中國機械工程學刊第四十四卷第五期第 435~446 頁(民國一百一十二年)
Journal of the Chinese Society of Mechanical Engineers, Vol.44, No.5, pp435~446 (2023)

An Integrated Garbage Management System Based on the Intelligent Internet of Things

Chun-Yen Chung * and Jong-Chao Yeh**

Keywords： Automated garbage sorting, Automated garbage compression, Internet of Things (IoT), LoRaWAN, Environmental monitoring.

ABSTRACT

As the demand for quality of life increases, the amount of waste generated also increases significantly. However, the earth's resources are limited, resource recycling and reuse are relatively important issues, and the operation of the recycling waste industry has also become an important part. The objective of this study is to propose an integrated garbage management system based on the intelligent Internet of Things. Therefore, this study developed a recyclable garbage sorting system and integrated LoRaWAN communication networks with garbage sorting equipment to create a system that offers automated garbage can operation, environmental monitoring, and graphical monitoring interface. The main academic contribution of this study is the system uses electrostatic capacitance-type proximity sensors to discriminate between the types of garbage deposited in garbage cans. Furthermore, by utilizing an embedded motor and some smart devices it can perform functions such as automatically opening and closing insertion points, sorting waste materials, initiating automated garbage compression, monitoring water levels, and issuing warnings when the water level reaches the threshold. Additionally, this system employs a graphical monitoring interface coded in C# language to remind users of garbage removal.

INTRODUCTION

Paper Received February, 2023. Revised April, 2023. Accepted May, 2023. Author for Correspondence: Chun-Yen Chung.

* *Associate Professor, Computer and Game Development Program, Kun Shan University, Tainan, Taiwan 710303, ROC.*

** *Assistant Professor, Department of Fashion and Performance, Kun Shan University, Tainan, Taiwan 710303, ROC.*

Nowdays, technological progres is usually made by its application and implementation in the human living environment, in which environmental protection, public health and energy efficiency play an important role (Espinosa et al., 2021). Reducing resource losses caused by waste management is the key to strengthen Taiwan’s circular economy. Although Taiwan is making progress by implementing ambitious waste policies and a circular economy framework, a large amount of valuable resources are still being lost due to inefficient waste management. Waste is not only an indicator of economic prosperity, but it is also a problem that affects urban development and relevant units must invest additional space and financial resources for its management (e.g., clean, bury, and burn)(Hoornweg et al., 2013; Espuny et al. 2021). This increases the physiological and financial burdens on the public. To lower the costs of waste management, Taiwan citizens must comply with waste disposal policies, particularly those on “waste source reduction and recycling,” formulated by the Environmental Protection Administration (Shen, 2008).

In a smart city, garbage collection is a key point of the environment, and its quality should be carefully considered (Medvedev et al., 2015; Sohag and Podder, 2020). The problem of trash cans is just like trees, street lights, benches and signs on the street, which are often overlooked by city planners, but they are one of the most important factors affecting the environment. From a Kansei engineering perspective, to turn public attention toward recycling, relevant units must design and install functional and convenient garbage cans (Yu, 2016; Gan et al., 2021). To facilitate the garbage cans aforementioned, Internet of Things (IoT) is one of the suitable candidates, since it has undergone flourishing global development in which data collection and communication have enabled devices to communicate with one another to provide various control, detection and identification services, which also greatly assists human health (Espinosa et al., 2021). Most IoT systems communicate through Wi-Fi, Bluetooth 4.0, radio-frequency identification, or Zigbee. However, these aforemetioned technologies are limited by space, distance, and power consumption-related problems, andtheir coverage is usually unable to support sensor devices to transmit data if end nodes are located in a large space (e.g., farms or factories). To solve these problems, long-distance, low-power-consumption wireless transmission technology such as LoRa, Sigfox, and NB–IoT have been introduced (Cerchecci, et al., 2018; Cruz et al., 2021).

This study proposed an IoT-based smart recycling and environmental monitoring system. This system can automatically open and close its garbage insertion point, sort and compress garbage, , perform environmental sensing to obtain regional parameters, use a LoRaWAN (LoRa for Wide Area Networks) wireless communication network to facilitate two-way communication between end nodes and gateways (Aoudia et al., 2018) and enable communication between monitoring stations and cloud servers. The proposed system corresponds with Kansei Engineering and technological trends, reveals to local residents the hazards identified in their living environments, elevates the recycling rates of front-end recycling equipment, and provides easier access to garbage collection data and information concerning the regional environment.

The remainder of this study is organized as follows. An analysis of existing Internet of things, smart waste collection system and Kansei Engineering is made in Section 2. Sections 3 is devoted to the structure of the proposed system, followed by materials and methods employed in the proposed system which are depicted in Section 4. Section 5 presents the main evaluation results. Finally, the conclusions are drawn in Section 6.

OVERVIEW OF INTERNET OF THINGS, SMART WASTE COLLECTION SYSTEM AND KANSEI ENGINEERING

Internet of Things

The maintenance of the smart urban environment requires the use of sensing systems and the IoT technology to design smart, sustainable and efficient urban applications; this research believes that the implementation of urban Internet of Things applications and its benefit in the human environment is unstoppable, and the integration of Internet of Things technology (Espinosa et al., 2021). The application of the Internet of Things and its multiple developments and advancements are unstoppable; sensors, smart devices, systems and advanced technical architecture provide a good development prospect for environmental protection (Feroz et al., 2021). To improve people's lives, management processes, as well as energy efficiency, environmental sustainability and people's health as the three pillars. In 2005, the International Telecommunication Union published the ITU Internet Reports 2005: The Internet of Things, which signified the arrival of a new technology in the world of information and communication technology and announced the third major evolution in the information technology industry. The combination of wireless communication technology and IoT has developed into a new model that has garnered increased attention from industries and academics and is heavily used in daily life. Statistics suggest that IoT equipment construction cost is expected to increase to approximately NT$50.1 billion by 2020 (Yu, 2016), as shown in Fig. 1.

