IoT Technology in Urban Waste Management: Smart Waste Bin Systems

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Abstract. With the acceleration of urbanization, municipal waste management has become a critical research topic. Concurrently, the Internet of Things (IoT) is rapidly evolving, closely paralleling the urbanization process. Many researchers have attempted to integrate IoT into municipal waste management, achieving notable results. However, there remains a significant gap in the development of smart waste bins, which serve as the nerve endings of IoT waste management systems. This paper proposes a smart waste bin design concept based on the STM32 microcontroller for real-time monitoring and management of urban waste, exploring the application of IoT in this domain. The smart waste bin integrates sensors, control systems, and Internet technologies to facilitate remote monitoring and automated control. Through real-time monitoring with components such as infrared sensors and MQ2 sensors, the system collects essential waste bin parameters. These parameters are then transmitted to the network using a GSM module. Simultaneously, users can remotely monitor and control the smart waste bin via a mobile application, allowing them to check the bin's capacity, receive alarm notifications, and remotely manage the bin's status. This design significantly enhances the efficiency of waste bin management in cities with decentralized locations, offering a convenient and intelligent solution for urban waste management and IoT applications. Despite these advancements, there is considerable room for improvement in the interaction capabilities of smart bins with IoT systems, users, and managers, as well as in their design and cost-efficiency.

Keywords: Municipal Waste Management, Internet of Things, Smart Waste Bins, microcontroller.

1. Introduction

Increasing pollution from urban waste has posed a significant problem for centuries. With urbanization accelerating and populations growing larger, the pressure on waste disposal is intensifying, making municipal waste management a crucial component of sustainable urban development. Waste disposal is a global issue that affects the health of the planet and its inhabitants. Traditional waste disposal methods face numerous challenges, such as scattered waste that is difficult to monitor, untimely collection and transportation, inadequate disposal of hazardous waste, and low resource recovery rates. Although efforts are being made across society to promote scientific collection and reuse of waste, limitations in funding, technology, and personnel make it difficult to cover all areas effectively, and often, the status of waste containers and optimal disposal times are unknown.

Simultaneously, the development and widespread adoption of Internet of Things (IoT) technology have entered a new phase. The IoT, or Internet of Things, is a network of physical objects that can communicate without human involvement, and is referred to as the ‘infrastructure of the information society’. The application of IoT technology will render urban waste management smarter, more user-friendly, greener, and sustainable. IoT technology acts as a central system connecting and integrating all aspects of waste treatment, such as smart waste bins, waste treatment stations, waste transportation trucks, waste storage stations, and inspection drones. This integration allows for close monitoring and management of all stages of waste transportation and treatment, forming a comprehensive waste management chain. By applying sensors and other IoT devices to waste bins, recycling stations, and waste treatment equipment, real-time monitoring of the waste treatment process is achievable, enhancing the efficiency of waste management and resource recycling.

Smart waste bins, in particular, will serve as the nerve endings of the IoT, playing a pivotal role in the waste management chain. Consequently, numerous scholars worldwide have focused extensively on smart waste bins. For instance, K. Mahindra Guptha and S. have studied IoT-based waste disposal systems, highlighting the significance of smart waste bin design within the overall system [1]. Researchers at the National University of Callao in Peru utilized OpenCV to conduct a study on smart wastebasket classification, yielding results that align with the vision and needs of the Peruvian context [2]. These and other innovative studies have guided this paper. However, relatively few studies have been conducted on smart waste bins, leaving ample space for further exploration [3]. This paper employs microcontrollers to investigate smart waste bins, aiming to identify a feasible path for IoT applications through the lens of efficient and cost-effective smart waste bin systems.

2. Related Theoriess

2.1. Definition and Development History of the Internet of Things

2.1.1 Definition of the Internet of Things

The Internet of Things (IoT) is a network that connects any object to a network by information sensing devices, based on an agreed protocol, allowing the objects to exchange information and communicate through the media of transmission. Such a network is capable of intelligent identification, positioning, tracking and supervision, leading to intelligent management of objects [4].

