IoT-based air pollution monitoring system

Yuxuan Yang *

International Education Department, Jinling Institute of Technology, Nanjing, China

* Corresponding Author Email: 15001020346@xs.hnit.edu.cn

Abstract. Air pollution seriously damages the ecological environment and affects the health of humans, animals and plants. In order to prevent and control air pollution, air quality monitoring has been proposed to accurately monitor the concentration of pollutants and abnormal conditions in a region, which can purify the air. However, conventional fixed monitoring stations are complex, expensive and power hungry, these characteristics lead to monitoring stations being unsuitable for most areas. Here an internet of things (IoT)-based air pollution monitoring system is reported including architecture, principles and monitoring objects, providing detailed information for effective environmental management. It manages the current status and trends of regional air pollution in a simple, portable and cost-effective way. The technologies and applications involved in IoT-based air pollution monitoring systems are also presented, contributing to the development of IoT technologies, cloud computing technologies and smart city. The rapid spread of such monitoring systems would add greenhouse gases, photochemical smog and light detection and ranging (LIDAR) gases to the group of objects to be monitored in the future.

Keywords: Air pollution; monitoring system; IoT; cloud computing; smart city.

1. Introduction

1.1. Air pollution

It is clear that air pollution is a crucial issue with negative influences on the ecosystems, worldwide environment and healthy life [1]. Air pollution causes extreme phenomena e.g., global warming and glacial melting, and harms plants and animals, as well as affecting people's health.

In general, air pollution also contributes to the depletion of the ozone layer and acid rain. To be specific, as to acid rain, it affects the ecological environment, owing to the severe damages on soil, water quality and forests [2]. Moreover, animals are unable to live in water destroyed by acid rain which influences biodiversity. In addition, ozone depletion is also a huge problem. Specifically, there is an over exposure to ultraviolet (UV) light, once the ozone layer is damaged [3]. On one hand, the productivity of the plant declines, its regenerative capacity is altered as well, as UV radiation cuts down on the leaf area available for photosynthesis. On the other hand, in terms of human health, people are susceptible to skin cancer, i.g., cortical cataracts, facing with long exposure to UV [3].

There is a close link between industrial activity and air pollution. Industrial growth caused a sharp increase of emissions in car manufacturing plants, printing plants and hardware factories, which results in disease rising, like respiratory diseases, lung cancer and heart disease, etc.

Thus, air pollution has become a matter of public concern. As the atmosphere is severely damaged, attention is being focused on how to monitor real-time air quality and make proper recommendations. In fact, in exception to the static monitoring stations, an IoT-based monitoring system is also proposed to measure concentrations and implement better air quality plans.

1.2. Conventional monitoring stations

Specifically, air pollution monitoring refers to the real-time monitoring of particular pollutants in the atmosphere, and then reasonable decisions are given to handle environmental pollution, after collecting and analyzing regularly data.

Typically, static monitoring stations are used to monitor air pollution conditions [4]. Such conventional monitoring stations generally involve numerous auxiliary tools i.g., samplers, thermometers, photometers, chromatography, filters [4], etc., which improves the reliability and

accuracy of measuring the concentrations of different pollutants. In addition, due to sparse deployments of static monitoring stations, they have the ability to perceive highly accurate values from a few stations [4, 5]. However, the conventional method of air pollution monitoring requires expensive, complex [4], and power hungry equipment [6]. Thus, there are extremely high maintenance costs. Besides, the monitoring station uses a particularly time-consuming model, which results in low spatial resolution, with several hundred kilometers [6].

1.3. Smart monitoring system

The smart monitoring system, due to lower cost, small size and ease of use, has attracted more and more attention, as traditional monitoring stations cannot meet the actual requirements of the current spatiotemporal monitoring of air pollution [7]. In fact, this is a system for monitoring air quality using the internet to reach a web server. Generally, in such a system, high-resolution figures are available at real time [4], while IoT technology is used to exchange and share information. Hence, smart air pollution monitoring system has a vital role to play in handling air pollution.