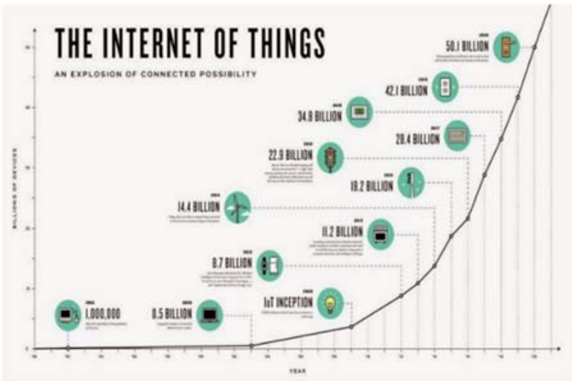


Fig. 1. Yearly development of Bigbelly smart garbage cans.

Therefore, the impact of IOT on the environment issues were reduce the consumption of natural resources and fuel, improve cleaner air, and reduce waste (Cerchecci et al., 2018). These are all advantages beyond the technical level. Otherwise, many study shows that the current waste management is done using GSM (Global System for Mobile Communications) sensors. The objectives of this study is to use LPWAN to expand the range and reduce costs and change the configuration time of communication providers. Past studies have shown that using LoRa as its network counterpart can be used for multi-purpose experiments, exploring a variety of distances, types, recycling waste containers, placing (underground or ground), and measuring LoRa sensors for waste levels of various commercially available products. This study will use the above advantages to link the IOT and LoRa to propose more practical methods for the goal of environmental sustainability and solve the problem of garbage.

Smart Waste Collection System

The IoT has been used to support smart city construction for many years, an example is the use of IoT to create smart waste collection systems because of the direct effect they have on urban image and urban management costs (Sohag and Podder, 2020). Many countries in Europe and North America have begun to invest in the research and development of IoT technology (Espinoza et al., 2020). An article titled "Smart Waste Collection System Based on Location Intelligence" stated that the goal of smart waste collection is not to improve waste collection routes for optimized waste collection but is rather to highlight the advantages and disadvantages of smart garbage cans and use these garbage cans to analyze daily garbage collection routes (Gutierrez et al., 2015). Current development trends suggest that future development directions include reducing equipment power consumption, increasing recycling accuracy, expanding equipment functions, and improving equipment appearance, such as the use of routing and clustering algorithms described in to reduce waste collection costs (Cotet et al., 2020).

Past study in Taiwan on smart garbage sorting systems revealed that many schools have utilized this concept and incorporated it into competitions, producing favorable results. American companies such as Bigbelly have even made smart garbage cans (i.e., solar-powered rubbish compactors) commercially available. These garbage cans are solar-powered and feature IoT technology and automatic compression functions. As shown in Fig. 2. , when the garbage can is almost full, a notification (containing information such as the geographical location of the garbage can and its status as full) is automatically sent to a processing center. The garbage can also assesses the effectiveness of garbage collection in the region (Culgin et al., 2013). Its use at the University of California San Diego (in the USA) and Blue Mountains National Park (in Australia) enabled the two regions to reduce the frequency of garbage collection considerably, thereby decreasing the number of garbage trucks dispatched, the personnel and maintenance costs incurred, overall costs (by 85%), and 52 tons of carbon dioxide emission. By contrast, this technology remains underdeveloped in Taiwan, and some garbage cans require substantial amounts of space to organize garbage, which defeats their purpose.

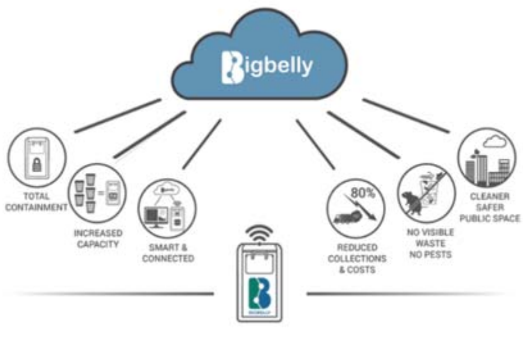


Fig. 2. Bigbelly smart garbage can functions

Kansei Engineering

Kansei Engineering is a consumer-oriented technology created. Kansei is derived from Japanese meaning “perception”, “feeling”, and “impression”. A psychological feeling generated by products. The purpose of Kansei Engineering in this study is to design new products based on consumers’ feelings and needs, and to “transform” or “correspond” people’s perception of products to design elements when designing products. Based on this methodology, designer tries to quantify the sensibility that people have, and from the exploration, who can learn which design decisions are in line with which sensibility of people (Nagamachi, 1995).

Kansei Engineering starts from the relevance of people and things, focusing on quantitative analysis, transforming the previously ambiguous perceptual image into a methodical norm that can be followed by the designer, and transforming it into reality. product design. This research uses the significance of perceptual engineering to construct the design of a smart recycling system by perceptual evaluation. By constructing the relevance between perceptual vocabulary and design elements, the perceptual quantity of the products monitored by users of this environment can be explained or predicted in terms of product morphological characteristics.

The design system in this study not only conforms to the situation of perceptual engineering and technology, but also achieves the effect of facilitating and attracting the people. It also allows managers to easily obtain information on garbage collection and regional environment, reducing the loss caused by unclear classification. Therefore, when developing the conceptual prototype of this research, follow the perceptual engineering to grasp the user's perception of this prototype, and multi-analyze the data to obtain the final design of this research. In other words, this research uses such a concept to design a prototype of a smart garbage collection system to solve the design problem of the collection system.

SYSTEM STRUCTURE

The system appearance and operation procedure were designed using Kansei engineering analysis methods (Agassi et al., 2020). This study connected environmental sensing nodes, garbage can monitoring nodes (for determining whether the garbage cans were full), and a monitoring interface using the IoT. The system contains three major structures: automated sorting equipment, an environmental monitoring system, and a graphical monitoring interface. The system structure is displayed in Fig. 3.

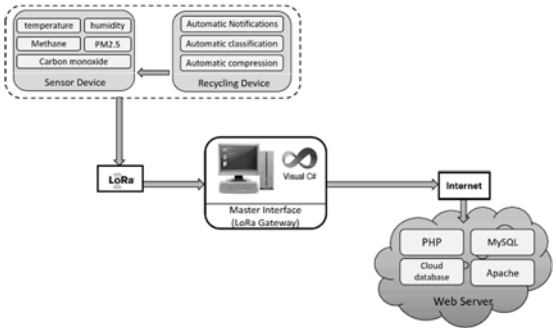


Fig. 3. System structure

Operating Procedure of the Environmental Sensor System

As shown in Fig. 4, the environmental sensor system uses multiple environmental sensors (e.g., a carbon monoxide sensor (MQ-7), methane sensor (MQ-4), and $PM_{2.5}$ and humidity sensor (Plantower PMS5003T)) to collect environmental parameter data. The data are subsequently organized and transmitted using Arduino and a LoRa module, respectively, in which data are received and displayed by the monitoring station. Next, the data are uploaded through the Internet and stored in a MariaDB cloud database constructed using Raspberry pi, where the data are viewed using a phpMyadmin web server.

