ASHESI UNIVERSITY

DEVELOPING A WASTE SEGREGATION ASSISTANT (MOBILE APPLICATION) FOR HOUSEHOLDS IN GHANA.

APPLIED PROJECT

BSc. Management Information Systems

Trixy Naa Momo Quaye

2021

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APPLIED PROJECT

Applied Project submitted to the Department of Computer Science and Information Systems, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Management Information Systems

Trixy Naa Momo Quaye

2021

DECLARATION

I hereby declare that this applied project is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

……

Candidate's Name:

Trixy Naa Momo Quaye

……

Date:

13 th May, 2021

……

I hereby declare that preparation and presentation of this applied project were supervised in accordance with the guidelines on supervision of applied projects laid down by Ashesi University.

Supervisor's Signature:

……

Supervisor's Name:

Francis Gatsi

……

Date:

13th May, 2021

……

Acknowledgements

I would like to express my special thanks of gratitude to my supervisor, Mr Francis Gatsi, who encouraged me and shared constructive feedback that allowed me to undertake and complete this project successfully. Secondly, I would also like to express my gratitude towards the Computer Science and Information Systems faculty, who have enabled me to acquire the skills I needed to carry out this project through their tutelage and guidance.

Abstract

As the planet's environment slowly continues to deteriorate, many organizations and sovereign states are responsible for innovating sustainable measures to reduce the production of harmful substances and repurpose materials by adding value to them. Ghana is a rapidly developing country. With this development comes a large amount of waste production, the majority of which ends up in the landfills, subsequently destroying the soil and releasing harmful gases into the air due to its poor waste management infrastructure. This project focuses on using deep learning and mobile application technology to take advantage of its massive privatized informal waste collection sector to redirect waste from landfills to treatment plants, thereby addressing specific gaps within the country's waste management infrastructure. Using transfer learning with a pretrained Keras model, a waste classification model with a 91% test accuracy was developed. This enabled the average household user to sort their waste visually. Results of the classification analysis are shared with waste collectors and recyclers registered on the mobile application to enable them to engage in the specialized collection. This approach would sensitize household users on the amount of waste they generated daily and prevent the contamination of waste items when transported to treatment plants because waste collectors would be collecting one type of waste from different locations at once.

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CHAPTER 1: Introduction

1.1 Background

Ghana is among the top five fastest-growing economies in Africa recognized for being one of the critical suppliers of precious raw minerals such as gold and diamonds to the world [1]. Despite this accomplishment, like many other third world countries, Ghana suffers from substandard waste management practices that inhibit the optimum exploitation of value waste produced. These poor waste disposal practices, including the lack of waste separation and improper collection, contribute to global warming, environmental pollution, poor health among the citizens, and the depletion of essential resources [2]. Unfortunately, the government has taken no legal actions to ensure waste segregation. The absence of the waste minimization Acts has negatively affected several private organizations such as Zoomlion from getting access to a sufficient amount of waste to be processed into raw materials to sell to local manufacturers [3]. Many scholars have appealed to the government to address the issues arising from the country's poor solid waste management infrastructure for over two decades but to no avail. Unlike the developed countries where waste is heavily segregated by the Internet of Things (IoT) systems and robotic arms running on high-level algorithms, the Ghanaian populace, just as many other third-world nations, cannot afford such technologies.

In a market survey conducted by Mr Bert Keesman under the Holland Circular Hotspot in 2019, commissioned by the Netherlands Enterprise Agency, it was stated that Ghana could be a circular economy despite the scarcity of recent and accurate data on waste generation. The researchers discovered that an estimated 22 500 tons of waste are being generated daily within the country. 61% of the waste was identified to be organic, plastic constituting 17%, electronic waste, 6%, paper waste, 4%, metal and glass 3% each, textile 2%, leather 1%, and 3% accounted for

miscellaneous materials. The data indicates that only about 8,100 tons of waste generated daily is recyclable. However, only 320 tons of materials are recycled among the 25 plastic waste recycling companies every day [4]. Out of the 320 tons, a significant amount is imported from Mali, Togo, and Burkina Faso to be recycled. There seems to be an alarmingly low volume of local waste being recycled than the amount being generated. However, the country's supply of recyclable waste appears to match its demand if not exceed it. These drawbacks in Ghana's waste management system are associated with the country's poor solid waste management infrastructure [3]. The knowledge of Ghana's potential to be a booming circular economy is the primary motivation behind this project's undertaking.

1.2 Problem Identified and Significance

One of the inconsistencies I noticed in the current waste management system was the poor household level management of waste, which is directly related to the low supply of sorted and uncontaminated waste needed to establish a booming circular economy. As a lower-middle-income country, most of Ghana's neighbourhoods fall into the lower-middle-income and low-income groups that depend on the informal waste management sector to manage the waste at their communal collection points.

In contrast, few high-income neighbourhoods benefit from the organized private door-to-door collection of garbage. Only 13.5% of the population, consisting of the few wealthy and upper-middle-class citizens, have access to Ghana's home collection system [5]. The distance between the houses and the few collection points in the high-density, low-income areas, according to residents, is quite lengthy. They, therefore, find alternative, usually indiscriminate ways to dispose of their rubbish. The improper dumping methods, combined with inconsistent collection schedules of the waste collectors assigned to the area, has led to the creation of large landfills at the collection

points and excessive burning to reduce those mounds. Unfortunately, most of the waste that is later salvaged from the collection points and illegal dumpsites is usually contaminated because the waste has been mixed with hazardous materials such as cleaning solvents. Although some collectors take time to sort out and clean the waste they pick, most do not even bother. Hence, no matter how much trash they can gather, most treatment facilities reject their waste and turn the collectors away because they do not wish to increase their operational costs by cleaning the waste. The turned-away collectors then proceed to dump their day's collections at the ever-growing landfills around. The problems stated above have led to the loss of a significant amount of valuable waste. Instead of this waste being recognized as a valuable resource for a developing economy, it is discarded, and capital that could have been invested in more profitable ventures is wasted on acquiring virgin raw material for development. Unfortunately, in Ghana, attention is given to only collection and transport with less emphasis on separation during disposal. The current system is heavily flawed due to many factors but mainly unsorted waste and inefficient collection. Separation and collection are vital stages in the waste management process that determine the amount of waste that can be recovered, recycled, and converted into a valuable resource. Addressing the waste management cycle's fundamental parts could help the country account for at least 80% of the waste generated and lead to a chain reaction in different aspects of their livelihood.

1.3 Proposed Solution

This project seeks to address insufficient source separation of waste and the waste collection system in the middle to low-income neighbourhoods in Ghana. A cost-effective technological solution would be a critical steppingstone in educating the citizenry on the benefits of acceptable waste management practices and integrating informal waste collectors in the collection process.

This project aims to develop a mobile application that guides people on how to sort their waste using deep learning technology to classify individual waste items. It also seeks to establish a strong connection between recyclers and collectors for communication purposes on collecting and recycling waste. Employing the multi-layered convolutional neural networks (CNN) model would make the application a useful waste classification tool [3]. Upon collecting data, the application's task would be to perform analytics and provide real-time data on the capacity of waste generated at specific intervals for both users and waste collectors.

Below is a flowchart of the supervised learning algorithm development cycle that would result in a practical model with high classification accuracy.

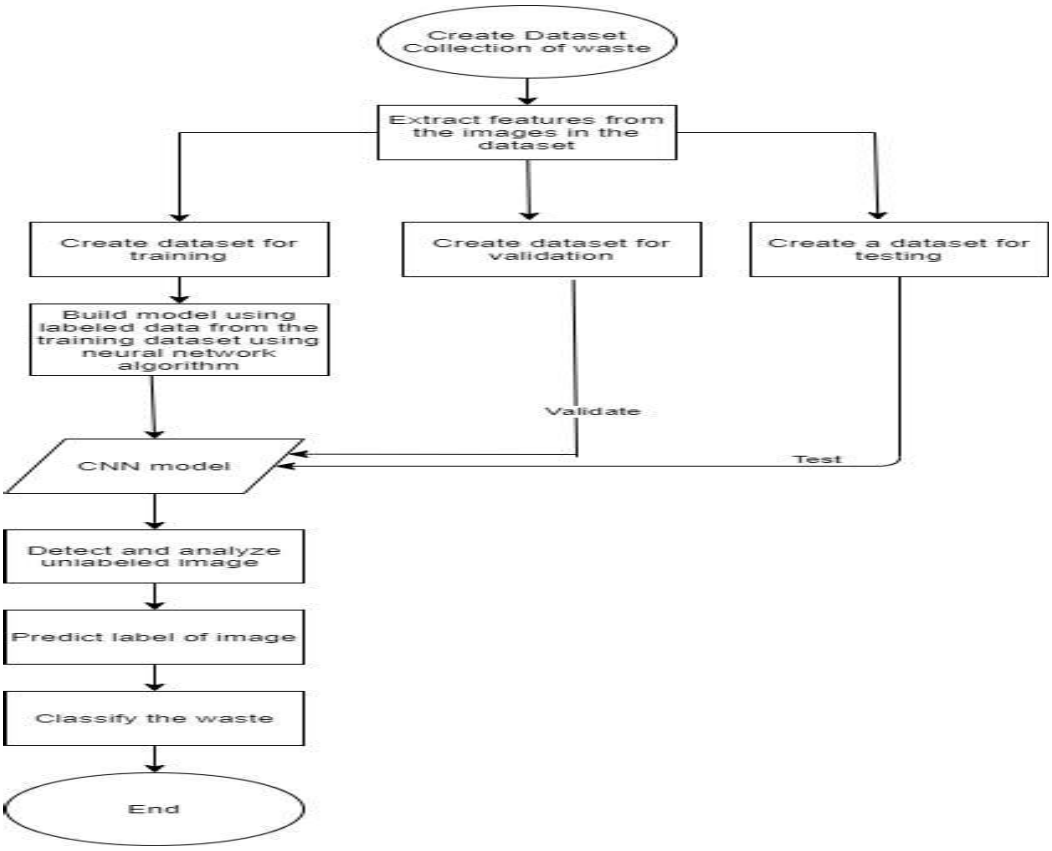


Figure 1.1: Flowchart of the supervised learning training and testing algorithm development cycle

The proposed solution holds the potential to commence source separation of waste on a large scale. It could as well, stimulate a specialized waste collection procedure within the large private

informal collection sector. Through all this, households and users of the app would be gradually sensitized and more aware of the need to reduce the waste they generate and practice a zero-waste lifestyle.

