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WASTE MANAGEMENT SYSTEM DRIVEN BY SMART TECHNOLOGY PLATFORM WITH A SOCIAL ENTERPRISE

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Abstract. *With increasing populations, the amount of waste produced has significantly increased. Some of these garbage streams contain a considerable amount of recyclable plastic that must be managed effectively to mitigate the impact of improper waste disposal. This paper discusses the application of smart technology to waste management via social enterprises. The main objective of the study is to design an automated garbage sorting system that makes use of image analysis techniques, as well as a collection of waste management applications for a social enterprise. Additionally, deep learning techniques were proposed to automate the segregation of four different categories of recyclable garbage. The smart bin was designed utilizing an embedded system that enabled microcontroller devices to simultaneously carry sorted waste to the appropriate container. On the basis of motion detection, a Raspberry Pi-connected webcam captures individual images of the waste. Following the image capture, a classification model predicts the waste class. Waste is directed to the appropriate bin using a motor-driven movable tray as a completely automated sorting device. Additionally, a social venture is being established to drive waste management systems of the university. These activities encourage students and faculty to recycle waste and convert it into reward points redeemable for university goods and services. The data collected by the automated garbage sorting system are stored in a cloud database for use in the analysis associated with waste management policies at the university including model retraining. The smart waste management platform has a significant impact on university environmental issues, as well as on students and faculty participation in garbage pickup points in an indirect manner. Qualitative surveys were conducted to ascertain satisfaction of participants with the system. According to descriptive statistics, around 52.6% of participants are satisfied with the environmental theme, while approximately 65% are satisfied with the smart garbage point system. Chi-square analysis revealed a value of 13.310 with a p-value of 0.001. They value the intelligent functionality and efficiency of trash identification with the Likert scale average 4.73. The findings of the study could be applied to enhancing waste management practices at other campuses across the country.*
Keywords: Waste management system, Recyclable waste sorting, Intelligence waste management, Smart bin, Social enterprise, Smart university

1. **Introduction.** In 2017, Thailand generates 27.37 million tons of municipal solid waste (MSW) [1]. Nearly 12.52 million tons of MSW (about 44% of the total MSW) have been recycled. Improper disposal of approximately 26% of MSW (7.17 million tons) continues to pose a long-term environmental issue. Disposal technologies are factors in an MSW management (MSWM), along with the waste generation rate and the distance from the collection area. Prior to the next management process, the MSWM system can promote proper separation for recycling, composting, and alternative energy. In order to solve the

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long-term ecological problem of waste, organizations should pay more attention to waste management. Hence, computer technology, particularly automatic systems, is essential to help waste classification successfully for such large-scale disposal, thereby eliminating erroneous solid waste sorting before to landfills.

Utilizing smart technology and embedded systems, there are automated methods that contribute to waste management systems. The first works utilized AI to automate garbage classification and investigated the use of supervised learning techniques to develop classification models based on computer vision and in-depth learning. Abdallah et al. [2] enhanced the waste management system in order to compare various AI methods in solid waste management (SWM). Guo et al. [3] used machine learning to classify municipal solid waste. The application-specific methods were summarized, with 99.95% accuracy (CNN+SVM) being highlighted. Gondal et al. [4] used a hybrid approach to classify waste. These include multilayer perceptron (MLP) and multilayer convolutional neural network (ML-CNN). Automatic waste classification and management is essential for better waste recycling that can reduce the waste sent to landfills by reducing the need to collect new raw materials.

The following are some examples of how embedded systems can be used to classify garbage using smart systems. Esmaeilian et al. created an IoTs waste disposal framework for sustainable and smart cities [5]. The study's goal was to figure out how waste management practices affect the entire life cycle. Gupta et al. [6] monitored waste at every waste terminal in Copenhagen. The image-based classifier sorted recyclables by contamination level. Sensor data were collected and categorized. Smart IoT trash cans were tracked using a camera prior to being measured with the Azure IoT platform in real time [7]. Mirchandani et al. [8] proposed IoTs enabled trashcans with RFID waste tracking that were connected to a web-based online platform. Input points were calculated by the host server.