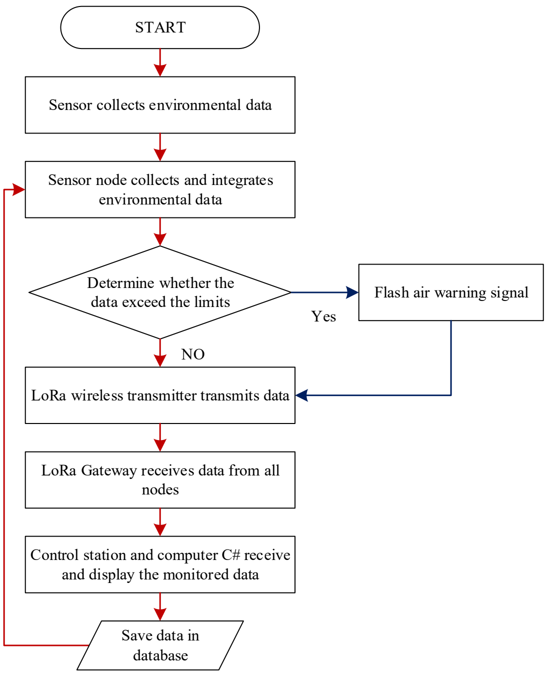


Fig.4. System environmental monitoring procedure.

"Garbage Full" Notification Procedure

As shown in Fig.5., an ultrasonic sensor determines whether the input side is open or closed and a platform is placed below the insertion point to hold garbage. An infrared light and electrostatic capacitance-type proximity switch are used to determine whether garbage is on the platform. If so, a dielectric property analysis is performed to distinguish between recyclable and nonrecyclable garbage. The monitoring nodes on the garbage can determine the garbage level using infrared sensors. If the garbage level exceeded the standard level, the compression unit is activated to compress the garbage. If the garbage level still exceeds the standard level after compression, a signal is transmitted to the monitoring station.

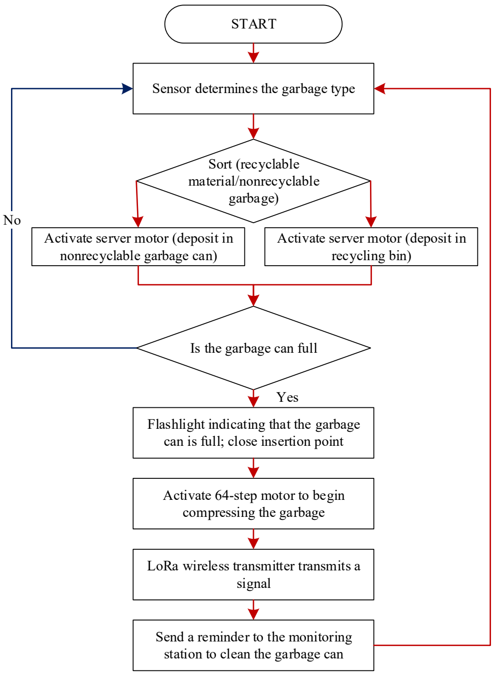


Fig. 5. System garbage full notification procedure.

Flood Notification Procedure

Taiwan has an ever-changing climate and is prone to torrential rain in the summer, the latter of which causes frequent floods in low-altitude regions that wash away garbage cans. The floods leave behind dirty environments and damaged garbage cans. To solve this problem, this study introduces a flood prevention measure, as presented in Fig. 6. This measure uses a water-level detection sensor with parallel wires to measure water volume, on the basis of which the water level is determined. When the water level exceeds the preset value, a notification is immediately sent to the monitoring station and linear actuators installed on the four sides of the garbage cans are activated, raising the garbage cans and preventing them from being damaged and washed away by floods.

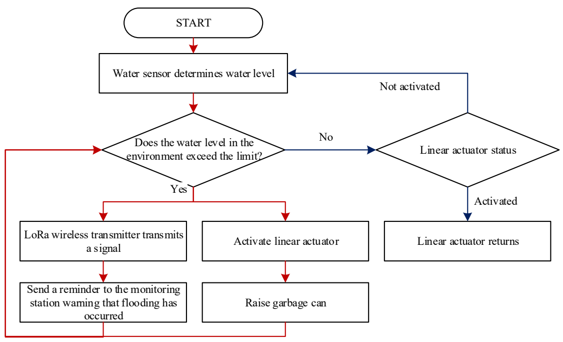


Fig. 6. System flood notification procedure

MATERIALS AND METHODS

The sorting equipment integrates various components to achieve automated operation. The hardware components of the automated sorting equipment are displayed in Fig.7.

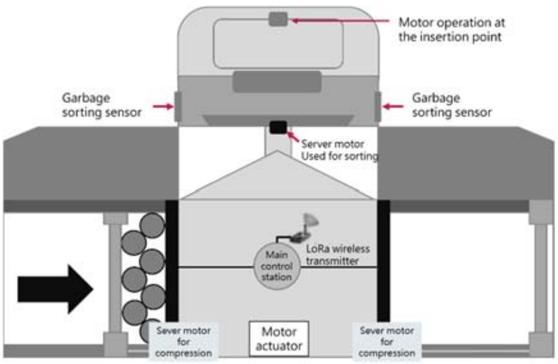


Fig. 7. Hardware components of the sorting equipment (simplified diagram).

