive nature of the opportunity, is required to move the sector through the initial stages of market growth and into maturity. In terms of service distribution, business and billing procedures, IoT service delivery capabilities, and the many demands these services will place on mobile networks, this market offers distinct qualities. It is hoped that by having a common understanding of IoT characteristics, industry participants would be better able to work together to advance the market for the benefit of consumers and society [8], [50], [311].

5. FUTURE DIRECTIONS

The "internet of things" is hard to leave off a list of creative and game-changing innovations in a world driven by artificial intelligence, data, and constantly improving connection technologies. In fact, IoT may be one of the most important technologies available right now, since it is the reason why many other technologies, like machine learning, work well. As machines get smaller, making things gets easier. In recent years, industries have moved away from a monolithic, single-device architecture and toward a more modular, microservices strategy. A network of devices may do all calculations and measurements instead of a single unit. Each gadget may have its own utility that benefits the overall network. This is the foundation of IoT technology [33], [68], [100], [112], [127], [152], [280].

The value of the IoT technology industry is anticipated to reach $1.39 trillion by 2026. This phenomenal rise is most likely owing to a combination of reasons, including [312]–[314]: 1) the COVID-19 outbreak has accelerated the development of remote monitoring, smart home devices, and data analysis solutions; and 2) enterprises are competing to build better artificial intelligence solutions. These usually need a network of sophisticated sensors and edge processors in the context of IoT; and 3) IoT networks can perform some tasks more effectively than centralized alternatives.

IoT solutions have gotten more expensive to create as a result of the high demand and limited availability of precious semiconductor chips. The epidemic has only made matters worse. Although manufacture of these chips has grown, the chip scarcity will persist for a long time. Instead of employing a just-in-time approach, some organizations prefer to order their semiconductor supplies months in advance. In 2022, a lack of semiconductors will limit IoT market growth by 10 to 15%. That may appear to be terrible news for companies eager to invest in new IoT solutions, but it isn't the full picture. There's some excellent news on the way. In February 2022, the European Union approved the European Chips Act, a mix of public and private spending aimed at bridging the supply chain gap [232], [315]–[317].

Bandwidth is the most critical constraint in IoT technology. The more the bandwidth, the lower the latency of an IoT network. The faster one device can communicate with another, the more fluid and efficient IoT technology will become. If there is too much latency, the Internet of Things offers no advantage over centralized alternatives. High-speed networking was formerly limited by cable and fiber connections. An IoT network may be severely confined if every device is connected by an Ethernet line. Wireless connections may be unstable and provide slower data rates. However, as 5G networks and Wi-Fi 6 have advanced, IoT has risen in prominence in recent years (802.11ax). The promise of the Internet of Things may be realized with faster wireless data rates than ever before [169], [255], [306].

5.1. Smart homes

The evolution of digital assistants such as Google Assistant, Amazon Echo, Apple's Siri, and others has transformed the smart home industry. With at-home IoT technology capable of handling a wide range of equipment such as lights, appliances, and even home security systems by 2022, the technology looks to have reached a tipping point. However, there is still room for growth, as we will see in the next years. According to Mordor Intelligence, the smart home business will grow at a 25% CAGR between now and 2025, reaching a value of $246 billion. One of the next stages will be to focus on smart home automation. Smart house IoT networks are fast extending their ability to automate functions such as lighting, climate control, and security. Customers can adjust them manually or automatically using AI algorithms that examine sensor and use data. MobiDev collaborated with CUJO AI to develop a mobile app that allows consumers to monitor the security of their home network on the IoT smart home device security side [312], [318]–[331].

5.2. Smart cities

IoT technology may be utilized in a variety of ways while building smart city networks. Traffic monitoring is one of the most critical challenges. The capacity to monitor traffic with sensors strategically positioned across the city enables better control over intersections and traffic management. Water level monitoring can also be used to detect and warn communities of imminent and current flooding. This information can also be used to guide future flood mitigation activities. Smart streetlights may be used for a variety of purposes. They may be used as sensor platforms to detect weather, traffic, host public Wi-Fi, and perform surveillance. These bulbs can also function as an edge device for digital roadside signs. They might even place the lamps on the light pole itself. Columbus, Ohio's Smart City, has tried self-driving shuttles. This futuristic experiment demonstrates how smart cities may help to decrease the demand for private automobiles in the future [20], [53], [105], [116], [188], [269], [279], [332]–[337].

