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Development of Waste Segregation Mechanism using Image Processing for Kalinisan: A Smart Trash Bin

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Abstract:- The United Nations (UN) has numerous goals outlined in its charter and subsequent resolutions. One of which is addressing environmental challenges such as climate change, biodiversity loss, and pollution. As a response to this call, Centro Escolar University(CEU) lodged the KALINGA program. Part of this program is to study ways the community could improve waste management. This study is a concerted effort to promote sustainable development practices, mitigate the impacts of climate change, protect ecosystems, and promote renewable energy. This developed prototype recognizes and classifies non-biodegradable and biodegradable materials with a 96% accuracy rate. The user-friendly system uses an ultrasonic sensor and image processing.

Keywords:- *Automatic WasteSegregation, Convolutional Neural Network, Waste Classification, Usability, Efficiency, Portability, Application, Accuracy.*

I. INTRODUCTION

The United Nations recognizes the critical importance of effective waste management in achieving sustainable development and protecting the environment. Through various initiatives and partnerships, the UN promotes integrated waste management systems that prioritize waste reduction, reuse, recycling, and proper disposal. By addressing the full lifecycle of waste, from production to final disposal, the UN seeks to minimize the environmental, social, and economic impacts of waste generation. Additionally, the UN emphasizes the need for cross-sectoral collaboration and the involvement of governments, businesses, civil society, and local communities to develop and implement comprehensive waste management strategies. Through these efforts, the UN aims to mitigate pollution, conserve resources, and create healthier and more resilient communities for present and future generations.

Centro Escolar University (CEU) recognizes the importance of aligning with the United Nations' efforts in waste management to contribute to global sustainability goals. As an educational institution committed to holistic development and environmental stewardship, CEU implements various initiatives to promote responsible waste management practices within its campuses and beyond. Through educational campaigns, recycling programs, and waste segregation efforts, CEU empowers its students, faculty, and staff to reduce waste generation and minimize environmental impact. Moreover, CEU engages in research and innovation to explore sustainable waste management solutions, contributing to the broader knowledge base in this field. By integrating principles of sustainability into its operations and curriculum, CEU endeavors to instill a culture of environmental consciousness and inspire future generations to become agents of positive change in waste management and beyond. This tenet has been the foundation of this paper. The development of waste segregation using image processing to produce a smart trash bin. The prototype streamlines waste separation and enhances waste classification through image processing techniques. This bin used image processing with an accuracy of 96% and can classify 4 different biodegradable wastes such, as plastic, glass, and metal waste.

The Waste Segregation Bin integrated a waste compactor to reduce waste volume and increase operational efficiency by expanding the image processing dataset to include diverse trash variations for more accurate waste recognition and classification, thus improving segregation. It incorporates IoT features to notify the building management if the bin reached its filled levels, thereby optimizing waste collection schedules. Additionally, a separate compartment for paper, plastic, glass, and metal waste within the biodegradable category simplifies recycling to ensure compatible paper types are processed together. These measures improved waste management and promoted recycling efficiency.

➢ *Objectives*

The general goal of this research is to improve current waste management by developing a system that can distinguish the difference between non-biodegradable and biodegradable waste materials using the Convolutional Neural Network. Specifically, it aimed for the following objectives:

- Create a system using image processing with the CNN model involves building a deep-learning solution to process and analyze images. Convolutional Neural Networks (CNNs) are specifically designed for image-related tasks and have achieved remarkable success in various computer vision applications such as object recognition, image classification, segmentation, and more.
- Determine the system's average level of confidence in distinguishing between biodegradable and non-biodegradable waste materials, an image processing solution using the CNN model can be implemented. The

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process involves collecting a diverse dataset of waste material images, properly labeled as biodegradable or non-biodegradable.

- Segregate efficiently the community's common biodegradable and non-biodegradable waste, an image processing system employing the CNN model can be developed. Assembling a well-labeled dataset of waste images, the CNN architecture can be designed to classify the waste materials accurately.

