

Article

Smart Trash Bin Model Design and Future for Smart City

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Abstract: The trash disposal system, using standard trash bags, has been adopted by the government of the Republic of Korea (ROK) for more than two decades. This has caused a sanitary problem, as well as some secondary pollution. It is possible to solve this problem by deploying more manpower, but considering the manpower and maintenance costs that impose a heavy burden on the local governments who are experiencing tight financial situations, it would not be feasible. Thus, an Internet of Things (IoT)-based Smart Trash Separation Bin model that can reduce the cost of trash separation work has been proposed in this paper. The three efficient designs that respectively use a sensor, image processing, or spectroscopy technology are presented. These IoT-based designs can bring significant merit to reducing the manpower costs, as well as the administrative cost involved.

Keywords: smart energy building; trash bin; IoT; smart trash bin; smart trash bin model



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1. Introduction

The Republic of Korea (ROK) government has used standard trash bags since it implemented the trash commission system in 1995. Since the implementation of this system, trash has been disposed of using standard trash bags, but many people have been culprits of unauthorized dumping of household trash and business trash into street trash bins, in order to save on the cost of standard trash bags.

The Seoul Metropolitan Government tried to solve the problem by removing the street trash bins. However, although the trash bin was removed, the problem of illegal dumping of trash was still serious. Trash dumping damages the city's landscape and causes various problems, such as hygiene and odors.

As a result, trash bins were installed throughout as part of the establishment of the “Extension of Street Trash and Management Improvement Plan” in 2013. Installing additional trash bins led to the cost of installation and management burdens on the local governments. The Seoul Metropolitan Government tried to reduce this burden, by offsetting some costs, but this did not solve the budget problems of all the local governments. Table 1 shows the number of trash bins and the number of sanitation workers in the Seoul Metropolitan Government each year [1–3].

Table 1. The Number of Trash Bins and Sanitation Workers in Seoul.

Year	Number of Trash Boxes	Sanitation Workers
1995	7607	8683
2007	3703	3256
2012	4724	3281
2013	4476	2996
2014	4884	2799
2015	5138	2563
2016	5640	2466
2017	5939	2239

Since 2018, it has been difficult to find bus stops and subway stations without trash bins, as disposable cups and others cannot be taken onboard the city bus [1]. If the number of trash cans is increasing, poor management can cause hygiene problems and problems that ruin the city's landscape, so regular management is necessary.

On Naver, a ROK portal site, we collected the titles of 10,000 news articles under the keywords, “Smart Trash Bin”, to turn the 30 top morphs into a Word Cloud and plot. Figure 1 shows the result of visualizing the top 30 words into a plot, and Appendix A Table A1 shows the result of the Korean-English translation of the top 30 words.

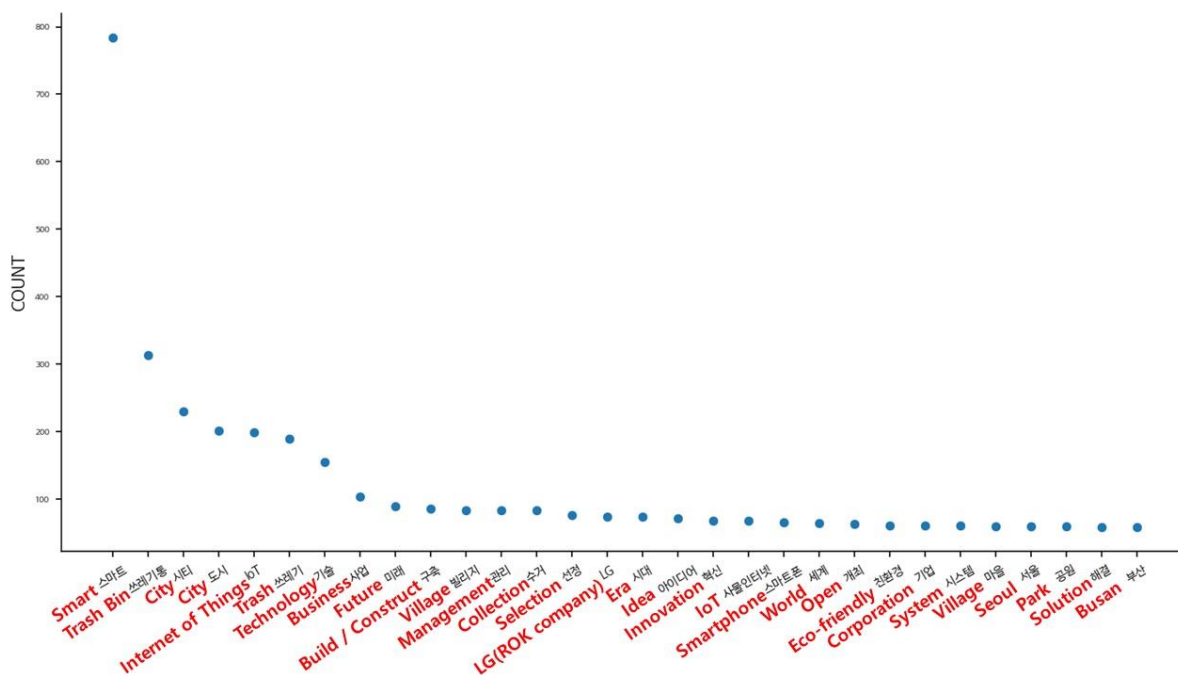


Figure 1. Plot for the Keyword “Smart Trash Bin”.

The ROK is pushing to install smart trash bins, starting with the Seoul Metropolitan Government, to build a smart city, and is holding various related contests. Due to this, we designed a smart trash bin model that can be installed in ROK.

In the United States (US), detailed laws on recycling apply differently from state to state. However, according to the US Environmental Protection Agency (EPA)’s “National Framework for Advancing the US Recycling System”, recycling is a great benefit to the US economy and it encourages recycling [4]. As a result, New York City (NYC) has been discussing the hygiene and traffic problems of excessive trash bags in the pedestrians’ way [5], and Chicago was dealing with most of its trash in the past with landfills and incineration but has now been using new trash bins since 2007 [6]. There is a lot of effort going on in the states.

Europe has been interested in recycling waste in the past. In 1994, the European Union (EU) was instrumental in encouraging more effective waste management policies, and since then countries in the EU have made various efforts to achieve annual goals. Thanks to this interest, research on waste disposal technology is also actively being carried out, and new technologies are being introduced quickly [7,8].

Therefore, this paper proposes an automated smart trash separation bin to minimize the management costs associated with street bins and to help citizens practice better recycling methods.

The rest of this paper is organized as follows. Section 2 describes the Smart Trash Bin model design, trash image classification, trash classification using spectroscopy, and related work. Section 3 presents a Smart Trash Bin model design and discussion. Section 4

discusses the analysis result based on a performance evaluation. Finally, Section 5 presents our conclusion and future work.