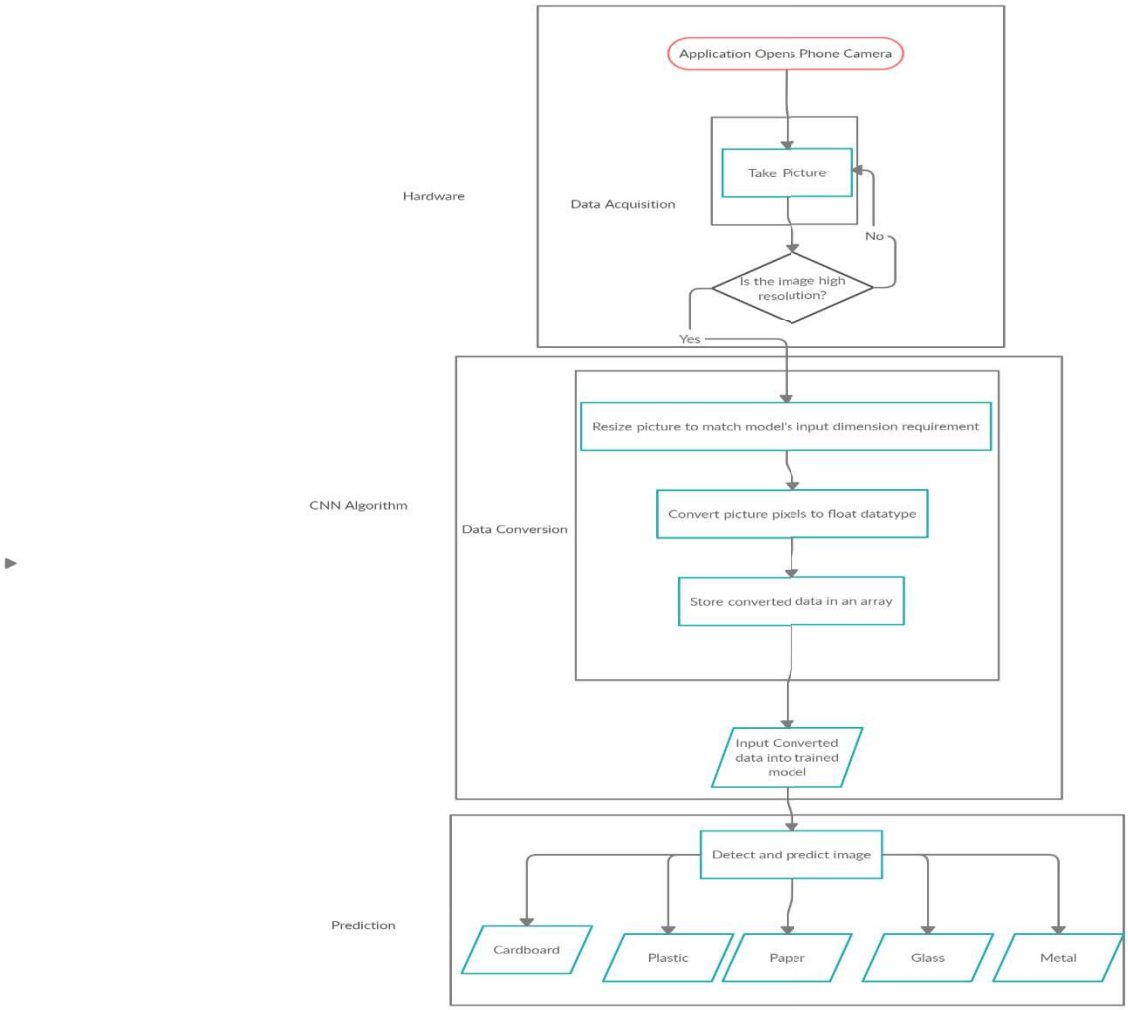


Figure 1. 2: Block diagram on image capturing process.

The image above is a visualization of how the application would function with the classification model. Once a high-resolution picture of a waste item is taken, the algorithm would convert the image data into the form that the algorithm can read and process. After conversion, the image data is processed, and the classification model would provide the recycling category the waste item falls under if it is recyclable.

CHAPTER 2: Requirement Analysis

2.1 Requirement Gathering

In the previous chapter, we identified a massive problem in Ghanaian homes; the lack of waste segregation before disposal and the apathetic attitude of most waste collectors working in the middle to low-income neighbourhoods. The solution proposed to address these two issues is software for classifying individual waste items via a simple camera and a deep learning algorithm and provide a live feed on the types of waste being generated to waste collectors using the app. A questionnaire was drawn to evaluate the locals' knowledge on the value of waste, how they prepare their waste for disposal, and, most importantly, if they would be interested in using an application to separate their waste and contact collectors. The questionnaire also contained a field where respondents could express their opinions on how the application should work and what they expect it to do for them. This section was analyzed to derive the functional requirements below.

The application should:

i. Display information on the private waste recycling and upcycling companies and organizations around them that accept their collection request.
ii. Send reminders for separation.
iii. Identify and Specify which kind of waste goes into which category.
iv. Make communication between households and collectors easy.
v. Be able to operate offline.
vi. Indicate time of pickup.
vii. Indicate the status of the household, that is, whether the waste has been collected.
viii. Show the volume of waste being recorded at various intervals on the user's dashboard.

2.2 Non-functional Requirements

For the non-functional requirements, the application should:

i. Display all collection requests on the map when they are made and disappear immediately when the user accepts a pickup request with a latency of almost an hour.
ii. Be able to run on both Android and iOS platforms.
iii. There should be at least 1GB of storage available on the user's device.
iv. Should not support any form of online transactions to ensure payment information of the users is not compromised in case of a security breach.
v. Passwords should not be displayed on the interface.
vi. Delete the house address of the user immediately after the waste collection is confirmed.
vii. Not disclose the name, contact, and the requester's house address to the waste collector, till the user approves that they can collect their waste.
viii. Be able to access the camera and GPS location of the user's device.
ix. Should include audio-visuals for people who might not be able to read
x. Easy to use regardless of literacy level by having a simple but efficient interface.
xi. Use a classification algorithm with at least 80% accuracy.

The primary stakeholders are:

i. Ghanaian households; as the primary users of the app.
ii. Waste collectors, independent (self-employed), and employees of solid waste management (SWM) companies.
iii. Private companies that buy specific waste items (recyclers).

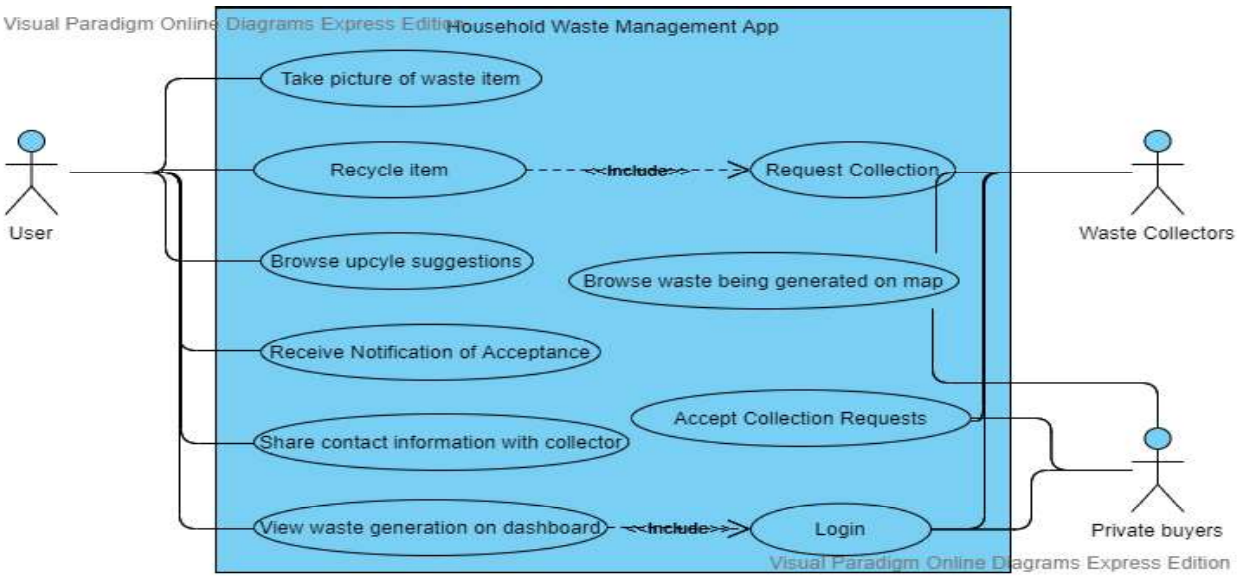


Figure 2.1: Use case diagram for the stakeholders.