Sensors are an essential component in this smart monitoring system. To be specific, two types of air sensors are provided for measuring gaseous and particulate concentrations, respectively. In general, they both have high sensitivity in response to target gases and particles [7]. In fact, with the rise of mobile sensor networks, portable sensors have developed rapidly, which has broad application prospects in the area of air pollution monitoring [4, 7]. In addition, in monitoring situations where there is a large demand, sensor networks (i.e. networks of several small sensors combined) are able to communicate with other systems nearby, which effectively increases the reliability of the monitoring system.

To sum up, the smart air pollution monitoring system flexibly places air sensors in specific areas for omnidirectional monitoring and provides data support for forecasting.

1.4. Aims of this article

In fact, the major objective of the essay would be to introduce IoT-based air pollution monitoring system which can monitor pollutant concentration instantly and provide plenty of suggestions about improving air quality to reach the world health organization (WHO) guideline values. Moreover, architecture, principles of the system and applied technologies, etc., are also proposed in the essay.

2. IoT-based air pollution monitoring system

2.1. Structure

Nowadays, with the implement of the IoT network, IoT-based air quality monitoring system combined with long range radio (LoRa) technology has been proposed [8]. In fact, the monitoring system is composed of sensors, gateways and a Wide Area Network (WAN). Notably, the sensors and gateways both embed LoRa technology [9]. In addition, the WAN is on the basis of the lora wide area network (LoRaWAN) protocol [10]. As a result, the radio frequency communication link between sensors, the gateway and the WAN provides good and extensive coverage. Besides, it is worth noting that this system is powered by solar cells, thus it has a long operating time compared with other monitoring methods [11].

Generally, there are three layers comprising in the system, the application layer, the network layer and the perception layer, as illustrated in Fig.1 [10]. To be specific, the perception layer contains a number of sensors embedded with LoRa, while the network layer includes a LoRa-based gateway and routers [10]. The sensors can communicate with the gateway, while the gateways can communicate with the IoT system management application in the application layer via the internet [10].

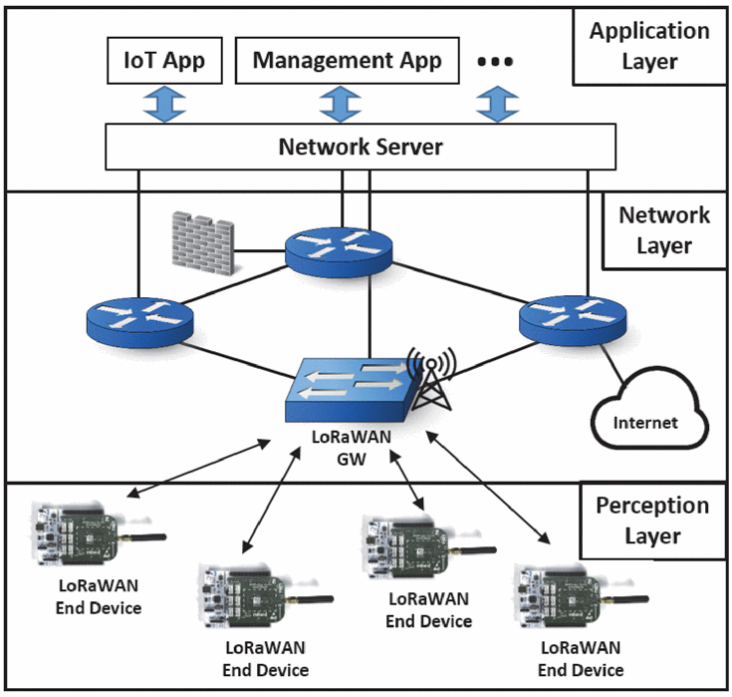


Fig.1 System architecture [10]

2.2. Working principles

In terms of working principle, firstly, LoRa-embedded air sensors are positioned at specific sites, i.g. freeways, schools, buildings, industrial areas and entertainment areas, to collect data on various gases and particles. The sensors then transfer the information wirelessly to a gateway with LoRa-based technology. What follows is the analysis of data in the network by an application server after the gateway has sent the above information to the network. Lastly, pollution alerts and environmental advice are supplied by the server to mobile devices i.g., tablets, computers and mobile phones.