II. RELATED LITERATURE AND STUDIES

This study is founded on several research to be able to produce the prototype. The Plastic Circularity Opportunities Report offered vital intel on the present state of plastic waste management in the country[3]. It also provided valuable information and suggestions for nurturing a circular economy for plastics as the basis for policymakers, stakeholders, and organizations to make informed decisions in combating plastic waste and advocating for sustainable practices in the Philippines.

In terms of technology, the differences Between Raspberry Pi and Arduino as platforms used in electronics and programming projects[4]. It provided useful insights into. understanding the features, capabilities, and applications of Raspberry Pi and Arduino. This helped the researcher to choose which platform was suitable for this development system. While, CNN Variants for Computer Vision: History, Architecture, Application, Challenges, and Future Scope [5] we used by the researchers to have a deeper understanding of CNN architecture, historical developments, and application relevance in computer vision tasks. A thorough study on Multi-stage CNN architecture tailored for accurate face mask detection [6], was used as a basis for developing an intelligent waste segregation system using computer vision, machine learning, and sensor technologies. Unlike traditional smart trash bins, the researcher's system incorporates sophisticated deep-learning models for accurate waste categorization and offers continuous learning capabilities to improve sorting accuracy over time. It is user-friendly, scalable, and adaptable, making it suitable for various settings. The different features of the researcher's smart trash bin lie in its advanced technology, continuous learning ability, and versatility, making it an efficient solution for effective waste management and environmental sustainability.

III. RESEARCH METHODOLOGY

The researchers have opted to utilize a prototyping system development methodology for the hardware and firmware development processes. These methods involved iterative cycles of building, testing, and refining the prototype until a satisfactory outcome is attained. This served as a foundation for the final system. For the hardware aspect, the team focused on creating the device prototype, which involves designing and assembling the necessary components to form a functional unit. In terms of firmware development, the researchers concentrated on programming the codes for the Raspberry Pi, ensuring that the software operates efficiently and interfaces seamlessly with the hardware. By employing prototyping methods, the researchers enhanced both the hardware and firmware components and gradually refined and optimized them to achieve the desired functionality and performance complete system.

A. Smart Trash Bin Architecture

The entire system comprises various components that are interconnected to the Raspberry Pi, functioning as the microcontroller. Acting as the central control unit, the Raspberry Pi houses the system program responsible for coordinating the operations of each component. To facilitate the integration of these components with the hardware, the researchers develop a schematic diagram as a reference. This diagram serves as a guide for rewiring and properly connecting the components to the corresponding pins on the Raspberry Pi. By following this schematic diagram, the researchers ensure the accurate and reliable establishment of connections between each component and the Raspberry Pi, enabling smooth communication and interaction within the system.

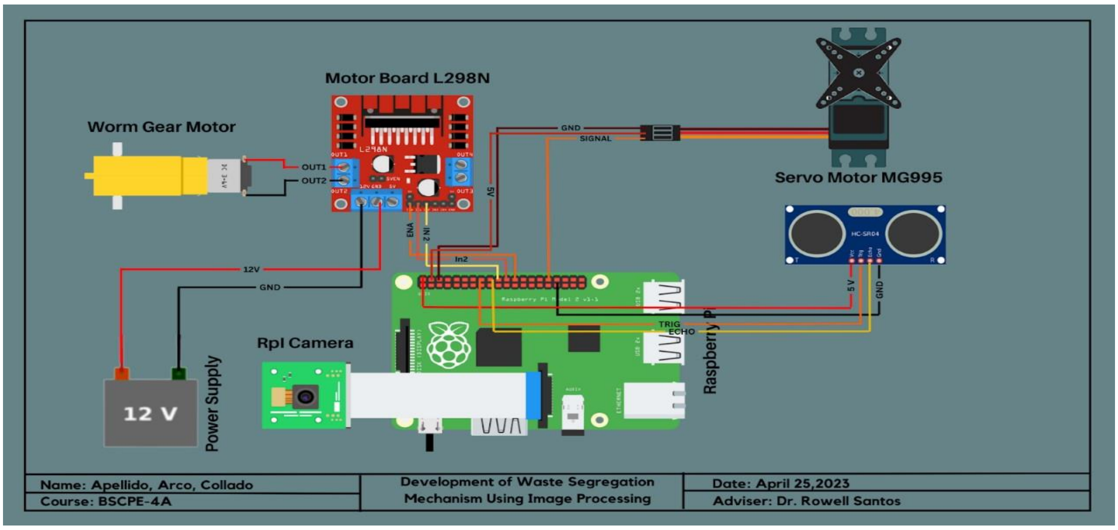

Fig 1 Schematic Diagram for Waste Detection Bin

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B. Hardware and Software Design