CHAPTER 3: Architecture and Design

3.1 High-level Systems Overview

The mobile application design must integrate a waste classification algorithm that will process user inputs, which are pictures of waste items, suggest upcycling methods from the web, provide recycling options and connect users to collectors and buyers. Upon selecting a recycling option, the user's location is retrieved from the database and uploaded to a live map and waste information, an output of the classification algorithm. Other users, who identify with a waste collecting, purchasing, or recycling role, would have information about waste interests made available to them in real-time. Recyclers and waste collectors would use the app to contact household users via messaging to discuss payment and collection time. After users confirm that the waste collector or recycler that contacted them has fulfilled their recycle request by collecting waste, the information uploaded to the map will be removed. At the time of collection, the data would be made redundant hence its deletion. Outputs of the processing by the waste classification algorithm will be stored in the database and later used to analyze the amount of waste being generated. This analysis would be displayed on the user's dashboard.

3.2 Modules

The modules upon which this application would function are the classification module, user module, upcycle module, recycle request module, data module, messaging module, and data analysis module.

The classification module holds the waste classification algorithm that will indicate the recycling category a waste item falls under. The user module consists of household users, waste collectors, individual recyclers, and recycling companies. The upcycle module provides

information on how a waste item can be utilized by pulling information from the internet. The recycle request module acknowledges a household user's decision to have their scanned waste items recycled and makes this information available to collectors via a map. The data module stores and organizes the classification algorithm's output for each unique user, location and personal information, and recycling request status. The Messaging module enables collectors and recyclers to contact households for their waste without exposing their exact location, phone number, and other personal details that are expected to be shared by both parties on their own accord upon communicating. The data analysis modules will access information in the database for waste generation analysis.

3.3 Architecture

The modules identified above would be implemented using the 3-tier architecture, as shown below.

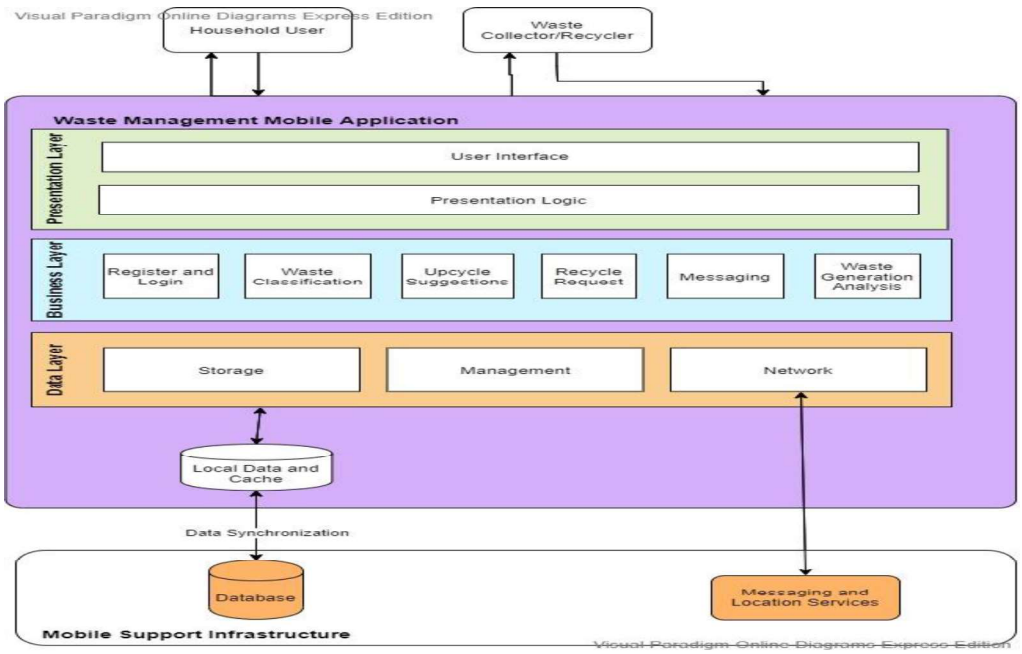


Figure 3. 1: High-level system architecture

This architecture was primarily chosen for its efficiency and flexibility. It employs a modular stack that ensures that each subsystem maintains some form of independence. This way, minor updates, including bugs, that are made in the future would not cause disastrous effects across the entire system, and they can be easily found and isolated. The architecture makes implementation quite simple and allows for scalability, which is essential when creating applications expected to attract an exponential growth in traffic and data. These features will positively affect the overall performance of the application, as well.

CHAPTER 4: Implementation

4.1 Implementation Overview

This section provides a high-level description of the implementation of the waste management application software known as Up-Re Cycle. It details how the frameworks, APIs, tools and languages were employed in designing the application.

4.2 Frameworks and Tools Used

Up-Re Cycle is a cross-platform application built natively within the Ionic 5 and Angular framework to enable compatibility for all major mobile operating systems, that is, androids and IOS, used by the target market, Ghana.

4.2.1 Ionic & Angular

Ionic is an open-source framework that provides developers with a user interface toolkit that is used to develop exceptional cross-platform mobile applications. It uses HTML, CSS and JavaScript. Angular is another open-source framework used in this application that provides authentication, routing, and client-server communication libraries for web applications. Here, the programming language used is TypeScript. For the user interface component in the Ionic framework to be fully functional, it requires Angular, hence integrating the latter.

4.2.2 Cordova

Cordova is an open-source framework that provides resources that enable native applications to run on multiple platforms and to access native resources of the hardware on which the application is running. Apache Cordova is being used to provide plugins within a native wrapper class to convert the native android app being built in ionic into code that can run on other mobile operating systems.

4.2.2.1 Cordova Plugins Applied

- **Camera –** The camera plugin enables users to take pictures of the waste that they wish to recycle. The image file is required for processing in the cloud storage where the CNN model is hosted.
- **Firebase Authentication –** This plugin has libraries that give access to methods that make the registration, login and logout process as seamless as possible for users.
- **Google Maps –** This plugin, visible on the waste collectors UI, enables them to see the areas generating waste in real-time.
- **Google Services –** The google services plugin enables analytics in the background while the application is running to track usage and potential errors or bugs that the users are encountering.

4.2.3 Firebase

Firebase is a software development kit (SDK) that provides an integrated backend as a service (BaaS) to web applications. Hosted by Google, this tool allows apps to get access to a real-time database, hosting, machine learning, authentication, and messaging services, as well as cloud storage. The platform operates a NoSQL database known as Firestore that would be acting as the primary database for this project. The platform holds a Python SDK that can be used to convert a keras model into the TensorFlow Lite format, which it reads to perform machine learning tasks within applications.

4.3 APIs

4.3.1 Keras

Keras is a deep learning API written in Python that supports backend neural network computations. The pre-trained Inception v3 architecture model, from the Keras opensource library, with a validation accuracy of 92.5%, was integral in creating the multi-convolutional neural network needed to act as a visual waste sorter within the application. Transfer learning methods were utilized in retraining the Inception v3 model.

4.3.2 Google Maps API

The google maps API provides a key that, in conjunction with the Cordova google maps plugin, shows the real-time location of places producing large amounts of waste on the waste collectors' UI.

4.3.2 Talk JS API

The Talk JS a JavaScript software development kit that comes with a prebuilt user interface and chats API. It provides the application with a classy UI messaging platform for users, waste collectors, and recyclers to communicate effectively.

4.4 IDEs & Emulators

During creation and production, Visual Studio Code and Android Studio were utilized. For testing the functionality of sensors such as the camera, Firebase emulators and an Android Pixel 2 API 30 with 1080 by 1920 resolution were used.

4.5 Implementation Techniques

4.5.1 Implementation for the User Module

The user module is one of the most important modules that sit on the application's presentation layer. Here, three main functions are being handled: sign-up, login, and password reset. Importing the AngularFireAuth, Firestore and Router module from the angular library and an Alert Controller from the Ionic UI component library, these classes' methods aid the user's essential functions. The AngularFireAuth module is accompanied by an inbuilt JavaScript validation that automatically ensures that password limits are met and that input fields give no way for any SQL injections. Hence, when a user signs up and enters valid information, their information is uploaded to the Firestore user collection for the application, and they are redirected to the login page. An AngularFireAuth method cross-checks the user's credentials with documents in the user collection during the login process. Once a match is found, users are redirected to their dashboard. However, if they happen to enter invalid details, an alert is shown where they could either navigate to the sign-up page or request a password reset. In the case of a password reset, a form collects the email address they used to sign up to the app and uses another method from the AngularFireAuth class to send a password reset link. This is the only link through which they can enter the profile settings page to make edits to only the password field.

4.5.2 Implementation for Waste Classification & Data Analysis Module

This module runs on the business layer to capture and upload images to the application's cloud storage in Firebase. Within the cloud storage sits the machine learning classification model, which is called using the machine learning mobile SDK in Firebase to process live camera streams and classify waste images. The live camera streams are made possible by the AngularFirestorage and the camera module components of Angular and the ionic native library. The image file is encoded and converted to base64 to be stored temporarily as a string in the Firestore images

collection. Once uploaded, the model is immediately called to process the image and classify it. The results are returned to when they close the camera, below the image they took. Again, using methods in the typescript file linked to the HTML file of the user's dashboard, the data from the classification is used to generate a data visualization of the waste that is being generated. In the backend, the number of items scanned along with the user's location general location is uploaded on to the map and another data visualization chart on the waste collector's UI. On that interface, the collectors and recyclers can see the types of waste that neighbourhoods are producing and the volume in percentages with the help of the google maps API and google maps Cordova plugin.

4.5.3 Implementation for Recycle Module

Given that the scanned items for every class are counted every day, and there is no IoT component to determine the actual volume of the waste, both users and collectors are expected to make requests for recycling at their convenience. The app would not notify a user with upward trend analysis on their dashboard to contact a recycler or collector that does not truly reflect the volume of waste in their homes and whether their waste bins had reached total capacity. This is where the firebase messaging service comes in. Based on places indicated on the map that record relatively high waste levels in certain materials, verified and registered waste collectors are permitted to send customized pushed notifications to a group of people living in a particular area. Once the request is made, the message is sent to the cloud messaging platform in Firebase, where developers can verify and authorize the message to be sent to the specified group of people to ensure collectors are not spamming household users.