2.3. Monitored objects

In general, IoT-based monitoring system can monitor various particulate matter (i.g., PM_{10}, $PM_{2.5}$ and PM_1) and gases (i.g., NO_2, CO, O_3 and SO_2). It is able to record different concentrations and characteristics (such as temperature and humidity) regularly. These pollutants with high concentrations pose a serious threat to people's health, therefore, they are important monitored objects.

2.3.1 PM_1

Apparently, PM_1 possesses a relatively small diameter and a great deal of toxic material. It reaches the heart through the blood, once people absorb an excessive amount of it. Consequently, it is of vast influence on health in humans. Generally, PM_1 is primarily produced by industrial activities, burning of fossil fuels and everyday power generation.

2.3.2 $PM_{2.5}$

Despite being a tiny constituent of the air, $PM_{2.5}$ is a significant factor in healthy life. To be specific, $PM_{2.5}$ has a small particle size and is highly reactive, making it easy to carry harmful substances. As $PM_{2.5}$ remains in the air for a long time, it has a large influence on both the quality of the environmental atmosphere and body health [12].

2.3.3 PM_{10}

PM_{10} can be responsible for a wide range of metal contamination and poisoning. The respiratory tract can be irritated by it, which can cause asthma. Meanwhile, PM_{10} increases the risks of heart disease.

2.3.4 CO

There are high levels of CO in the city air. Generally, it comes mostly from city activities and commercial production. In fact, absorbing high concentrations of CO over a brief period of time will lead to toxicosis, as well as causing harm on the lungs, brain and heart. People who have been poisoned even die rapidly owing to the difficulties of breathing.

2.3.5 SO_2

SO_2 is mainly produced by the burning of coal and fuel oil. When people absorb SO_2 in the atmosphere through the respiratory tract, sometimes there are different symptoms of irritation. People can develop pulmonary oedema, ulcers and death in the serious cases.

2.3.6 NO_2

Beyond its natural origin, NO_2 is primarily produced by the high temperature combustion processes, i.g., motor vehicle emissions. What's more, it is a factor in the production of acid rain that affects the visibility of the atmosphere, and harms to fish, shrimps and crabs in water. Then, as to human, when people absorb NO_2, they have some problems with throat, chest and lung.

2.3.7 O_3

O_3 usually causes air pollution, when it combines with other gases in the atmosphere. It is clearly that the leaves of plants will be yellow and wither, facing with high O_3 concentration, which reduces economic benefits. People can experience symptoms such as coughing, vision loss and memory loss, when they are constantly exposed to high concentrations of O_3 directly.

2.4. Benefits

In fact, air pollution monitoring systems using LoRa technology have a lot of benefits. Firstly, the monitoring system can present reasonable suggestions about air pollution in the experimental area, which can solve the pollution issues in the problem area. Secondly, the system can be operated easily and installed at low cost, as the sensors do not connect with power source [8]. In addition, compared to other wireless technologies, the LoRa technology allows the system to cover a wide area and also has a low power [9]. Therefore, the IoT-based monitoring system is a suitable choice when monitoring air quality.

3. Technologies and applications

In fact, IoT-based air pollution monitoring system involves many technologies and applications, including IoT, smart city and cloud computing.

