An effective waste classification system: a system of a portable device that classifies the waste in real-time and is connected to a tracking app that contains the related environmental updates

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Abstract

The benefits of sorting trash for reusing and recycling waste seem straightforward; however, not so many people do it. On an individual level, have you ever found yourself struggling to put your hot latte coffee cup in the right trash bin? Currently, waste classification is not easy, inconvenient and time-consuming. The confusion with waste categories also plays the main role in demotivating people to sort the trash. In tackling this problem, our team aims to develop a more effective and customer-friendly system, consisting of:

- A device installed in the waste collection location. This device will help sort the trash to the right bin by capturing the image of the trash, classifying the trash using deep learning, and informing the customer of the category of the trash.
- An online tracking app. This app will provide the map of locations for trash bins/special trash collection, information on personal recycling rate, and a review section including improvement section, complaint section and adding for the new type of trash.

By using this system, people will sort the trash faster and more accurately under the guidance of the device, hence it will help improve the waste separation and collection systems and waste recycling. In this research paper, we will introduce in detail our system by discussing the technological aspect and providing concrete data analysis, given the use of the system, in economics and environment aspects, specifically in the United Arab Emirates.

1. INTRODUCTION

United Arab Emirates' current vision, efforts, and challenges

In order to have effective and sustainable waste management both economically and environmentally, there has been a wide range of worldwide and nationwide efforts in creating and enhancing waste reduction, reuse, and recycling methods. For the past decade, the United Arab Emirates (UAE) has been effectively implementing sustainability and environmental-friendly methods, including recycling, incineration, waste-to-energy, chemical treatments [2]. According to the UAE's vision 2021, the Ministry of Climate Change and Environment was able to treat 28.58% of the total waste that was generated in the country and are in continuous efforts to increase such records [2]. However, despite these great efforts, waste management in the UAE still poses a lot of challenges in waste separation and collection systems [1]. This is especially true given the rapid economic growth and population increase from 9.2 in 2017 to 9.89 million in 2020 [3]. Such rapid changes were associated with an even higher amount of generated waste reaching up to 6,376.90 tons per day on average making the UAE of the largest waste producers [3]. The future prediction of the collected waste is much higher in the upcoming years, thus emphasizing the need and requirement to address the current waste issue in the country.

In 2008, Abu Dhabi established Tadweer, a Centre of Waste Management, that is responsible for the policy, strategy and contractual systems of waste management in hopes of addressing these ongoing concerns [1]. The company collected a total of 39.188 million metric tons of waste in 2017 from which only 20% was considered suitable for recycling and the rest of the waste is mainly sent to landfills [3][4]. Dubai and Sharjah had similar efforts to treat, manage and recycle waste in the past years through projects, such as the Dubai Integrated Waste Management Master Plan in 2012 and Bee'ah in 2007 [1]. Therefore, we hope our project can make valuable

contributions to such efforts by decreasing these higher records of collected wastes and increasing the percentage of recycled wastes as is predicted by the UAE Vision 2021.

Awareness survey about recycling at NYU Abu Dhabi

Taking a look at a smaller scale, at New York University Abu Dhabi (NYUAD), we conducted a survey to collect responses from students on campus as well as people living in local areas in the UAE to understand how people perceive the efficiency of the waste separation and collection systems that sort specific trash into three indicated categories: general waste, paper, cans & plastics. Only a small percentage of participants have the recycling trash bin system at their homes, and most of them never recycle and categorize their waste. The reasons behind such behavior have varied based on the survey. However, the main reasons are the lack of user-friendly technologies, the lack of awareness of classifying and managing the waste, and the high dependency on institutions and environmental organizations to sort the waste rather than individuals [5].

Vision of our project

Based on the collection of the aforementioned information, we believe that our project is capable of adding an environmental improvement to the UAE market through the application of deep learning technology. Guiding the users through a small device installed in the trash bin location to sort the trash properly within the time range of seconds can help increase the efficiency in waste categorization. This will create transparency in the currently existing waste management system consisting of environmental organizations, such as Tadweer and Bee'ah, as it will help strengthen their recycling strategies through short and effective procedures. Moreover, the portable feature of the device gives the users the freedom to install it in any place they want. For example, the device can be installed in the household for trash classification, which will make it easier later for them when they throw the trash in the public trash bin. Our goal is to apply our project to individual households, workplaces, universities, and environmental-related activities and therefore would emphasize the role of individuals and citizens in the waste management process in a practical strategy that ensures the increase of waste management awareness in the society.