The core of IoT lies in connecting various 'smart objects' to the Internet for real-time information sharing and intelligent collection, transmission, processing and execution. These objects include, but are not limited to, consumer products, industrial components, living things, and various environmental monitoring devices [5]. IoT technology is not only limited to human-to-human interaction, but also human-to-machine and machine-to-machine interaction, aiming to achieve more efficient, energy-saving, safe and environmentally friendly ‘management, control and operation’ integration.

2.1.2 Development History of the Internet of Things

As a new type of technology integrating physical, network and computing technologies, Internet of Things (IoT) technology has become the hotspot and frontier field of today's information technology development. Its development history can be divided into three stages: infrastructure construction stage, application promotion stage and intelligent upgrading stage [6].

First, the infrastructure construction stage. The development of IoT technology originated from the fusion of computer technology and physical sensor technology. In the mid-1990s, computer network technology has been widely used, but the application of physical sensor technology is still affected by a lot of limitations [7]. After 2000, the physical sensor technology has been rapidly developed, and the IoT technology based on the sensor network has been initially applied, at this time, the Internet of Things technology is at the stage of infrastructure construction. Infrastructure construction stage.

Second, the application promotion stage. From 2010, IoT technology entered the application promotion stage. IoT technology is not only widely used in industry, agriculture, medical care and other fields, but also widely used in daily life fields such as smart home, intelligent transportation and intelligent medical care [8]. In the application promotion stage, the application scope of IoT technology is expanding, forming an IoT technology ecosystem centered on cloud computing big data and artificial intelligence.

Third, the intelligent upgrading stage. In recent years, IoT technology has entered the intelligent upgrading stage, which is also known as the era of all things intelligent connection [9]. The application of IoT technology in this stage is no longer simple data collection and transmission, but to realize the intelligent processing and application of data. IoT technology will integrate with artificial intelligence blockchain and other new technologies to form a more intelligent, safer and more reliable IoT ecosystem [10].

2.2. Architecture of IoT Systems

The Internet of Things (IoT) is a global network connecting billions of physical devices and sensors that communicate and exchange information with each other over the Internet to achieve interconnectivity and intelligence between things.

The three main features of IoT are comprehensive sensing, network transmission and intelligent processing. Comprehensive sensing is to collect information about objects anytime and anywhere through various identifiers and sensors, and analyze the information comprehensively to understand the state of the objects. Network transmission is to connect to the Internet through short-distance wireless communication technologies such as WiFi, Bluetooth, RFID, and mobile communication technologies, to transmit object information efficiently and safely, and to realize the sharing and effective use of information. Intelligent processing refers to the utilization of various intelligent computing technologies. It analyzes and processes a large amount of received data and information to realize intelligent processing and control.

The realization of IoT technology depends on the support of a variety of technologies such as sensor technology, network communication technology, cloud computing technology, artificial intelligence technology, M2M technology, NB-IoT technology. Sensors are the indispensable infrastructure of IoT technology, through which various information of objects can be collected, such as temperature, humidity, light, air pressure, sound, motion, and more to realize the perception and control of objects. At present the commonly used sensor technology mainly includes RFID, infrared, ultrasonic, photoelectricity, gas, and so on. RFID is radio frequency identification technology, electronic tags are the ID card of each object, and RFID technology is the scanner that reads the ID card. As the Internet of Things requires a network to realize the interconnection between objects, network communication technology is an essential support to construct the Internet of Things. The currently commonly used IoT communication technologies mainly include wireless network, wired network, Bluetooth, NFC and so on. Based on the huge amount of data generated by the Internet of Things, traditional data centers are difficult to meet the computing needs, so it is necessary to rely on cloud computing technology for data storage and processing. Through cloud computing technology, the data transmission and processing in IoT can be centralized in the cloud to realize the rapid analysis and application of data. At the same time, cloud computing technology can also achieve device management, data backup and other functions. In addition, artificial intelligence technology also plays an important role in the Internet of things, through the reasonable use of artificial intelligence technology can implement the modeling of the Internet of things data, predictive analysis, anomaly detection and other functions to improve the operational efficiency and accuracy of the Internet of things. M2M is a general term for technology that enhances the communication and networking capabilities of machines and devices, including communication between people and people, people and machines, and machines and machines. M2M allows people, machines, and systems to connect, enabling communication and information sharing among the three. NB-IoT technology, or narrowband IoT. It reduces power consumption by sacrificing rate and can act as a cost-saving way to reduce operational burden. It also has the characteristics of mobility, high number of connections and low cost.

