AUTOMATIC GARBAGE SEGREGATION USING IMAGE PROCESSING AND MACHINE LEARNING

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Abstract

A capital city in India on an average, produces over 5000 tons of unsegregated waste per day. This rate of garbage production has doubled in the last 5 years but the methods to deal with it still remain the same with a manual work force. A better method to combat this problem is to automate the process of segregation with the use of smart technology in small and large scales. This research model proposes a framework to segregate waste into recyclable and non-recyclable waste using machine learning strategies such as Convolutional Neural Network (CNN) to analyse the waste before it is sent to dispose. The model makes use of an image processing framework You Only Look Once (YOLO) to classify the garbage into different categories. The information generated is sent to a physical robotic arm that will dispose the waste into the appropriate bins. The machine learning model can identify the types of solid waste based on the material i.e. Wood, Metal, Paper, Plastic and Glass. The goal of this research work is to use the model in semi-urban and urban territories to make segregation more efficient and effortless, along with some modifications to physical components if necessary. The current model has achieved a mean average precision of 61.47%, precision of 0.65 and recall of 0.52.

Keywords: Waste Segregation, Machine Learning, Image Processing, Convolutional Neural Network, Raspberry Pi, YOLO

1. Introduction

In today's world, garbage disposal has become a cause of major concern. An astounding amount of 0.1 million tons of waste is generated each day in India alone. Unfortunately, only 5% of this colossal amount of waste is recycled [1]. This collection of garbage is then improperly disposed in landfills without any segregation and also requires much more transportation facilities than necessary. This method of dumping causes adverse effects on the environment while failing to utilize the potential of the recyclable waste. Hazardous emissions and climate change are some effects caused by mishandling of waste. Despite the government's efforts to prioritize the separation of dry and wet waste, the norms are hardly followed and thus not effective. Moreover, any attempt to separate waste manually in small or large scale would require an extensive taskforce and countless hours of effort which would decelerate the process significantly.

In this work a model is developed that can automatically segregate the waste without requiring any human intervention to tackle this problem. Machine learning techniques are very effective when it comes to classification and is used in the model to classify different types of waste. By using Image Processing algorithms: such as You Only Look Once version 3 (YOLOv3), the model can analyse the waste present in its workspace. Deep learning technique is used to train the model that can accurately isolate different types of waste based on the requirements. This would reduce the amount of garbage being transported and dumped in landfills while allowing maximum reusability. This solution can be ideally applied at primary levels i.e. where the wastes are produced. Raspberry Pi is used to control and segregate the waste.

The proposed system aims to replace the manual process in waste segregation process by using image processing for waste detection and sorting based on machine learning algorithms.[2] The system consumes minimal power and does not require complex hardware.

2. Literature Review

Several works have been done on the issue of automating waste segregation, proposing numerous ways of tackling the challenge with varying degrees of success.

"Automated Waste Segregator" [3]: In this paper a more physical method to automatically segregate wet is suggested and dry waste. The proposed system uses proximity sensors to detect incoming waste, after which a metallic detection system will separate metallic waste. Following this, the waste falls into capacitive sensing module which distinguishes between wet and dry waste using a dielectric constant, and a rotating circular container base collects the corresponding garbage. Although an effective method to separate the different types of waste, it entirely depends on sensors and cannot differentiate between any categories other than dry, wet and metal. Since there are different methods to process various types of recyclable waste, it would still lead to human intervention if they plan on effectively recycling the dry waste.

"Classification of Trash for Recyclability Status" [4]: The objective of this project was to take images of single pieces of recyclable garbage and classify each item into one of the classes: Paper, Glass, Plastic, Metal, Trash, etc. Machine learning implementations were used to identify the waste. SVM with SIFT features and a CNN were the models used for this project. The CNN was an eleven layered network which is very similar to AlexNet. Although SVM achieved an accuracy of 63%, the CNN could only meet an accuracy of 22% and only took single items of garbage as input. A lack of data and training time was the downfall of the neural network. Moreover, classifying single objects would take an impractical amount of time to truly segregate waste as it is produced.