Ziouzios et al. [9] established a powerful accurate computational model for decentralized smart recycling architectures. A cloud-based design combined with limited embedded devices could have a significant influence on people. With 96.57% accuracy, CNN showed promise and a robotic waste disposal system is in progress. By incorporating litter behavior into a waste separation model, Sidhu et al. [10] introduced smart bins with weight scales and smart applications that forecast the amount of plastic generated for each bin at different times. A smart waste classification and collection system based on ICT has been presented to solve the waste collection issue. With an improved convergence factor and a fast non-dominated sorting method, Lu et al. [11] proposed a multi-objective hybrid algorithm, which can help sanitation companies collect waste more efficiently and sustainably.

Practically, embedded computing and social entrepreneurship could also be integrated to develop an automated waste management system as well as to motivate citizens accepting their social responsibility. One example is the smart IoT-based integrated system with an Arduino Uno microcontroller, sensors, and communication. The system constantly monitors waste and displays it on a liquid crystal display (LCD). As soon as the garbage bin is full, the communication system alerts the authorities [12]. Dubey et al. investigated waste collection and decomposition using smart technology, the Internet of Things (IoTs), and machine learning to develop waste management systems for households and society [13]. Inefficient recycling has resulted in the retention of the existing recycle bin. Waste management data could be monitored in real time using IoT and AI. Sheng et al. [14] created a smart waste sorting system using LoRa and TensorFlow. Metal, plastic, paper, and general waste are separated in the bin automatically. The Raspberry Pi, along with ultrasonic sensors and a real-time bin GPS were utilized as the system unit to send the ensembled RFID identification.

To encourage people to participate in social responsibility, social enterprises have been introduced to promote best practice regarding sustainable solid waste management. Zaman [15] proposed a waste management social business model based on two case studies from low and high-consumption cities. A non-profit organization can recycle household waste to help less organized cities. Eventually, the business model could create more value as well as contribute to social development. For that reason, an organization that encourages residents to utilize space on a consistent basis could advocate for an automated waste management system to assist in mitigating the impact of improper waste disposal. Kasetsart University Chaleomphrakiat Sakon Nakhon province campus (KUC-SC) has two major areas namely academic and accommodation area. The composition of recyclable waste comprising 44.44% [16] can determine its potential for reuse or recycling. The key success factors in solid waste management are awareness and practice [17]. Therefore, practical tools should be developed. Furthermore, there should be incentive to participate using rewards, while a smart bin can assist in sorting waste prior to landfill.

In this research, the KUSESmartBin, an automatic waste sorting machine that utilizes artificial intelligence (AI) technology, is introduced. Deep learning is used in robotic waste management to classify waste into four categories (metal, PETs, plastic, and trash) automatically. Users accumulate points that can be redeemed for university credits. This system displays the amount of waste generated in real time and provides statistics on waste management. Furthermore, the sorted waste increases the recycle rate, reduces waste sorting time, and allows more waste to be disposed of.

The paper is organized as follows. The second section describes our smart waste system, while the waste management application for a social enterprise is represented in Section 3. Section 4 includes the results and discussion. The final section is the conclusion and suggestions for additional research.

2. **Our Waste System Design and Development.** In this section, the authors discuss the proposed classification model construction techniques as well as the hardware system design. The smart waste management system framework (see Figure 1) was investigated by three functions as follows. First is the automatic sorting machine so-called the smart bin. The bin was designed and built up by using craftsmanship material and embedded devices to provide mechanical rubbish tray and containers. The graphical user interface (GUI) was developed to interact with users who bring trash turning to points working on the LCD screen. Secondly, to enable users connected the system, a GUI was implemented for both members and non-members. Membership authorization, member point collection, and waste information are all functions of the GUI system alternatively via mobile and