Waste Sorting Unit

This study introduces a new form of smart sorting technology. A review of domestic patents and relevant literature reveals that most sorting technology involves the use of image recognition or RFID. Although these types of technology are remarkably precise, they pose the problems of incurring high construction costs and being inconveniently large. Additionally, databases for these technologies are difficult to construct. This study attempts to solve the aforementioned problems and achieve the goals of reducing cost, maintaining precision, reducing space requirements, and establishing flexible usage (i.e., allowing the technology to be used in various locations). This study performed analyses and research and subsequently used an electrostatic capacitance-type proximity switch and infrared sensor to distinguish between recyclable and nonrecyclable materials (as shown in Fig. 8). An infrared sensor was used to determine whether garbage had been deposited into the garbage can; if so, an electrostatic capacitance-type proximity sensor was activated to measure the permittivity of the garbage. The results were then transmitted back to the control station. Recyclable material (e.g., metal, aluminum foil, and paper) and nonrecyclable material (e.g., plastic bags, wood, and toilet paper) are assigned values of 1 and 0, respectively.

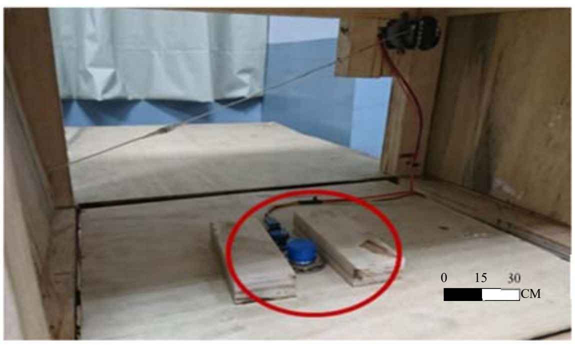


Fig. 8. Sensor module for the sorting equipment.

Electrostatic Capacitance-Type Proximity Sensor

Proximity sensing is a sensing method that replaces touch-based sensing such as that employed by limit switches. Japanese Industrial Standards (JIS) defines a proximity sensor as a sensor that detects its targets without touching them. Common proximity sensor types include inductive-type, electrostatic capacitance-type, ultrasonic-type, photoelectric-type, and magnetic-type proximity sensors. Proximity sensors can be further divided into flush and nonflush-mounted proximity switches based on the manner of their installation. Compared with touch-based sensors, proximity sensors feature the following advantages.

1. Use a detection method that is not touch-based: Do not wear down or damage the object being tested.
2. Generate semiconductor output: Benefit from increased service life (except for magnetic-type proximity sensors).
3. Suitable for various environments: Are less affected by materials such as oil, water, and dirt.
4. Are not affected by the color of test objects: Judgments are made based on the dielectric properties of the test objects.
5. Make quick judgments: Increase the number of tests performed every second.
6. Possess two-wire type wiring: Reduce wiring time and costs.

Fig. 9. and 10. display electrostatic capacitance-type proximity sensors, which sense by transmitting high-frequency oscillation signals (measuring intensity in hundreds of kHz to several MHz) to detect electrode plates. These electrode plates generate high-frequency magnetic fields. When objects enter within the range of the electrode plate surface, the electric fields of the object and electrode plate surfaces change, thereby increasing or decreasing the overall capacitance. Sensor materials that may be used include metals, plastics, liquid, and wood. Fig. 11. depicts the sorting method.

Fig. 9. LJC18A3-B-Z/BX-based electrostatic capacitance-type proximity sensors.

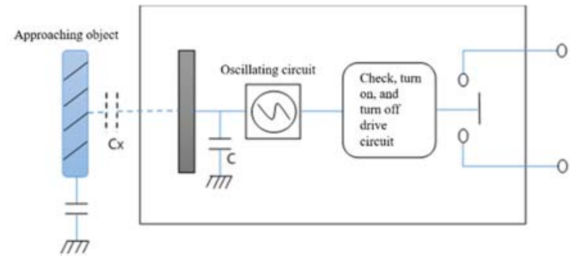


Fig.10. Internal circuit diagram of an electrostatic capacitance-type proximity sensor.

Fig. 11. Object placement platform of the sorting equipment.

Electrostatic Capacitance-Type Proximity Sensors

Mediums in applied electric fields generate charge, which diminishes the electric field. Permittivity is the ratio between an original applied electric field (in a vacuum) and the electric field in the final medium. Permittivity, also called capacitance rate or relative permittivity and represented by the symbol ε, is a crucial indicator of the electrical properties of dielectrics or insulation substances. In a capacitor, the ratio between the dielectric of a substance and the capacitance of the substance in a vacuum reflects the relative ability of the dielectric to store electrostatic energy in an electric field. The lower the level of permittivity, the more effective the insulation becomes. Thus, permittivity is a measure of the ability of a substance (compared with that of a vacuum) to improve the capacitance of a capacitor. Table 1. presents the relative permittivity of some commonly used substances.

In variable electromagnetic fields, the relationship between the permittivity and frequency of a substance is commonly referred to as its dielectric coefficient. Therefore, permittivity is also called a dielectric constant, dielectric coefficient, and capacitance rate, and is a coefficient indicating insulation ability. Permittivity, represented as ε, is measured in terms of Farads per meter. In electromagnetism, relative capacitance rate (or relative permittivity) is defined as the ratio between the permittivity of a substance in its current state to that in a vacuum, where ε_r is relative permittivity, ε is permittivity; and ε_0 is the permittivity of the substance in a vacuum.

$$\varepsilon = \varepsilon_r \times \varepsilon_0 \qquad (1)$$

Relative permittivity, ε_r, in an electrostatic field can be measured using the following method. (a) Measure the capacitance of a capacitor (C_0) when the space between the two plates is a vacuum, (b) insert a dielectric into the space between the two identical capacitance plates and measure the capacitance (C_x), and (c) calculate the relative permittivity using the following equation:

$$\varepsilon_r = C_X / C_O \qquad (2)$$

Adding a material with a permittivity of ε to the capacitance plate increases the capacitance by a factor of ε. In the following equation, A is the plate area and H is the distance between plates.

$$\mathrm{C} = \varepsilon_0 \frac{A}{H} \qquad (3)$$

A dielectric can increase or decrease the actual storage space of a substance. For example, when a dielectric material is placed between two charges, it reduces the force between them in a manner comparable to moving them away from each other. When an electromagnetic wave passes through a dielectric, the wave speed decreases. The following equation represents the relationship between electric displacement and an electric field, where E and P are the electric field and electric polarization intensity, respectively.

$$\mathrm{D} = \varepsilon_0 E + P \qquad (4)$$

For isotropic, linear, and uniform dielectrics, electric polarization intensity is directly proportional to the electric field:

$$\mathrm{P} = X_e \varepsilon_0 \times E \qquad (5)$$

X_e: electric polarization rate

Generally, permittivity is not a constant and is influenced by parameters such as dielectric position, electric field frequency, humidity, and temperature; all of these parameters may cause changes in permittivity. For nonlinear dielectrics, their permittivity may change with changes in electric field intensity. When permittivity is measured as a function of frequency, its value may be a real or complex number.