The waste segregation bin hardware involves the development and implementation of a physical system that includes Raspberry Pi, an Ultrasonic Sensor, a Camera Module, a Servo Motor, and a Motor board. These components are necessary for the automated process of waste segregation. The hardware is specifically designed to work in conjunction with the software application, ensuring accurate identification and sorting of waste materials. Through the coordinated functioning of both the hardware and software, the system achieves precise and efficient waste management.

➢ *The Hardware Specifications used in " Development of Waste Segregation Mechanism using Image Processing for Kalinisan: A Smart Trash Bin" and their Functions are as Follows:*

- The camera module is designed to function similarly to human eyes. There is a lens, an image sensor, and an aperture. It will require many images of each material to train the model to detect and distinguish between biodegradable and non-biodegradable materials.
- The motor board is used to control the direction and the speed of the motor's rotation.
- Raspberry Pi has emerged as a superior alternative to the Arduino, with a clock speed that is 40 times faster. This enhanced processing power allows for the efficient connection of a camera module and the development of tools for real-time photo analysis and storage using Python and specialized libraries. The Raspberry Pi also boasts a more powerful CPU pair, further demonstrating its advanced capabilities.
- To properly segregate waste materials, a servo motor is used to control the timing of the gate opening and closing at the hardware.
- This device is used to measure the distance of the trash from the top of the trash bin. The distance measured will be the basis of the notification level of the waste materials.