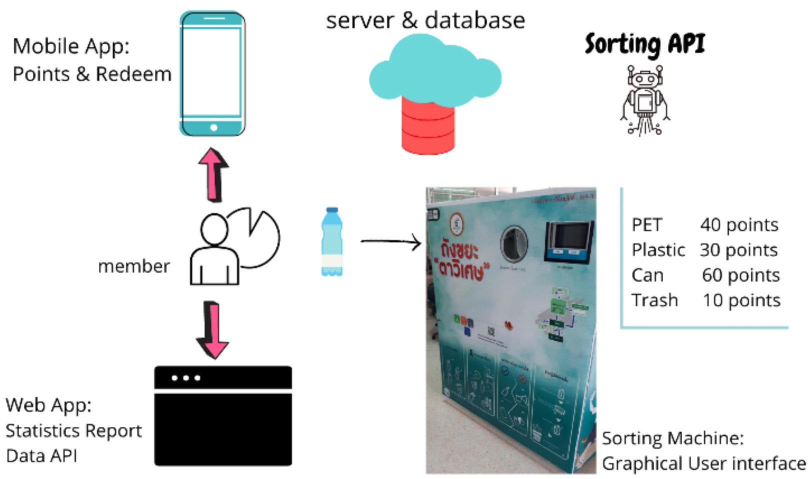


Figure 1. A smart bin system

web applications. The final function is the disposal database management system. The transaction on throwing solid waste into the smart bin from users was collected in real time on cloud database to show statistical reports including API web services.

2.1. An image analysis-based automated wasted sorting system.

Data Collection and Preparation: Deep learning approaches were applied to constructing the classification model. The dataset was derived from two sources: 1) a TrashNet dataset [18] containing 2,527 images of various types of waste, and 2) a locally created dataset containing 2,799 images. All waste images were reclassified and labelled to fall into one of the four classes: plastic (general plastic bottle), metal, PETs (clear plastic bottle), and trash. Additionally, another input data, waste items, was collected manually using an image sensor under the same conditions as the TrashNet dataset. In total, 5,326 images were classified by waste type as 558, 1,608, 929, and 2,231 for PETs, plastic, metal, and trash, respectively.

The 5,326 images in the collecting data were subjected to data preparation processing to emphasize indicated characteristics and provide a balanced dataset. The data preparation processes commenced by resizing the images to 224 × 224 pixels. After applying the augmentation algorithms (horizontal flip, Gaussian filter, median filter, 90-degree and 270-degree angle rotation, and image conversion to grayscale and HIS color information), a total of 31,956 augmented images were obtained.

Construction of Classification Model: To create the garbage classifier, a machine learning method, known as deep learning, was introduced. The input datasets of pre-processed images were divided into 70% for training and 30% for testing. The Google TensorFlow development kit's built-in function, Keras was used to pre-train the classification model. The stratified random technique was used to divide the training and testing datasets several times until the best fit was obtained. The learning model's parameters were set as follows. We studied the classifier models 50 and 152 layer pre-trained deep residual network (ResNet-50 and ResNet-152) in Muangnak et al. [19]. The model was activated using ImageNet's load weights. The Softmax function set the parameters for transfer learning. Four labelled labels were included. Figure 2 shows the training accuracy and loss plots of ResNet-50.