4.5.4 Implementation for Messaging Module

The messaging module is where the TalkJS API is implemented. With a simple JavaScript link at the bottom of the app root HTML, users can receive notifications when the app is closed

and send messages within the messaging page while interacting with a straightforward UI. The configurations on the messaging typescript file that is linked to the HTML file pull the logged-in user's email address and ID and that of whomever they are trying to communicate with to establish a session.

CHAPTER 5: Results and Analysis

5.1 Component Testing

In testing the application's performance, it was deployed live on a Chrome browser viewed using an iPhone X interface and an android emulator via Firebase. The application is expected to perform optimally and have an easily navigable user interface on Android and iOS mobile operating systems. In testing the accuracy of the Keras waste classification model, a test dataset of about 15000 images belonging to 7 classes was used passed through the model in the google cloud laboratory environment.

5.1.1 Register and Login Testing

Before householders can communicate with recyclers and collectors and vice versa, they are registered users of the application and must be signed in. Due to this, a test was carried to check whether users can successfully provide their names, password, and other essential credentials without any system hindrances. Also, users should be prevented from creating accounts with email addresses that are already existing in the database. Neither should they be permitted to log into the system with credentials that have not been registered.

Table 5.1: Table showing testing results of the sign-up and login components.

TEST	**ERROR/SUCCESS MESSAGE**	**EXPECTED OUTCOME**
Providing two different passwords when signing up	Passwords do not match	Pass
Ignoring compulsory sections (First name and Last Name) of	POST error creating a new user in the cloud database	Fail

the sign-up form and trying to register		
Signing up with an already existing email in the database	This email address is already in use by another account	Pass
Attempting to sign up by providing a valid email address, password, and names.	Success [Welcome Message displays] and redirects user to the login page	Pass
Attempting to submit an sign up empty form	The email address is poorly formatted. Prohibits redirection to login page	Pass
Log in attempt with a wrong password	The password is invalid, or the user does not have a password	Pass
Log in attempt with an unrecognized email address	There is no user corresponding to this identifier. The user may have been deleted. Redirects user to sign up page.	Pass
Log in attempt with correct credentials	User is redirected to their dashboard.	Pass

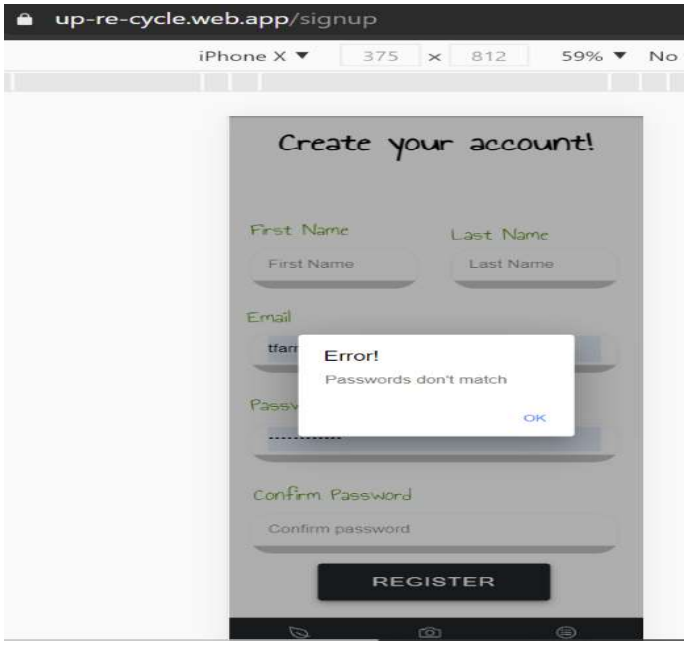


Figure 5.1: Passwords do not match error message during registration

Figure 5.2: POST error message when submitting an uncompleted registration form

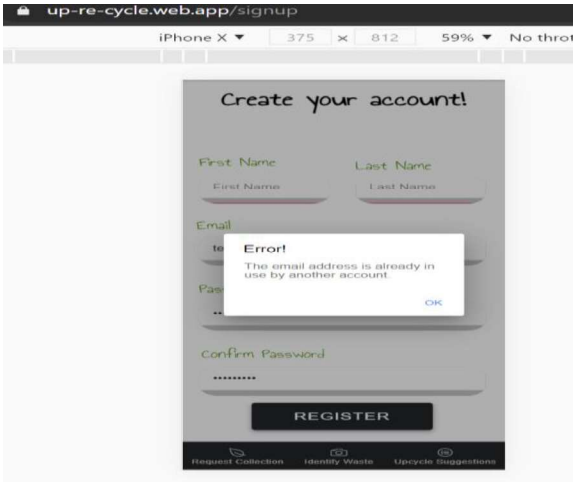


Figure 5.3: User already in use error message during registration with a recognized email

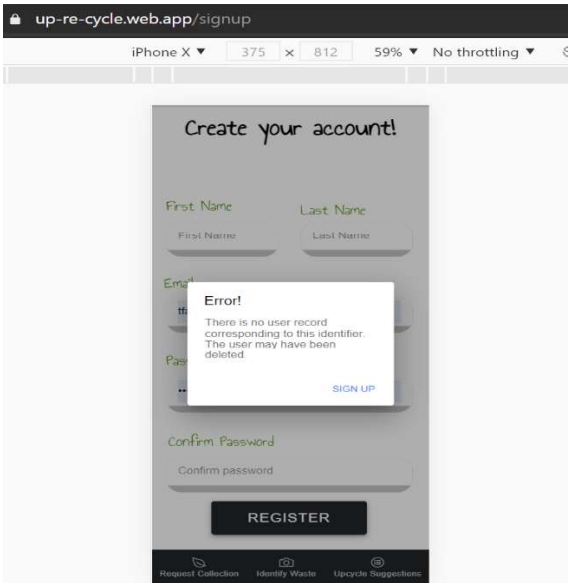


Figure 5.4: Sign-in error message when signing in with an unrecognized email

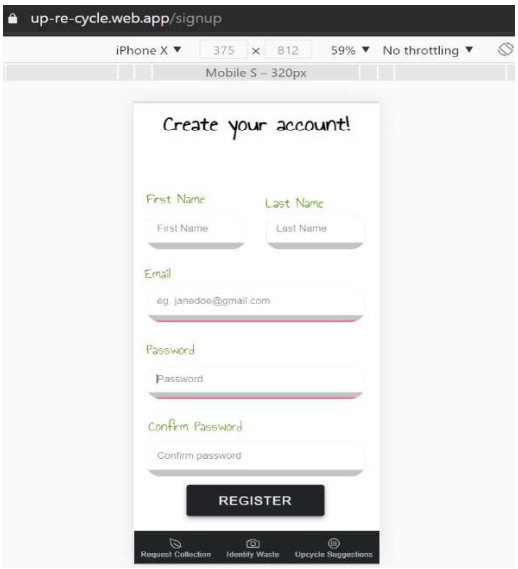


Figure 5.5: Attempting to submit an empty sign-up form

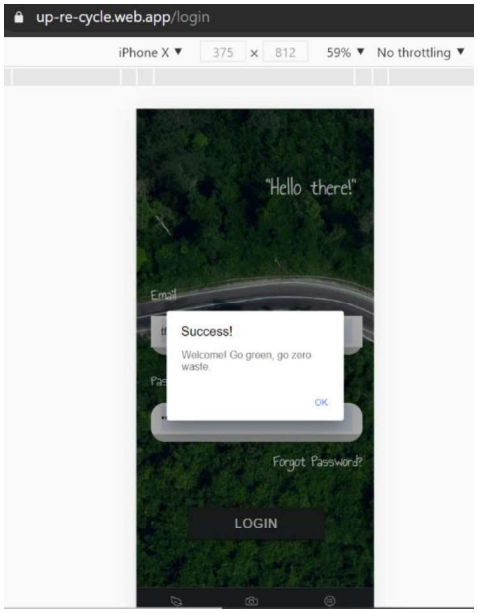


Figure 5.6: Success message shown after signing in with valid credentials

5.1.2 Waste Generation Analysis Module Testing

The classification model results are compounded and used in a line graph to visually analyze the number of waste items that the user has scanned over a week. After being retrained, the waste classification model had a validation accuracy of 91% compared to 85% from previous training. The model's accuracy was tested on test data of over 15000 images with seven classes, namely cardboard, glass, metal, paper, glass, organic waste, and trash (non-recyclable waste).

Table 5.2: Table showing testing results of the waste generation analysis component

TEST	**ERROR/SUCCESS MESSAGE**	**EXPECTED OUTCOME**
Loads data into charts within 5 seconds of opening the dashboard page		Pass

User can easily interpret the line graph		Pass
The line graph is legible	The "metal" graph with yellow data points on a white background is not suitable for users experiencing some form of colour blindness	Fail

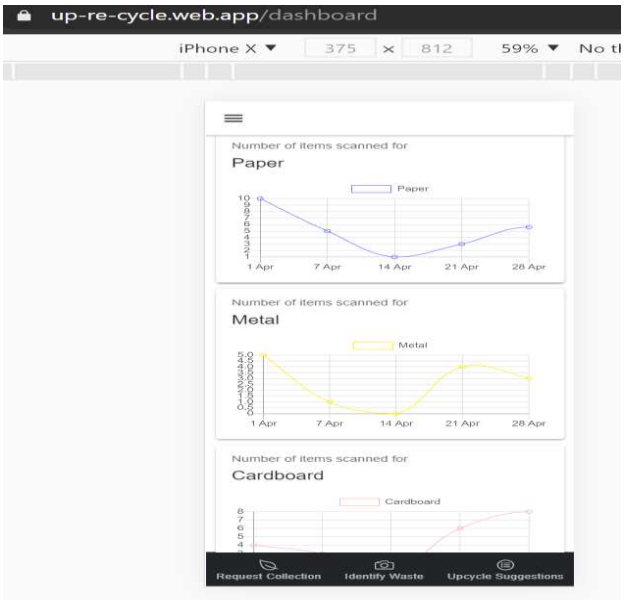


Figure 5.7: Data visualization of waste being generated displayed on user's dashboard

5.1.3 Waste Classification Module Testing

When users want the app to identify their waste items, upon tapping the "identify waste" button, they should be redirected to a page where they can take a picture or upload an image file onto the application for processing. Once uploaded, the TensorFlow lite waste classification model file sitting on the cloud should be called. If that fails, the classification model bundled with the

application should take up processing the image locally. The classification model was tested using the google cloud laboratory.