2. METHOD

2.1 Building deep learning model for waste classification

In our system, we develop a software program in Python to classify the waste, using the available training and testing dataset from Kaggle [6]. In specific, we use Convolutional Neural Networks (CNNs) to classify the trash into two categories: organic (0) and recyclable (1). In our Jupyter notebook of the software program (github.com/phamleyennhi/wasteclassification), there are five main steps:

i. Installation and Setup

In this step, we install necessary packages, including tensorflow, numpy, pandas, matplotlib.pyplot, and prepare our training and testing dataset. Our training set consists of 12566 images for Organic category, and 10000 for Recyclable category. Our testing set consists of 1402 images for Organic category, and 1113 images for Recyclable category.

ii. Data Pre-processing

In our dataset, the images require modification before feeding the model. We create the function modify_image to resize the images into the desired size (32, 32), change the mode to 'RGB', and save the images in the array names[]. While doing this step, we also store the labels (waste category) in the array labels[] correspondingly. Initializing these two arrays names[] and labels[] also makes it easier for future waste category addition. After having these modified arrays, we convert them into numpy arrays in order to use the imported packages.

We also do a normalization step for the dataset, converting pixel value range into [0,1]. This step is important as it helps the neural networks learn faster.

iii. Building the CNNs

In order to build the CNNs, we construct different layers, briefly introduced as follow:

Convolutional layer: computes the output volume by calculating the dot product between filter and image. This is the first layer to extract features from an input image, and it preserves the relationship between pixels by learning image features.

ReLU layer: We use ReLU as activation function with equation A(x) = max(0, x). Its nature is non-linear, and we can easily backpropagate errors and multiple layers of neurons being activated by the ReLU function.

Pooling layer: reduces spatial size of the Convolved features, decreases computational power to process data, and is used for extracting dominant features which are rotational and positional invariant so that we can train the model effectively.

Fully connected layer: The result of the whole aforementioned layer process feeds into a fully connected neural network structure that drives the final classification decision.

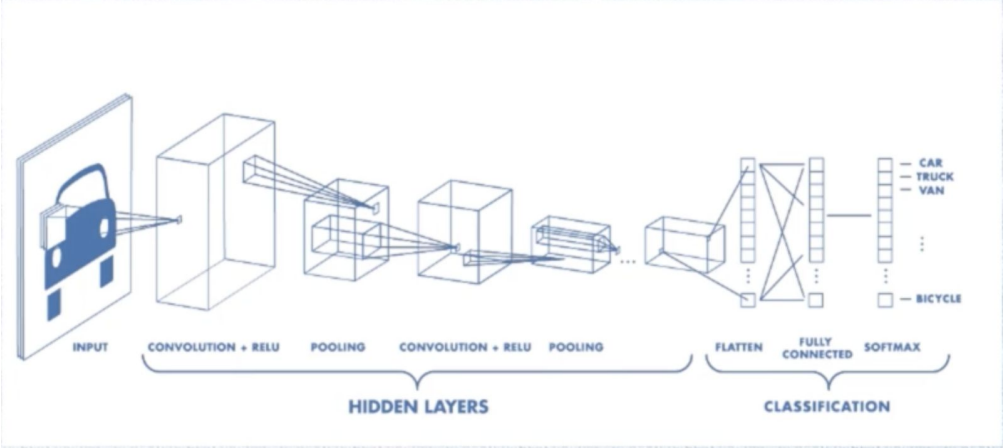

Fig. 1: Layers in CNNs model that we apply in our project

iv. Training the model

After constructing the model, we train the model with the training dataset 10 times and reach the accuracy at nearly 90%. This is our first attempt to see how effective and accurate this model can classify the waste into two types of waste, organic (O) and recyclable (R). In the future, we can increase the number of training times for the model to reach even higher accuracy.