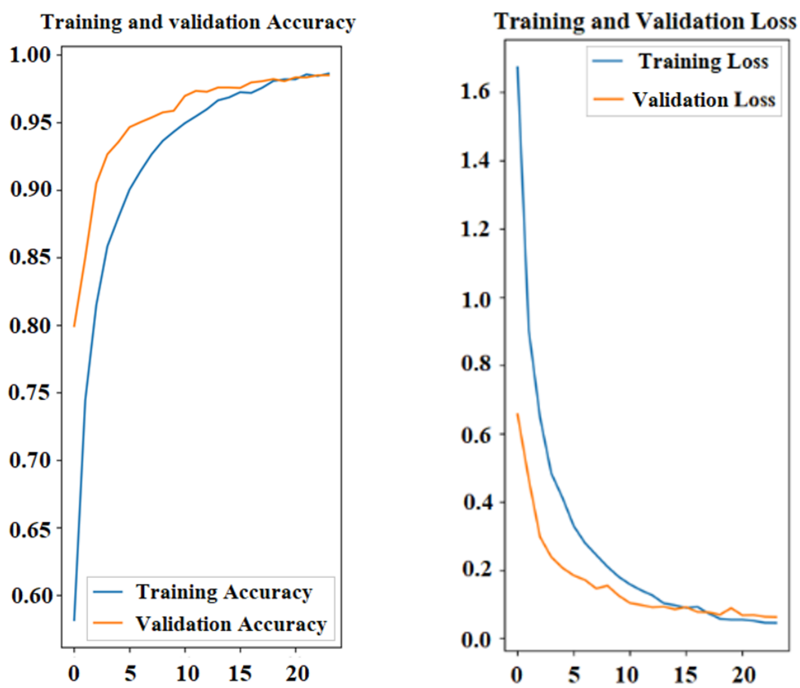


Figure 2. Learning performance and errors, ResNet-50 with 24 epochs

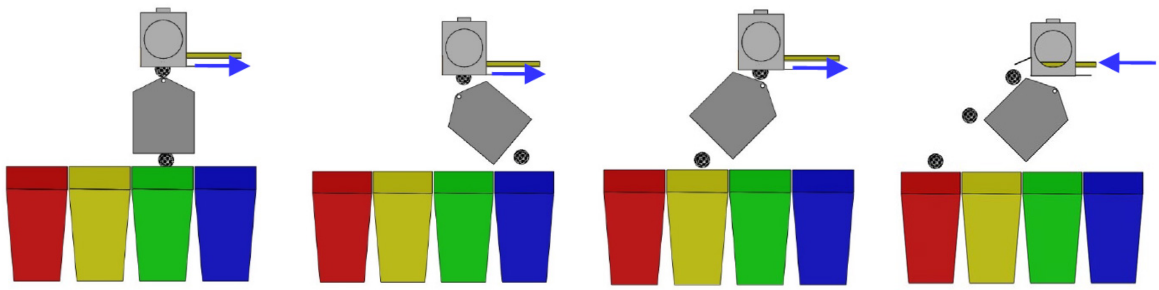
Contrary to expectations, the image post-processing did not reach the prediction confidence trim set by the pilot training. The model achieved 98.81% accuracy after 24 training epochs with a learning loss of 0.0346. ResNet-50's performance was evaluated in two ways. The first approach was a model evaluation scheme. To assess the model's classification ability, it was compared to an unclassified dataset. The classification model was embedded in the microcontroller unit to analyze and return the waste type.

2.2. **Automated waste sorting machine.** A smart bin system based on IoTs and image-based deep learning is made up of three major components: a control system unit, a disposal mechanism, and a GUI. A classification model and an image sensor module comprise the control system unit. Our transfer learning model of choice is ResNet-50. The disposal mechanism and the GUI unit are described further below.

The Sorting Machine: To accommodate the control system unit, the smart bin model is divided into three sections 1) a drop litter component with an IoT devices, garbage is processed piece by piece; 2) after the trash has been classified, a box connects it to the recyclables; and 3) a trashcan organized by metal, PETs, non-recyclable trash, and plastic.

Waste Sorting Mechanism: The design of the waste sorting automaton in Figure 3 demonstrates a waste sorting automata design. The system was built to dispose of the waste without liquid being left behind. Dropped waste can be placed into a trash can with a size of 100 mL to 1.5 liter.

The machine mechanism of disposal is repeatedly controlled by an inserting litter door. In the control unit of smart devices, a machine analyzes waste piece by piece as a part of the automated classification system. After determining the waste type through sorting, the control unit transported the classified waste to one of three recycle bins or a non-recycled bin. The machine required user action to identify the next litter drop. The machine mechanisms are depicted in Figures 3(a)-3(d), case by case. The direction of discard lids mainly depended on the waste type. The lid was of the sliding out type for the first three recyclable waste types, while the lid pushes the litter out of the non-recycled bin (see also Figure 3(d)).



(a) (b) (c) (d)

FIGURE 3. Waste disposal mechanism based on waste type: (a) Plastic, (b) PETs, (c) metal, and (d) trash

Sorting Machine System: The sorting machine consists of two parts: the system function and the design of the application module. The sorting machine's hardware functionality is made up of a microcontroller core module, a motor drive module, an input/output module, a sensing module, and a camera module. Furthermore, the application modules were created to serve the collecting point system via mobile and web platforms. The image analysis module was also investigated to acquire sorting images to send to the cloud-based model. The summary of sensors and hardware devices is shown in Table 1.

