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A Survey on Algorithms for Intelligent Computing and Smart City Applications

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Abstract: With the rapid development of human society, the urbanization of the world's population is also progressing rapidly. Urbanization has brought many challenges and problems to the development of cities. For example, the urban population is under excessive pressure, various natural resources and energy are increasingly scarce, and environmental pollution is increasing, etc. However, the original urban model has to be changed to enable people to live in greener and more sustainable cities, thus providing them with a more convenient and comfortable living environment. The new urban framework, the smart city, provides excellent opportunities to meet these challenges, while solving urban problems at the same time. At this stage, many countries are actively responding to calls for smart city development plans. This paper investigates the current stage of the smart city. First, it introduces the background of smart city development and gives a brief definition of the concept of the smart city. Second, it describes the framework of a smart city in accordance with the given definition. Finally, various intelligent algorithms to make cities smarter, along with specific examples, are discussed and analyzed.

Key words: cyber physical systems; Internet of Things (IoT); intelligent computing algorithm; Quality of Service (QoS); smart city

1 Introduction

With the rise of 5G (i.e., 5th generation mobile networks), our society is gradually entering a new era. Apart from rapidly converging links across various industries, 5G technology also keeps them updated. This technology has resulted in fast, intelligent, and high-quality environments. Therefore, the concept of "smart city" has been highly visible in recent years. Examples of its applications include smart homes, smart wearable devices, smart healthcare, smart energy, smart transportations, smart logistics, driverless technology, smart communities, smart industries, smart agriculture, etc. These emerging technologies are all part of a smart city.

To understand the need of a smart city, we first analyzed the urbanization of the world's population and its major effects. According to statistics, in the 1950s, only about 30% of the world's population lived in cities. By 2014, the level of global urbanization has reached 54%. The United Nations (UN) has analyzed and predicted the urbanization problem of the world's population, predicting that by 2050, the proportion of urbanization around the world will reach 66%[1]. The irreversibility of urbanization will lead to the emergence of more and more cities and megacities. Given that cities are not only the center of human activity, but also where social, economic, and environmental needs are magnified, urbanization has induced important

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social, economic, and demographic transitions[2]. Indeed, urbanization has greatly improved people's quality of life. In particular, as cities become the economic, political, and cultural center of a region, they can improve the living conditions to people in many ways. However, urbanization can also inevitably bring about a variety of negative effects, resulting in more challenges and problems faced by cities: the ecological environment has been devastated; natural resources are gradually being depleted; pollution (air, water, and sound) is increasing; and infectious diseases and cancer cases are growing; criminal activities remain rampant; and so on[3]. A study in 2011, found that 493 urban areas in the United States had high traffic congestion, which caused Americans to purchase an additional 1.9 billion gallons of fuel and spend more than 4.8 billion hours on their travels. The estimated cost of traffic congestion is $101 billion[4]. Meanwhile, gas and particulate emissions in Mexican cities have increased significantly in recent years, affecting their air quality[5]. Japanese researchers have conducted statistical studies on the crimes in their countries, and their results revealed that urbanization can be considered the main cause of crime[6]. Citizens, stakeholders, and national governments have given great attention to the problems and challenges brought about by urbanization. In particular, stakeholders and government departments are actively responding to the calls to adopt reasonable policies and technical approaches to alleviate these urbanization-related problems. Under these various impacts, how to use information technology to cope with urban population growth and address the problems of urbanization have become extremely urgent concerns.

Information technology offers several ways by which people can cope with the problems brought about by urbanization. Some of these technologies include cloud computing, Internet of Things (IoT), big data, and other emerging technologies[7–12]. Cloud computing is a computing model that maximizes the benefits of limited resources by allocating such limited resources reasonably.

In many ways, cloud computing technology can help alleviate the shortage of resources brought about by urbanization. Such a technology can, for example, be used to minimize a city's electricity consumption by distributing power resources to each building in the city. IoT refers to a huge network representing a combination of the Internet network and various information sensing devices, such as laser scanners, Radio Frequency Identification Devices (RFIDs), infrared sensors, and global positioning systems[9]. The goal is to have all the devices connected through the network. The system can automatically locate, track, identify, monitor, gather, and trigger such data in real-time. By acquiring hard-to-access data through remote sensors, IoT technology makes it possible to remotely control devices, enabling the effective monitoring, maintenance, and management of the basic water and power systems, as well as transportation hubs in cities[8]. Big data technology refers to the data generated by "human, machine, and object" interactions and their integration in cyberspace, which are readily available on the Internet[13]. People can dig deeper and maximize such data to understand the law of development and make predictions about the future. Big data technology can also be used to alleviate various problems brought about by urbanization. For example, to avoid unnecessary damage to the society caused by suspicious activities, relevant departments can fully maximize the data generated by human behavior patterns, analyze them, and predict possible suspicious activities that can pose threats to society. Then, from such information, necessary precautionary measures can be taken. These emerging information technologies can effectively mitigate the problems brought about by urbanization. The emergence of these information technologies has promoted the formation of smart cities.

In recent years, the term "smart city" has been widely seen in people's field of vision, and the construction and development of a smart city is also being promoted all over the world. The concept and origin of the term "smart city" have also attracted the interest of countries all over the world, including companies, research institutions, universities, and governments. Different organizations have different views on the emergence of smart cities. The latest industry research report published by Deloitte Co., Ltd., entitled "Super Smart City Report", presents the number of smart cities under construction across the world, as shown in Fig. 1. In response to the pressure of the rapid urbanization of the world's fast-rising population, China has initiated the development of smart cities in the country. As the largest developing country, its efforts are far ahead of other countries in the world.