Table 5.3: Table showing testing results of the waste classification model

TEST	**ERROR/SUCCESS MESSAGE**	**EXPECTED OUTCOME**
Asking for user's permission before accessing their camera	Permission denied message when the user does not grant permission. The camera cannot open	Pass
The camera closed after capture	The camera remains open in the background. Poses a security risk	Fail
The camera functions properly on emulators		Pass
Appealing User Interface	Image captured fills half of the screen.	Fail
The application can access the user's photo library on the device		Pass
Image upload from phone library	Firebase storage error. Specified collection for image storage is unknown.	Fail

Waste classification model accuracy on 302 batches of test images	Test accuracy: 91% Test loss: 13%	Pass
Converting Keras model to a TensorFlow Lite model to be compatible with the firebase backend service	Success bundling model with the application.	Pass
Uploading TensorFlow lite model onto the application's cloud storage	Model validation error due to size (155MB) exceeding the limit of 40MB	Fail
Attempting to reduce TensorFlow lite binary size for optimum performance on user's device		Fail

Figure 5.8: Error message displayed when user refuses the application access to the device's camera

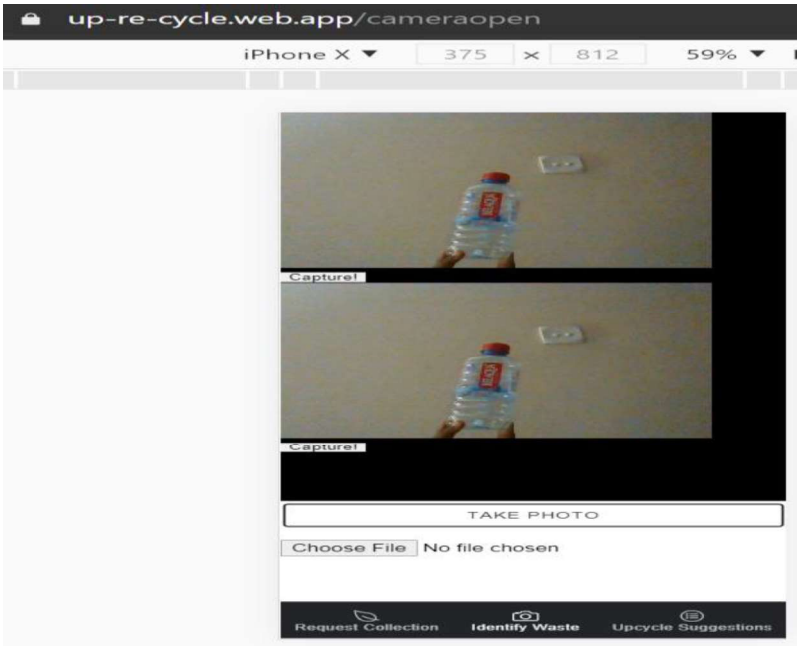


Figure 5.9: Taking a photo of a waste item for identification

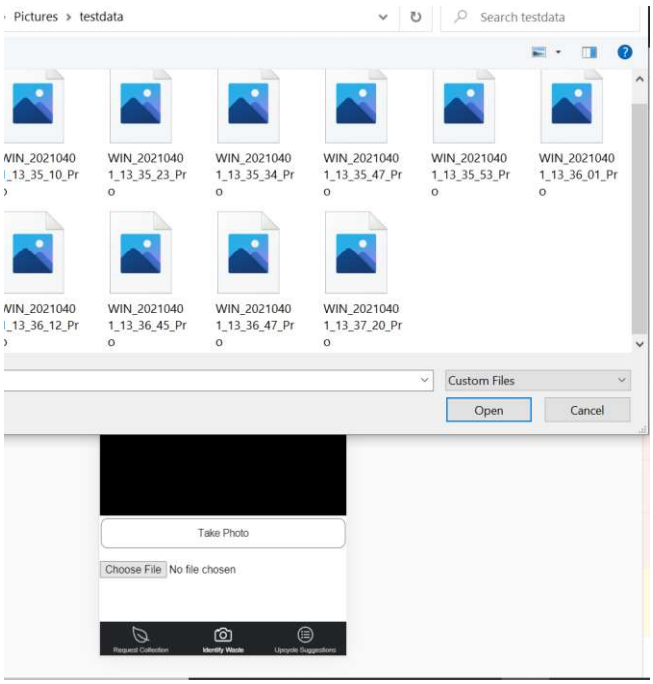


Figure 5.10: Uploading an image file from the device's photo library

Figure 5.11: Image file upload error

```
model.fit(train_gen, validation_data=val_gen, epochs=10, verbose =2)

Epoch 1/10
121/121 - 711s - loss: 0.2356 - acc: 0.8722 - val_loss: 0.2222 - val_acc: 0.8584
Epoch 2/10
121/121 - 687s - loss: 0.2050 - acc: 0.8811 - val_loss: 0.2358 - val_acc: 0.8811
Epoch 3/10
121/121 - 686s - loss: 0.1938 - acc: 0.8696 - val_loss: 0.2155 - val_acc: 0.8585
Epoch 4/10
121/121 - 685s - loss: 0.1743 - acc: 0.8659 - val_loss: 0.2153 - val_acc: 0.8583
Epoch 5/10
121/121 - 690s - loss: 0.1724 - acc: 0.8666 - val_loss: 0.2133 - val_acc: 0.8612
Epoch 6/10
121/121 - 719s - loss: 0.1578 - acc: 0.8798 - val_loss: 0.2017 - val_acc: 0.8724
Epoch 7/10
121/121 - 701s - loss: 0.1485 - acc: 0.8669 - val_loss: 0.2324 - val_acc: 0.8584
Epoch 8/10
121/121 - 686s - loss: 0.1500 - acc: 0.8604 - val_loss: 0.2092 - val_acc: 0.8591
Epoch 9/10
121/121 - 683s - loss: 0.1471 - acc: 0.8753 - val_loss: 0.2164 - val_acc: 0.8613
Epoch 10/10
121/121 - 685s - loss: 0.1375 - acc: 0.8657 - val_loss: 0.2299 - val_acc: 0.8595
<tensorflow.python.keras.callbacks.History at 0x7f8ad3bc51d0>
```

Figure 5.12: Validation accuracy of the waste classification model

```
#callbacks = myCallback()
model.fit(train_gen, validation_data=val_gen, epochs=5, verbose =2)

Epoch 1/5
121/121 - 712s - loss: 0.4197 - acc: 0.6756 - val_loss: 0.2602 - val_acc: 0.9344
Epoch 2/5
121/121 - 718s - loss: 0.2488 - acc: 0.8675 - val_loss: 0.2480 - val_acc: 0.8869
Epoch 3/5
121/121 - 678s - loss: 0.2189 - acc: 0.8973 - val_loss: 0.2243 - val_acc: 0.9352
Epoch 4/5
121/121 - 679s - loss: 0.1937 - acc: 0.8978 - val_loss: 0.2364 - val_acc: 0.8952
Epoch 5/5
121/121 - 691s - loss: 0.1800 - acc: 0.8941 - val_loss: 0.2149 - val_acc: 0.9086
<tensorflow.python.keras.callbacks.History at 0x7fcfa2d5a4d0>
```

Figure 5.13:Improved validation accuracy of after fitting model again

```
[ ]  # Evaluate the model on the test data using `evaluate`
     print("Evaluate on test data")
     results = model.evaluate(test_gen)
     print("test loss, test acc:", results)
```

```
Evaluate on test data
302/302 [==============================] - 612s 2s/step - loss: 0.1360 - acc: 0.9170
test loss, test acc: [0.13599176704883575, 0.9169853925704956]
```

Figure 5.14: Test accuracy achieved on test data

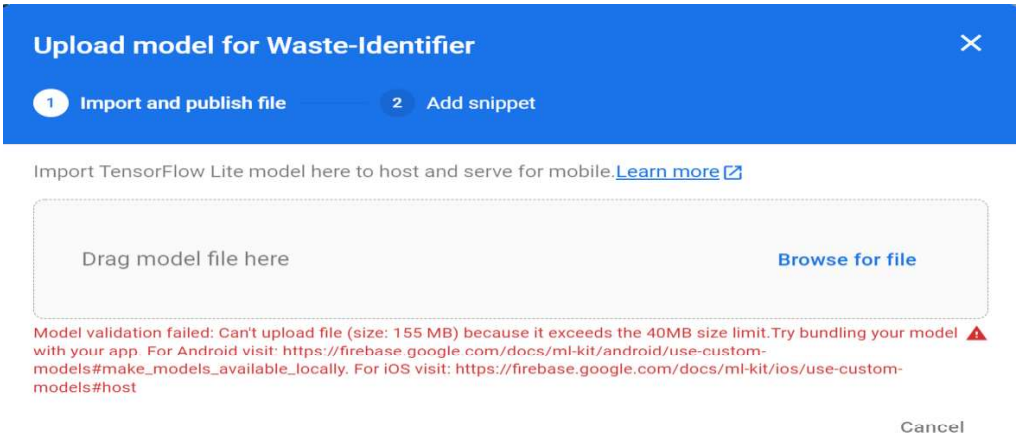


Figure 5.15: TensorFlow lite model upload error

5.1.4 Recycle Request and Messaging Module Testing

Upon viewing waste statistics on items being generated in certain areas, waste collectors and recyclers should be able to send an official request to every user within the specified geographical area, expressing the interest in wanting to collect a particular kind of waste there. If users are interested, they should be able to reply to these requests on the platform without having to disclose their exact location and expose their phone number unless they trust the collector and are willing to share such details.