Table 1. Summary of sensors and hardware devices

Devices	Description
Ultrasonic sensors	measure the distance of a target object by emitting ultrasonic sound waves
Proximity sensors	detect a metal object by emitting a high frequency magnetic field
Raspberry Pi 4 Model B	a small single-board computer
Arduino Mega	a microcontroller
Touchscreen LCD 7”	user interface screen
Webcam 720P	capture an object
Servo motor	to drive a machine gate
Gear motor	to drive and release an object

3. **Development of Waste Management Applications for a Social Enterprise.** The system software is composed of the following components: a smart bin application that controls the garbage classification algorithm; a computer server that acts as a single point of access for disposal information and user information; the web-based administration application, which is used to keep track of status of smart bins and manage waste data; the smartphone application used to gather waste history data and accumulate points.

Web and mobile technology applications are also available to administrators and general users. Administrators can view composting transactions, account information, analysis reports, and application requirements via the web application. Prior to litter segregation, the Android application provides a graphical interface through which students and faculty members can manage their subscriptions, composting history, collect and redeem points, and connect to the smart bin GUI.

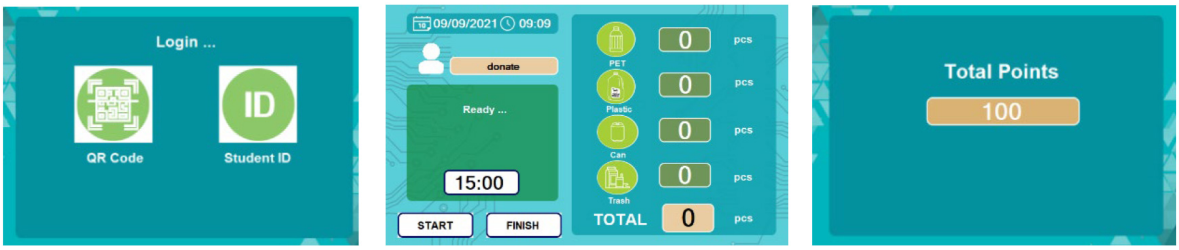
Database Design: The database system is divided into two sections: an image database derived from intelligent trash dumping, user information, waste type data, trashcan data, disposal data, and the accumulated points earned by the user during disposal. Waste images from the smart bin were saved on a cloud database in two folders: 1) the original image files and 2) the garbage classification image.

Garbage collection GUI displays the machine status and usage history. Additionally, users can accumulate points and redeem them for rewards. A relational database was created to store transaction data about bins, waste sorting transactions, waste categories, user data and usage history. After capturing a waste image, the waste sorting algorithm analyzes the predicted class in real time before uploading the original image and a predicted class to the database server. Additionally, the user's interaction with the devices and a record of discarded waste via a GUI on the touchpad screen.

For general users, a proposed GUI for a smart bin machine and mobile application software is provided. To begin, members must log in via QR code scanning or by entering their user id. Then, they can collect points or donate waste, as illustrated in Figure 4(a).