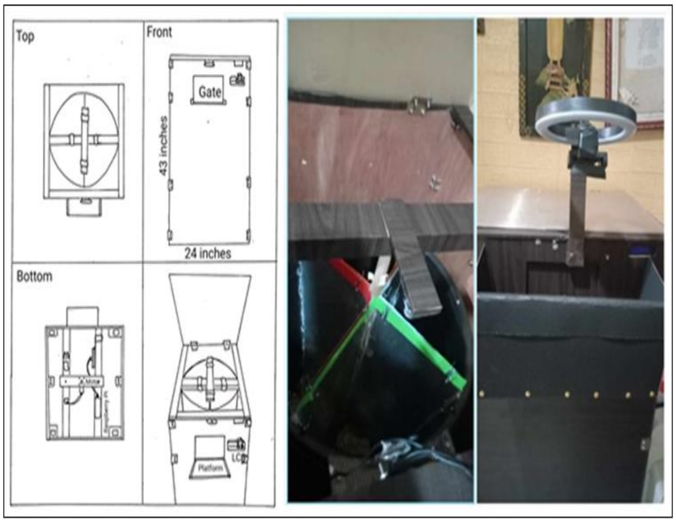

Fig 2 Hardware Prototype for Waste Segregation Mechanism using Image Processing

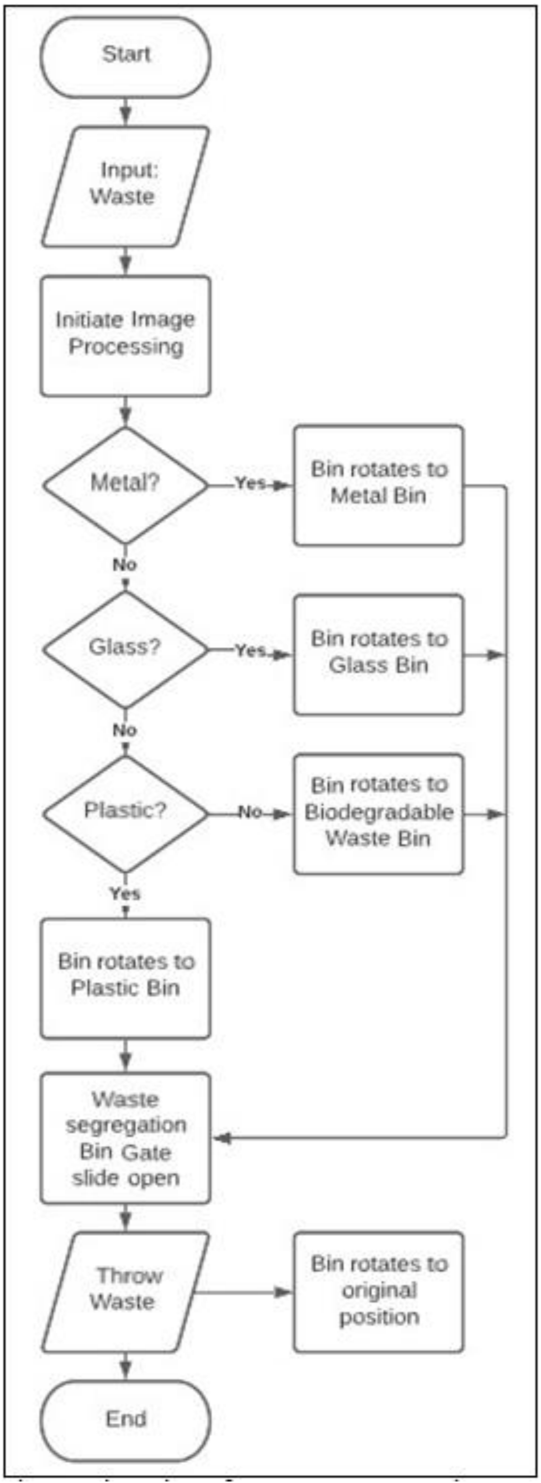

Fig 3 Flowchart for Waste Segregation Mechanism using Image Processing

The software for the waste segregation bin entails the development of an algorithm and software application that utilizes image processing and machine learning methodologies to detect and categorize different forms of waste. The software is designed to capture images of the waste during the deposition process, leveraging sensors and cameras integrated within the waste bin. By employing these techniques, the software enables efficient identification and sorting of the waste based on its visual characteristics.

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IV. USE CASE

Fig 4 Waste Segregation Mechanism using Image Processing Use Case Model

The user will place the waste to the holding area to capture its image to process. Then after capturing an image, the program will automatically identify if the waste is metal, glass, plastic, or biodegradable. Then the bin inside will automatically rotate to the identified waste classification before opening the gate for the user to throw in the waste inside. And lastly, the bin inside will automatically return to its original position after the waste is thrown. To be able to do this, there's a need to install the required dependencies and libraries to ensure a smooth run. Next, the PyTorch version compatibility is checked to ensure the correct version is available. The program then proceeds to download the datasets from Roboflow, which will be used for training the model. With the datasets in place, the model is trained using algorithms and techniques provided in the program code, including data preprocessing, model initialization, and optimization through forward and backward passes. Once the model is trained, it undergoes testing on a separate set of test data to evaluate its performance. Finally, the program displays the results, which may include metrics, visualizations, or other relevant information summarizing the performance of the trained model.

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```
!cat /proc/meminfo
!nvidia-smi -L
!pip install ultralytics==8.0.20 -U
import torch
torch.__version__
rm -r /content/WasteDectection-5
!yolo task=detect mode=train epochs=100
data=/content/datasets/WasteDectection-5/data.yaml
model=yolov8n.pt imgsz=640
!yolo task=detect mode=predict
model=/content/runs/detect/train/weights/best.pt conf=0.5
source=/content/datasets/WasteDectection-5/test/images save=True
import glob
from IPython.display import Image, display
for image_path in
glob.glob(f'/content/runs/detect/predict/*.jpg'):
display(Image(filename=image_path, width=600))
print("\n")
!zip -r train.zip /content/runs/detect/train/*
from google.colab import files
files.download('/content/train.zip')
```

Fig 5 Program Code for Sorting

The waste segregation program code for Raspberry Pi is a software implementation designed to facilitate the automatic sorting of waste materials. It utilizes various components connected to the Raspberry Pi, such as sensors, cameras, and motors, to detect and categorize different types of waste. The program code incorporates image processing and machine learning algorithms to analyze the captured images of waste and determine their classification as biodegradable or non-biodegradable. Based on this classification, the code controls the system to appropriately segregate the waste into respective bins or containers. The program also ensures the synchronization and coordination of the hardware components through the Raspberry Pi, allowing for efficient and accurate waste segregation.