2 What Is a Smart City?

The term "smart city" first appeared in the early 1990s, when research scholars emphasized the roles of innovation, technology, and globalization in the rise of

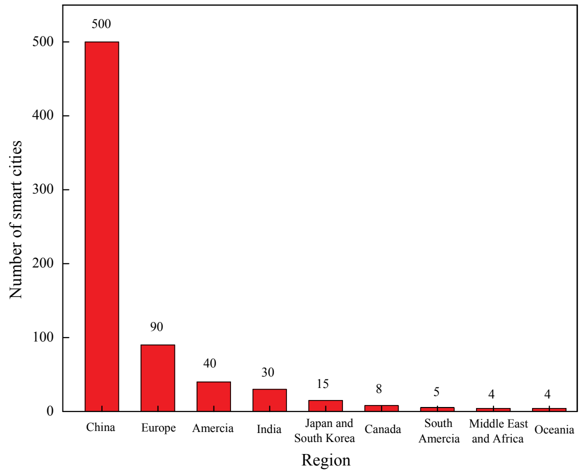

Fig. 1 Number of smart cities under construction across the world.

urbanization[14]. Since IBM Corporation first proposed a smarter planet in 2008, smart cities have attracted great attention from countries around the world. Since then, people have formed different opinions on the definition of a smart city, and as a result, different stakeholders have tried to understand and explain smart cities from their perspective, resulting in the continuous development of the "smart city" concept. Harrison et al.[15] defined a smart city as an instrumented, connected, and intelligent city. Giffinger and Gudrun[16] suggest that smart cities have six intelligent features, namely, governance, environment, economy, mobility, people, and life. Silva et al.[17] pointed out in their work that a "smart city" refers to a city that can enhance freedom of speech and access to public services through Information Communication Technologies (ICTs). Balakrishna[18] referred to the work of European smart city researchers and argued that a smart city can be divided into six dimensions, namely, smart governance, smart people, smart economy, smart mobility, smart environment, and intelligent life. Given that smart cities are based on digital cities and are connected to the real city through ubiquitous sensor networks, the decision-making calculation, analysis, and massive data storage are handled by cloud platforms. Therefore, some scholars believe that "smart city = digital city + IoT + high performance computing"[19].

Although cloud computing[20,21] is considered an efficient computing model, it does not handle time-sensitive tasks very well. In addition, more data are generated at the edge of the network. Thus, all tasks are submitted to the cloud for calculation, which can increase the transmission costs of certain tasks. Moreover, relatively speaking, the development speed of the network bandwidth is much slower compared to the rate at which data are being generated. Therefore, in recent years, edge computing has gradually begun to receive widespread attention from researchers and the public alike. Edge computing[22] is a further development that emerged from cloud computing technology. In the current paper, we define a smart city as a combination of a digital city, IoT, and edge computing based on our study of relevant literature and our understanding of the smart city concept.

2.1 What is IoT?

IoT refers to the collection of interacting objects or processes that must be connected and monitored in real-time through various means, such as radio frequency identification technologies, information sensors, global positioning systems, laser scanners, infrared sensors, and other devices and technologies. The information collected will be accessed through the network, thus facilitating the analysis of the ubiquitous connection between objects and objects, and that between objects and people. Such technologies also help realize identification, intelligent sensing, and management of articles and processes. IoT is a type of information carrier based on the traditional telecommunication networks, the Internet, and so on, which allows all common physical objects, which can be independently addressed, to form an interconnected network. Thus, it is also possible to obtain difficult data through remote sensors and to control the physical world remotely. Based on the characteristics of IoT technology, its applications in the urban system cover a wide range, including those in the agricultural, industrial, environmental, logistics, transportation, security, and other infrastructure fields.

Over the years, IoT technology has effectively promoted intellectual development in these areas, resulting in the rational allocation of limited resources and the improvement of industry efficiency and revenue. The application of IoT technology in areas closely related to people's lives, such as medical health, home furnishings, education, tourism, and finance and services, has dramatically improved the scope of services, service quality, and service methods, vastly improving people's quality of life. Therefore, we believe that IoT technology is one of the key technologies for achieving a smarter city.

2.2 What is edge computing?

According to Liu and Peng[19] and Dameri et al.[23], the smart city's data processing platform is based on the cloud computing framework. However, as users' demands for Quality of Service (QoS) are becoming increasingly higher, cloud computing defects have also become more evident. Therefore, in the current paper, we replace the cloud computing platform with an edge computing platform in the smart city framework. Edge computing is a further expansion based on cloud computing, and its role is to make up for the deficiencies and shortcomings of cloud computing. Compared with the architecture of cloud computing, the framework of edge computing is closer to the edge layer of users and terminal devices. When a task is submitted, the edge computing agent can analyze the attributes of a task according to certain restrictions and specific strategies and then determine the execution place of that task. If the task is more sensitive to time, the system can assign a task to the edge server for execution. The distance from the user to the edge service is negligible compared to the distance from the user to the center of the cloud. For this type of task, if the users have offloaded it to the edge server, they can receive a timely response to reduce unnecessary delays. For example, large-scale online games require very low latency. If the users have submitted them into the cloud center for calculation, they need very high bandwidth to satisfy the user experience. However, if the calculations happen on the edge server, network bandwidth requirements become less stringent.

The essence of a smart city is to achieve green and sustainable development. Therefore, in the framework of a smart city, compared to cloud computing, the processing model with edge computing as its core can prominently reflect the development concept of a smart city.

2.3 From digital city to smart city

Big data technology, which is founded upon digital technology, is one of the critical technologies for the operation of a smart city. Digital cities cannot be separated from numbers, so a smart city cannot be separated from numbers. Based on the above logic, some researchers believe that digital cities are equivalent to a smart city. In a strict sense, there is a big difference between a digital city and a smart city, and the former is not smart. A digital city[24] is based on computer, multimedia, and large-scale storage technologies, and uses broadband networks as a link. It uses global positioning system, remote sensing, geographic information system, simulation-virtualization, and engineering measurement technology to make cities multi-scale, multi-resolution, multi-temporal, and multi-dimensional 3D description. Li and Lin[24] use information technology to digitally virtualize the past, the current status, and future of the city on the network. Digital cities have created conditions for urban planning, location-based services, network management and services, urban security emergency response, intelligent transportation, and so on, which are essential means of harmonious urban development in the information age. However, the digital city has yet to integrate and coordinate the informationization architecture of the entire city. In contrast, smart cities are based on data and combined edge computing, cloud computing, and IoT to integrate the city's organizational structures, giving full play to the overall performance of the city's informatization. In other words, a smart city focuses on the people's subjective states, creating more values for the city, giving more attention to citizen participation and user experience, and realizing the concept of green and sustainable development. Therefore, we believe that digital cities are the basis for the city to transform from digital to smart. Smart cities represent the further development of digital cities combined with emerging technologies, such as edge computing and IoT.