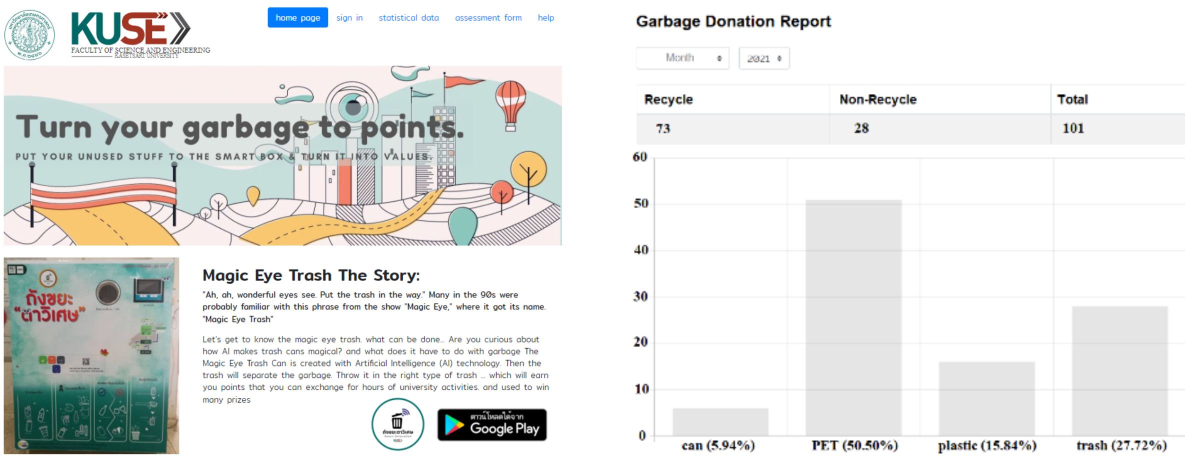
The smart bin is activated by clicking on a waste button. Following that, litter section is established for users to deposit waste, with a machine counting the waste inserted and displaying several options for waste sorting on the screen. Clicking the score button displays the total points on the screen, as illustrated in Figures 4(b) and 4(c).

Web Application: The web application's user interface is divided into two sections: a data collection point for intelligent trash management and a statistical report on the garbage data. The web application's home page is accessible via https://kusesmartbin.csc.ku.ac.th, as illustrated in Figure 5(a). By monitoring the status of a smart bin, configuring user information, and mastering data, an administrator can access the waste



(a) (b) (c)

FIGURE 4. (a) Login screen, (b) waste counter screen, and (c) earning point screen



(a) (b)

FIGURE 5. KUSESmartBin web application – waste disposal information

disposal transaction and manage the system's configuration. Additionally, as shown in Figure 5(b), a statistical report and a user evaluation are included.

The user interface contains information about the transaction of garbage dumps. The university account can be used to access the system's activity history, account settings, and services. There will be a feature that allows users to redeem points for user service during activity hours, transfer points to other users, and conduct assessments to improve services.

Mobile Application: The mobile application has been implemented for members as the reward points application. The user interface is designed for ease of use ("user friendly"). Additionally, members can transfer points and request redemption activity hours. The KUSESmartBin mobile application screens are shown in Figure 6.

4. **Evaluation Results and Discussions.** In this section, we examined two performance metrics. The first was to emphasize and validate the efficiency of our classification model. The other metric was a quantitative statistical report on the degree to which the users are satisfied with KUSESmartBin.

We deployed the ResNet50 classification model on IoT devices using computer vision and an IoT-based system to simulate an automated waste segregation machine. The fully automated system was meant to evaluate the categorization model in two dimensions, which produces more accurate findings with a 98.81% accuracy. The findings of the experiment testing ResNet-50 revealed that it outperformed Adedeji and Wang's [20] method with accuracy by 95.72% with the identical parameter settings prior to selecting the model.