2. Related Research

Smart Trash Bins have been researched since the 1990s. It was in 2013 that the word “Smart Trash Bin” first appeared in a paper based on a Google scholarly search. Since then, the number of papers has increased, especially in 2017, they quadrupled from the previous year, and 82 were found from 2020. Table 2 shows the number of papers searched under Smart Trash Bin and “Smart Trash Bin” in Google’s scholarly search. Smart Trash Bin was used to find comprehensive research, and “Smart Trash Bin” was used to search for papers directly mentioning Smart Trash Bins.

Table 2. The Number of Papers with the Keywords Smart Trash Bin and “Smart Trash Bin”.

Year	Smart Trash Bin	“Smart Trash Bin”
2013	998	4
2014	1080	2
2015	1070	6
2016	1140	5
2017	1250	20
2018	1280	32
2019	1460	45
2020	1334	82

Fauziah et al. [9] reviewed Google scholarly search and ScienceDirect papers on Smart Trash Bins from 2015 to 2019. R. P. Chandra et al. [10] analyzed the literature and surveys on the recognitions of bins part of smart trash bin projects and concluded that smart trash bin projects could affect people’s interest in disposing of trash in its place and the community’s way of treating trash. Henita Rahmayanti et al. [11] in their research, applied smart trash bins to schools, which would be an educational tool to help students understand the type of trash. P Haribabu et al. [12] analyzed mobile applications connected to smart trash bins to achieve Smart City goals and save human resources.

Ujwala Ravale et al. [13] designed a solid trash classification management system. The system delivers trash to recycling centers and biodegradation centers depending on the type of trash. Oscar Karnalim et al. [14] proposed a system that provides smart bins and trash disposal trackers to pursue both the objectives of disposal of trash in appropriate locations and reduction of trash. Slamet Kristanto Tirto Utomo et al. [15] consider security and reward systems to be problems in public trash bins, and to compensate for them, propose a blockchain-based reward system consisting of a compensation system for using smart trash bins, wearable payment devices, and Ethereum smart contracts. Feisal Ramadhan Maulana et al. [16] mentioned an information technology-based trash management system that handles trash management problems and developed a prototype of a trash management system for solid trash that focuses on the separation and trash collection stages.

Related research was divided into three sections: “Smart Trash Bin Model Design”, “Trash Image Classification”, and “Trash Classification Using Spectroscopy” related to our proposed model.

2.1. Smart Trash Bin Model Design

The research on smart trash bin models consists of using Internet of Things (IoT) technology and various sensors to monitor smart trash bins and send status information.

Hamza Sohail et al. [17] proposed an Intelligent Trash Bin (ITB). The proposed model has Trash Level, Flame Alert, and Live Map functions, which can be checked through an Android application. It also has a Trash Collection efficiency function, which, for example, identifies filled bins and the directions to the bins through the application. Another Smart Trash Bin proposed by Ankit Mishra et al. [18] has various functions. It is different from

other models in that it provides rewards using a Radio-Frequency Identification (RFID) card and profits from advertising.

Tae-Kook Kim [19] proposed a smart trash bin to check trash levels, compress the trash, and check and control the trash bin through an Android application.

Mohd Helmy Abd Wahab et al. proposed another Smart Trash Bin. The proposed model is a simple model with an Auto-Open/Close function, but it is different from other models in that it gives rewards according to the type of trash by weighting it and has an online platform to check and manage rewards [20]. The model proposed by S. Vinoth Kumar et al. can check the trash bin and is unusual for measuring the weight of the trash using a Force Sensor [21].

Fady E. F. Samann [22] proposed a model design of an intelligent trash bin that uses an ultrasonic sensor, a Global System for Mobile Communication (GSM) module, a gas sensor, and a Passive Infrared (RIP) sensor. The model proposed by Steffy Thankam Wilson et al. [23] can check whether the smart trash bin is full or smells bad. Table 3 shows studies related to smart trash bin model designs.

Table 3. Studies Related to Smart Trash Bin Model Design.

Author	Component	Function
Hamza Sohail et al. [17]	Ultrasonic Sensor Flame Sensor GPS	Trash Level Flame Alert Live map Android Application Trash Collection efficiency
Ankit Mishra et al. [18]	Wi-Fi Module Ultrasonic Sensor RFID reader Infrared Sensor LED Screen	Auto-Open/Close Function Trash Level Send Message to authority Provide Reward Profit from advertising
Tae-Kook Kim [19]	Ultrasonic Sensor Bluetooth Direct Current (DC) motor	Trash Level Trash Compression Android Application
Mohd Helmy Abd Wahab et al. [20]	Digital weight scale RFID Motor LCD	Auto-Open/Close Function Provide Reward Online Platform
S. Vinoth Kumar et al. [21]	Ultrasonic Sensor Force Sensor GPS	Trash Level Weight Measure of Trash Trash collection efficiently
Fady E. F. Samann [22]	Ultrasonic Sensor GSM Module RIP Sensor Speaker Solar Cell Panel	Trash Level Send Short Message Service (SMS) Play Audio When People Approach Power Bank Self Power
Steffy Thankam Wilson et al. [23]	Ultrasonic Sensor Gas Sensor Wi-Fi Module	Trash Level Bad Smell Alert Android Application

2.2. Trash Image Classification

Along with the research on smart trash bin models, there are also studies on trash classification for segregated collection. Many studies have classified trash images using various machine learning algorithms, including the Convolutional Neural Network (CNN).

Irfan Salimi et al. [24] used a Support Vector Machine (SVM) for trash detection and classification to apply to a smart trash bin robot. Mandar Satvikar experimented with

Support Vector Machine (SVM), Random Forest (RF), eXtreme Gradient Boosting (XGBoost), k Nearest Neighbour (kNN), and CNN models for trash classification tasks, with 65%, 62%, 70%, 52%, and 89% efficient performance, respectively, and showed that CNN performs well on trash classification tasks [25].

Cenk Bircanoğlu et al. [26] proposed RecycleNet for trash classification tasks and conducted comparative experiments with various models such as the Residual Neural Network 50-layer (ResNet50). ResNet50 is also called the Deep Residual Network and has won the ImageNet Large-Scale Visual Recognition Challenge (ILSVRC). Among them, ResNet50 is the most commonly used model in residual network architectures. RecycleNet is a model that changes the connection pattern of skip connections within dense blocks in the Densely Connected Convolutional Networks (DenseNets) to improve predictive performance. DenseNets is one of the more efficient deep CNN architectures because it contains shorter connections between the layers close to the inputs and outputs, also called the densely connected convolutional networks. RecycleNet and ResNet50 achieved 75% and 81% accuracy in the trash classification task, respectively.

He-Qun Yang et al. proposed a trash classification model, RecycleTrashNet [27]. The proposed model was built on a deep residual network and used composite polling, a new polling method for building network architectures.

Deep Neural Networks for Trash Classification (DNN-TC) proposed by Anh H. Vo et al. are based on Aggregated Residual Transformations for Deep Neural (ResNeXt) [28]. ResNeXt was introduced as Computer Vision and Pattern Recognition (CVPR) in 2017 by Saining Xie et al. [29]. ResNeXt has a new factor called “cardinality” (the size of the set of transformations), in addition to the dimensions of depth and width. The authors have shown on various datasets that ResNeXt can be introduced to improve accuracy.