2.4 Proposed smart city framework

Varying perspectives have resulted in numerous definitions of a smart city, thus leading to different descriptions of the smart city architecture. The framework of the earliest smart city was proposed by IBM[15]. In this architecture, IBM introduced the technical capabilities of a smart city, emphasizing that a smart city was based on ICT infrastructure and information services. However, the IBM developers did not mention the importance of data cities. Chourabi et al.[25] proposed an initial framework, which explained the integration of organization, technology, and strategy in a smart way. The system includes natural environment, built-in infrastructure, governance, and human communities; however, that work does not discuss the more detailed techniques and structures of the framework. SmartSantander[26], a smart project proposed and implemented by the European Union, is a city-scale test platform for IoT and future Internet experiments that provides an integrated framework for implementing smart city services. Memos et al.[27] analyzed the smart project and proposed a three-layer model and three aspects of smart city architecture. The former refers to the three-layer network node architecture, including the IoT node, the gateway node, and the server node layers. The IoT node layer consists of a variety of IoT devices. The gateway node layer is used to connect IoT devices with the Internet and the core network infrastructure. The server node layer consists of powerful server devices with high availability, stable storage, and strong processing capacity. These three aspects refer to the IoT experimentation, infrastructure management, and smart city services.

Balakrishna[18] reported that a smart city can be divided into six dimensions: intelligent mobility, smart people, smart economy, smart governance, smart environment, and intelligent life. Based on this definition, Balakrishna believed that the smart city architecture consists of three basic modules. The first module, which is also the most basic requirement for a smart city, is the instrumentation of urban infrastructure, including government, environment, utilities, transportation, and industrial manufacturing infrastructure, as well as various actuators, sensors, readers, and sensing devices. The second module is a high-speed network infrastructure that is deployed to facilitate the connectivity, mobility, and transmission of information across various vertical domains as well as to distribute products and services to end-users. The third module is a data management module, which requires the efficient management of aggregated intelligent data from various vertical domains.

According to Al-Hader et al.[28], a smart city is like a house that is piled up by stones. Therefore, Al-Hader visualizes the framework of a smart city into a five-layer pyramid structure. The first layer is the infrastructure; the second layer is the data layer, which is used to store data resources; and the third layer is the intelligent management layer. The fourth layer contains the API interface layer and the standard operating platform of the integrated web service. The fifth layer is the combination and integration layer of the system, which is used to unite the four bottom layers. This proposed architecture has a good description of the smart city planning. However, the connection between the facilities at each level is not yet clarified.

A smart city is a complex and comprehensive data-intensive computing and application system. Therefore, data play a vital role in a smart city. Rong et al.[29] proposed a data-oriented, six-layer smart city architecture from the perspective of data. The first layer consists of the data collection layer, which is the data source of the smart city, and is composed of sensors for collecting various data. The second layer is the data transport layer, which is essential for end-to-end communication services in a smart city layered architecture. Therefore, the data transport layer comprises the network technology, the advanced communication hardware, and transmission control. The third layer consists of the data activation and storage layer, which is the core of the entire framework, with the data activation being the critical step. This process emphasizes the cleanup, evolution, association, and maintenance of data. The fourth layer is the support service layer. Once the data are processed in the third layer, this layer is meant to use the data. The fifth and sixth layers are the domain service and event-driven intelligent application layers, respectively, which directly interact with the public. The performance of these two layers directly affects the user experience and significantly determines the “level of the smart city”.

Bélissent[30] argued that the essential foundation of a smart city is that it must be a city that is further developed into a smart city. Therefore, Zygiaris[31] regarded the urban layer as the lowest level of the smart city and proceeded to introduce a six-layer smart city architecture, which includes the green city, interconnect, instrumentation, open integration, intelligent, and innovation layers.

Liu and Peng[19] proposed a four-layer smart city framework, which is being adopted through research and analysis of smart cities in China. A distinguishing feature of the architecture is the separation between information processing and information transfer. Each process is defined as a single layer, which facilitates the sharing and reuse of resources. The other two layers are the sensing and application layers, respectively. The perception layer identifies targets and collects information. The transport layer is used to transmit data and exchange information using the access and transport networks. The processing layer intelligently processes and controls information as well as provides various functions and services to public users. The application layer provides a solution set for smart applications, thus allowing a smart city to ultimately achieve deep collaboration between industry-specific technologies and information technologies.

2.5 Smart city framework

To better understand the smart city, based on the definition of smart city and the description of a smart city from other research scholars, we have created a master plan for the framework of smart city, as shown in Fig. 2. We define the architecture of a smart city as having four layers, which include from bottom to top, the data acquisition, data transmission, data processing, and application layers.

2.5.1 Data collection layer

A smart city is a comprehensive and complex data-intensive computing and application system. Data play a crucial role in the existence and operation of smart cities. According to statistics, every 1 second, a Boeing 787 will generate about 5 GB of data. Every 1 minute, Google will generate 2 million search records; 300 000 new posts will be added to Twitter; YouTube users will upload 72 hours of video content; and 220 000 new photos will be added to Instagram. Every hour, a High Definition (HD) camera produces 3.6 GB data, and thousands of cameras produce data per hour at PetaByte (PB) or even ExaByte (EB).

Based on the above description, we can understand that massive amounts of data are being generated in every corner of the city at all time. To use these data, it is necessary to use various sensors deployed in every corner of the city based on the Internet of Things system to collect these data. General sensors include force sensors, energy sensors, speed sensors, radiation sensors, etc.

2.5.2 Data transmission layer

After data collection, the next phase is to transfer the data to the specified area for further processing. Given that data collection points are scattered in different areas of the city, a reliable communication technology must be established, which can cover a wide geographical area and handle multiple data streams. A single communication technology cannot balance both limits and non-limiting nodes. Therefore, Bluetooth, infrared, Wi-Fi, Universal Mobile Telecommunications System (UMTS), and Long Term Evolution (LTE) communication are used for the non-limiting nodes. These technologies are highly reliable, with short delay time due to their fast transfer rates. Limit nodes use more reliable communication technologies, such as IEEE 802.11 and New Field Communication (NFC).