5.3. IoT technology in healthcare

There are many uses for the IoT technologies in this industry. When used in conjunction with IoT networks, for instance, WebRTC may make it possible to offer more effective telemedicine in locations where edge devices may be more effective than a conventional Internet connection. There are also a great number of usual applications for the IoT, such as sensors in hospital rooms that may keep track of a patient's vital signs throughout the day to assist medical professionals with diagnosis and treatment. The widespread distribution of COVID-19 has accelerated the development of this technology [48], [55], [123], [125], [136], [149], [204], [253], [297], [304], [319], [330], [338]–[341].

5.4. IoT connectivity: 5G, WiFi 6, low power wide area networks (LPWAN), and satellites

Wireless data rates have been the most difficult barrier for IoT networks to overcome in recent years. Sensors, edge computing, wearables, smart homes, and other components of IoT technology will improve as these technologies advance. More infrastructure has recently been constructed for additional communication types, making IoT solutions more realistic. 5G, WiFi 6, LPWAN, and satellites are examples of connection technologies. In order to maintain an array of edge devices, sensors, or other devices, the installation of communication infrastructure is required for many IoT technology solutions. Mobile networks, such as LTE, can, nevertheless, be a viable option in some conditions, such as outdoor settings. However, bandwidth constrains 4G LTE. However, 5G networks are substantially quicker and can accommodate the data processing required by IoT networks much more efficiently. WiFi operating on the 6 GHz band significantly increases the interior bandwidth capacity of IoT technologies. The greater the speed at which components in a network can interact, the more reliable the system. WiFi 6 may also be used in houses, which implies it can bring considerable advantages for smart home IoT networks. Low-power wide-area network connectivity is a novel technology that links devices with low bandwidth consumption and low bit rates over greater distances. This makes it a good option for Internet of Things devices that link through machine-to-machine communication. LPWANs are less costly since they utilize less energy. If you need to connect a large number of devices over a large geographical area, LPWAN is a viable option. Satellites can power IoT technology in some circumstances for geographically dispersed networks. Traksat's satellite-powered IoT devices, which are powered by Globalstar satellites, enable humanitarian employees to report emergency occurrences and promptly request help. GPS data is promptly captured and transmitted to HQ for rescue preparations [301], [312], [342]–[351].

5.5. Big data analytics in IoT

An IoT system is made up of a large number of interconnected devices and sensors. As the IoT network grows and expands, the number of these sensors and devices increases. These devices communicate with one another and transfer massive volumes of data via the internet. Because this data is vast and streams every second, it has earned the term "big data." As IoT-based networks proliferate, challenging difficulties such as data management and collection, storage and processing, and analytics emerge. The IoT big data framework for smart buildings is highly useful for dealing with a number of smart building difficulties, such as monitoring oxygen levels, analyzing smoke and harmful compounds, and deciding brightness. This sort of framework is capable of acquiring data from sensors installed in buildings and doing data analytics for decision making. In addition, an IoT-based cyber-physical system outfitted with information analysis and knowledge acquisition approaches might be employed to boost industrial production. Congestion is a major issue in smart cities. Real-time traffic data may be collected and analyzed in an IoT-based traffic management system employing IoT devices and sensors installed at traffic lights. IoT sensors installed on patients provide a vast quantity of data about their health every second in healthcare analysis. To make speedy, correct decisions, this huge volume of data must be integrated into a single database and examined in real time, and big data technology is the appropriate solution. The Internet of Things, in conjunction with big data analytics, may also help in the transition of traditional industrial practices into new ones. The sensing devices generate data that may be analyzed and utilized to help in a number of decision-making processes utilizing big data approaches. In addition, cloud computing and analytics may help with energy development and conservation by cutting costs and enhancing customer satisfaction. Massive volumes of streaming data are generated by IoT devices, which must be efficiently stored and processed in real time for decision-making. Deep learning is quite effective at dealing with such massive amounts of data and can generate highly accurate results. As a result, Internet of Things (IoT), big data analytics, and deep learning are all important to the growth of a high-tech society [22], [28], [74], [77], [89], [92], [93], [101], [103], [110], [114], [126], [149], [152], [155], [183], [188], [202], [232], [265], [318], [352].