Table 5.4: Table showing testing results of the recycle request and messaging components

TEST	ERROR/ SUCCESS MESSAGE	EXPECTED OUTCOME
Collectors cannot make requests without being logged in and verified		Pass
Collectors can send a request message		Pass
Collector's interface is simple and easy to understand no matter education level		Pass
Collectors receive a notification when a user accepts a request		Pass
Collectors can view the waste generation breakdown of any highlighted area on the map		Pass

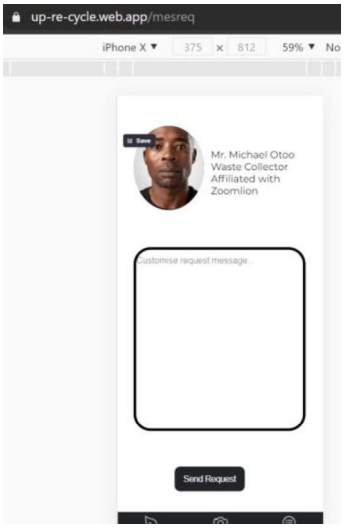


Figure 0.16: Collector collection request interface

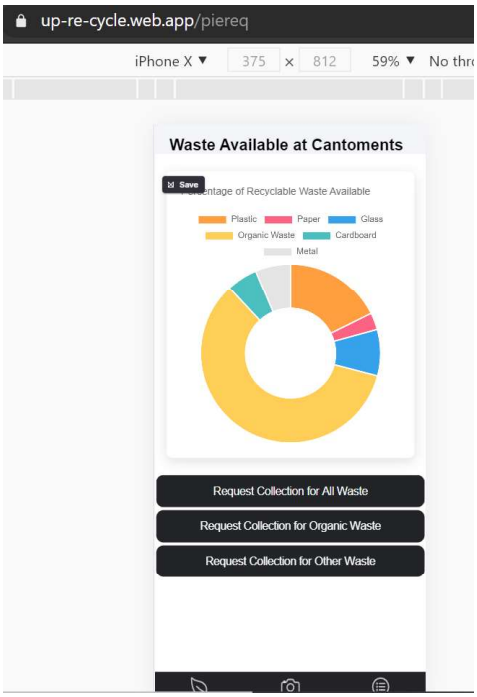


Figure 5.17: Waste generation breakdown for a selected area on the map

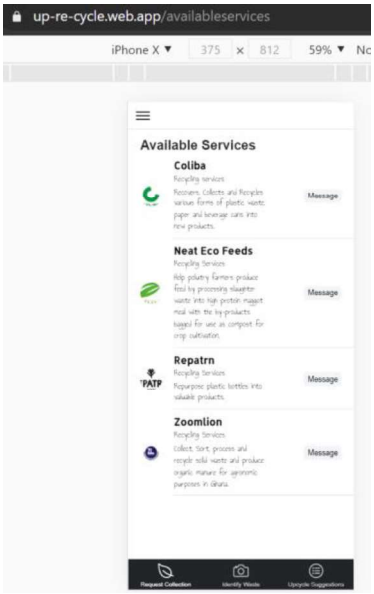


Figure 5.18: User recycler request interface

CHAPTER 6: Conclusion and Recommendations

This project shows how mobile and machine learning technology can be used to improve the waste management process at the household level and collection-level despite the issues with the current waste management infrastructure of Ghana. The Up-Re Cycle application will stimulate specialization in collecting waste in the country due to the growing scale source separation. With the new form of collection in place, Ghana would divert a significant amount of their waste from being dumped at landfills to be transported to treatment facilities because of the reduced contamination of waste products due to the new categorized collection practice. In the long run, Ghana would create a circular economy and adopt a zero-waste lifestyle, where waste is given value and becomes an essential resource in its development.

Upon completion of this project, approximately 83% of the milestones were met. Out of the eight functional requirements listed for the application, only five were met. The requirements that were not carried out were the separation reminders, pickup times and collection status of the household user. For these three, since the application was acting as a medium of communication between the collectors and the household users, it was not entirely necessary or practical for the app to control such parameters. For the separation reminders, it was not practical to include that component because the app has no sensors to track whether the user is generating some form of waste unless they open the app and take a picture of the waste. It could become an unwanted feature as frequent reminders could lead the user to unconsciously generate unnecessary waste for the sake of using the application at every hour. Also, because collectors would be communicating privately with users once the collectors' collection requests are approved, pickup times would be negotiated at the convenience of both parties. They will not need to be tracked by the application due to traffic, the sudden absence of one party at the pickup destination and other unpredictable

factors. Setting a collection schedule for a user could hinder them from contacting other collectors. The intention was for a collection status to be set up for a user after they accept a collection request to track collectors and recyclers that fulfil their commitment. However, in a case where a collector is assigned to a user and fails to show up for some time, the household user would be at a disadvantage as the system would not make their coordinates available to waste collectors interested and ready to collect the same category of waste. Due to this, they would not receive new requests either and would find it difficult to be contacted by other verified collectors and recyclers on the platform.

6.1 Limitations and Flaws in Design

For this project, the major flaw was the design of the waste classification model. Due to its inefficient construction, which resulted in its large size, the model could not be hosted on the cloud. Therefore, the model had to be bundled together with the application, making its Android Package Kit (apk) and iOS App Store Package (.ipa) large and lengthening the installation process for the user. This reduced the application's overall performance as there was no real-time live camera processing of the images.

6.2 Future Development

This project seeks to address many issues regarding the sustainability of the environment and improve solid waste management practices in Ghana and in many developing countries. Below are a few recommendations that could be considered in the advancement of this software.

a. Introducing an external Internet of Things (IoT) component such as a smart bin with a camera and an ultrasonic sensor to know the levels of each category of waste disposed or

a detachable robotic arm to physically sort large piles of waste at a time to work in conjunction with the app.

b. Utilize audio-visuals to aid individuals who cannot see or read to have a better user experience.
c. Implement a lighter but efficient model to reduce the overall size that the application occupies on the user's device.
d. Users not comfortable with the English language should be able to choose their preferred language. Therefore, the integration of local Ghanaian languages via the open-source initiative for natural language processing for Ghanaian languages, known as Kasa, should be considered.

References

[1] Newell, M. 2019. Top 5 fastest-growing economies in Africa. *Worldfinance.com*.

[2] Huiyu, L., O., O. and Kim, S., 2019. Automatic Classifications and Recognition for Recycled Garbage by Utilizing Deep Learning Technology. *Proceedings of the 2019 7th International Conference on Information Technology: IoT and Smart City*, pp.1-4.

[3] Oteng-Ababio, M., 2011. JOURNAL ARTICLE Missing links in solid waste management in the Greater Accra Metropolitan Area in Ghana. *GeoJournal*, 76(5), pp.551-560.

[4] Keesman, B., 2019. *Market Survey Waste and Circular Economy in Ghana*. Available from https://www.rvo.nl/sites/default/files/2019/08/Ghana-Market-Survey-Waste-Circular-Economy.pdf

[5] Boadi, K. and Kuitunen, M., 2005. Environmental and Health Impacts of Household Solid Waste Handling and Disposal Practices in Third World Cities: The Case of the Accra Metropolitan Area, Ghana. *Journal of Environmental Health*, 68(4), pp.32-36.

[6] Azis, F., Suhaimi, H. and Abas, E., 2020. Waste Classification using Convolutional Neural Network. *Proceedings of the 2020 2nd International Conference on Information Technology and Computer Communications*, pp.9-13.

Appendices

Appendix I: Questionnaire used to conduct the survey and gather requirements from the public.

Household Waste Management Application Survey

Thank you for agreeing to participate in this survey. This survey seeks to collect data on the waste management practices of individuals living in Ghana. The survey is being conducted to help us determine the significance of an application that is expected to guide households when separating their waste and establish consistent communication with waste collectors and homes that do not benefit from Ghana's door-to-door collection system. We assure you 100% confidentiality for this survey.

*Required

1. 1. Do you live in Ghana? *

Mark only one oval.

- ◯ Yes
- ◯ No

2. 2. If you responded "yes" in the previous section, what type of waste collection system is currently run in your neighborhood? *

The door-to-door collection system is a system whereby a private company such as Zoomlion collects trash from houses in a specified area probably because all the households have paid for that service. The central collection point system is a system whereby residents are required to take their waste to a designated collection point in their community.

Mark only one oval.

- ◯ Door-to-door collection
- ◯ Collection Point
- ◯ Other: _____

3. 3. If you chose "other", please explain why.

4. 4. If you selected the "Collection Point" option, how often do waste collectors clear the collection points?

Tick all that apply.

- [ ] Never
- [ ] Rarely
- [ ] Occasionally
- [ ] Often
- [ ] Always

5. 5. Do you separate your waste before you dispose of it? *

Mark only one oval.

- ◯ Yes
- ◯ No

6. 6. Please explain your answer. *

7. 7. Please select the categories you usually separate your waste into.
   Check all that apply

   Tick all that apply.