"Electronically Assisted Automatic Waste Segregation" [5]: The proposed system is based on a robotic assembly and machine learning classification. The robotic arm is used to move the object from one place to the classifier platform. The robot senses the object using ultrasonic sensors to calculate the distance to the target object. It uses CNN based classifier to identify the class. An Arduino board is used for controlling the assembly. This system uses a key idea of using a small processor like an Arduino for controlling the assembly to bridge the gap between software and hardware units, however also makes use of a single object at a time and adds an additional step of transferring an object to the classifier platform.

"Waste Segregation using Machine Learning" [6]: This paper suggests a method to create an anonymous system for segregation of waste using CNN that is trained with a TensorFlow framework. It segregates biodegradable and non-biodegradable waste using image processing algorithms and then with the help of a hardware unit, separates the waste into appropriate bins.

The current proposed model approaches the problem with similar tactics, using YOLO as the image processing framework to incorporate faster and more efficient garbage classification.

3. Proposed System

The model introduced in this paper consists of a software unit comprising of a CNN trained using tiny-YOLOv3 framework that can identify the type of garbage and its location in the workspace, as well as a hardware unit that requires a Pi cam to capture images, a Raspberry Pi model 3 to load the software model and a robotic arm to segregate the waste. The robotic arm can be used to pick any kind of physical component and is capable of using co-ordinates to locate and segregate the waste objects.

The first step followed to implement this model is to compile and collect an extensive real-world dataset for the types of waste that needs to be classified. The dataset consists of over 10,000 images with 2,000 different pictures for each category of recyclable waste. Then a convolutional neural network i.e. tiny-YOLOv3 is trained on this dataset until it can accurately identify and locate the required waste. Figure 1 provides the proposed architecture for building the model.

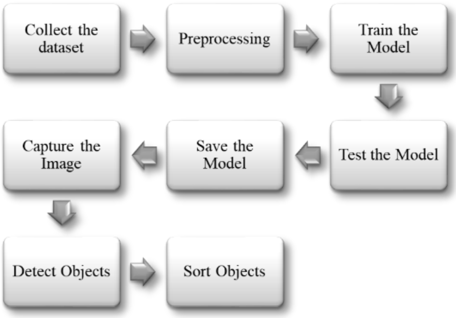

Figure 1: Block diagram of the Proposed System

You Only Look Once or YOLOv3 is a state-of-the-art, real-time object detection neural network. On a Pascal Titan X, it processes images at 30 Frames Per Second (FPS) and has a mean average precision of 57.9% on Common Objects in Context (COCO) test-dev set. The network divides an image of the garbage in the mapped workspace into thirteen regions and predicts bounding boxes and probabilities for each region. By default, YOLO can detect up to five objects per region. YOLO makes predictions with a single network evaluation. It is more than 1000x faster than Region with Convolutional Neural Network (R-CNN) and 100x faster than Fast R-CNN. This model has several advantages over classifier-based systems as it looks at the whole image at test time so its predictions are informed by global context in the image. [7] In this research work tiny-YOLOv3 version of the framework is used to save computation and training time and is as shown in Figure 2.