3.1. IoT

In fact, the IoT is an information carrier based on the internet, traditional telecommunications networks, which is a way for generally physical stuffs capable of being independently addressed to create the inter-web. It is also a system made of intelligent devices which senses its surroundings and interacts with the user or other systems [13]. Thus, the IoT is intelligent, with only addressable things or sensors depending on its communication protocol. In general, the hardware consisting of sensor nodes, interface circuits and embedded communication, the middleware for data storage and handling and a representation layer that consists of efficient visualization tools can form a complete IoT architecture. For the IoT model, there are three designed layers, the application layer, the network layer and the sensor layer, as indicated in Fig.2 [13]. In the sensor layer, data is collected using IP cameras, readers and pollution sensors [13]. Information is transmitted at the network layer which acts as middleware between the sensor layer and the application layer using cellular, remote and broadcast networks [13]. The application layer merges and processes the received data to enable smart monitoring in areas such as industry, transport, and cargo [13]. Furthermore, the development of IoT usually involves radio frequency identification (RFID) technology, sensor networks and machine to

machine (M2M) system frameworks. To be specific, in the terms of RFID, it is a wireless system consisting of readers and tags. The technology allows IoT to have traceability. People can keep track of the location of items and their surroundings. For the sensor network, a vast sensor network is formed as the micro-electro-mechanical systems (MEMS) are equipped with their unique operating systems, data transfer pathways, applications and stored functions. It allows IoT to monitor and protect people through objects. M2M is an application and service with intelligent interaction with machine terminals at its core. It enables objects to be intelligently controlled.

IoT has been called the third revolution in the development of the world's information industry, therefore it brings many benefits to society.

IoT has led to the development of smart, networked products and equipment, which has a great potential to enable industry to evolve from an electrified, mechanized manufacturing approach to one that is managed and controlled by networks. It solves the problems of serious resource consumption, sever environmental pollution and large disparities between urban and rural development.

It can use radio frequency signals to achieve contactless information transmission and identification through the transmitted information, which effectively combines resources.

IoT can be integrated into larger systems to improve operational efficiency and reduce costs. It makes it easier and faster to communicate between electronic devices.

While IoT has made our lives smarter since its inception, it still faces a number of challenges. To be specific, firstly, security has become an important issue as IoT devices proliferate. IoT security requires the security of devices as well as the protection of software applications and network interactions. As a result, it is difficult to ensure the privacy of businesses and consumers. Next, as IoT is a large and diverse network, a single software or hardware failure can have serious consequences. In a network where a node is damaged, and there is no spare node to automatically replace it, that network will not function properly. Finally, as more and more devices and components are connected to each other, there are difficulties in identifying and monitoring IoT compatibility, because different devices have different interfaces and technical standards.

IoT applications are mainly focused on transport, agriculture, industry, logistics, furniture, healthcare, electricity and environment, etc., leading to changes in productivity, production methods and lifestyles. IoT drives economic development and technological progress between industries, as well as improving management efficiency. For example, in environmental monitoring, an IoT that combines sensing devices and integrated communication technologies allows for data analysis and information transfer. IoT will provide real-time bidirectional communication through the combination of information and communication technologies between users and monitoring systems. IoT can be used to model fire detection and deal with forest fires in real time to reduce forest damage [14]. IoT technology can also be adopted to regularly evaluate the proportion of toxic or flammable gases and pollutants' concentrations to address air pollution caused by industrialization and urbanization [14]. Specifically, the air pollution monitoring system is based on IoT, using sensor network to achieve smart monitoring of air quality. At present, IoT technology is already the premier method of air monitoring, meanwhile it plays a prominent role in the advancement of society. In other words, the acquisition, transfer, storage and analysis of air quality can be achieved thanks to IoT technology, which promotes the continuous development of environmental management.