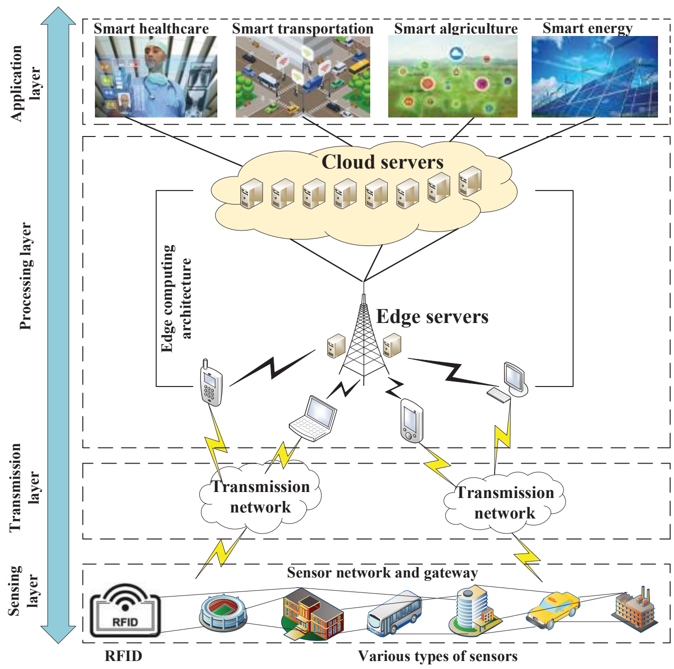

Fig. 2 Smart city framework.

2.5.3 Data processing layer

The data collection layer sends the data collected from various sources to the data processing layer through the data transmission layer. The primary purpose of the data processing layer is to solve problems, such as data fragmentation and unshareability, by data mining, data association, and data activation. The data processing layer consists of data centers of various industries, departments, and enterprises, as well as dynamic data centers and data warehouses established at the municipal level for data sharing and data activation. These data processing technologies are mainly operated on the edge computing platform.

2.5.4 Application layer

The application layer refers to different application systems established on the data collection, data transmission, and data processing layers, just like the top level of the overall architecture of the smart city we designed. This layer directly faces and interacts with the user. The performance of the application layer directly affects the experience of each user in the city. Thus, the application layer's performance is also the embodiment of the smart city's knowledge.

Based on the above analysis and description of each layer of smart city framework, it can be understood that the four-layer smart city framework proposed in this article is closely connected to each other. First, we collect real-time data based on the IoT system, after simple pre-processing; next, through the data transmission layer, upload the data to the edge computing platform for calculation and storage; then, according to different applications, use big data and other information technology, to obtain different types of data, and analyze and optimize; finally, the results are feedback to different application scenarios to serve people and reflect the city's smart level.

3 Case of a Smart City

Whether a city is actually "smart", that is, whether it makes people's lives more convenient is determined by the "smart" level of every small system and module in the city. Only when every system and module reaches a level of intelligence can a city become a real smart city. Therefore, in recent years, with the gradual advancement of the smart city blueprint, smart government, smart transportation, smart healthcare, smart energy, smart agriculture, smart communities, smart security, smart education, and other small areas have also been promoted and implemented. Smart City Global Solutions Private Limited (SCGS Pte Ltd.) conducted a tracking survey on the hot areas of the smart global city and identified the Compound Annual Growth Rate (CAGR) of each smart area until or up to 2020, as shown in Fig. 3. As can be seen, there have been excellent market prospects in recent years in the fields of smart healthcare, smart energy, smart agriculture, and smart transportation. In this section, we focus on the smart transportation, smart energy, smart healthcare, and smart agriculture systems in a smart city.

3.1 Smart transportation

Smart transportation has been proposed to address the low levels of motor vehicle traffic guidance as well as problems in urban traffic congestion and the discrepancy between supply and demand of parking facilities. This is achieved by deploying a large number of roadside fixed sensor network nodes and in-vehicle mobile sensor network nodes as well as by constructing a batch of intelligent traffic service application systems based on IoT technology. In this way, a widely interconnected traffic element awareness network is constructed through the comprehensive processing of intelligent transportation IoT for the collection, processing, analysis, management, and service of massive information. The goals are to achieve a more productive, accurate, and humane public information service, and to form a smart and harmonious transportation environment so that the city's transportation system can operate more efficiently[32].

Traffic congestion is one of the most challenging issues to achieve smart transportation. At the moment, many research scholars have proposed various intelligent methods to alleviate urban traffic congestion. In general, traffic congestion is often caused by road sections with large traffic volumes. However, it is almost difficult to cause traffic congestion at intersections with low

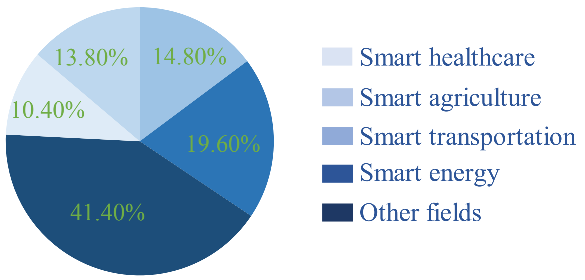

Fig. 3 Compound annual growth rates of smart city segments.

traffic volume due to vehicles waiting for traffic lights. Hence, setting the traffic lights for the same duration at all intersections would be unreasonable. To avoid this kind of situation and to control the duration of each traffic light, researchers have proposed some adaptive control of traffic lights, depending on real-time traffic flow. Figure 4 presents the workflow of adaptively controlling traffic lights based on edge computing.

As shown in Fig. 4, a sensor network consisting of different sensors can obtain real-time traffic flow information on various roads. At the same time, the electronic monitoring system on the road can also obtain information, such as traffic flow at each period. The information and data collected are transmitted to the data processing platform for data processing and analysis. Eventually, according to the data analysis results, the traffic light management system at each intersection adaptively adjusts the length of the lights' duration, thus achieving smart traffic signal light.

To further improve the efficiency of signal control, many researchers have proposed different methods for adaptively controlling traffic signals based on various algorithms. For example, Mannion et al.[33] proposed a single-agent adaptive traffic signal control method based on parallel Reinforcement Learning (RL). The experimental results show that parallel learning strategies can enhance the agent's ability to explore and reduce the delay time. However, the adaptive traffic signal control system based on the single-agent is not enough to deal with complicated traffic routes. To be more practical, the next year, Mannion et al.[34] also proposed a multi-agent adaptive traffic signal control method, where an independent RL agent controls each intersection. The authors conducted a case analysis of the simulation test platform based on the multi-agent control framework. Their results show that the multi-agent adaptive traffic signal control method effectively reduces the waiting time of cars at intersections compared with the fixed traffic signal duration. The average speed of cars has also increased significantly. In previous works, Wei et al.[35] also proposed an efficient adaptive traffic signal control method based on RL and proved the effectiveness and accuracy of their proposed methods. The traditional RL framework is shown in Fig. 5, in which RL can be seen as a continuous trial-and-error learning process[36]. First, the agent selects an action based on the state of the current environment. After executing the action, it will immediately receive reward value from the environment and transition to the next state. The value represents a judgment on the pros and cons of the action chosen by the previous decision. Immediately after, the agent will make the next decision based on the current state and the reward value. The ultimate goal of RL is to obtain the long-term maximum reward value.