   - [ ] Cardboard
   - [ ] Glass
   - [ ] Paper
   - [ ] Organic Waste (eg. banana, yam, orange peels etc)
   - [ ] Metal
   - [ ] Plastic

8. 8. Would you be more willing to separate your waste, if you were to receive monetary returns upon disposal? *

   Mark only one oval.

   - ◯ Yes
   - ◯ No
   - ◯ Maybe

9. 9. Do you believe waste is valuable? *

   Mark only one oval.

   - ◯ Yes
   - ◯ No
   - ◯ Maybe

10. 10. Please explain your answer

11. 11. Do you reuse items instead of disposing of them right away? *

Tick all that apply.

- [ ] Never
- [ ] Rarely
- [ ] Sometimes
- [ ] Often
- [ ] Always

12. 12. Would you be interested in using an app that could simplify your waste separation process and easily connect you to waste collectors in your area? *

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Maybe

13. 13. Please explain your answer. *

_____

_____

_____

_____

_____

14. 14. Are there any suggestions or recommendations you would like to share concerning the functionalities of the application? *

Mark only one oval.

Yes

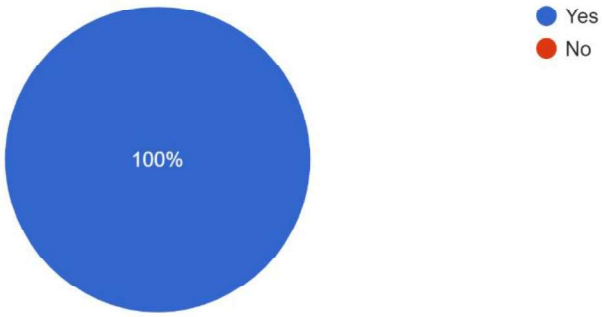
No

15. 15. Please state them.

Appendix II: Survey responses

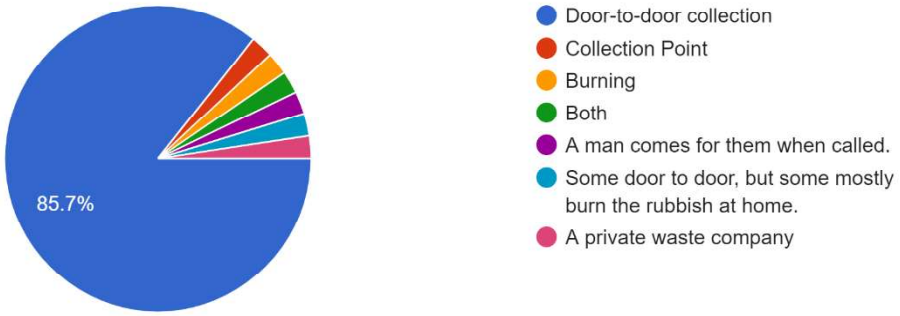
1. Do you live in Ghana?

42 responses



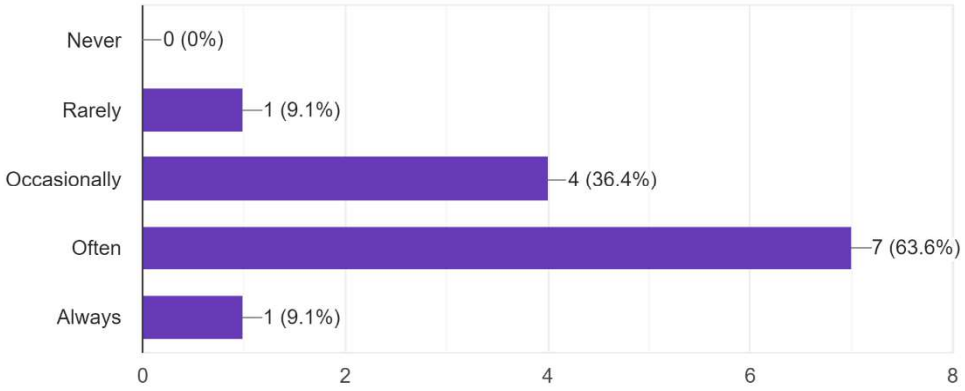
2. If you responded "yes" in the previous section, what type of waste collection system is currently run in your neighborhood?

42 responses



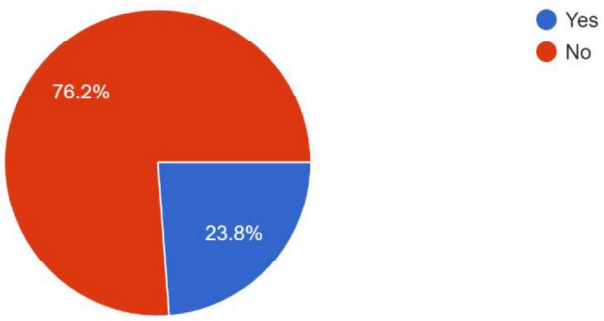
4. If you selected the "Collection Point" option, how often do waste collectors clear the collection points?

11 responses



5. Do you separate your waste before you dispose of it?

42 responses



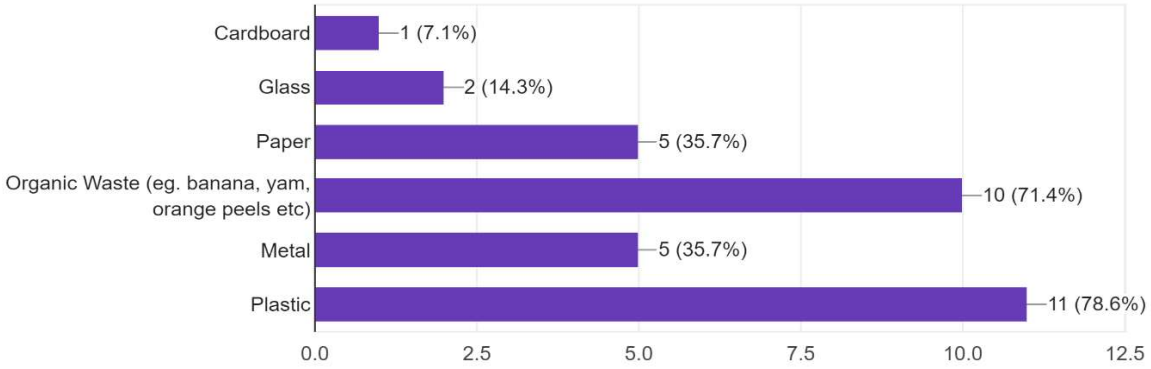
6. Please explain your answer.42 responses

We separate the plastics/rubbers from the rest of the waste
Segregation with colour coding plastic bags
I just put all in
I just put everything in the big dustbin. Even if I separate it, the waste collectors will end up mixing them together.
We separate bottled water
We dispose of everything together
The collectors do not require it
Mixed waste
Put them in rubber bags and tie them and place them in the bin

Kitchen rubbish, grass and sand are all in the bin
We do not need to separate before burning
Even if I separate them, they'd all go in one place in the end, so what is the point anyway
Into perishables and plastics
It depends.
It is not separated because we have only one bin
Burn the plastic and inorganic waste
Plastics, glass, paper, etc. together
Because at the end everything is collected as one unit and all sent to the same place, there will not be a need to separate the rubbish.
We do not separate our waste. It is all together
Every waste goes into one bin to be disposed of later.
Everything is grouped in bags and disposed of.
We just put everything together
Divided into plastic, glass, metal, food waste and paper
We mix the waste, whether organic or inorganic, into the same bin
All waste is put in the same bin
To make it easy for the waste collector
Because there is only one waste bin
Just them all in
Not all the time
I just dump them all in one bin.
It all goes into one big polybag.
Separate combustible stuff from non-combustible stuff
It does not seem necessary.
Waste at home is placed in bin bags before it is disposed into a more significant bin. So, the bin is not separated before it is collected.
My home mostly burns waste cos the door to door was not effective. They seldom cleared the rubbish. Moreover, outsiders would mostly fill up the bin, and we had to pay the charge when the collectors came by for the rubbish.
We put them all in one bag.
Because that kind of system is not active in Ghana, but if I had my way, I would separate it

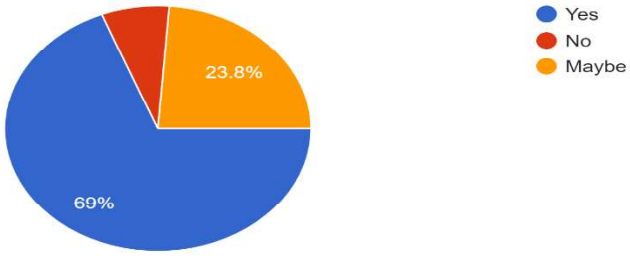
7. Please select the categories you usually separate your waste into.

14 responses



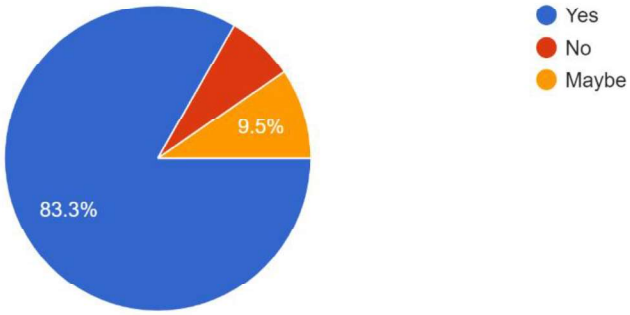
8. Would you be more willing to separate your waste, if you were to receive monetary returns upon disposal?