Environmental Sensor Unit

The environmental sensor unit contains multiple environmental sensors (e.g., $PM_{2.5}$, methane, and carbon monoxide sensors) embedded in the sorting equipment. A select area was monitored, and a SX-

1278 radio-frequency chip (designed by Semtech based on LoRa) was used to design a LoRa transceiver module (model AS62-T30) for wireless transmission. Under Mode 1, the Class A low-cost transmission method can be used to establish a set of wireless sensor networks to monitor the environmental conditions of an area at any time. Sensor data are displayed on the sorting equipment to facilitate public access. A Kansei engineering procedure was adopted to increase public interest in depositing garbage into garbage cans and thereby prevent littering. The sensor unit can also be used in kitchens to monitor methane and natural gas data, offering sensor units that are convenient and safe to use by the public. The sensor specifications are listed in Table 2.

Table 1. Relative permittivity of various substances.

Gas	Temperature	Relative dielectric coefficient	Solid	Temperature	Relative dielectric coefficient
Water vapor	150	1.007850	Solid ammonia	−90	4.01
Gaseous bromine	180	1.012800	Solid acetic acid	2	4.10
Helium	0	1.000074	Polystyrene	20	24.00–2.60
Hydrogen	0	1.000260	Radio porcelain	16	6.00–6.50
Oxygen	0	1.000510	Ultrahigh-frequency porcelain		7.00–8.50
Nitrogen	0	1.000580	Rubber		2.00–3.00
Argon	0	1.000560	Paper		2.50
Gaseous mercury	400	1.000740	Dry sand		2.50
Air	0	1.000585	Salt		6.20
Vacuum	20	1.000000	Sulfur		3.00–4.00
Carbon dioxide	20	1.585000	Carbon		3.30
Methanol	20	33.700000	Mica		6.00–8.00
Ethanol	16.3	25.700000	Wood		2.00–8.00
Water	14	1.500000	Glass		2.80
			Yellow phosphorus		2.80

Table 2. Sensor material specifications.

Component	Model	Function
Arduino microcontroller	Mega2560	A control station
Sensor expander board	Arduino MEGA V2	Expands pin leg
LoRa Module	AS62-T30	A wireless transmission module
Temperature and humidity sensor	Plantower PMS5003T	Senses temperature and humidity
$PM_{2.5}$ sensor	Plantower PMS5003T	Senses $PM_{2.5}$
Methane sensor	MQ-5	Senses flammable gas
CO_1 sensor	MQ-9	Senses CO_1

Wireless Transmission Module: LoRa Module

This study used the wireless transmission module (model AS62-T30, developed by Zeyao Technology using SX1278 main chips) displayed in Fig. 12. This module is an industrial-grade wireless data transmission module featuring high stability, a working frequency between 410 and 441 MHz, 32 orthogonal channels, interleaver matrix loop codes, and a data error correction algorithm. The module increased the amount of data transmitted and prevented the loss of transmission data.

Fig. 12. LoRa wireless transmission module (model AS62-T30).

The AS62-T30 model conducts wireless communication using the Universal Asynchronous Receiver/Transmitter (UART) transmission method. As indicated in Fig.13. , the use of simple and convenient wiring greatly reduced wire loss and maintenance difficulties, providing more flexibility in tests and installations.

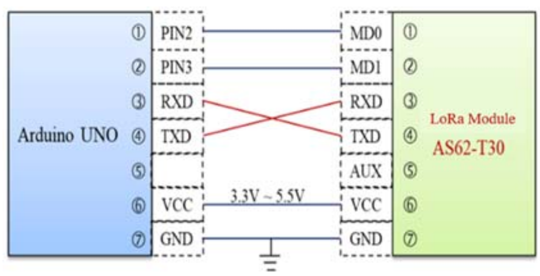


Fig. 13. AS62-T30 and UART

Today’s wireless sensor networks have given rise to a massive IoT network that uses popular communication protocols such as Zigbee, Bluetooth, and Wi-Fi. Although these communication protocols are indispensable and each possess their own advantages, they are limited by distance, power consumption, cost-related problems, and government regulations. LoRaWAN, which is a wireless network that features low power consumption and long-distance capability, was invented to solve these problems. This study used LoRa as the communication technology to develop its system after considering current market conditions and possibilities for future development. The flowchart for communication transmission and reception tests is displayed in Fig. 14.

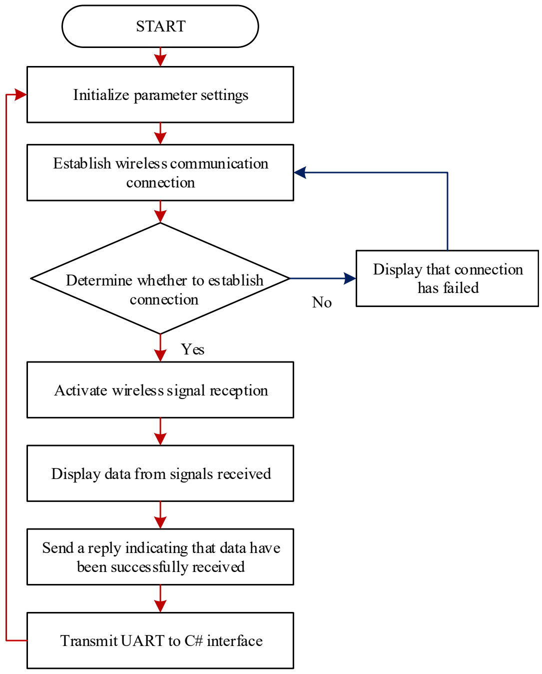


Fig.14. LoRa communication transmission and reception flowchart.