To obtain the optimal control strategy, the agents at each intersection must learn to obtain the traffic signal control scheme through separate learning while also cooperating with the agents at other intersections. Considering these two goals will result in conflict. Thus, to better coordinate these two goals, Tahifa et al.[37] proposed a collaborative traffic signal control method using particle swarm RL, which is based on Particle Swarm Optimization (PSO) and RL. Here, the agent at each intersection identifies the most suitable learning parameters by performing RL to obtain an optimal local solution and then combining optimization through PSO. This process ultimately maximizes the traffic signal's total revenue. The author simulated an actual scenario. As shown by the simulation experiment results, the efficiency of the particle swarm RL-based adaptive traffic signal control method is significantly higher than that of the single RL-based adaptive traffic

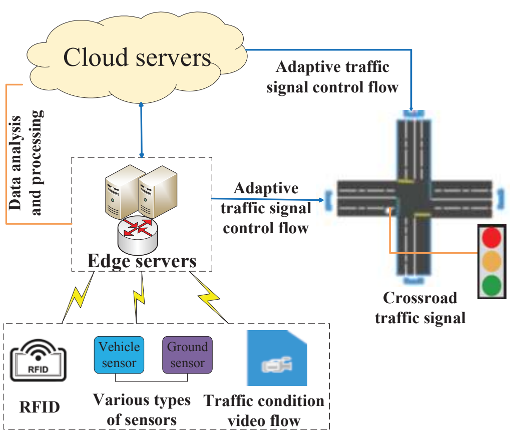

Fig. 4 Adaptive control traffic signal workflow.

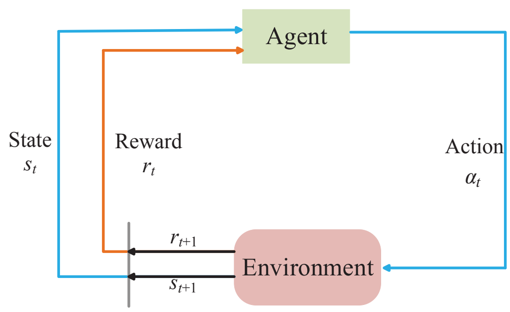

Fig. 5 Framework of reinforcement learning.

signal control method. Collaborating with agents at all intersections in a specific area's transportation network results in the extremely high dimensions of the state space and action space of the scene. In turn, this can quickly cause a dimensional disaster based on the RL framework. The RL-based adaptive traffic signal control method alleviates traffic congestion problems to a certain extent. However, in more complex urban transportation networks, using Deep Reinforcement Learning (DRL) agents instead of RL agents can further enhance the learning ability of adaptive traffic signal control. This approach can also solve the disadvantage of RL, which is its vulnerability against dimensional disasters. Therefore, in past papers[38,39], the authors proposed a DRL-based adaptive traffic signal control method. Their simulation results show that, in terms of alleviating traffic congestion problems, their proposed method is more effective than the RL-based adaptive traffic signal control method. The method is also more robust than other classic algorithms. Since its introduction by Mnih et al.[40], DRL has been mainly used in-game scenarios to accelerate the convergence rate of the games. With the breakthrough of DRL[41] in the field of Artificial Intelligence (AI), it has been gradually applied to various industries as well.

3.2 Smart energy

Energy is a vital material resource for human survival. With the intensification of population urbanization, energy consumption[42] has also increased at record levels. However, this has also resulted in the decrease of various non-renewable and renewable energy sources. Recently, many countries have begun to consider the severity of the problems of energy regeneration and consumption. To address these problems, they formulated some development strategies of green and renewable energy sources. With the rapid development of computer technology, smart energy has been proposed to solve the problems of green, stable, safe, and sustainable development of energy.

Smart energy is a voluntary energy integrated management system that is open, transparent, and decentralized. It uses the Internet and communication technology to conduct real-time monitoring and analysis of the production, use, scheduling, and efficiency of energy; it also performs real-time detection, reporting, and optimization based on big data, IoT, cloud computing, and edge computing to achieve the best state[43]. The smart energy system plays a vital role in the smart city operation, as it can not only achieve various energy-related value-added services but also intelligently promote the integration and automatic operation control of various energy systems[44]. The energy management framework based on IoT and edge computing in a smart city can be seen in Fig. 6.

As shown in Fig. 6, a sensor network consisting of RFID, sensors, positioning systems, etc., can perform the real-time collection of information about various energy sources and monitoring of the energy usage of various energy-consumption terminal equipments. The obtained data and information are sent to an edge computing based processing platform through a transmission network for analysis and processing. Based on such information, various energy sources can be reasonably allocated to each energy consumption terminal, thereby achieving the efficient distribution and utilization of energy.

It is not easy to achieve green and sustainable development of energy, especially for irreversible and non-renewable energy sources. To make non-renewable energy sustainable and ensure that renewable energy is greener, cleaner, and more stable, it is not enough to save energy alone. What is needed is the combination of new technologies to optimize the energy structure and ensure the efficient use of energy. Recently, many studies have proposed an intelligent method to solve the energy efficiency problem. The accurate prediction of electricity load is one approach in achieving efficient energy management. Electricity load forecasting is an important part of task scheduling, reliability analysis, and electrical equipment maintenance in the electricity industry. In order to improve the accuracy of electricity load forecasting, Dong et al.[45] proposed a novel electricity load forecasting method by combining the Convolutional Neural Network (CNN) and traditional

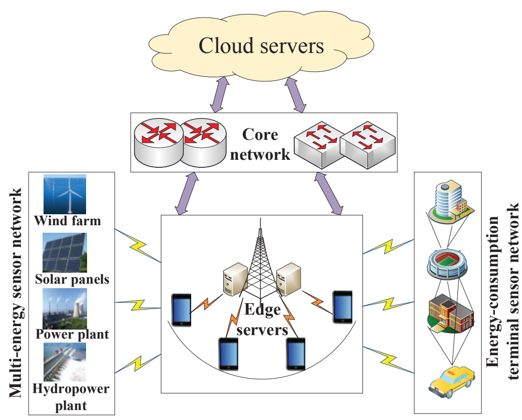

Fig. 6 Energy management framework for smart cities.