3. Analysis on Smart Waste Bin Systems

3.1. Control Module

The control module adopts STM32F103C8T6 microcontroller as the core chip, the main frequency of its core is up to 72MHz, including ADC, DAC, PC, SPI, USART and other peripherals, and provides an expansion interface with 64KB Flash memory and 20KB SRAM memory, and has multiple interrupt controllers and timers with low cost of use. It also has multiple interrupt controllers and timers for low cost of use, ensuring performance with low power consumption. As shown in Fig 1.



Figure 1. STM32F103C8T6 microcontroller (Photo credit: Original)

3.2. Sensor Technology

3.2.1 Infrared Sensing Technology

Infrared sensors use the physical properties of infrared light to make measurements. Infrared rays also have the properties of reflection, refraction, scattering, interference and absorption. Any substance, as long as it itself has a certain temperature (above absolute zero), can radiate infrared light. Infrared sensors measure without direct contact with the object to be measured, thus there is no friction, and have the advantages of high sensitivity and fast response. As shown in Fig 2.

Therefore, infrared sensors are ideally suited for monitoring and analyzing the capacity status of smart waste bins, as well as detecting temperature anomalies in the waste bins in time for judging fire or emergency.

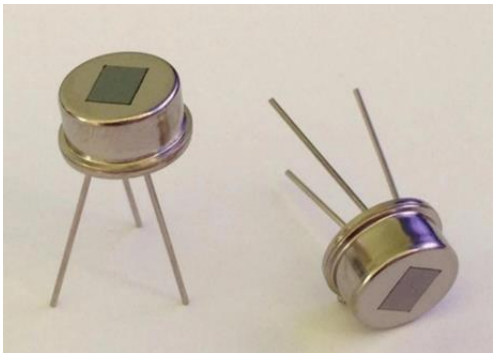


Figure 2. Infrared sensors (Photo credit: Original)

3.2.2 Poisonous Gas Sensing Technology

This system allows a smart waste bin to sense gases by using the MQ2 gas sensor module. The MQ2 sensor is a multifunctional sensor that detects LPG, smoke, alcohol, propane, hydrogen, methane and carbon monoxide concentrations in the air ranging from 200 to 10,000 ppm. This makes the MQ2 gas sensor module an excellent choice for building an indoor air quality monitoring system, a breathalyzer, or an early fire detection system. The MQ2 gas sensor operates at 5V and consumes approximately 800mW of power. As shown in Fig 3.



Figure 3. MQ2 sensor (Photo credit: Original)

3.3. GSM SMS Interaction

GSM module, which integrates GSM RF chip, baseband processing chip, memory, amplifier devices on a circuit board, has independent operating system, GSM RF processing, baseband processing and provides standard interface function module. GSM module has all the basic functions of sending SMS, voice call, GPRS data transmission based on GSM network for communication. It is very suitable for the network connection function of smart waste bin. As shown in Fig 4.



Figure 4. GSM module (Photo credit: Original)

3.4. Alarm Devices

This system uses a buzzer and a red light to alert to hazardous gases and emergencies in the smart waste bin. Also includes alerts by sending alarm text messages to administrators and users.