v. Model Evaluation and Prediction

In this step, we create a prediction dataset after the training and compare the prediction data with our testing data. Our confusion matrix is given as below:

[[1319 82]
[151 961]]

This matrix reflects the performance of our classification model. The diagonal elements represent the number of points for which the predicted label is equal to the true label, while off-diagonal elements are those that are mislabeled by the classifier [8]. From this matrix, we calculate the accuracy score of our model, which is $\frac{1319 + 961}{1319 + 82 + 151 + 961} \approx 90.7\%$.

This is our initial step in training the model and testing the accuracy of the model. The performance of the model is sufficiently high (around 90%) for the available dataset in Kaggle. The model itself is designed with the potential of adding more waste categories and images by directly adding images and their labels to the correct folder of the training and testing dataset and correspondingly adding the labels in the array (labels[]) and

(names[]). Therefore, in the future when we are able to work with the real waste data in the UAE, given the proper amount of time for data training, we expect the accuracy of the model to remain relatively high.

2.2 Design

As we can see, the software part of the project, which applies deep learning to classify trash into the right category, is the heart of the whole system. We want to implement this model into a portable device, connected to an online tracking app for related information.

a. Portable device

Our portable device is currently in the designing process. It will consist of *Raspberry Pi with a camera module* for object detection and *a protecting house*. Since we want the device to have a wide range of applicability, we choose to use Raspberry Pi, which is considered as a low-cost portable computer in the size of a credit card. The CNNs model we mention above can be programmed into the Raspberry Pi, and the waste can be detected and classified from the camera in real-time.

The Raspberry Pi also plays an important role in creating the Wi-Fi, continuously connecting and sending the waste data to Google Firebase where we store the real-time data. Google Firebase has a high level of security which means that only clients who are allowed can get access to. From the Google Firebase real-time database, we can send the users waste classification update to the app for personal recycling/waste management statistics in milliseconds. It can also help to create a rigorous database in the waste management system of the UAE that can be utilized for studying and researching purposes in the future.

We also choose to have the protecting cover for our device to minimize the outside damages as much as possible. The idea is inspired from the Solar Powered WiFi Weather Station. Here is one similar 3D design we plan to use for our device [7]. Since our device will have a camera, the protecting house would be open on one side facing the users and the object/waste for detection and classification. This design will also enable users to install the device in different environments.

Fig. 2: Image taken from [7]

b. Online tracking app

We are aiming to develop the app for both Android and iOS platforms. This app will update the data in real time from Google Firebase for users to track their recycling rate. It also provides a map of locations for public trash bins and special trash so that the users know the nearest public trash location at any place they may travel to.

We also plan to add a review section on the app. In this review section, it will consist of suggestions from users, improvements, and manual data adding for new types of trash (which may require review and approval from a qualified person in waste classification).

3. THE UAE WASTE MANAGEMENT MARKET ANALYSIS

3.1 Overview of the Waste Management Market in the UAE

According to a 2017 report, it was recorded that 35.269 millions out of 39.188 millions metric tons of waste are generated by three out of the seven emirates, namely Abi Dhabi, Dubai and Sharjah [4]. As a matter of fact, Abu Dhabi generates 9.797 millions metric tons of waste on its own. This issue is becoming more on demand as the government starts to focus on developing new energy industries besides the oil industry, such as heavy and light manufacturing, refineries, chemical plants, power plants, and mineral extraction and processing, all which

are known to generate heavy amounts of wastes [4]. According to the *Mordor Intelligence,* a corporation that excels in market research and studies, Abu Dhabi generates more hazardous wastes than all of the other emirates combined while Dubai is leading in the non-hazardous waste industry as shown in Figure 3.