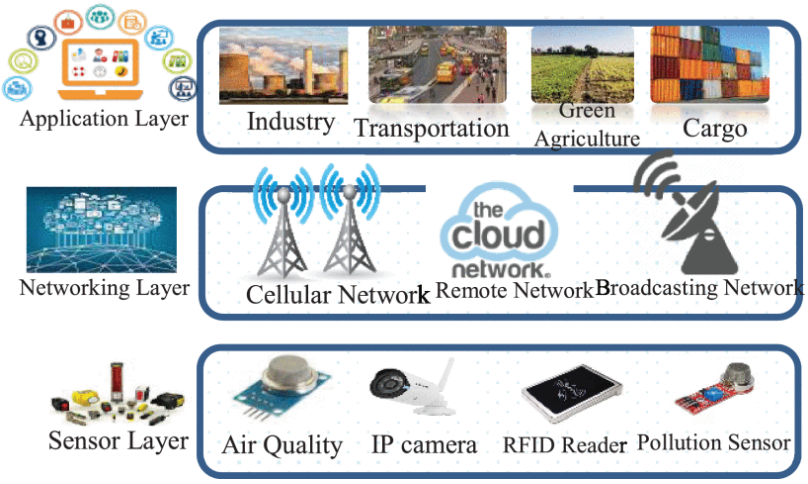


Fig.2 Architecture of IoT [13]

3.2. Smart city

Nowadays, the smart city is attracting more and more attention around the world. It uses information and communication technologies (ICT) to perceive, analyse and combine urban spaces and public services, in order to achieve sustainable urban and regional development [15]. The major driving force behind the creation and development of smart city is technology, including cloud computing, IoT technology and ICT, as smart city stands out in the new competition in the information technology industry. The smart city consists of three layers, the application layer, the network layer and the perception layer. Firstly, in the perception layer, it can identify objects and collect information through 2D bar code, cameras, GPS, sensor terminals, etc. [15]. Next, in the network layer, the smart city transmits the information obtained in the perception layer through a network management centre and an information centre [15]. Finally, at the application layer, it uses intelligent technologies such as cloud technology and fuzzy recognition to analyse and process massive data [15]. In general, a smart city can respond intelligently to urban services, industrial activities and environmental issues [15]. For example, it can effectively address the problem of 'urban diseases' caused by rapid urbanization, i.g., traffic congestion and exhaust pollution.

Moreover, smart city is used for a variety of applications e.g., healthcare, environment, mobility, buildings, infrastructure and education [15], as shown in Fig.3 [16]. A key aspect of smart city is a clean and green environment. As advanced lifestyles continue to develop, people's behaviour is a major cause of environmental degradation, thus, controlling man-made pollution is necessary. Smart environment becomes an important application for smart city. In fact, smart environment takes advantage of new technological tools such as the IoT, big data and mobile connectivity to achieve smarter environmental management, which promotes the harmony and unity between humans and nature. Smart Environment senses, analyses and integrates environmental information in the monitored area, meanwhile, intelligently responding to environmental needs and allowing decision makers to take measures in line with environmental developments. In addition, smart environment is an extension and expansion of digital environment, which usually uses some new generation of information technology to embed sensors and equipment into different environmental monitoring objects, so that smart management decisions can be made in a fine-grained and dynamic way.

Therefore, smart environment is of great importance to governments, businesses and the public. To be specific, firstly, smart environment can provide regulatory tools for environmental authorities and improve management efficiency. Then, as for businesses, smart environment can monitor the levels of exhaust gases, waste water and sludge to prevent them from not being fully treated by purification devices. This can avoid fines arising from substandard emissions. Finally, the public can use the environmental information website to learn about the various monitoring indicators of the environment in their area, and can also lodge complaints and reports to the environmental authorities, which will increase awareness of environmental protection.

Smart environment has built an all-round, multi-level, three-dimensional, full-coverage ecological and environmental monitoring network, which effectively solves the problem of air pollution. For example, OSIRIS is a comprehensive European programme for effective environmental management, which monitors air quality and pollution in real time through a network of sensors. It consists of three phases: on-site monitoring systems, data integration, and information management and services. In Valladolid, Spain, several fixed air quality monitoring stations and sensors are used to monitor concentrations of CO, CO_2, NO and O_3, etc. Then, the monitoring data is transmitted wirelessly to a monitoring centre and combined with information from nearby stationary weather stations to achieve the prediction of pollutant dispersion.

In fact, in smart environment, people often solve air problems with IoT-based air monitoring systems. In general, smart environment can use air sensors combined with IoT technology in such monitoring system to monitor changes in parameters, e.g., dust particles, harmful gases, temperature and humidity in the air. In addition, all the monitored data can be automatically stored so that it can be viewed and downloaded by managers at any time. Thus, as a vital application for smart environment, the monitoring system can keep track of air quality conditions and provide air pollution warnings and solutions.