Fig. 15. The campus map at Kun Shan University

Research lab I4301 at Kun Shan University measures approximately 430 × 420 m and is located on the third floor of the university's College of Information Technology (marked by the purple star on the map). Installed at this location is a LoRa transceiver base station that performs signal transmission and reception to test the communication coverage distance.

- Areas marked in blue (Fig. 15. indicate areas with favorable and smooth signal reception where both the transmitting and receiving parties can receive and return data at the right time.
- Areas marked in red indicate areas with poor signal reception where neither the transmitting nor receiving parties could receive data promptly or at all.

The wireless transmission range of the LoRa module used in this study covered almost the entire campus. Although many locations in areas filled with buildings demonstrated poor signal, the overall penetration and coverage of the system outperformed those of other types of wireless communication technology. Additionally, the proposed system employed in this did not require the construction of relay points, which reduced installation costs. However, it is necessary to use a repeater to extend the transmission coverage when the end sensor node is allocated in a wilder area or an urban crowded with more high-rise buildings. Usually, a city is fulfilled with high-rise builidings, and such builidings exactly impact the delivery of LoRa pakckets. Therefore, a LoRa repeater (Liu et al., 2021) should be employed in this proposed system to prevent the loss of LoRa packets due to shielding of building blocks or power loss incurred by the transmission distance.

The repeater has been proved to extend the transmission coverage (Liu et al., 2021). Under normal conditions, one repeater is placed between the end node and the gateway as show in Fig. 16. In a environment with a complex topography or crowded tall buildings, two or more re`peaters are necessary to assure the delivery of LoRa packets. Under such a condition, two or more repeaters need to be placed between end node and gateway in order to extend the transmission range (shown in Fig. 17.). However, this placement conducts another problem which is called deadlock. In Fig.17, Repeater 1 reproduces the packets sent by end node and transmits the ones. While Repeater 2 receives the reproduced packets, Repeater 2 will reproduce the packets and then transmit them. Therefore, the packets sent by Repeater 2 will not only reach the gateway but also return to Repeater 1. It is obvious the endless reproduction and transmission of the same packets between two repeaters will happen. To solve the problem aforementioned, a smart working flow is employed in the implementation of the proposed system using repeaters.

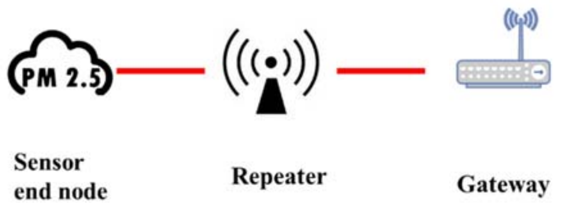


Fig. 16 Placement of one repeater

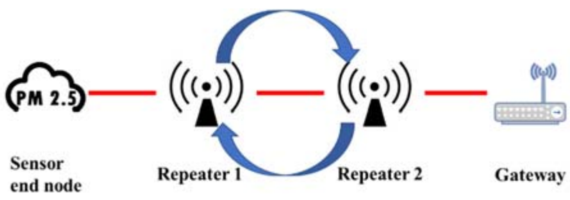


Fig. 17. lacement of two repeaters

The repeater employed in this system is composed of a ESP8266 SoC and a LoRa module based on SX1278. The working flowchart is as Fig.18 in which the key point to solve the deadlock problem is to check whether the received packets are redundant or not before the repeater reproduces and transmits them. The repeater will discard the packets which had been reproduced and only reproduce the new received packets.

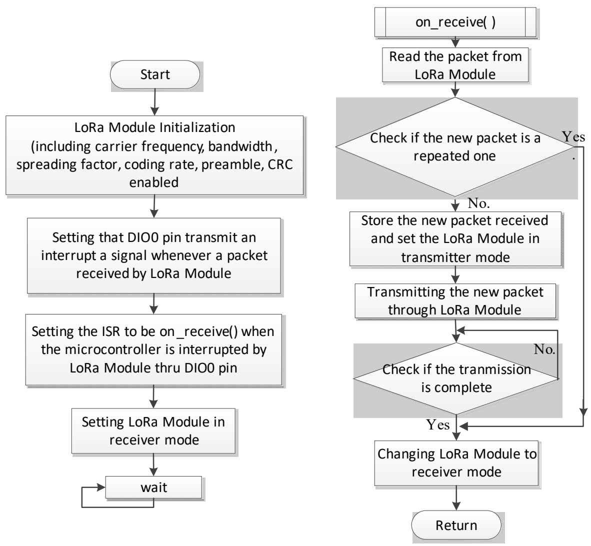
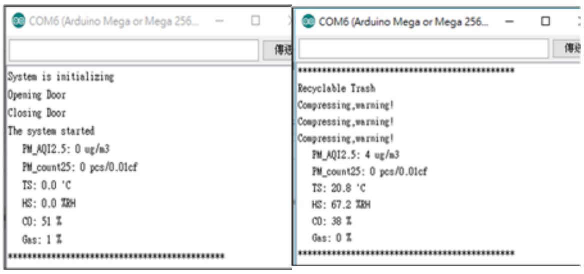


Fig. 18. Working flowchart of a smart repeater

EXPERIMENTAL SECTION

Sensor data obtained by the various sensors of the system are collected by the LoRa node and uploaded onto the LoRa gateway for data analyses. Subsequently, data are transmitted to a monitoring computer through UART transmission and displayed on a Visual C# graphical interface, which enables convenient access to information channels for users. Users can also query records previously stored in the cloud database. Fig. 19. presents the LoRa node receiving data, which includes environmental data, sorting system compression status, status of the sorting system insertion point (i.e., whether it is open or closed), and the garbage can level (i.e., whether it is full).



(a) (b)

Fig. 19. LoRa node receiving data: (a) status of the sorting system insertion point and environmental sensor values (b) sorting and compression status and environmental sensor values.

Monitoring Screen of the System

The monitoring screen of the system consists of the main screen and subscreens for each area, in which the main screen displays sensor data such as temperature, humidity, CO_1, and $PM_{2.5}$. Sensor data that exceed the preset standard values turn red. As indicated in Fig. 20., the main screen can display six types of sensor data. When the interface receives a notification that a particular garbage can is full, the garbage level status changes immediately and the green light signal turns bright red, reminding users to clean the garbage can.