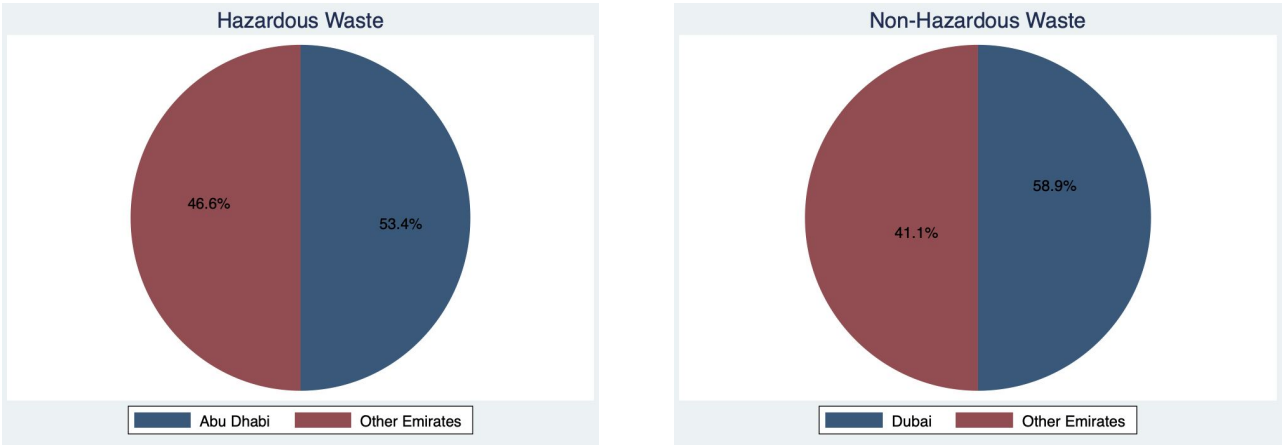

Fig 3: Self drawn by Maryam Khalifa Al Marzooqi

Since 2015, the amounts of total waste that has been collected are gradually increasing [10]. The industrial and commercial industry has been one of the main contributors to these increases, especially since there was a drop in the wastes generated from the construction and demolition industries. The United Arab Emirates are actively trying to reduce the adverse per capita environmental impact through various methods [4]. However, it seems that this goal is still one of the challenges that the country is facing as the amount of municipal wastes per capita per day has increased from 1.3 in 2017 to 1.76 in 2018 in abu Dhabi alone [10]. Figure 4 demonstrates the wastes collected annually in tons as a total as well as all the industries in the emirate of Abu Dhabi that contributes to these amounts. Today, even though C&D (Construction and Demolition Wastes) wastes has seen a great drop since 2012, it still accounts for around 42% of the overall wastes that are generated [4]. These wastes include many building materials, such as, insulation, nails, electrical wiring, and rebar, as well as waste originating from site preparation, such as dredging materials, tree stumps, and rubble. These materials if not managed properly can cause environmental damages on soil, water, air, and the surrounding ecosystem in addition to depletion of finite resources [4]. This emphasizes on the need to increase awareness regarding how certain waste materials should be classified and managed properly by both individuals and institutions.