Bernardo S. Coat et al. approached trash classification using AlexNet and VGG-16 [30]. AlexNet is neural network architecture using CNN and won the 2012 ImageNet competition. VGG-16 is a significantly accurate CNN architecture and also achieved state-of-the-art accuracy in the ILSVRC classification task. Table 4 shows studies related to Trash Image Classification.

Table 4. Studies Related to Trash Image Classification.

Author	Model	Classify Trash	Accuracy
Irfan Salimi et al. [24]	SVM	Organic, non-organic, non-trash	82.7%
Mandar Satvilkar [25]	CNN	Cardboard, glass, metal, paper, and plastic	89%
	XGBoost		70%
	SVM		65%
	RF		62%
Cenk Bircanoğlu et al. [26]	kNN	Paper, glass, plastic, metal, cardboard, trash	52%
	ResNet50		75%
He-Qun Yang et al. [27]	RecycleNet	Cardboard, glass, metal, paper, plastic, and other trash	81%
Anh H. Vo et al. [28]	RecycleTrashNet	Glass, paper, cardboard, plastic, metal, and trash	88%
Bernardo S. Coast et al. [30]	DNN-TC	Glass, metal, paper, and plastic	94%
	AlexNet		91%
	VGG-16		93%

2.3. Trash Classification Using Spectroscopy

Spectroscopy is the study of measuring and analyzing the absorption or radiation of light by dividing it into a spectrum using a spectrometer. Among them, FT-IR spectroscopy provides structural information on the molecular properties of a wide range of compounds

with two generations of infrared spectroscopy, which made a lot of progress in the 1970s, and has the advantage of enabling nondestructive analysis in room temperature and room pressure environments [30].

FT-IR spectroscopy is used in various fields such as olive oil and wine analysis. In particular, much research has been conducted in the field of waste management and analysis of biological and chemical treatments during the waste disposal process [30–33].

3. Model Design

3.1. A Design of the IoT-Based Smart Trash Bin

The proposed smart trash bin that was adopted is shown in Figure 2. As for the mechanism, a label indicating the type of recyclable material is scanned by the camera attached to the slot. If it confirms that the trash is recyclable, the trash cover will be opened to drop the trash down into the storage. If there is no label to be read, the type of trash will be identified by the spectroscope and image classification and stored based on the resulting calculation value. Depending on its value, when the trash approaches the proximity sensor attached to each recycling bin slot, the slot opens and enters the space. The degree of trash bin filling can be checked through the displacement sensor. When the trash bin is 80% full, it sends an alarm to the central server using a communication module.

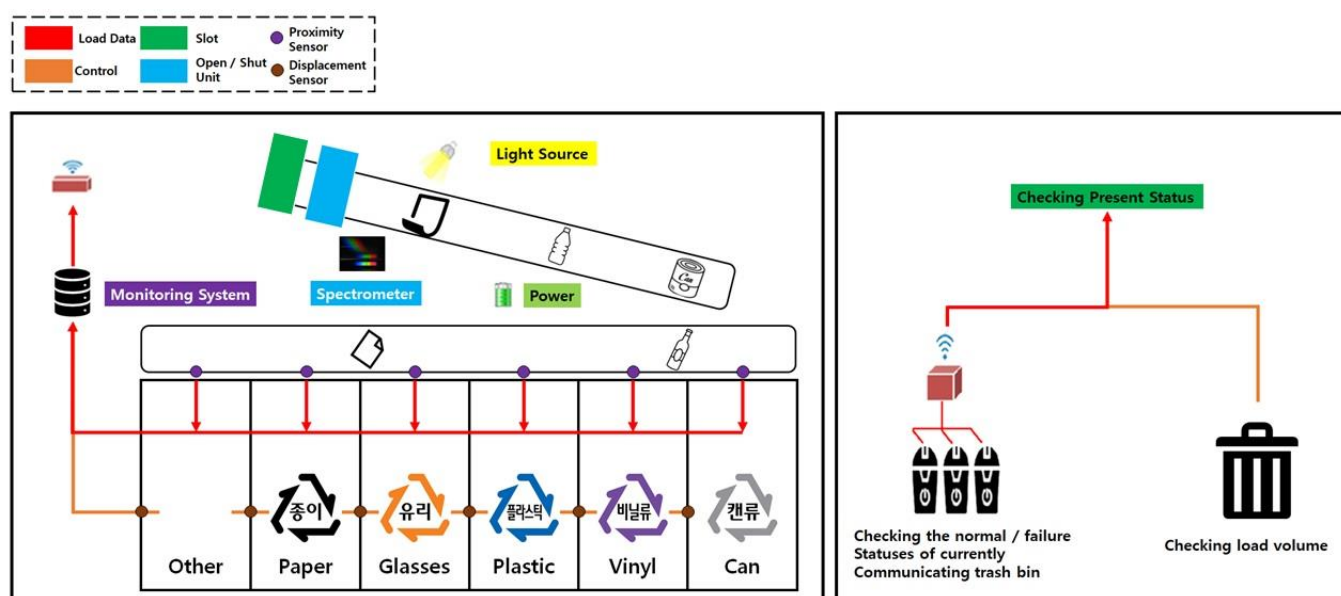


Figure 2. A design of the Smart Trash Bin.

The operation of the Smart Trash Bin starts with the Check Status and Send Alarm processes. First, when a trash bin user approaches the trash bin, the trash bin checks its own status and then sends an alarm to the server, or shows a message to the user about its status.

When it is decided whether to put the trash in, the trash bin will proceed with recycling label recognition through photography. In the absence of label recognition, spectroscopy and image classification tasks determine the type of trash. After that, separate collection is carried out according to the type of trash. Figure 3 shows the Flowchart of Smart Trash Bin operation processes.