```
import RPi.GPIO as GPIO
import tensorflow as tf
from tensorflow.keras.preprocessing.image import
ImageDataGenerator
import tensorflow.keras as keras
import cv2
import matplotlib.pyplot as plt
import glob
from tqdm import tqdm
from sklearn.model_selection import train_test_split
import os
import tensorflow.keras.layers as layers
from keras.models import load_model
import numpy as np
from PIL import Image as pil_image
from collections import deque
import time
import pigpio
import RPi.GPIO as GPIO
import time
import RPi.GPIO as GPIO
in1 = 24
in2 = 23
en = 25
temp1=1

GPIO.setmode(GPIO.BCM)

GPIO.setup(in1,GPIO.OUT)
GPIO.setup(in2,GPIO.OUT)
GPIO.setup(en,GPIO.OUT)
GPIO.output(in1,GPIO.LOW)
GPIO.output(in2,GPIO.LOW)
p=GPIO.PWM(en,1000)
p.start(25)

GPIO.setwarnings(False)
GPIO.setmode(GPIO.BCM)
buttonCapture = 20 #Blue
buttonIdentify = 21 #Yellow
sPlastic = 10
sMetal = 27
sGlass = 22
sBio = 23
sPaper = 24
motorPin1 = 26
motorPin2 = 16

GPIO.setup(buttonCapture, GPIO.IN) # Set pin 20 for
capture
GPIO.setup(buttonIdentify, GPIO.IN) # Set pin 21 for
processing
GPIO.setup(motorPin1, GPIO.OUT)
GPIO.setup(motorPin2, GPIO.OUT)
pi = pigpio.pi()
prediction_classes = {

0: 'Undetected',
1: 'Glass',
2: 'Metal',
3: 'Paper',
4: 'Plastic',
5: 'Biodegradable',}

def motorRotation(sleep):

GPIO.output(motorPin1, True)
time.sleep(sleep)
GPIO.output(motorPin1, False)
time.sleep(1)
GPIO.output(motorPin2, True)
time.sleep(sleep)
GPIO.output(motorPin2, False)

def servoMove(pin, degreeOpen, degreeClose, sleep):