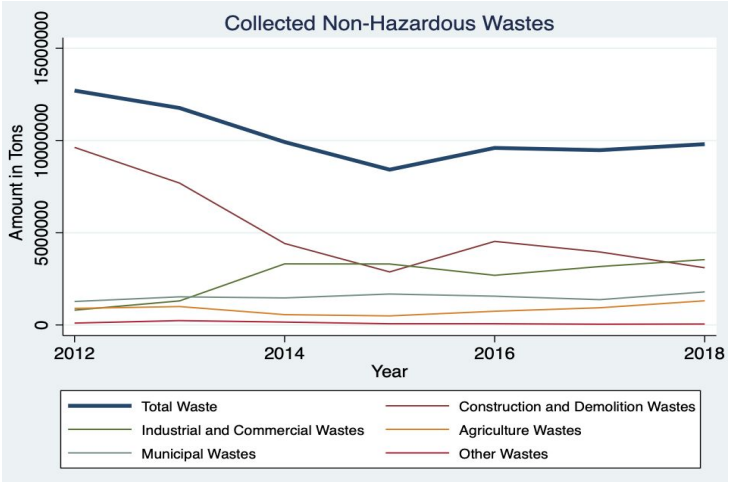

Fig. 4: Self drawn by Maryam Khalifa Al Marzooqi

Given the above facts, the UAE waste management market has adapted some new trends that are currently the key feature of the whole market. The first key feature is innovative technologies and advanced waste collection solutions. After the establishment of Tadweer in 2008, there were many strategies and plans that were created in order to properly manage and process the waste [1]. However, there was no actual record of the amount, type and solution methods used until the Ministry of Climate Change and Environment created a database in 2018 in which all the information was stored [4]. Based on this database, the ministry has been publishing monthly and annual reports in which it discusses the latest updates in the waste management industry across all emirates [4]. These recordings have created a new motive for people and various sectors to pursue sustainable methods and solutions in order to keep up with the country's goals and vision. In addition to that database, Dubai was one of the first cities in the GCC region to install electronic gates and smart weighbridges at all of its waste disposal sites in order to emphasize the need for smart and sustainable waste method categorization [4]. Some of the waste-to-value methods that have been used include recycling, refurbishment, and refining facilities [4].

Some of the main disposal methods that the United Arab Emirates has adapted over the years are incineration, landfills, recycling, composting, and other dumpsites [10]. According to Dr Thani Bin Ahmad Al Zeyoudi, Minister of Climate Change and Environment, 77% of the total amount of wastes ends up in Landfill, which is among the world's highest recording [11]. However, the new UAE federal law is aiming to recycle 75% of the total municipal wastes that are collected [11]. As Figure 5 shows, Abu Dhabi has been gradually moving towards its goal of 75% recycled amount of wastes. We believe that the increase would be even much higher if the role of individuals was enhanced, especially since the current system is highly dependent on targeting institutions and recycling centers as the UAE still lacks an infrastructure for organic waste recycling for residents [12]. Therefore, by applying our device we are planning to install some basic infrastructure that guides the residents with the proper method of recycling.

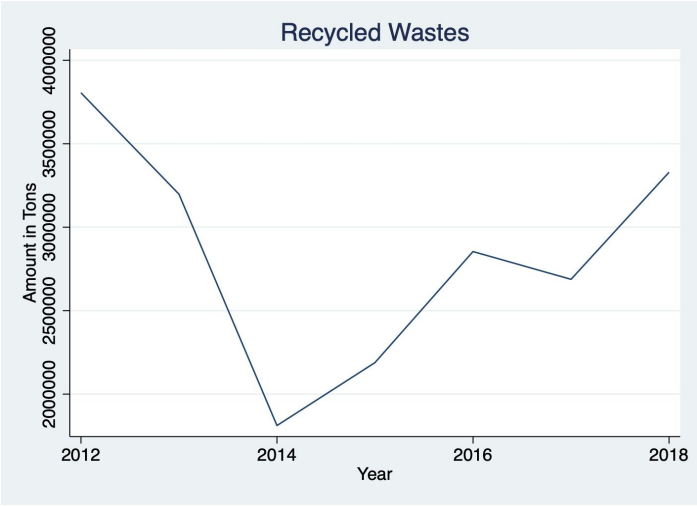

Fig. 5: Self drawn by Maryam Khalifa Al Marzooqi

3.2 The Competitive Landscape of the Market

The UAE waste management market is made up of small, medium and large sized companies. This structure causes the overall market to be fragmented in nature, which allows companies to constantly enter and exit the market [4]. However, despite the fragmentation in the market there are some key players in the market including:

1. **Averda:** It is an international company that provides services from cleaning, collection, recycling, waste disposal and energy producing services. They create projects that aim to increase the efficiency of projects for businesses, healthcare, industries and municipalities in environmental ways [13].

2. **Green Mountains:** One of the largest domestic companies that specialized in hazardous and non-hazardous wastes collection, transportation, treatment and disposal of both liquid and solid wastes. They perform services to transform wastes to energy through recycling and other methods [14].
3. **Adgeco Group:** It is a company in Abu Dhabi that operates in various business industries such as construction, engineering, real estate, oil and gas, energy and power, water and desalination, marine, legal and multi-media services. It provides services such as, cleaning and waste management, construction services, crane and heavy lift solutions and chemical decontamination services [15].
4. **Veolia:** One of the global groups in optimized resources management that provides water, waste and energy management solutions. Its projects concentrates on creating profit using sustainable growth and providing access to resources as well as preserving and renewing available resources [16].
5. **SembCorp Industries:** A business that provides three main sectors: energy, marine and urban. Under the energy sector, the company contributes to a sustainable future through innovative renewable energy and environmental solutions, including total water management and waste-to-resource offerings [17].