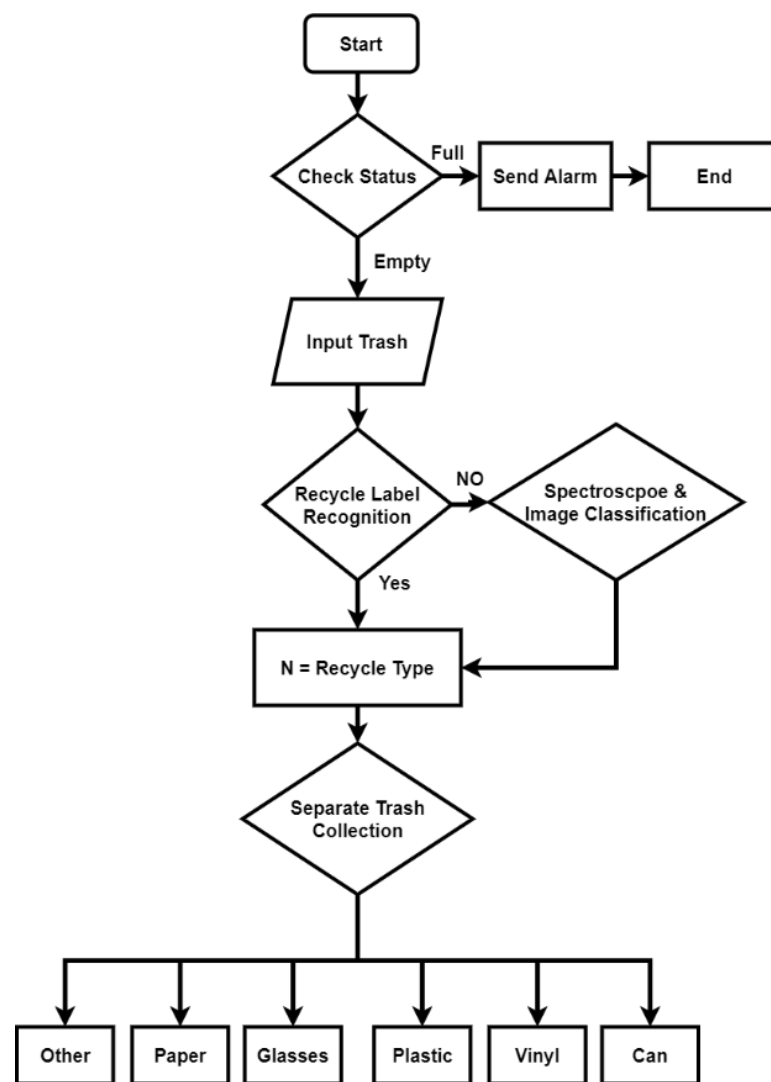


Figure 3. A flowchart of Smart Trash Bin operation processes.

Figure 4 shows the pseudocode of the Smart Trash Bin and a series of operational processes. According to the pseudocode, one must check the status of the trash bin before putting the trash in to see if it can receive the trash. It sends an alarm to the server, telling the user that the trash bin is full. If there is space, one can put the trash in the trash bin. First, make sure that there is a recycling label on the trash. As soon as the label is confirmed, it enters the separation collection process, and if not, it checks the type of trash through spectroscopy and image classification. If the type of trash is confirmed through this process, it will determine whether it is recyclable and collect it separated into recyclable waste (paper, plastic, cans, glass, and vinyl) and non-recyclable trash.

```

Smart_Trash_Bin(Trash, Trash_Bin):
  Check_Status(Trash_Bin)
    if Trash_Bin == full then
      Send Alarm
    End
  else
    Input Trash

    if Recycle_Label in Trash then
      N = Recycle Type
    else
      N = Spectroscopoe & Image Classification(Trash)
    Separate_Trash_Collection(N)

```

Figure 4. Pseudocode of the Smart Trash Bin.

First, we reviewed the adequacy of our methods of distinguishing the materials with each sensor after selecting five companies in the ROK. The problem was that it was difficult to find suitable sensors for the applications in our separation/collection system. We plan to apply an image processing technique and a spectroscope for the system implementation instead of the sensors that exhibit a high rate of error.

Similar to human eyes, the image processing technique distinguishes various situations and objects by using a camera linked to the computer. This technique is developing rapidly, as artificial intelligence has become one of its supporting elements.

Second, the merit of this technique is that the images and words (specified as “Can”, “Plastic”, “Vinyl”, or “Glass”) on the trash labels can be recognized with a low-cost camera. These will be used to determine what the materials are made of, with relatively high accuracy and efficiency. If this system is combined with a low-level spectroscope, which usually demonstrates a low reading accuracy, better results can be obtained, while maintaining a moderate cost.

Figures 5 and 6 show the image processing system + spectroscope. Spectroscopes have been mostly used in the field of science, but their application in the IoT-based trash bins was hardly considered in the ROK because of their high prices. However, the prices are becoming lower over time and they are currently used for various purposes and products.

For instance, they are being used by banks, airport immigration, and customs to check counterfeit bills, fake passports, and other imitation products. We attempt to identify the quality of materials by using the spectrum absorption rate of each element. In the design, a spectroscope was installed internally [34–37].

Uniquely, we used Fourier-transform infrared (FT-IR) Spectroscopy to classify trash. FT-IR spectroscopy uses the fact that absorption in the infrared region has different energy when each object receives energy (light). Therefore, a unique spectrum can be obtained for each component, which can be analyzed to classify trash.

We conducted an experiment to classify cans, plastic, glass, and paper using FT-IR spectroscopy at the cooperative research center (Dong Eui Univ., Busan, Korea). According to 2000 experiments, the trash could be correctly classified with 99.8% accuracy. Additionally, the center was able to calculate the percentage of each material within the trash.

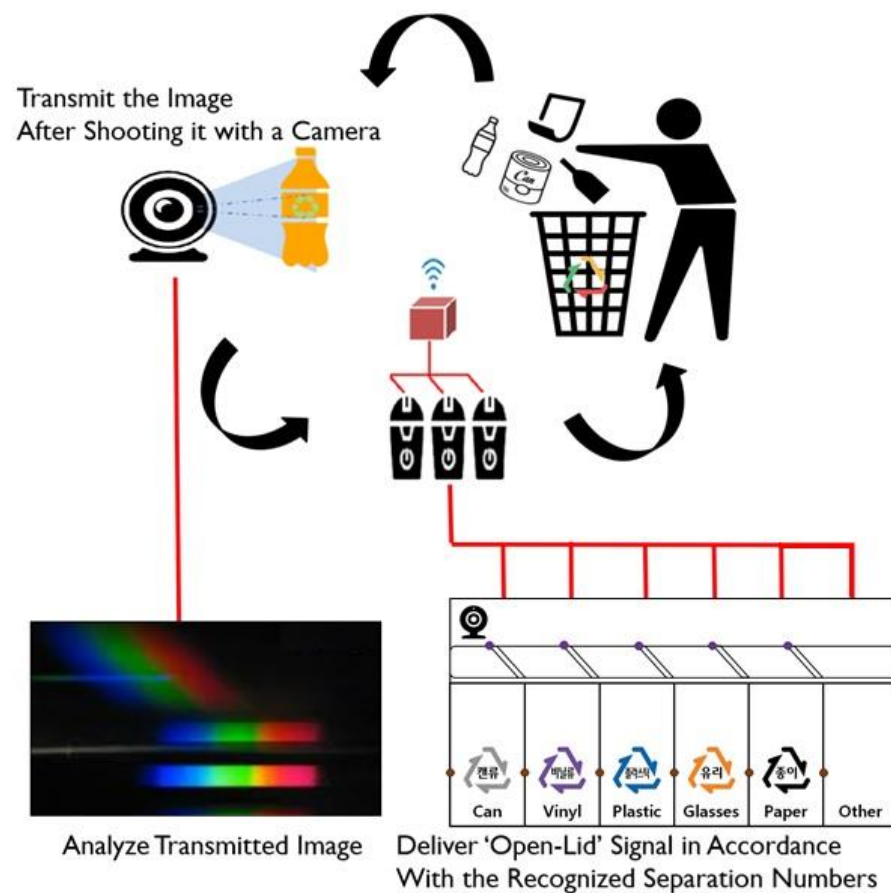


Figure 5. Solution (Image Processing System + Spectroscope) for future implementation.