# setup pin as an output
pi.set_mode(pin, pigpio.OUTPUT)
pi.set_servo_pulsewidth(pin,degreeOpen)

#motor rotation
motorRotation(5) #calibrate to change the degree
```

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```
time.sleep(sleep)
pi.set_servo_pulsewidth(pin,degreeClose)
time.sleep(0.5)

def create_encoder():

model = tf.keras.Sequential([
tf.keras.layers.Conv2D(32, (3, 3), input_shape=(384, 512,
3), activation='relu'),
tf.keras.layers.MaxPooling2D(2, 2),

tf.keras.layers.Conv2D(64, (3, 3), activation='relu'),
tf.keras.layers.MaxPooling2D(2, 2),

tf.keras.layers.Conv2D(128, (3, 3), activation='relu'),
tf.keras.layers.MaxPooling2D(2, 2),
tf.keras.layers.Dropout(0.4),

tf.keras.layers.Flatten(),
tf.keras.layers.Dense(256, activation='relu')])
return model

def create_classifier(encoder, trainable=True):
for layer in encoder.layers:
layer.trainable = trainable

inputs = keras.Input(shape=(384, 512, 3))
features = encoder(inputs)
features = layers.Dropout(0.1)(features)
features = layers.Dense(512, activation="relu")(features)
features = layers.Dropout(0.1)(features)
outputs = layers.Dense(6, activation="softmax")(features)

model = keras.Model(inputs=inputs, outputs=outputs,
name="classifier")
model.compile(

optimizer=keras.optimizers.Adam(0.001),
loss=keras.losses.SparseCategoricalCrossentropy(),
metrics=[keras.metrics.SparseCategoricalAccuracy()],

return model

def identify():
encoder = create_encoder()
classifier = create_classifier(encoder)

model = load_model('gbg_clt.h5')

print("Model loaded without the custom object class:",
model)

Q = deque(maxlen=1)
frame = cv2.imread('test/trash.png')
frame = cv2.resize(frame, (512, 384)).astype("float32")
test_image = frame.reshape(1, 384, 512, 3)
preds = model.predict(test_image)
prediction_class = np.argmax(preds,axis=1)
prediction = prediction_classes[prediction_class[0]]
GPIO.setwarnings(False)
servo_pin = 12
GPIO.setmode(GPIO.BCM)
GPIO.setup(servo_pin,GPIO.OUT)
pwm = GPIO.PWM(servo_pin,50)
pwm.start(5)
print("CLOSE BIN")
pwm.ChangeDutyCycle(5)

time.sleep(1)
print("OPEN BIN")
pwm.ChangeDutyCycle(10)
time.sleep(1)
print("CLOSE BIN")
pwm.ChangeDutyCycle(5)
time.sleep(5)

if prediction == 'Plastic':
print("plastic servo")
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.LOW)
GPIO.output(in2,GPIO.HIGH)
time.sleep(5)
p.ChangeDutyCycle(0)

servo_pin2 = 13
GPIO.setmode(GPIO.BCM)
GPIO.setup(servo_pin2,GPIO.OUT)
pwm2 = GPIO.PWM(servo_pin2,50)
print("Starting at zero...")
pwm2.start(5)
print("Setting to zero...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)
print("Setting to 180...")
pwm2.ChangeDutyCycle(10)
time.sleep(1)

print("Setting to 90...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)

p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.HIGH)
GPIO.output(in2,GPIO.LOW)
time.sleep(5)
p.ChangeDutyCycle(0)

elif prediction == 'Metal':
print("metal servo")
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.LOW)
GPIO.output(in2,GPIO.HIGH)
time.sleep(5)
p.ChangeDutyCycle(0)

servo_pin2 = 6
GPIO.setmode(GPIO.BCM)
GPIO.setup(servo_pin2,GPIO.OUT)
pwm2 = GPIO.PWM(servo_pin2,50)
print("Starting at zero...")
pwm2.start(5)
print("Setting to zero...")
```

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```
pwm2.ChangeDutyCycle(5)
time.sleep(1)
print("Setting to 180...")
pwm2.ChangeDutyCycle(10)

time.sleep(1)
print("Setting to 90...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)

p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.HIGH)
GPIO.output(in2,GPIO.LOW)
time.sleep(5)
p.ChangeDutyCycle(0)

elif prediction == 'Glass':
print("glass")
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.LOW)
GPIO.output(in2,GPIO.HIGH)
time.sleep(5)
p.ChangeDutyCycle(0)

servo_pin2 = 5
GPIO.setmode(GPIO.BCM)
GPIO.setup(servo_pin2,GPIO.OUT)
pwm2 = GPIO.PWM(servo_pin2,50)
print("Starting at zero...")
pwm2.start(5)
print("Setting to zero...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)

print("Setting to 180...")
pwm2.ChangeDutyCycle(10)
time.sleep(1)
print("Setting to 90...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)

p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.HIGH)
GPIO.output(in2,GPIO.LOW)
time.sleep(5)
p.ChangeDutyCycle(0)

elif prediction == 'Biodegradable':
print("Scrap")
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.LOW)
GPIO.output(in2,GPIO.HIGH)
time.sleep(5)
p.ChangeDutyCycle(0)

servo_pin2 = 26
GPIO.setmode(GPIO.BCM)
GPIO.setup(servo_pin2,GPIO.OUT)
pwm2 = GPIO.PWM(servo_pin2,50)
print("Starting at zero...")
pwm2.start(5)
print("Setting to zero...")
pwm2.ChangeDutyCycle(5)