Machine Learning (ML) method. First, CNN is used to preprocess the original load record data; second, the dataset is divided into training and test sets by using K-means algorithm in ML; finally, the training set is trained on CNN to obtain the prediction of the model, after which the test set is tested on the prediction model. Experimental results show that the algorithm has good performance in terms of predicting the electricity load accuracy. Meanwhile, S. Hosein and P. Hosein[46] proposed a short-term electricity load forecasting algorithm combining the ML and CNN methods. They considered using stacked autoencoders, CNNs, recurrent neural networks, and long-short-term memory to construct the algorithm framework. Experimental results show that the performance of the proposed algorithm is better than that of traditional algorithms, reducing the error rate and extending the running time. The CNN structure[47] consists of different types of layers, such as pooling, convolutional, and fully connected layers. Its hierarchical pattern is shown in Fig. 7.

Li et al.[48] proposed a novel, RL-based smart energy management system, which was first modeled using Markov decision processes. Then, an energy management algorithm based on Q-learning was also proposed. Their results revealed that the smart energy management algorithm can effectively learn energy allocation strategies and reduce energy costs[49]. Zhou et al.[50] proposed a smart energy management algorithm, which models the energy trading process as a Markov decision process and uses the RL method to find the optimal strategy for solving the energy management problem. Through the analysis of numerical experimental results, they demonstrated that the proposed energy management algorithm can effectively save electricity costs.

Meanwhile, Liu et al.[51] considered the energy scheduling problem in the smart grid scenario. They proposed an energy management system based on the IoT and edge computing architecture, after which they designed an intelligent scheduling algorithm based on the IoT and edge computing architecture on the DRL method. Their experimental results show that the solution can improve the management performance of energy systems and effectively reduce energy and time costs. Mocanu et al.[52] used DRL methods to optimize the building energy management system online in the smart grid environment. They proposed two optimization algorithms to explore the best strategy using the deep Q-learning and deep policy gradient methods. Numerical experimental results show that these two proposed optimization algorithms have a significant impact in terms of reducing energy costs. Furthermore, they found that the deep policy gradient based algorithm is more suitable for online energy scheduling[53] than the algorithm based on Q-learning[53]. Hua et al.[54] considered the energy management problem in the energy Internet system and expressed the actual energy management problem as the objective optimization problem under multiple constraints. Due to the complexity of the optimization problem, their research used the DRL method to make decisions. The numerical experimental results show that the proposed energy management method effectively reduces the power exchange between the energy Internet system and the power grid, thereby reducing the cost of power generation.

3.3 Smart healthcare

With the continuous improvement of living standards, the public has paid increasing attention to physical and mental health issues. However, the medical systems in

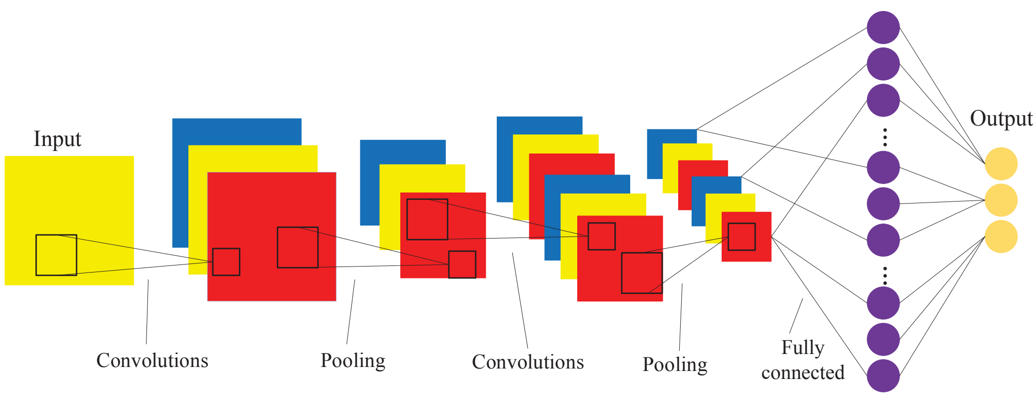

Fig. 7 Structure of the CNN model.

some more deprived areas remain insufficient, along with the relatively backward state of their medical equipment and environments. Medical issues have become the focus of many countries, and their resolution is a challenging issue in the process of building a smart city. With the rapid development of the Internet, computer, and other technologies, the establishment and improvement of smart medical systems have the advantages of promoting medical information sharing and improving medical status.

Smart healthcare is an intelligent medical system, which uses information technologies, such as big data, sensor networks, edge computing, and cloud computing, to connect the infrastructure related to medical construction through perceptual, IoT, and intelligent means. The edge-computing-based smart healthcare framework is shown in Fig. 8.

As shown in Fig. 8, the smart healthcare system uses sensors to collect and monitor medical data, which are transmitted to the edge computing platform for subsequent analysis and processing. Using such processes information, doctors can provide online and remote treatment via the healthcare platform, thus improving doctors'efficiency. Patients can know their conditions through the application installed in a mobile device and obtain corresponding medical prescriptions. The use of a smart healthcare system can reduce medical costs, save time, and effectively respond to sudden medical conditions.

Amin et al.[55] proposed a healthcare framework based on IoT-cloud technology for pathological detection and classification. The proposed framework uses smart

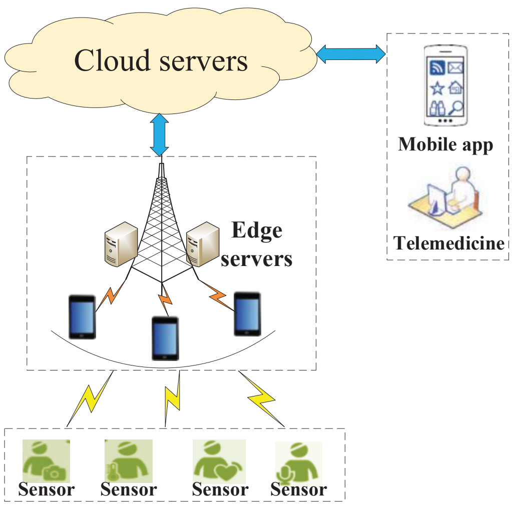

Fig. 8 Smart healthcare framework based on edge computing.

sensors to collect medical data and process patient electroencephalogram (EEG) signals in the cloud. To achieve a more accurate detection of EEG pathology, they used the DL[56,57] method to classify the EEG signals. Their experimental results show that the algorithm has high classification accuracy. Combining the advantages of edge computing and cognitive computing, Chen et al.[58] proposed a smart healthcare system based on edge cognitive computing. Their proposed system uses the cognitive computing method to analyze users' health status and gives corresponding health risk levels. The system can also adjust resource allocation in the edge computing system according to the users' risk level and improve their survival rate with a higher risk level.