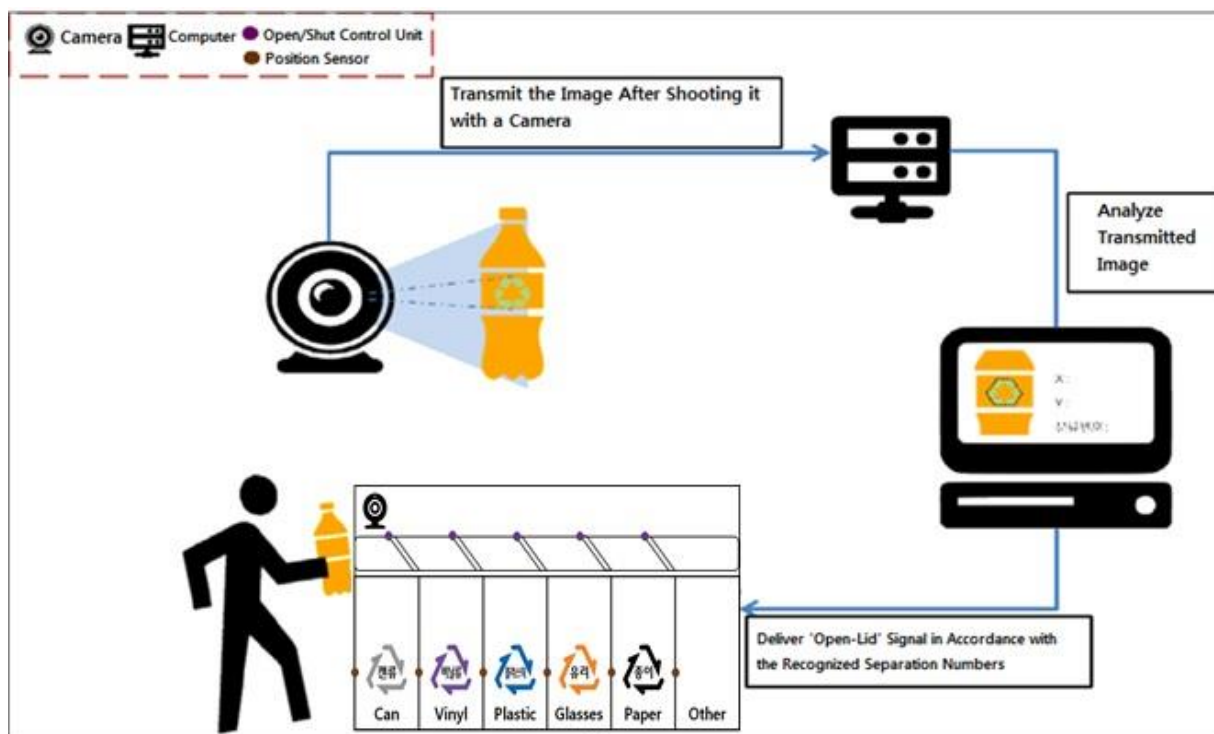


Figure 6. Design model processing process mechanism (Image Processing System + Spectroscope).

However, performance degradation occurred when adding vinyl to the experiment. So we included image classification in our proposed smart trash bin model. Also, the experiment was conducted inside the laboratory, not in the actual smart trash bin environment. Therefore, the introduction of spectroscopy into the actual smart trash bin model may result in lower classification results. To compensate for this, we tried to use spectroscopy and image classification at the same time for trash classification.

3.2. Expectation Effectiveness

The price of a spectroscope varies from a few hundred to millions of Korean won, depending on its accuracy level. The most suitable one for the system should be selected based on the application purposes, considering both the cost and the accuracy. Nonetheless, we find that the spectroscope is still an excellent piece of equipment for the system.

In particular, in ROK, smart trash bins that help urban landscape and hygiene are competitive because they can be financially supported by the Ministry of Environment.

The predicted expenditure saving by the local governments was estimated to be approximately 50 million won per sanitation worker in each year when the system has been adopted. Therefore, since there are roughly 2200 sanitation workers in the Seoul Metropolitan area, billions of won can be saved and used to increase the number of Smart Trash Bins on the streets and public areas to improve the urban environment.

4. Comparison with Other Cases and Performance Evaluation

Dr. Boomerang and CleanCube are the experimental products for the Korean domestic market developed by Ecosave and E-cube Lab, respectively. The following are their descriptions [35,36]. Dr. Boomerang by Ecosave in Figure 7 has a bar code reader that scans the bar codes printed on the cans or plastic products disposed of through the separate exclusive slots. The weight of each disposed item is calculated and converted to mileage, which will be returned to the user to be used as usable points for his/her transportation or cash-back cards. This unit had been used by the Seoul Metropolitan Government and test-operated at the Pedestrian-Friendly Street in front of Hongik University in the ROK.



Figure 7. Prototype Dr. Boomerang by Ecosave.

Figure 8 shows Dr. Boomerang currently on sale at Ecosave. Compared to previous products, miniaturization has been carried out, information that can be displayed through the display has diversified, and various functions have been added, such as advertising through receipts.