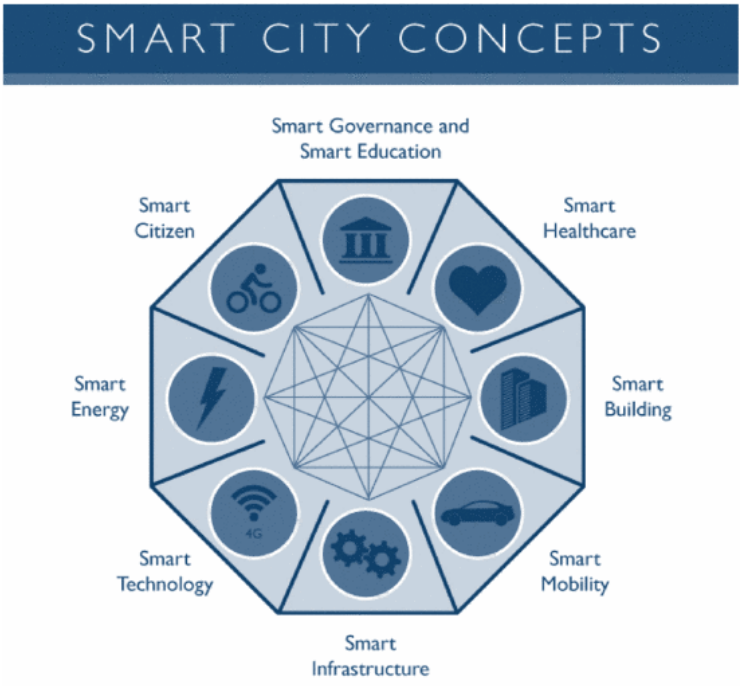


Fig.3 Concepts of smart city [16]

3.3. Cloud computing

It is notable that cloud computing plays an essential role in IoT-based air pollution monitoring system, because the received information about air quality by the gateway needs to be stored and processed on the cloud.

With the growth in the quantity of IoT services, the high demand in terms of data storage and computing volume has led to the birth of cloud computing. Cloud computing is a development of distributed computing, parallel computing and grid computing, therefore it can accomplish thousands of figures in only a brief duration, forming a powerful web service. In general, cloud computing is, at its core, the capacity to gather numerous computer resources together and automate their management. Hence, It allows users to access infinite resources via the web, and the accessed resources have no constraints of space or time.

In comparison to conventional network application models, cloud computing offers significant benefits in terms of security, suitability and data management. To be specific, the most safe and

dependable data storage centre is provided by the cloud computing, thus users do not need to worry about virus intrusion, data loss and any other problems. Furthermore, it is extremely easy to operate, since it has minimal device requirements on the user side. Lastly, cloud computing improves management efficiency by easily sharing data and applications between different devices.

Thus, cloud computing is an essential technology in air pollution monitoring systems. It can summarize and process the hundreds of billions of historical monitoring data and report this data on air quality for processing. Raw data can also be stored in real time, as well as generating indexes. It not only responds to modern IoT applications, but also solves the problems about data storage and management in traditional computing method.

4. Conclusion

An IoT-based air pollution monitoring system that allows real-time and continuous monitoring of pollutant levels has proposed. The structure, working principle and benefits of this smart monitoring system are identified, compared to a conventional monitoring station. Due to the rise of IoT, smart city applications and cloud computing technology also have a significant effect on air quality monitoring systems. The IoT-based air pollution monitoring system is a key expression to the development of information technology and modern sensing. It solves the problem of air monitoring in urban or commercial areas under the strength of low energy, low cost and high coverage. Meanwhile, it promotes smart urban management and sustainable development. In the future, portable air monitoring systems are expected to be widely applied in the market. Apart from monitoring conventional gases and particles, the monitoring systems can also monitor greenhouse gases, photochemical smog or LIDAR gases.

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