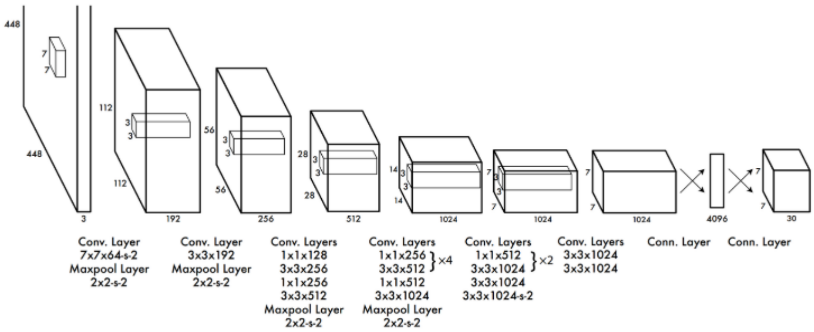

Figure 2: Architecture of Tiny-YOLOv3 Network

The tiny-YOLOv3 based neural network is trained on over ten-thousand images of different types of waste: Wood, Metal, Paper, Plastic and Glass to accurately classify the objects into these categories. Training occurs for 10,000 iterations and a weights file is saved after every 1000 epochs. The ideal weights file chosen is based on the mean Average Precision (mAP) score. The weights after 9000 iterations showed the most potential and highest mAP and Intersection over Union (IOU) values when tested on the validation set for the current model.

The generated model will then be loaded into the Raspberry Pi using the pre-trained weights file for detection. This reduces the amount of space and computation required by the hardware unit, thus making the system to be easily implementable.

The sequence of operations followed by the system is as shown in Figure 2. A Pi cam is used to capture an image of the waste in the workspace and this image is then analysed by the pre-trained tiny-YOLOv3 model. Once the model has detected the location and type of waste, it transfers the knowledge of the co-ordinates of each respective object to the Raspberry Pi which controls the robotic arm to isolate these objects and separate them to the corresponding bin.

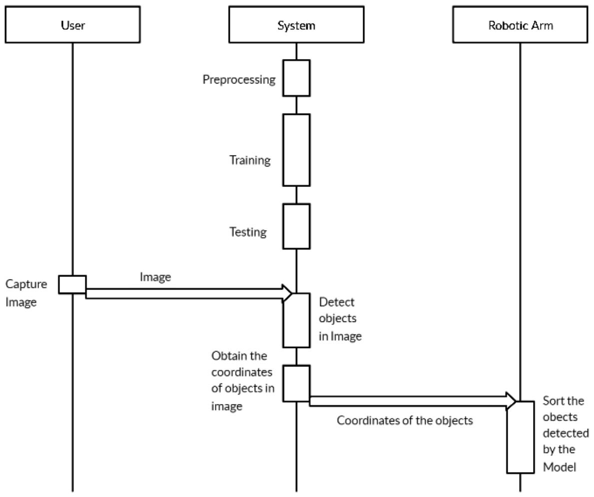

Fig 3: Sequence Diagram of Proposed Model

4. Pseudo Code

The working model can be differentiated into various modules. The algorithm of the complete sequence is presented below in Figure 4.

```
Algorithm Segregation:
While(NoOfObjects > 0)
    Image = Capture_Image();
    NoOfObjects,midpoints,Predictions = Yolo(Image);
    Show_Image(Predictions.jpg);
    For x,y in midpoints:
        Pick_Up_Recylable_Waste(x,y)
        Move_Arm_to_Bin(bin_position)
        Reset_Arm()
End while
```

Fig 4: Algorithm for Automatic Waste Segregation

The detection of recyclable objects takes place within the YOLO function where the image is partitioned into 13x13 cells in which it is capable of detecting up to five objects per cell. The image is only processed once through the tiny-YOLO network and each cell is examined carefully where a class prediction and bounding box prediction is done and appended to the final predictions of the entire image. This is demonstrated in the algorithm for YOLO in Figure 5.

```
Algorithm Yolo(Image):

#default image size is 260x260
read(TestImage)
NoOfClasses= 5
#image is partitioned to 13x13 parts
NoOfCells = 13
#size of step to take when moving across the image.
step = height(image)/NoOfCells
#stores class-prediction of each class
predictionClass = array[NoOfCells, NoOfCells, NoOfClasses]
#stores 2 bounding box suggestions for each cell
#cell will have 2 bounding boxes, with
#x, y, width, height and confidence predictions.
predictionsBox = array [NoOfCells, NoOfCells, NoOfCells, NoOfCells]
#final_predictions in which the final list of
#predictions will be added
final_predictions = []
for (i,j) in image:
    #each cell will be of size (step, step)
    cell = image(i:i+step,j:j+step)
    #First make a prediction on each cell
    predictionClass = class_predictor(cell)
    #Predictions of bounding box is made based on
    #x, y, width, height and confidence values
    #2 suggestions are made
    predictionsBox[i,j] = boundingBoxPredictor(cell)
    best_box = [0 if predictionsBox[i,j,0,5] > predictionsBox [i,j,1,5] else 1]
    #Get the class which has the highest probability
    predicted = maxValueIndex(predictionClass[i,j])
    #the prediction is an array which has the x, y
    #coordinate of the box the height and the width
    prediction = [predictionsBox[i,j,best_box,0:5], predicted]

    final_predictions.append(prediction)

NumberOfObjects = length(final_predictions)
midpoints = CalculateMidpoints(final_predictions)

return(NumberOfObjects, midpoints, Predictions.jpg)
```