5.6. Edge computing: low latency and security

Edge computing is critical for real-time applications. Instead of calculating everything at a central location, edge networks process information closer to the user, lowering total network load for all users. Edge computing has the potential to not only reduce the latency of IoT technology, but also to increase data processing security. When data can be processed on an edge device rather than transmitted to a central server, hackers have less opportunities to intercept it. All that is necessary is for the information to be exchanged with the edge device and then returned to the user. In this case, the information does not need to be remembered. Edge computing is useful in any situation that necessitates quick decisions. This is especially true in circumstances concerning security and safety. One way that IoT edge computing may be used to protect humans is to automatically shut down machines when someone enters a prohibited area at a factory. Autonomous cars require data in order to make critical real-time decisions that might mean the difference between life and death on the road [24], [26], [67], [100], [109], [133], [145], [184], [186], [216], [220], [221], [267], [268], [293], [297], [335].

5.7. Connected networks aid manufacturers

IoT technology has huge potential to improve the industrial company. This industry has become more automated than ever before, thanks to arrays of sensors installed on production floors. One of the most significant results of the proliferation of IoT sensors in manufacturing is that these networks now offer sophisticated artificial intelligence applications. Without sensor data, AI cannot offer solutions such as predictive maintenance, defect detection, digital twins, and generative design. The future of IoT technology lies in each of the previous developments and beyond, with applications ranging from retail to indoor navigation. It's also important to realize that the Internet of Things isn't a stand-alone technology in many cases. Combining technologies such as IoT and AI helps businesses to stimulate innovation while remaining competitive. All it needs to get started is a notion or a vision for upgrading your company's infrastructure in order to confront the future head on [312], [313], [353]–[362].

5.8. Wearable IoT Technology

While sensors and edge devices are critical components of many IoT technology solutions, wearable IoT devices must not be overlooked. Wearable IoT products such as smart watches, earbuds, and extended reality (AR/VR) headsets are making waves in 2022 and will only grow better. Wearable technology, particularly smartwatches, was predicted to someday replace smartphones and desktop computers. However, it does not appear that this forecast will become a reality very soon. Wearable gadgets, such as smartwatches, are less likely to be beneficial for tasks that can be completed on a smartphone or laptop due to their restricted practicality. Wearable IoT technology, on the other hand, has huge potential to assist in medical activities because to its ability to monitor patient vitals. These devices can do things like immediately warn others in the case of an emergency and collect continuous health data. If IoT technology can provide devices with real-time contextual data, it's simple to see how this can improve the performance of augmented reality (AR) and virtual reality (VR) devices. Sensor data and real-time network information shown on a head-mounted display might be particularly beneficial in specific scenarios for professionals [120], [156], [322], [330], [331]: 1) head-mounted AR assists surgeons during surgery by providing data from wearables and other sensors; 2) a manufacturer is studying a virtual reality digital twin simulation of an industrial layout. In order to compare performance, IoT sensor data from the actual production floor may be shown alongside the digital twin, and 3) IoT devices help locate the item and transmit directions to the worker as a distribution center employee uses augmented reality on a mobile smartphone to locate a specific item in a warehouse.

5.9. Artificial intelligence and IoT technology (AIoT)

The ability to allow AI software is one of the most exciting uses of IoT technology. AI and the Internet of Things are mutually beneficial. IoT improves AI by dispersing data, and IoT benefits AI by improving management. IoT sensors are a significant addition to the machine learning data pipeline since AI technologies are essentially data-driven. By 2026, the value of AI in IoT technologies would be $14,799 million. High-quality data is essential for machine learning algorithms to be effective. For example, real-time data from IoT sensors monitoring industrial equipment may help machine learning algorithms forecast when equipment will need to be fixed in the future, a process known as predictive maintenance and one of the most important applications of AI in manufacturing. Visual inspection is another area where IoT technology and AI combine to improve the industrial and distribution industries. Watch our video on AI-driven visual inspection tools to see this in action. Although machine learning is extremely adept at detecting patterns, it cannot do so in the absence of high-quality data. Machine learning will grow increasingly popular in the next years as bandwidth expands and IoT networks take center stage in a variety of industries [353], [363]–[380].