Overall, all the main key players function based on business plans that are either heavily dependent on their own efforts or the management of business and industries. It is rare to find a company that facilities recycling and disposal methods through educating residents and their efforts in waste management. We believe that involving the people in the wastes categorization process many of the services that are provided by companies such as the five mentioned above will be simplified and conducted more efficiently. As a matter of fact many of the wastes are not recycled and reused due to the mixture and contamination that takes place when wastes are not categorized and separated properly. We hope that our device can act as the guide that directs people towards the proper way of categorizing their waste in a method that saves time and effort due to its technical characteristics of picture identification and classification. This will lead to an increase of awareness, reducing costs and maximizing the amount of recycled wastes in the UAE.

3.3 NYUAD Conducted Survey Statistics and Analysis

As a matter of fact based on the survey that we have conducted which included around 80 participants including students, employees and housewives living in the UAE, we have found out that 61% of the households in the lacks recycling bins and 42.6% of the people never recycles or seperate their wastes [5]. As a matter of fact, even when households were provided with recycling bins many people have explained that they were not confident with how to separate their trash in most cases. This leads to many of them using all the trash bins as general waste instead of trying to figure out how to separate the waste as that required them both time and a lot of effort. Despite that, many participants have expressed that they would like to recycle and contribute to a sustainable future, however they needed clear guidelines that both educats and teach them the method of separating their wates.

4. DISCUSSION AND FURTHER DEVELOPMENT

Currently, we use available online datasets taken from Kaggle. We want to create a more consistent system where the model is trained and tested by the real data collected in the UAE. By doing so, we hope to expand our collaboration with UAE Ministry of Climate Change and Environment and environmental organizations, including Tadweer and Bee'ah, to collect the real database in the past.

In addition, we hope to build upon the current recycling and waste symbols such as Mobius Loop or Tidyman [9], using those current symbols to detect the category for the trash faster and more accurately. By doing so, we can fully exploit the use of the present codes and symbols for recycling, and also inspire the curiosity of people who want to understand more about the current labeling system for waste management.

Moreover, besides using deep learning for waste classification, we are aiming to develop a system of QR code for a faster and efficient waste detection and separation. The idea is inspired by the enormous number of unique QR codes that can be generated which is enough to label every item on earth. Given the difficulties and incomprehensibility of the current labeling symbols in waste management and recycling, it is much more

efficient if we can label each product with an QR code, send the related data of the product and QR code into a shared database connected to the device, and the device can then scan the code on the product and sort into the right category with nearly 100% of accuracy. Obviously, this is challenging to implement since it involves a lot of changes in the production and manufacturing phase on a national scale. However, if we can implement this idea, the waste separation would be more efficient, automatic, and faster than the current system.

Last but not least, one of the problems with trash sorting is the contamination level of the trash. Currently, it is significantly problematic for our system since the model may not be able to detect the type of trash because of the contamination. Even if it is able to detect the right category, the contaminants will still negatively affect the whole trash bin. Therefore, we are aiming to implement a checking system where the device asks whether the trash is cleaned before thrown into the bin. This is going to be extremely challenging as it might be even more time-consuming than not using the device. However, if the government can enforce the rule of fining people not cleaning the trash and sorting it correctly, in the long run, people will create a habit of cleaning trash and sorting trash given the implementation of our system.

CONCLUSION

The application of the project in real life will create a change in waste classification at an individual level, thus spreading to a larger scale of waste management scale in the UAE. Given its high portability, sufficient accuracy and low cost, we hope to make waste categorization an easier and more convenient task for each individual and reduce the financial and environmental burden that waste management organizations, such as Tadweer and Bee'ah, are facing at the present.

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