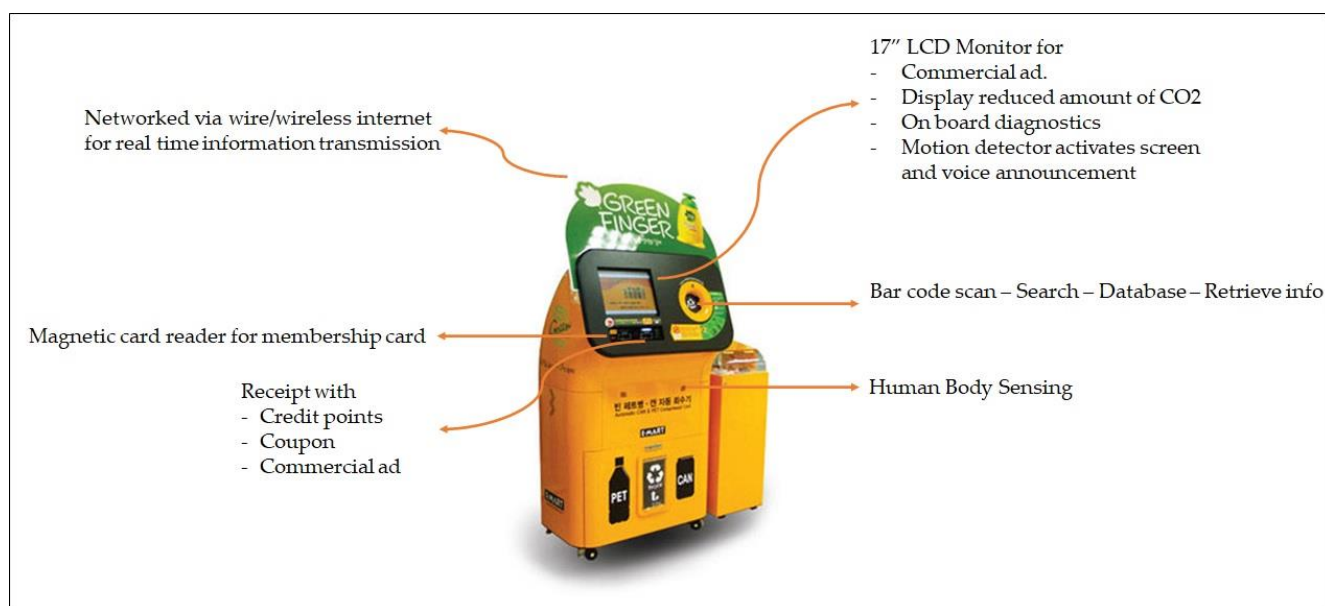


Figure 8. Dr. Boomerang by Ecosave.

The disadvantage of this product is that it does not distinguish between other materials without bar codes. Also, it is not feasible to store all the bar codes that will be able to distinguish between materials in its internal database (DB), and the accuracy cannot be guaranteed.

Meanwhile, CleanCube by E-cube Lab, in Figure 9, compresses the collected waste so that it can store more volume. The other advantages are that the unit does not require any separate wiring, as it utilizes solar power and, installed with monitoring software, it can check the current load, the remaining battery power, and the mechanical errors in real-time. However, while the unit's compression function may be helpful in reducing the manpower and costs, it lacks efficiency as the collected waste must be sorted out again following the recycling rules because all sorts of waste are compressed without any distinctions.



Figure 9. An experimental product by E-cube Lab.

The notable products in the global market are Puggedon. Puggedon [37] discharges a certain amount of animal feed at the bottom when the user puts the plastic trash into the slot. This machine is powered by solar energy. Its disadvantage is that only plastic is recyclable so it does not completely serve the purpose of recycling.

For the Trash Bin by Incom Recycle, Figure 10 shows the cash-back system [38] that compensates for the disposed recyclables, currently being used in Beijing and Shanghai. This service offers cash-back when one puts recyclables into the system.



Figure 10. The cash-back system for recyclables in Shanghai.

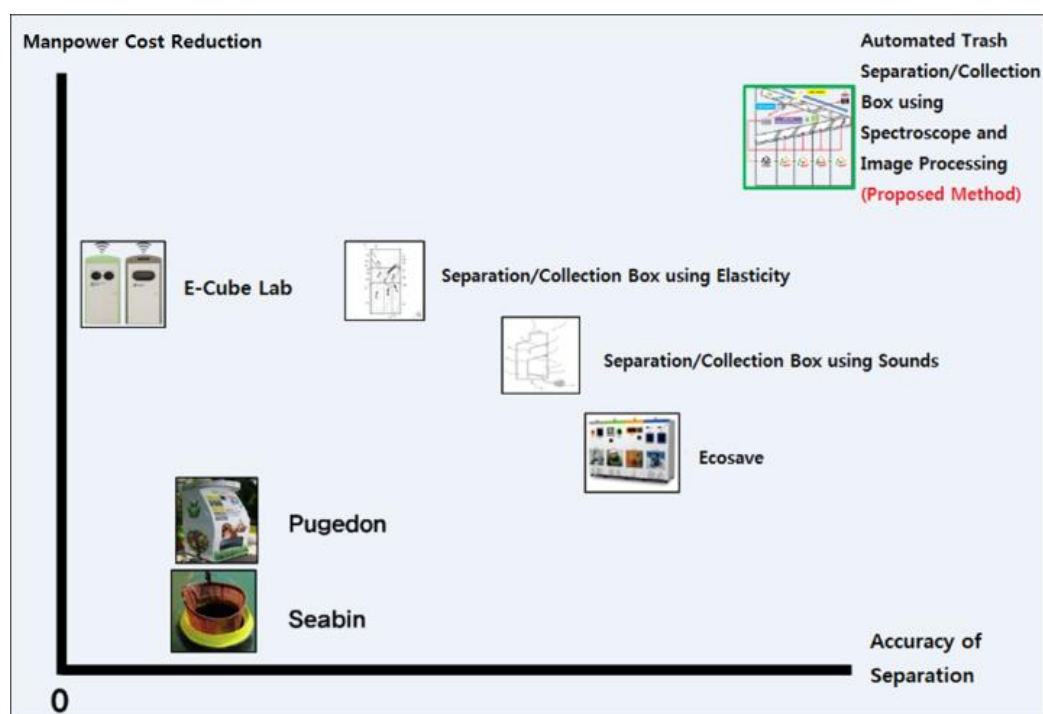
Founded in 2003, INCOM is one of China's second circular economy pilot units and standing directors of the China Packaging Federation. With China's special approval in 2006, INCOM established a polyester production line for food-grade recycled bottles. It can handle 50,000 tons, which is 2.2 billion trash PET bottles per year, and can produce 30,000 tons of recyclable PET pieces and 20,000 tons of recyclable clean polyester chips. In this way, INCOM was able to adequately fill the gap in China's recycled polyester chip market. In 2012, it successfully developed China's first intelligent recycling machine for the IoT, and an intelligent management platform for recycling resources and flow control [38].

Table 5 shows a comparison of each of the models. The proposed model is designed to be specialized for the trash classification task. Therefore, spectroscopy and image classification techniques were used to classify various types of trash. Even though the proposed system was primarily developed for public use and its principal agents are the local governments, it is quite possible to expand the range of use by supplying the system to the general population for individual use at home. A little modification in design and a change in the price level will be required for this purpose.

The adequacy of existing system designs was compared with that of the proposed system in Figure 11. Those designed in the past were not much attractive to the users as they usually displayed a low functionality level (i.e., inconvenient, low-applicability, and inaccurate) despite their high installation and operation costs [35–43].

Table 5. Comparison of Each Model.

Model	Classifiable Types	Function
Proposed Model	Can, vinyl, plastic, glasses, paper, and other	Trash Level Trash Classification Using Spectroscopy and image classification
Dr. Boomerang	Plastic bottles and cans	Trash Classification Using barcode Provide Reward
E-Cube Lab.	-	Trash Level Trash Compression Utilizes Solar Power Monitoring Software
Incom Recycle	Plastic bottles	Provide Reward

**Figure 11.** Adequacy of each design.

5. Conclusions and Future Work

The main purpose of the existing manual or semi-automatic trash separation boxes is to promote recycling. In most cases, recycling has been carried out by separating the trash depending on the information values concerning the material's elasticity, sound, or bar-code labels, but applying these factors alone does not guarantee better performance as many other factors should be considered in order to achieve a more precise recycling practice/system. Currently, many newly patented systems use the bar-code scanning mechanism. Meanwhile, most of the major waste management companies perform recycling by adopting physical methods (i.e., using magnetism, wind power, and densities) that separate the trash, depending on their properties. To increase the work accuracy, trash is manually separated before putting it into the automated separation process. There is no doubt that such a dual process will incur more expenditures.