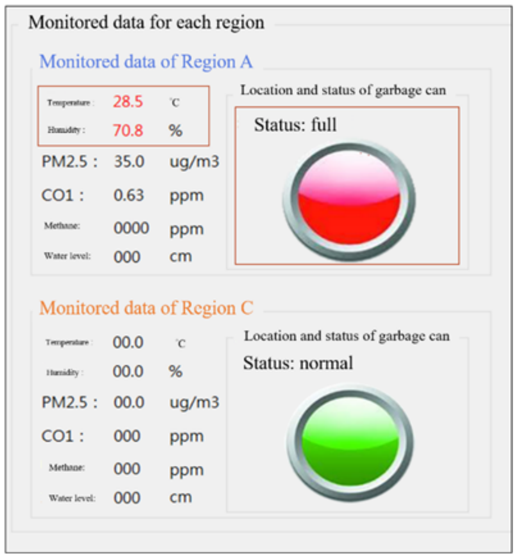


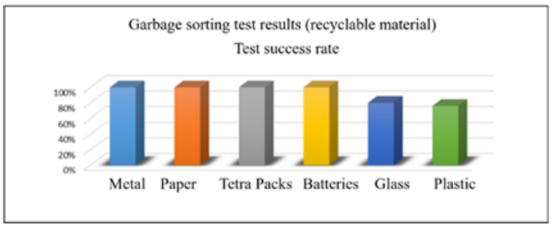
Fig. 20. Main screen of the monitoring interface.

Sorting Test Results

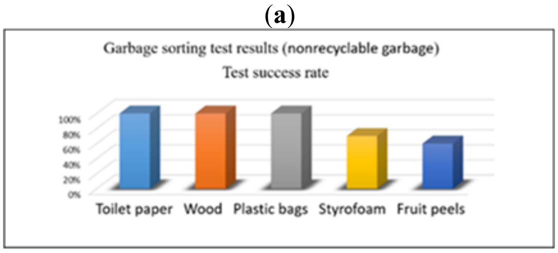
Until now most waste is sent to incinerators for destruction and then buried. Thus, if recyclable material is not recycled prior to shipment to incinerators, the incinerators are likely to become clogged and malfunction, thus shortening their service lives. Sorting garbage reduces garbage processing costs, prolongs incinerator service life, and facilitates the sustainable use of resources (Espinoza et al., 2020) (Table 3). Article 12 of the Waste Disposal Act stipulates that waste should be separated into three categories: recyclable material, compost, and general waste. Accordingly, this study adopted the same waste categories specified by the Environmental Protection Administration for detection analyses. The analytical results are presented in Fig. 21.

Table 3. Recycling percentage and benefits.

Material	Percentage in relation to overall materials	Benefits of recycling
Paper	26%–27%	Can save approximately 75% of energy and 50% of water and reduce air pollution by 75%–90%
Plastic	17%–21%	Can be used to produce new products such as bathtubs, plastic bags, artificial carpets, and apparel accessories, extending the service lives of burying facilities
Iron and aluminum	4%–8%	Can be repeatedly recycled and reused; recycled aluminum can save 95% of energy
Glass	4%–8%	Can be recycled and processed to manufacture building materials such as glass, asphalt, floor tiles, wall tiles, and landscape stones
Compost	10%–35%	By not mixing compost with garbage, the moisture and chlorine content of the garbage can be reduced, prolonging service life and enabling more effective waste incineration



(a)



(b)

Fig. 21. Garbage sorting test success rate results: (a) recyclable material (b) nonrecyclable garbage.

DISCUSSION

Improve the Sensor Data Collection Interface

Considering that a C# graphical interface is unable to support garbage collection if the garbage collection areas increase in size, an Open Street Map-based interface can be used to display the locations of recycling equipment in each region. The collected data can be uploaded to the Thing Speak website and the jsoup Thing Speak messages can be used to enter databases, from which Open Street Map will be utilized to display real-time data.

Expand the Functions of Collection Equipment

For schools and private residences, the system introduced in this study can be combined with RFID management systems to limit the amount of garbage deposited and calculate the average quantity of garbage deposited per person in each area for use in subsequent management and statistics.

Environmental Monitoring Systems in Township Areas

This study helped local schools and district and village offices to construct environmental monitoring systems using environmental parameters. As illustrated in Fig. 22. , this study helped them create platforms for environmental testing. Temperature, humidity, and $PM_{2.5}$ sensors were established, and various environmental monitoring mechanisms (e.g., for ultraviolet measurement and toxic gas detection) were installed to provide information for schools to reference when planning outdoor courses. The data collected by environmental monitoring mechanisms were transmitted to the network access points of elementary and junior high schools as well as district and village offices through wireless transmission, after which data were transmitted to database servers (set up in the schools) through the Internet. Concurrently, web servers were used to display local environmental quality-related data to enable students and the local public to query the quality of their environment at any time using mobile or computer devices.

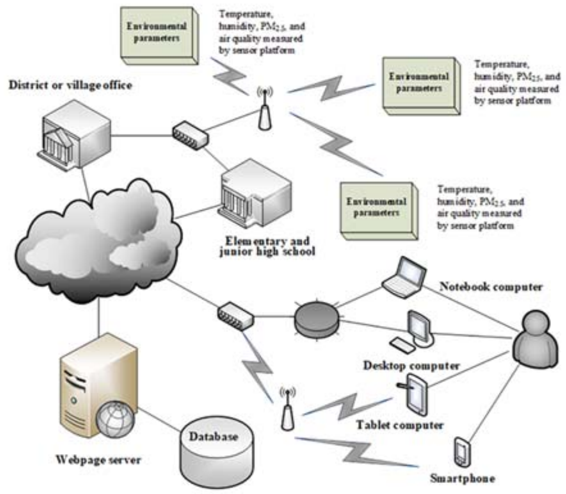


Fig. 22. Environmental monitoring system.

CONCLUSIONS

This study reviewed research on environmental monitoring and smart garbage sorting systems based on LoRa wireless transmission technology and discovered that studies conducted in Taiwan have focused on incorporating smart recycling systems into future smart city development, whereas studies conducted in other countries have focused on garbage-related big data statistics such as planning garbage collection routes (Chung et al., 2018). However, research has generally overlooked the key matter of "waste reduction and recycling." Therefore, this study introduced a garbage sorting system to change people's habits rather than passively developing a system based on their existing habits.