Meanwhile, Fadlullah et al.[59] argued that transmitting healthcare data to the cloud for processing could easily cause network congestion, which in turn, may affect patients' timely treatment. Therefore, they proposed a DL-based edge analysis algorithm of the IoT. Their proposed algorithm processes healthcare data on computing nodes near the source of data generation and uses the DL method to analyze the generated patient healthcare data. Their experimental results show that the algorithm has an excellent performance in improving the speed and accuracy of real-time analysis. Shukla et al.[60] proposed a hybrid approach that combines fuzzy learning and RL in the fog computing environment. The proposed method uses RL to arrive at the best resource allocation decision, thereby reducing the delay time in the healthcare system and improving overall system performance. Using game theory and ML methods to simulate attacks and defenses, Boudko and Abie[61] proposed a novel adaptive security framework for healthcare. Their simulation results show that the security framework can effectively defend against attacks and protect the healthcare network's data and infrastructure. Tseng et al.[62] proposed an automatic radiation adaptation framework based on the DRL method. The framework uses a Generative Adversarial Network (GAN) to process data on patients' physical characteristics, use Deep Neural Networks (DNN) to simulate an artificial treatment environment[63], and assess the transfer probability of the personalized radiotherapy process using the original and synthetic data. Their experimental results show the effectiveness of the proposed framework, thereby proving that the Deep Q-Networks (DQN) algorithm is suitable for exploring the best radiation therapy strategy. This method provides a new lung cancer treatment approach in the medical field.

3.4 Smart agriculture

Agricultural food production is the basis for human survival. However, due to the backwardness of traditional farming methods and natural disasters, agricultural productivity in some deprived areas remains low, resulting in insufficient food supply. Relevant data indicate that, around the world, over 10 million people die from hunger every year[64]. In order to increase food production more effectively and improve people's livelihood, smart agriculture was proposed and applied in practice.

Smart agriculture is an agricultural system that utilizes information technologies, such as big data, IoT, cloud computing, and edge computing. The combination of such technologies makes agricultural production more efficient through interconnection, sensing, and intelligent means. The smart agriculture framework based on edge computing is shown in Fig. 9.

As shown in Fig. 9, the smart agriculture system uses sensors of various functions to obtain relevant data in the farmland, which can affect the growth of crops in real-time. Such data include temperature, carbon dioxide content, soil moisture, air humidity, soil pH (pondus Hydrogenii), light intensity, and so on. The collected data are transmitted to the edge computing platform for analysis, processing, and storage through the Internet. In such a system, the analyzed results of the computing platform and the crop-related data collected by sensors are displayed by smart terminal devices. After conducting data analysis, the smart agriculture system can perform the real-time calculation of the environmental variables that can help improve crop growth and adjust the dependent variables that may affect crop growth.

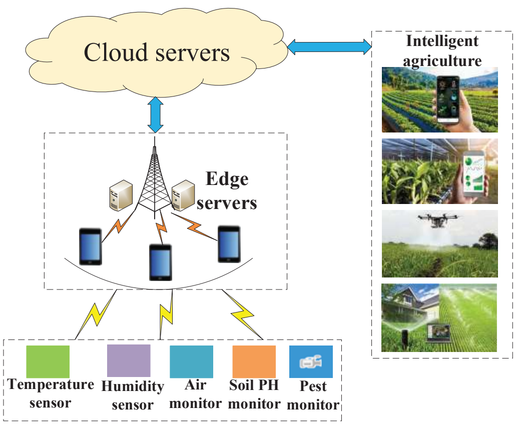

Fig. 9 Smart agriculture framework based on edge computing.

In order to effectively reduce the risk of disease and pests during the growth of crops and improve crop yield, many researchers have proposed methods to solve this kind of problem. Ding and Taylor[65], for example, proposed a DRL-based pest detection method. Their proposed method uses the sliding window detection pipeline based on CNN as an image classifier. An evaluation index for pest detection is proposed based on the manual detection method. Experimental results show that the proposed method has high accuracy and excellent real-time performance. Similarly, Cheng et al.[66] proposed a pest identification method based on deep residual learning in a complex environment. The proposed method is compared with the detection methods based on the traditional Back Propagation (BP) neural network, support vector machine, and ordinary CNN. Their experimental results show that the pest detection method based on deep residual learning has high recognition accuracy and performance.

Meanwhile, Lu et al.[67] proposed an automatic wheat disease diagnosis framework based on deep multiple instances of learning methods to effectively monitor the health status of crops. First, the proposed framework performs local feature extraction and local disease estimation on crop images using a fully convolutional network. Then, the local values are inputted into a multiple-instance learning framework to evaluate the entire image. Finally, it locates the crop disease position accurately by using a bounding box approximation. Experimental results show that the framework can locate the diseased region of crops more accurately than the traditional convolution-based network architecture.

According to relevant statistics, agriculture consumes the greatest amounts of water in the world; however, about 60% of irrigation water is wasted due to inefficient agricultural irrigation in most regions[68]. In recent years, many studies have proposed some efficient irrigation models to address this problem. For example, Huong et al.[68] proposed an automatic and efficient irrigation method based on the Markov Decision Process (MDP). In this system, the agent makes a reasonable decision based on the two indicators (i.e., energy consumption and water consumption) at each time decision point. In this way, the optimal irrigation strategy is obtained through continuous learning to obtain a maximum long-term reward value. Experimental results show that the proposed method can effectively reduce water and energy consumption compared with ordinary irrigation methods. Varman et al.[69] applied DL and IoT technology to agricultural systems, after which they proposed an intelligent irrigation method based on DL to predict crop planting time and improve irrigation efficiency. This method uses sensors to regularly monitor soil parameters and the field environment, after which it uploads the collected data to the cloud center for prediction and analysis via the DL model. Their simulation results prove the feasibility of the proposed method. Meanwhile, Sun et al.[70] proposed a DRL-based irrigation control technology to reduce water waste and increase crop yields. Their proposed method uses RL to achieve online decision-making and learning of the data collected by the sensors. Aside from using the time difference method to delay the reward value, the training set is also used to train the neural network model offline. Their simulation results show that the irrigation method based on DRL can greatly reduce the amount of water resources used and increase crop yield and total revenue.