Smart Trash Bin designs were introduced in this study. They use sensors, image processing techniques, and spectroscopes to sort the trash, following the pre-defined separation rules after evaluating the materials within them. The individually stored trash

will then be recycled by the recycling companies. These systems can be managed remotely by the administrator through a wireless network. The systems can be modified, depending on the intended uses, and because of their cost-effectiveness, the scope of application can be expanded as well.

In future work, the authors aim to implement the system and design a framework for the trash separation bin. Figure 12 shows the areas to be explored in future work in blue boxes. We will manage the pictures taken with DB and provide analysis and control data for viewing in web and mobile applications. In addition, all data will be handled in a virtual environment on a cloud server.

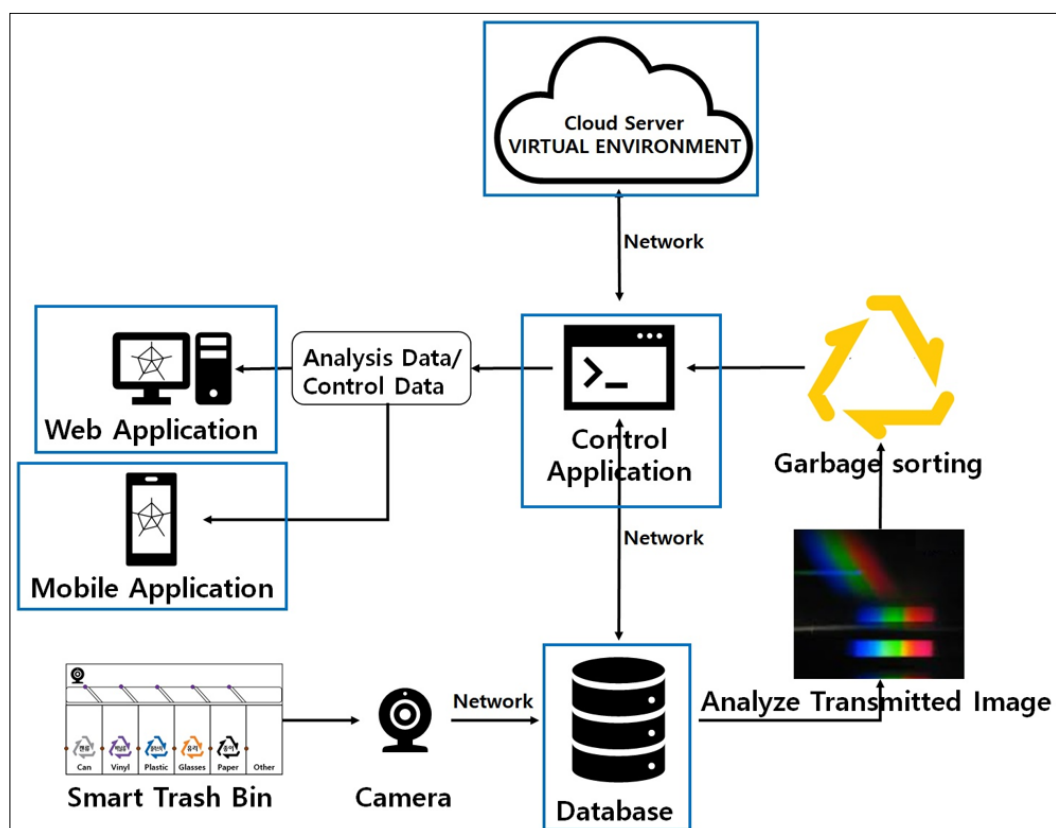


Figure 12. Future work plans.

The patent applications for the technological contents will proceed after publishing this study in a scientific journal, followed by the disclosure of relevant codes (open source). The authors hope that this study will contribute to the development of more sophisticated trash separation systems.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

ROK	Republic of Korea
IoT	Internet of Things
U.S.	United States
EPA	Environmental Protection Agency
NYC	New York City
EU	European Union
ITB	Intelligent Trash Bin
RFID	Radio-Frequency Identification
GPS	Global Positioning System
LED	Light-Emitting Diode
DC	Direct Current
LCD	Liquid Crystal Display
GSM	Global System for Mobile Communication
RIP	Passive Infrared
CNN	Convolutional Neural Network
SVM	Support Vector Machine
RF	Random Forest
XGBoost	eXtreme Gradient Boosting
kNN	k Nearest Neighbor
ResNet50	Residual Neural Network 50-layer
ILSVRE	ImageNet Large-Scale Visual Recognition Challenge
DenseNets	Densely Connected Convolutional Networks
DNN-TC	Deep Neural Networks for Trash Classification
Res-NeXt	Aggregated Residual Transformations for Deep Neural
CVPR	Computer Vision and Pattern Recognition
DB	Database
FT-IR	Fourier-Transform Infrared

Appendix A

In this research work, a model of a Smart Trash Separation Bin designed to separate trash effectively with less cost by using IoT technology was introduced. For the model, there are three different design types but they all use the same sensor, image processing, and spectroscopy technologies in an IoT environment, which is expected to reduce operational costs including the labor cost.

On Naver, a ROK portal site, we collected the titles of 10,000 news articles containing the keywords, “Smart Trash Bin”, to turn the 30 top morphs into a Word Cloud and plot. Figure A1 shows the WordCloud based on “Smart Trash Bin”.

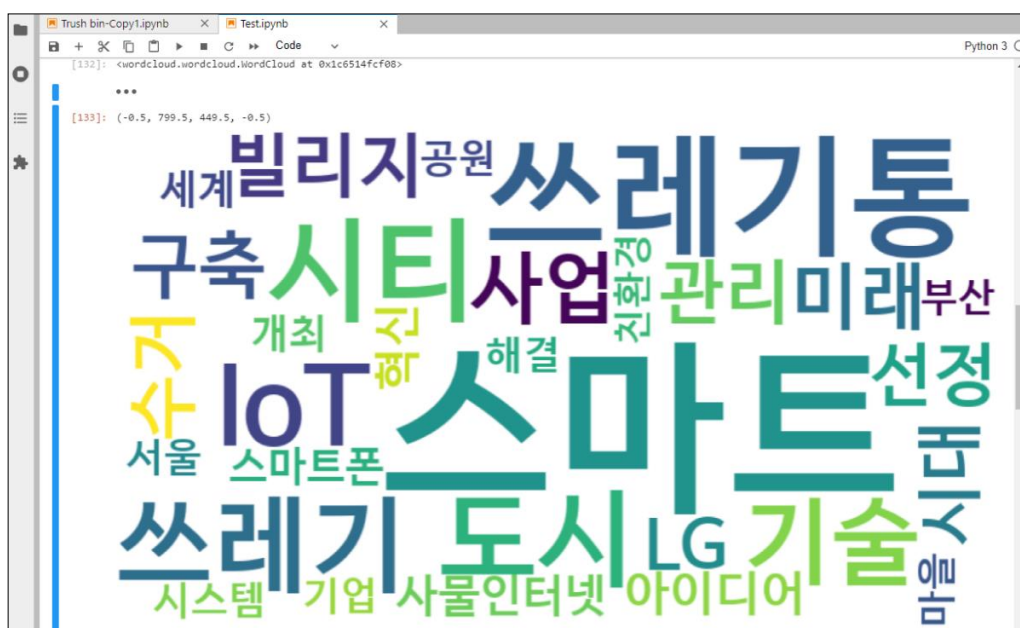


Figure A1. WordCloud based on “Smart Trash Bin.”