time.sleep(1)
print("Setting to 180...")
pwm2.ChangeDutyCycle(10)
time.sleep(1)
print("Setting to 90...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.HIGH)
GPIO.output(in2,GPIO.LOW)
time.sleep(5)
p.ChangeDutyCycle(0)

else:
print("Undetected")
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.LOW)
GPIO.output(in2,GPIO.HIGH)
time.sleep(5)
p.ChangeDutyCycle(0)
time.sleep(5)
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.HIGH)
GPIO.output(in2,GPIO.LOW)
time.sleep(5)
p.ChangeDutyCycle(0)

servo_pin2 = 26
GPIO.setmode(GPIO.BCM)

GPIO.setup(servo_pin2,GPIO.OUT)
pwm2 = GPIO.PWM(servo_pin2,50)
print("Starting at zero...")
pwm2.start(5)
print("Setting to zero...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)
print("Setting to 180...")
pwm2.ChangeDutyCycle(10)
time.sleep(1)
print("Setting to 90...")
pwm2.ChangeDutyCycle(5)
time.sleep(1)
p.ChangeDutyCycle(25)
GPIO.output(in1,GPIO.HIGH)
GPIO.output(in2,GPIO.LOW)
time.sleep(5)
p.ChangeDutyCycle(0)

print("Prediction: {}".format(prediction))

def capture():
camera = cv2.VideoCapture(0)
result, image = camera.read()
if result:
cv2.imwrite("test/trash.png", image)
print("Capture successfully")
```

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```
While True:

print(GPIO.input(buttonCapture))
print(GPIO.input(buttonIdentify))
if GPIO.input(buttonCapture) == 0:
print("Capture")
capture()
elif GPIO.input(buttonIdentify) == 0:
print("identify")
identify()
else:

print("No Input from user")
```

During the trial run, the participants rated the system's usability using a Likert scale survey. Table 1 shows that it comprises the following individuals: Five (5) BMS who manage waste in CEU, ten (10) students, Computer Engineering Experts, and CEU staff.

Table 1 Table for Mean Score per Group of Respondents

Group of Respondents	Mean SUS Score	Grade	Adjective Training	Acceptable or Not Acceptable
BMS	72.5	B	Good	Acceptable
Students	83	A	Excellent	Acceptable
COE	78	B	Good	Acceptable
CEU Staff	83.25	A	Excellent	Acceptable
Total Respondents	77.5	B	Good	Acceptable

Table 1 summarizes the mean System Usability Scale (SUS) scores for different respondent groups. The table reveals that the CEU Staff group had the highest mean SUS score of 83.25, indicating a high level of perceived usability. while the BMS group had the lowest mean SUS score of 72.5, suggesting slightly lower perceived usability but still within acceptable limits. Overall, all groups' SUS scores were acceptable, meeting the minimum requirements for system usability.