4 Challenge and Opportunity

With the rapid development of societies, smart city has become an essential direction for global urban construction in the future. At present, many countries are formulating the development strategy for smart cities. However, in doing so, they also face many challenges in building smart cities. In developing the concept of smart cities, the problems and challenges in the process of smart city construction have raised widespread concern among builders.

The application of big data is a key technology in establishing a smart city. However, the development, design, and application of big data technologies in a smart city face many challenges. In this section, we analyze the challenges and problems that smart cities may encounter when using big data technology.

4.1 Variety of data

Data are generated all the time, and big data come from every corner of a smart city. However, the formats of the data produced by different data sources vary, thus leading to the creation of data diversity. These differentiated data include unstructured data, semi-structured data, structured data, and so on. Notably, before unstructured data, such as audio, images, text, etc., are effectively used; they must be pre-processed with advanced databases, such as Oracle and MySQL, to transform them into a structured format. The diversity of big data raises some problems, such as heterogeneity problems when data are incompatible, identification problems when data are merged, and so on. In order to effectively solve the problems caused by data diversity, some methods have been proposed, including the analysis of multi-level heterogeneous data, automatic recognition and denoising of data, and in-depth analysis of data for data modeling.

4.2 Volume of data

With the rapid population growth and the development of technologies, such as IoT and the Internet, huge amounts of data are being generated on a daily basis. At this level, the amount of data generated by an ordinary city every day is unimaginable; it can even reach the order of ZettaByte (ZB) in a short time, which would inevitably cause data storage problems. The storage and management of big data have led to severe problems in the construction of a smart city. In order to effectively solve the problem caused by large amounts of data, many researchers have proposed some solutions, such as technologies of data filtering, reading and writing; timely deletion of bad data; and the creation of cloud computing as the core storage system. Although these solutions can relieve the pressure of data storage to a certain extent, there are still some disadvantages. Yet, with proper development, future edge-computing-based storage architectures may have enormous potential.

4.3 Velocity of data

The high speed of data is related to the data generation's speed and processing, which is an essential characteristic of big data. The speed of data generation and acquisition depends on the Internet-connected sensing equipment deployed in the city. In a smart city, such data are converted into useful information through analysis and processing once acquired. However, there are many problems in the data conversion process, such as delay in obtaining data remotely, data failure, and the lack of accuracy of data intelligence. For these problems, related studies have proposed several solutions, such as efficient implement decision-making by developing a context-aware platform between data sources and services. The Bayesian algorithm based data prefetching method can accurately predict the data generated by terminal equipment in time and quickly transfer such data from remote to local storage.

4.4 Reality of data

Intelligent decision-making in a smart city is based on the processing and analysis of real data; hence, reality is an essential feature and an essential attribute of big data. The reality of data is related to the uncertainty, quality, and reliability of data management. Noisy and unreliable data sources must be discarded in order to ensure the reality of data. However, there are many challenges in the process of ensuring the quality of the data, such as finding the correct data analysis model and ensuring that the generated data are used correctly. In order to effectively solve these problems, researchers have proposed some solutions, such as technologies of heterogeneous data set analysis, large-scale data activation, and development of context-aware platforms. Yet, more effective technical methods may need to be developed in the future construction of a smart city.

4.5 Sharing of data

The links among various industries and fields have become closer due to the rapid development of Internet technology, and data sharing and general use have become increasingly common as well. However, there may be differences in the focus of the same dataset in varying fields, along with the storage management employed. It is often difficult to establish a unified data semantic understanding specification. Moreover, data sharing is constrained by privacy conditions, making it difficult to collect and utilize big data. Based on these issues, the smart city must find better methods to share and exchange data in the future construction process.

4.6 Security and privacy of data

In a smart city, data must be used effectively to make reasonable decisions and ensure data security and privacy. Data should not be accessed, breached, attacked, and leaked by unauthorized applications. Underlying security and privacy requirements include data integrity, availability, privacy, and confidentiality[71]. Thus, one of the important challenges of establishing a smart city is ensuring data security and privacy. Data from generation to use within a smart city generally go through the stages of data collection, transmission, storage, and processing. Unfortunately, data can be maliciously destroyed at every stage. For example, during the data collection stage, criminals can invade the equipment to steal data, resulting in the disclosure and illegal use of private data. Meanwhile, during the data transmission stage, criminals may launch attacks on the data stream, which could mean that data may be distorted during transmission. Furthermore, due to the heterogeneous, multi-source, and related nature of big data transmission, the dataset may suffer from information leakage. In order to resolve these data security challenges, many researchers have proposed different solutions, such as anonymous processing, encryption processing, access acquisition control, and the effective management of data perception frameworks. To a certain extent, existing data protection methods can guarantee data security and privacy. However, establishing a more mature and reliable data protection system is essential in ensuring that massive data in a smart city are not violated and used illegally.

5 Conclusion

The concept of green, people-oriented, and sustainable development in a smart city has encouraged global cities to develop in a smart direction in the future. This article first reviewed the literature related to the construction of a smart city. Based on the existing works, the concept of a smart city has also been briefly defined. We believe that a smart city is a new type of digital city that incorporates emerging technologies, such as IoT, big data, cloud computing, and edge computing, to make a city smarter. Thus, we can say that “smart city = digital city + IoT + edge computing”.

Then, we design a new four-tier smart city architecture based on our definition of a smart city. This is the core part of the article. The four layers include the following: data acquisition, data transmission, data storage and processing, and data application layers. The four-tier architecture of the smart city is based on data and their interconnections, thus enabling a smart city to operate efficiently and arrive at reasonable decisions.

We also conducted in-depth discussions on several popular areas in smart city research in recent years. We mainly analyzed how various intelligent algorithms used in these areas can make resource allocation more rational, how to make these areas greener and more sustainable, how to minimize the use of energy in smart cities, and how to ultimately make them smarter in the future. Finally, we analyzed the difficulties and challenges that may arise in the construction of smart cities in the future, after which we proposed some solutions and future research directions. Our research review aims to help research scholars engaged in smart city and workers involved in smart city deployment gain a deeper understanding of smart cities while also providing references for their further research.

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