The ROK is pushing to install smart trash bins, starting with the Seoul Metropolitan Government, to build a smart city, and is holding various related contests. Due to this, we designed a smart trash bin model that can be installed in ROK. Table A1 shows the translation of the WordCloud top 30 words.

Table A1. Translation of WordCloud Top 30 Words.

Rank	Korean	English	Rank	Korean	English
1	스마트	Smart	16	시대	Era
2	쓰레기통	Trash Bin	17	아이디어	Idea
3	시티	City	18	혁신	Innovation
4	도시	City	19	사물인터넷	IoT
5	IoT	Internet of Things	20	스마트폰	Smartphone
6	쓰레기	Trash	21	세계	World
7	기술	Technology	22	개최	Open
8	사업	Business	23	친환경	Eco-friendly
9	미래	Future	24	기업	Corporation
10	구축	Build/Construct	25	시스템	System
11	빌리지	Village	26	마을	Village
12	관리	Management	27	서울	Seoul
13	수거	Collection	28	공원	Park
14	선정	Selection	29	해결	Solution
15	LG	LG (ROK company)	30	부산	Busan

Meanwhile, pseudocodes proposed in this study are as follows: The Check Status and Send Alarm processes are described in Figure A2 where the trash bin initially checks the condition of the trash bin when a user attempts to use it and sends an alarm to the operating system server or notifies the user regarding the present condition of the bin, subsequently.

The first step the trash bin will take is reading the “Recycle” labels on the trash by acquiring their images but if the labels are unavailable, the trash types are classified through the spectroscopic image analysis and classification process, based on which separate trash collections will be made. These processes are described in Figure A3, followed by the overall process and the performance result of the Smart Trash Bin in Figure A4.

```
[1]: def Check_Status(Trash_Bin): # Status has a value from 0 to 100 in proportion to the extent that the Trash bin is full.
    return Trash_Bin.Status

[2]: def Send_Alarm(Status): # Send an alarm when Status is higher than 80.
    if Status == 100:
        Alarm = "Trash Bin is full!!!"
        Send = "< Send Alarm to Server >"
    elif Status >= 80:
        Alarm = "Trash Bin is almost full!!, Please, Input Trash"
        Send = "< Send Alarm to Server >"
    else:
        Alarm = "Please, Input Trash"
    return Alarm
```

Figure A2. Define Check Status and Send Alarm Process using Python pseudocode.

```
[3]: def Recycle_Label_Recognition(Trash): # Recognize recycling Label through photography.
    if Trash.Recycle_Label != None:
        Recyclable_Status = ["<Can Recognize recycling labels(Paper, Plastic, Can, Glass, Vinyl, Other)>"]
    else:
        Recyclable_Status = None
    return Recyclable_Status

[4]: def Spectroscope(Trash): # Trash passes through the spectroscope.
    print("Trash without recycling label passes through spectroscope.")
    Spectroscopy_Array = ["< 1x6 Array Form(each element is 0~1 value) >"]
    return Spectroscopy_Array

[5]: def Image_Classification(Trash): # perform image classification tasks with photography.
    print("Trash without recycling label passes through Image Classification Process.")
    Image_Classification_Array = ["< 1x6 Array Form(each element is 0~1 value) >"]
    return Image_Classification_Array

[6]: def Classification_Result(Spectroscopy_Array, Image_Classification_Array): # Summarize the results of Spectroscopy and Image Classification.
    Recyclable_Status = "Soft Voting Classification using Spectroscopy_Array and Image_Classification_Array"
    return Recyclable_Status

[7]: def Recycling(Recyclable_Status): # Collect separately based on the results.
    if Recyclable_Status == "Paper":
        Message = "Move the trash to Paper"
    elif Recyclable_Status == "Plastic":
        Message = "Move the trash to Plastic"
    elif Recyclable_Status == "Can":
        Message = "Move the trash to Can"
    elif Recyclable_Status == "Glass":
        Message = "Move the trash to Glass"
    elif Recyclable_Status == "Vinyl":
        Message = "Move the trash to Vinyl"
    else:
        Message = "Move the trash to Other"
    return Message
```

Figure A3. Define Recycle Label Recognition and Classification Process using Python pseudocode.

```
[8]: if __name__ == "__main__":
    class Trash_Bin:
        def __init__(self, Status=0):
            self.Status = Status # show the extent of the trash bin full in 0 ~ 100%

    class Trash:
        def __init__(self, Recycle_Label=None, Recyclable_Status=None):
            self.Recycle_Label = Recycle_Label # Recycling Label in the trash(Paper, Plastic, Can, Glass, Vinyl, Other)
            self.Recyclable_Status = Recyclable_Status
            # if Recycle_Label is not None, Recyclable_Status equals Recycle_Label but, Recyclable_Status is result of Spectroscope and Image_Classification

    # default value
    Trash_Bin = Trash_Bin(Status=30)
    trash = Trash(Recycle_Label="Paper")

    print("< Show Trash Bin Status >")
    Status = Check_Status(Trash_Bin)
    print("Present Trash Bin Filled Status: ", Status, "%")

    print("< Send an Alarm >")
    Alarm = Send_Alarm(Status)
    print(Alarm)

    print("< Recognize recycling label through photography >")
    Recyclable_Status = Recycle_Label_Recognition(trash)
    print("Result of Recognizing recycling label: ", Recyclable_Status)

    if Recyclable_Status == None:
        print("< If the recycling label is not recognized, it goes through spectroscope and image_classification >")
        Spectroscope_Array = Spectroscope(trash)
        Image_Classification_Array = Image_Classification(trash)
        Recyclable_Status = Classification_Result(Spectroscope_Array, Image_Classification_Array)
        print("Result of Spectroscope and Image Classification", Recyclable_Status)

    print("< Result of Trash Recyclable >")
    Message = Recycling(Recyclable_Status)
    print(Message)

< Show Trash Bin Status >
Present Trash Bin Filled Status: 30 %
< Send an Alarm >
Please, Input Trash
< Recognize recycling label through photography >
Result of Recognizing recycling label: ['<Can Recognize recycling labels(Paper, Plastic, Can, Glass, Vinyl, Other)>']
< Result of Trash Recyclable >
Move the trash to Other
```

Figure A4. Smart Trash Bin Main Process and Result using Python pseudocode.

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