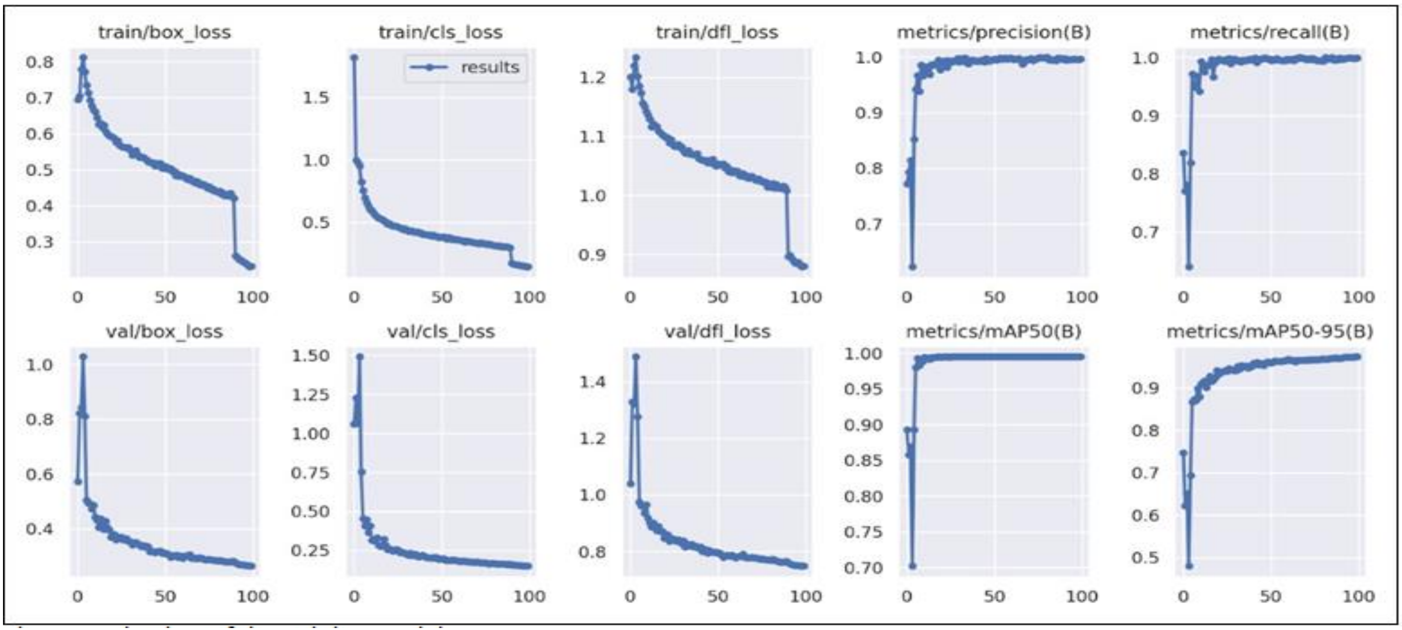

Fig 6 Evaluation of the Training Model

Figure 6 illustrates the evaluation of a training model using key metrics represented on the y-axis, while the x-axis denotes the number of iterations during the training process. The researchers conducted 100 epochs of training to optimize the model. The graph provides insights into the model's performance trends. As the training progresses, there is a noticeable enhancement in the model's proficiency in accurately determining bounding box coordinates, indicated by the decreasing values of box loss. Moreover, the model's ability to classify waste materials improves, as evidenced by the decreasing values of class loss. This signifies the model's increasing capability to recognize and categorize various types of waste. Additionally, there are positive advancements in the precision and accuracy of waste classification, as evident from the increasing values of metrics/precision(B), metrics/mAP50(B), and metrics/mAP50-90. These metrics highlight the model's accuracy in predicting the waste classification of materials. Overall, these results indicate that the trained model exhibits promising performance in accurately identifying and classifying waste materials.

V. CONCLUSION

In conclusion, the researchers have successfully created a functional prototype device and achieved the study's objectives. By addressing the recommended improvements and considering future research opportunities, the Waste Segregation Mechanism using Image Processing has the potential to become a highly innovative and practical solution for segregating waste. The research on Waste Segregation

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Using Image Processing supports its implementation at Centro Escolar University - Manila (CEU). It achieved a pinpoint accuracy of 96% in waste segregation, with positive ratings from the CEU community using the System Usability Scale (SUS) questionnaire. The system's effectiveness and usability are evident. The successful sorting of materials based on their waste class, combined with the system's efficient image processing, validates its potential as a practical waste management solution. The prototype's inclusion of advanced features enhances its functionality and lays a strong foundation for future development. Considering the achieved accuracy, positive usability ratings, effective waste sorting, and advanced features, implementing this system at CEU becomes a clear and pressing need. It will significantly improve waste management, promote sustainability, and align with the university's mission of fostering an environmentally responsible campus.

RECOMMENDATIONS

➢ *However, there are Opportunities for Future Work and Improvements to Further Enhance the Device. Some Areas that can be Explored Include:*

- Additional Compressor to reduce the garbage volume thereby increasing its capacity to accept more waste.
- Additional trash variation for its data sets to expand the capability of the trash bin to accept various types of trash.
- Additional Waste level sensors to send notification level systems and notify the BMS to prompt collection.
- Installation of additional compartments for paper.

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