5.10. Metaverse with the internet of things

IoT will allow virtual spaces to interact and access the real world seamlessly whereas Metaverse technology will offer the necessary 3D user interface for the IoT device cluster. This will provide a user-centered IoT and metaverse experience to the users. This means that IoT's main objective will be to provide the necessary link between the outside world and the virtual world. IoT stands for the internet of three-dimensional physical things. The metaverse has a 3D user interface, allowing for a more personalized user interface environment for IoT. As a result, the metaverse connects the real and digital worlds, allowing people and things to work together more naturally in complicated circumstances. As a 3D interface for IoT, the metaverse will render the real and digital indistinguishable, enhancing our human ability to make better-informed judgments [381]–[389].

Virtual simulations employing digital twins in the metaverse allow us to design and evaluate training techniques in conditions that we cannot perform in the actual world. A digital twin is a virtual representation of a real-world physical system or process (a physical twin) that serves as the indistinguishable digital counterpart of it for practical purposes, such as system simulation, integration, testing, monitoring, and maintenance. Digital twins can vehicles, buildings, factories, or people. The most complex digital twin is the Digital Human or Virtual Human. A digital twin may be used in real time and regularly synchronized with the corresponding physical system. As the metaverse becomes more realistic, training simulations will assist equip people and AI/software to collaborate to spot problems and limit their effect in real life. Complex virtual simulation will enable us to run multiple long-term planning scenarios and decide the best designs for our energy, transportation, and healthcare systems, as well as to dynamically operate these techniques as the real-world evolves. The metaverse, enabled by AR and IoT, will set an altogether new standard for work and collaboration, allowing organizations to function at far higher speed and scale [381]–[389].

The primary component of perception of the elements in the environment is critical for the second generation of virtual people since it informs them of what is changing and what is static. A virtual human's position and activity must be constantly updated, which alters its perceptions. As a result, sensory information and IoT have a significant impact on virtual human behavior. Sensors that mimic the functioning of their biological counterparts, namely for vision, audition, and tactile sense, should be used in virtual humans. Virtual senses convey decisions about the limb motion allowing not only to avoid obstacles, but also to walk on uneven terrains and climb stairs or even jump in case of narrow obstacles like little river or rocks. To obtain a genuine feeling of autonomy - a core human trait - virtual individuals should have an internal representation of self that includes drives, motivation, personality, and emotion. Such internal states can then control the behavior of virtual humans in reaction to events and interact in a dynamic real-time environment.

The main problem here is to create a cohesive computational model that replicates these internal traits and their influence on the reasoning process and the resulting behavior of the virtual people. Empowering Virtual Humans to better interact with us and offer us quality based services is the ultimate goal of Metaverse. It is the ultimate goal to empower our capacity to learn, to get help if we have disabilities, to prepare us in advance for unexpected events and enable us to answer the question "what will happen if" [381]–[389].

IoT is set to transform the metaverse at it seamlessly connects the 3D world to a large number of real-life devices. The real connection between IoT and the metaverse relies on cloud technology. The smooth interoperability of AR and IoT data will be critical to the metaverse's success, contributing to a common vision of user-centric multimedia services for modern nomadic people with high levels of mobility and network connectivity most of the time. By reducing spatial limits in our everyday activities, it will expand personal media spaces for modern nomadic existence.

6. CONCLUSION

The IoT has swiftly expanded and enhanced operations in a wide range of real-world applications, from consumer, commercial, manufacturing, and industrial IoT, including smart homes, smart cities, wearables, healthcare, big data analytics, edge computing, connected networks, aid manufacturers, AI, and metaverse. This paper has covered the current state of the IoT ecosystem; its key uses and benefits; important architectural stages; some of the problems and challenges it faces; and its future. This paper has also described how an adequate IoT architecture that preserves data, analyzes it, and suggests corrective action enhances the process's ground reality. This IoT system architecture is divided into three layers: device, gateway, and platform. This then cascades into the four stages of the IoT architectural layout: sensors and actuators; gateways and data acquisition systems; edge IT data processing; and datacenter and cloud, which use high-end apps to collect data, evaluate it, process it, and provide remedial solutions. An IoT architecture that preserves, analyzes, and offers corrective action might improve the process. This IoT system architecture is comprised of devices, gateways, and platforms. The data is then collected, assessed, processed, and remedial solutions are proposed by high-end apps. This appealing combination provides great benefit through automatic action. The value of the automatic action provided by this sophisticated combination is exceptionally high.
In the future, there will be many more technologies built upon the IoT. Over the next few years, machine learning is likely to become more popular as IoT networks become more important in more fields.

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