4. Overall Structure Research of Smart Waste Bin System

The overall structure of the system design system uses STM32F103C8T6 single-chip microcomputer as the processing core, measuring the parameters that require collection on the tour, analyzing and processing the collected data, the overall structure of the system is shown in Fig 5.

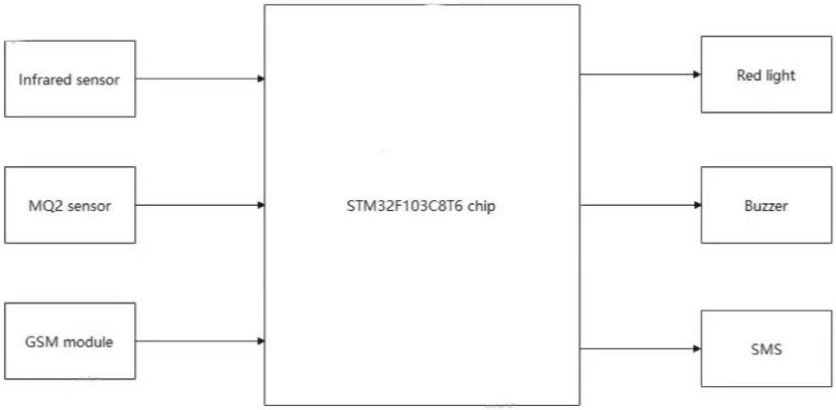


Figure 5. Structure of the system (Photo credit: Original)

The system has the following functions: The infrared sensor is used to measure the volume of remaining capacity of the present waste bin, and analyze the data by using STM32F103C8T6 microcontroller. if the garbage is overflowing, the smart waste bins will send text messages to the users and administrators, which is convenient for the users to get the timely information about the status of the waste bins in order to make a better decision.

The infrared sensor can detect whether there are burning objects or explosion or any other dangerous situations in the waste bin. If so, the waste bin will emit red light and beep to warn the surrounding passers-by to stay away and send SMS to alert the manager.

MQ2 sensor can detect whether there is any toxic gas in the waste bin. If so, the waste bin will emit red light and beep to warn the passers-by around, and send SMS to remind the administrator.

Users and managers can remotely control the switching status of the waste bin by sending SMS. If the smart waste bin completes these actions, it will respond with a text message.

The function of this system is relatively simple, focusing on the tips of overflowing waste bin, toxic and hazardous objects reminding, remote control and human- machine interaction, which can improve the management efficiency and real-time to a certain extent, prevent other unrelated people from turning over the garbage to cause pollution and injuries, and solve the problems of waste pollution and municipal garbage management appropriately.

5. Conclusion

This paper utilizes the STM32F103C8T6 as the core controller, leveraging IoT sensor technology to present a solution for achieving the sensing, networking, and control functions of a smart waste bin. It also discusses the application value of IoT for real-time monitoring and management of municipal waste. Through a detailed introduction to each component of the smart waste bin and an analysis of its application, the paper demonstrates the application prospects and advantages of IoT in municipal waste management. The smart waste bin collects data on waste bin capacity through real-time monitoring with infrared sensors and MQ2 sensors, determining the presence of harmful gases and hazardous situations. The GSM module transmits this information to the network, enabling users and administrators to remotely monitor and control the smart waste bin via a mobile application. This includes checking the bin's capacity, receiving alarm notifications, and remotely managing the bin's status. By designing smart waste bins with low-cost sensors, it is possible to deploy these bins on a large scale throughout different parts of the city. This approach reduces costs and optimizes waste collection times, as the smart waste bin is equipped with location coordinates, simplifying the collection and monitoring process.

Future enhancements could include integrating additional sensors to enable automatic sorting within the smart waste bin, further increasing its efficiency and accuracy. Such advancements would elevate the intelligence and automation levels of municipal waste management, contributing significantly to the sustainable development of urban environments.

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