This study combined three fields of research: (a) system appearance and operating procedures were designed using methods in Kansei engineering analysis to develop an innovative and interdisciplinary system that uses electrostatic capacitance-type proximity switches to achieve efficient recycling. Compared with systems that use identification methods such as image recognition and radio-frequency identification, this system reduced related costs and space requirements and facilitated the recycling process. However, the system could still be improved in terms of system precision. (b) The automated garbage compression device developed in this study decreased the number of times that garbage was required to be collected, which lowered labor costs. Additionally, the incorporation of environmental sensor systems increased the space usage rates of garbage cans and rendered the garbage cans more convenient and attractive for public use. (c) The use of a LoRa wireless sensor network, which is a communication-based system, lowered network distribution costs, maintenance costs, and power consumption compared with the use of common wireless transmission modules, thereby providing local regions with a low-cost, low-power-consumption, and highly efficient garbage sorting system with optimized environmental monitoring capability.

REFERENCES

Agassi, T. N., Ushada, M., and Suyantohadi, A., "Industrial design of Kansei Engineering-based Sensor for industry," *Manag. and Prod. Eng. Rev.,* Vol.11, pp.13-22 (2020)

Aoudia, F. A., Gautier, M., Magno, M., Le Gentil, M., Berder, O., and Benini, L., "Long-short range communication network leveraging LoRa™ and wake-up receiver," *Micr. and Micros.* No.56, pp.184-192 (2018).

Cerchecci, M., Luti, F., Mecocci, A., Parrino, S., Peruzzi, G., and Pozzebon, A., "A low power IoT sensor node architecture for waste management within smart cities context," *Sens.* Vol.18,No.4, pp.1282 (2018).

Chung, C.Y., Peng, I.T., and Yeh, J.C., "Intelligent classification and environment monitoring system combined with LoRa wireless transmission technology," *In 2018 International Symposium on Computer, Consumer and Control (IS3C)*, pp. 173–177 (2018).

Cotet, C. E., Deac, G. C., Deac, C. N., and Popa, C. L., "An innovative industry 4.0 cloud data transfer method for an automated waste collection system," *Sust.* Vol.12, No.5, pp.1839 (2020).

Cruz, N., Cota, N., and Tremoceiro, J., "LoRaWAN and Urban Waste Management—A Trial," *Sens.* Vol.21,No.6, pp.2142 (2021).

Culgin, K., Mangan, D., and Pool, J., "Benefit-cost analysis of BigBelly solar trash compactors in the sity of seattle parks," *Evans. Sch. Rev.,* Vol.3 ,No.1, pp. 50-61(2013).

Espinosa, Á. V., López, J. L. L., Mata, F. M., and Estevez, M. E. E., "Application of IoT in Healthcare: Keys to Implementation of the Sustainable Development Goals," *Sen.,* Vol.21, No.7, pp.2330 (2021).

Espinoza, H., Kling, G., McGroarty, F., O'Mahony, M., and Ziouvelou, X., "Estimating the impact of the Internet of Things on productivity in Europe," *Heli.* Vol.6, No.5, e03935 (2020).

Espuny, M., Neto, A. F., da Motta Reis, J. S., dos Santos Neto, S. T., Nunhes, T. V., and de Oliveira, O. J., "Building new paths for responsible solid waste management," *Env. Mon. and Ass.,* Vol.193, No.7, pp.1-20 (2021).

Feroz, A. K., Zo, H., and Chiravuri, A., "Digital transformation and environmental sustainability: A review and research agenda," *Sust.* Vol.13,No.3,pp. 1530 (2021).

Gan, Y., Ji, Y., Jiang, S., Liu, X., Feng, Z., Li, Y., and Liu, Y., "Integrating aesthetic and emotional preferences in social robot design: An affective design approach with Kansei Engineering and Deep Convolutional Generative Adversarial Network," *Int. Jol. of Ind. Erg.*, No.83, pp.103128 (2021)

Gutierrez, J. M., Jensen, M., Henius, M., and Riaz, T., "Smart waste collection system based on location intelligence," *Proc. Com. Sci.,* Vol.61, pp.120-127 (2015)

Hoornweg, D., Bhada-Tata, P., and Kennedy, C., "Environment: Waste production must peak this century,"*Nat. News.,* Vol.502, No.7473, pp.615(2013).

Liu, Jun-Ting, Chung, Chun-Yen, and Jhou, Jhih-Syue., "Implementation and investigation of a repeater employed in low power long-range wide area network", *2021 Workshop on Consumer Electronice* (2021).

Medvedev, A., Fedchenkov, P., Zaslavsky, A., Anagnostopoulos, T., and Khoruzhnikov, S., "Waste management as an IoT-enabled service in smart cities. In Internet of Things," *Smart Spaces, and Next Generation Networks and Systems*, pp.104-115 (2015).

Shen, C. C., "Aspects of Taiwan trash growth with the population," *Eng. Sci. and Mang.* Jol, No.2, pp.121-132 (2008).

Sohag, M. U., and Podder, A. K., "Smart garbage management system for a sustainable urban life: An IoT based application," *Int. of Thi.*, Vol.11, pp. 100255(2020).

Yu, H.Y., "Exploration of Types, Forms, and Installation Environment for Public Trash Can–A Case of Taipei Expo Park," *Thesis for Master of Design, Department of Nidustrial Design*, (2016).

具智慧物聯網設計之垃圾分類管理系統

鐘俊顏

崑山科技大學電腦與遊戲發展科學

葉仲超

崑山科技大學時尚展演事業系

摘 要

隨著人們對生活品質要求的提高，產生的垃圾量也大幅增加。本研究目的為提出一種可用於多種場域的資源回收分類設備，協助解決垃圾分類不均勻的問題。本研究以 LoRaWAN 通信網路建置一個提供自動化垃圾桶操作、環境監控和圖形監控界面的系統。本研究主要貢獻為系統使用靜電容式近接感測器來區分垃圾桶中存放的垃圾類型。此外，透過搭配嵌入式馬達可使垃圾桶執行自動打開和關閉、分類垃圾、啟動自動垃圾壓縮、監控水位及發出警告等功能，更採用 C#語言編寫的圖形化監控界面，提醒使用者進行垃圾清理。