42 responses



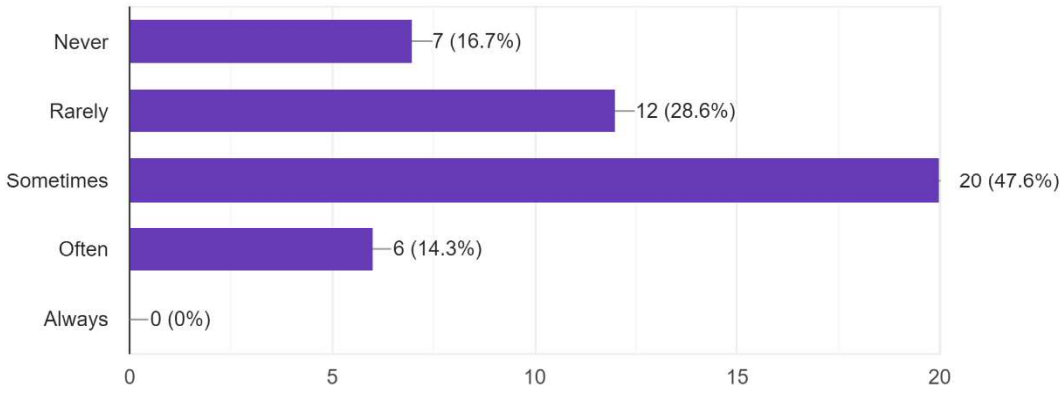
9. Do you believe waste is valuable?

42 responses



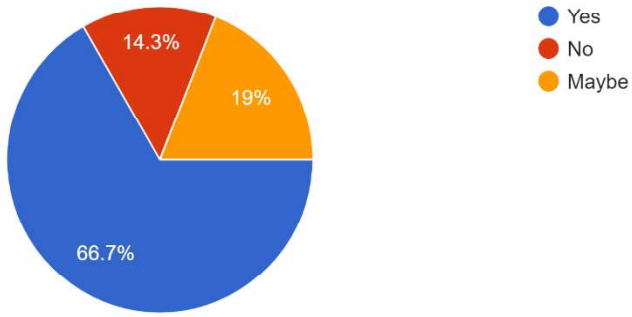
11. Do you reuse items instead of disposing of them right away?

42 responses



12. Would you be interested in using an app that could simplify your waste separation process and easily connect you to waste collectors in your area?

42 responses



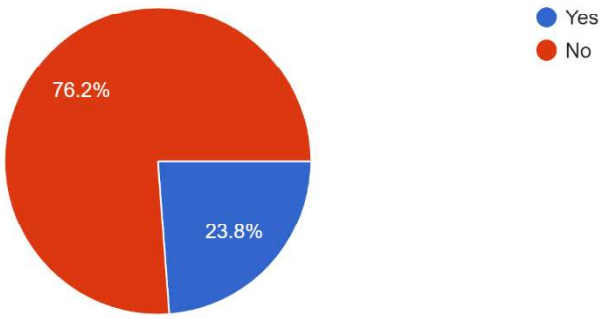
13. Please explain your answer. 42 responses

The current system I use suits me well.
Only if the waste will not be remixed after collection
An app that will help waste collection will help
I would be glad to have such an app
It would make it easier to separate the waste based on material, and it would provide info on the various private waste companies that are available
It would make things easier
Improve sanitation
Interested

It would be cumbersome and non-practical. Getting one waste collector to pick up waste weekly is fine
It might be much work
I might be interested
If it is simple and works in Ghana, here
An app that sends a reminder on separations
To make it easier
It will make it easy
Not too sure
It makes waste disposal prices competitive
I believe if the waste is collected separately, it could be effectively utilized in the recycling process.
Once I get such a connection, I can always dispose of my waste
The waste collectors might be conversant with the use since most of them are illiterates but do collect waste for income
Yes, I would be interested. However, in my area, the people who collect waste are not people who look technologically inclined, so I am curious as to how that would work
It makes waste collection and communication between the disposal agency and customers easier
With the app, I think it would be easy to know when the waste would be collect and what should go into which bin
It will help conserve the environment
We are in a digital world now, and it will make thing more accessible and faster
Might need data to operate the app
It depends if it is catchy
It would be nice to segregate my waste.
For the earlier purposes stated
In the end, it will make the country better, so why not?
It will educate me more on waste disposal
Sometimes waste collectors do not come often
Waste collectors dump waste at specific garbage site, which ends up polluting the environment. In other words, it is like taking my well-disposed waste and sending it to another place where all waste is placed. The value is the same. There are very few recycling plants in the country. I would prefer that the waste collectors instead do the waste separation so that it can help those in areas who cannot access such apps
I am contemplating how effective it would be, considering that my home no longer uses the door to door collection. Nor the primary collection method work effectively in my hood. I could honestly appreciate an app like that in the future, however.
It should be educative
That would make things easier

14. Are there any suggestions or recommendations you would like to share concerning the functionalities of the application?

42 responses



15. Please state them. nine responses

There should be a local language option in the menu
Time of waste pickup, price comparisons
It should be user friendly and easy to use since we have a population that is not 100% literate
To be honest, it should be simple. I should just click a button. The waste collector should receive a ringing notification, which should come with my location. Sometimes, the waste collector would not be able to go immediately. He/she receives a notification, so it is vital that you also have some schedule. What id love is for people in the neighbourhood to click a button to show that they are ready to have their waste collected. The waste collector will then be able to see that "about ten people are ready", so he/she can go today.
I have none.
Should have various local languages. And audio-visuals for people who may not be able to read.
There should be a scale of measure for pricing.
Kindly consider the aged and not-so-literate groups. They could be interested but would not appreciate it so much if it does not suit their needs. Also, try to research and consider other forms of waste collection besides door to door & central ones. Thanks.
I think the government should make separation of waste a law so that citizens will comply

Appendix III: Code for deep learning classification model

```
# -*- coding: utf-8 -*-
"""CNN_Classification_model.ipynb
Automatically generated by Colaboratory.
Original file is located at
    https://colab.research.google.com/drive/1ClUs_F-axFreddIHsFXYc6y0jyZmkEYH
"""
import numpy as np
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers


from tensorflow.keras.preprocessing import image
from tensorflow.keras.applications.inception_v3 import preprocess_input, decode_predictions
from tensorflow.keras.applications.inception_v3 import InceptionV3
from tensorflow.keras.preprocessing.image import ImageDataGenerator
import matplotlib.pyplot as plt


from google.colab import drive
drive.mount('/content/gdrive')


import zipfile as zf
import os


# load the dataset
file = zf.ZipFile("/content/gdrive/MyDrive/Dataset2-resized.zip",'r')
file.extractall()
file.close()
```

```
#path to data
path = os.path.join(os.getcwd(),"dataset-resized")

#Create a dataset
image_size = (299, 299)
batch_size = 64

train_ds = tf.keras.preprocessing.image_dataset_from_directory(
    path,
    validation_split=0.2,
    subset="training",
    seed=1337,
    image_size=image_size,
    batch_size=batch_size,
)
val_ds = tf.keras.preprocessing.image_dataset_from_directory(
    path,
    validation_split=0.2,
    subset="validation",
    seed=1337,
    image_size=image_size,
    batch_size=batch_size,
)

pre_trained_model = InceptionV3(input_shape=(150, 150, 3) ,
include_top=False, weights='imagenet')

for layer in pre_trained_model.layers:
  layer.trainable = False
```

```
from tensorflow.keras.optimizers import RMSprop

#Flatten the output layer to 1 dimension
x = layers.Flatten()(pre_trained_model.output)
#A layer with 1,024 hidden units and relu activation
x =layers.Dense(1024, activation = 'relu')(x)
#Adding a dropout rate of 0.2
x = layers.Dropout(0.2)(x)
#Adding a final sigmoid layer for classification
x = layers.Dense (1, activation = 'sigmoid')(x)

model = keras.Model(pre_trained_model.input, x)

model.compile(optimizer = RMSprop(lr=0.0001), loss=
'categorical_crossentropy', metrics=['acc'])

train_dsr = ImageDataGenerator(rescale=1./255.,
                               rotation_range= 40,
                               width_shift_range=0.2,
                               height_shift_range= 0.2,
                               shear_range=0.2,
                               zoom_range=0.2,
                               horizontal_flip=True,
                               validation_split=0.2)

test_ds2 = ImageDataGenerator(rescale=1./255.)

train_gen = train_dsr.flow_from_directory(path,
                                          batch_size=100,
```

```
                                        class_mode='categorical',
                                        target_size = (150,150),
                                         subset= 'training')

val_gen = train_dsr.flow_from_directory(path,
                                        batch_size=50,
                                        class_mode='categorical',
                                        target_size = (150,150),
                                       subset = 'validation')

class myCallback(tf.keras.callbacks.Callback):
  def on_epoch_end(self, epoch, logs = {}):
    if(logs.get('acc')>0.959):
      print('\nReached 99.9% accuacy. Cancelling training...')
      self.model.stop_training = True

#callbacks = myCallback()
model.fit(train_gen, validation_data=val_gen, epochs=5, verbose =2)

test_gen = test_ds2.flow_from_directory(path,
                                        batch_size=50,
                                        class_mode='categorical',
                                        target_size = (150,150)
                                        )

# Evaluate the model on the test data using `evaluate`
print("Evaluate on test data")
results = model.evaluate(test_gen)
print("test loss, test acc:", results)
```

```
# Generate predictions (probabilities -- the output of the last layer)
# on new data using `predict`
print("Generate predictions for sample")
predictions = model.predict(test_gen)
print("predictions shape:", predictions.shape)

predictions.mean()

test_gen.classes = test_labels = {
  0: "Cardboard",
  1: "Glass",
  2: "Metal",
  3: "Organic",
  4: "Paper",
  5: "Plastic",
  6: "Trash"
}
test_gen.classes
model.summary()

#Convert keras model to tflite format to enable compatibility with
Firebase backend framework
converter = tf.lite.TFLiteConverter.from_keras_model(model)

tflite_model = converter.convert()

#save the model
with open('model.tflite', 'wb') as f:
  f.write(tflite_model)
```