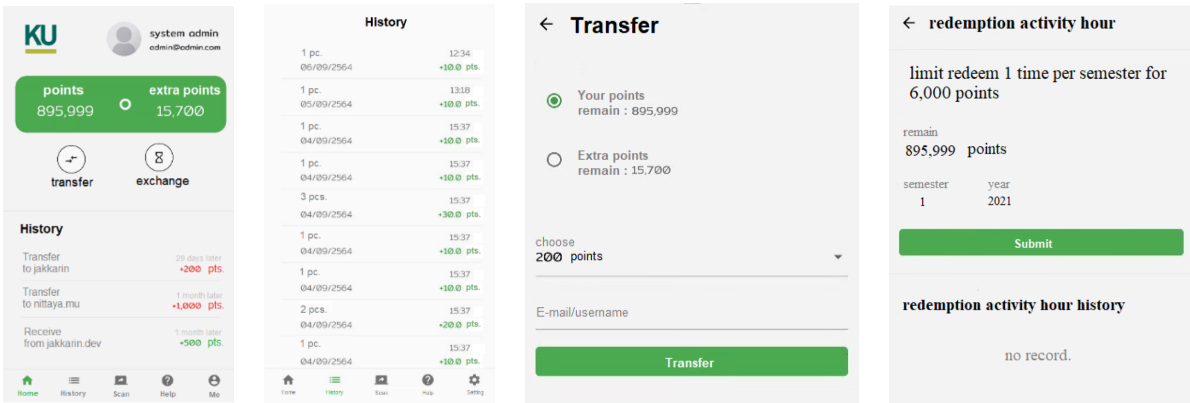


FIGURE 6. Screens of members' disposal information, point transferring, and redemption activity hours via the mobile app

Our fully functional sorting machine was also compared to Ziouzios et al. [9] (MobileNet V2), which combined a distributed smart recycling architecture with machine learning and a low-cost embedded device solution. The IoTs devices were built using a microcontroller, a Raspberry Pi model 3B+, and a version 2.1 Raspberry Pi camera. The accuracy of the tests revealed a promising result of up to 96.57%.

The qualitative questionnaire was collected to evaluate satisfaction of the smart bin. The 135 sampling participants in our research were the university's faculty members and students. In addition, to examine the relationship between satisfaction variables, environmental concerns, and the point-accumulating smart trash application, a Chi-square independence test [21] was applied, as shown in Equation (1):

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{1}$$

where O_{ij} represents the observed frequency (participants) in row i (accumulating points smart trash variable) and column j (environment variable) and E_{ij} represents the expected frequency defined using Equation (2):

$$E_{ij} = \frac{R_i C_j}{n} \tag{2}$$

where R_i and C_j are the count totals of each row and column, respectively and n is the sample size. Let the p-value be a chance of the computed test for χ^2 based on assuming a null (natural) hypothesis to be correct; if it is less than the significance level, then the two variables are not independent.

Table 2 represents the relative satisfaction of KUSESmartBin's importance. According to descriptive statistics, around 52.6% and 37.0% of participants are high and extremely satisfied with an environmental theme, respectively, and approximately 65% are high and

TABLE 2. Relative satisfaction of KUSESmartBin's importance

Satisfaction			Environmental issue importance			R_i
			Moderate	High	Extremely	
Smart bin for accumulating points	Moderate	O_{1j}	10.0	26.0	10.0	46.0
		E_{1j}	4.8	24.2	17.0	46.0
	High and extremely	O_{2j}	4.0	45.0	40.0	89.0
		E_{2j}	9.2	46.8	33.0	89.0
		C_j	14.0	71.0	50.0	$n = 135$

extremely satisfied with gaining points in the smart garbage. The Chi-square analysis yielded a value of $\chi^2 = 13.310$ and a p-value of less than 0.001. The findings focused on environmental issues, and having trash accumulate points in the trash was significantly related. After the system was installed to use on our campus for the users to place their garbage. Users were asked to complete a post-survey to express their gratitude for the intelligent functions and efficiency of garbage sorting, which received ratings of 4.73 and 4.56 on the Likert scale, respectively. These survey results indicate that our smart bin functions may be required to assist users in recycling waste as a result of the warming world.

5. **Conclusions.** We considered how to manage waste effectively in social enterprises. This research project was divided into two sections: 1) developing an automated waste sorting system through image analysis; and 2) developing a suite of waste management applications for a social enterprise. Robotic automation sorted recyclables correctly by utilizing deep learning and image processing. The smart bin features a garbage sorting model that utilizes an embedded microcontroller to automatically separate four different types of garbage. Additionally, a university-based social enterprise assists with waste management via mobile apps. These programs encourage students and faculty to recycle waste and exchange it for university-provided goods and services. Finally, waste management policies at the university were analyzed using data collected via the proposed system. The findings of this study have the potential to improve waste management practices at other universities across the country.

However, there is scope for further improvement such as enhancing the classification model using image data collected from the sorting machine, expanding the robotics' multi-waste disposal system and developing a waste management ecosystem that draws attention to the architecture of distributed intelligent composting learning algorithms, such as a federated learning.

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