Fig 5: Algorithm of Tiny-YOLOv3 Network Used

Once the co-ordinates of the recyclable objects are obtained, it is easily picked mapped to the workspace and segregated by the robotic arm. This is done repeatedly till no recyclable objects remain and new waste can be dumped.

5. Results and Observations

The analysis of this research work is done on the basis of 2 modules that includes software developed and hardware used. Software analysis is based on the values of mAP or IOU and hardware analysis is based on how fast and accurately the arm sorts objects. For every 1000 iterations a weights file is updated and a file with highest mAP or IOU is considered for the detection purpose.

IOU is an evaluation metric used to measure the accuracy of YOLO model on particular dataset. IOU is the average intersect over union of objects and detection for a certain threshold. Precision is the ratio of true positive and the total number of predicted positives where true positive is when the prediction is positive and the ground truth is also positive. Recall is another evaluation metric which can be defined as ratio of true positive and the total of ground truth positives. It gives the basic idea about how good the model detects all objects in the given testing data. mAP is the mean value of 'average precisions for each class'. It can also be defined as the area under precision-recall curve. The highest mAP means that the model detects all the objects in the image as precisely as possible.

The model that is developed achieved an IOU, mAP, Precision and Recall as mentioned in Table 1 after training for 9000 iterations.

Table 1: Evaluation Metrics

IOU	mAP	Precision	Recall
49.49%	61.47%	0.65	0.52

There are some issues with identifying the object if it is transparent in a light background and not sufficiently visible, but the accuracy of the objects to classify once detected is effective. The detection of objects using this software model is as shown in Figure 4.

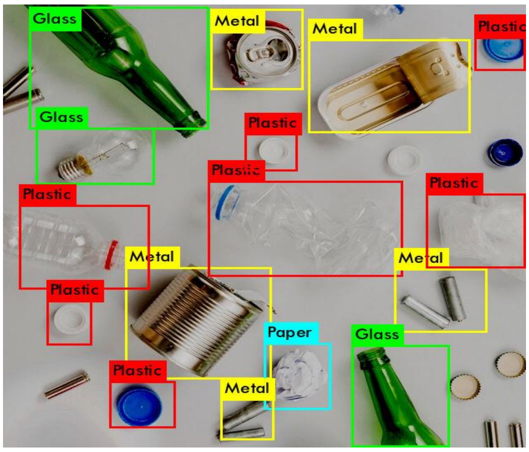

Figure 6: Classification of waste using Tiny-YOLOv3

The time taken to detect the garbage varies between 3 – 300 milliseconds depending on the number of recyclable objects present in the workspace and the availability of GPU.

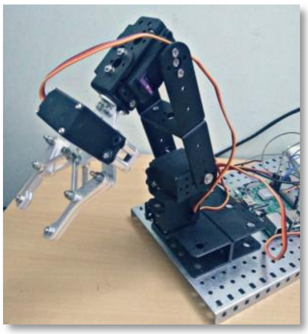

Figure 7: Robotic Arm used for the Project

The type of trash used for this experiment are lightweight and relatively small in dimensions in order to fit into the workspace, but this is merely a limitation of the robotic arm as shown in Figure 5. Once the detection is done, the robotic arm is highly accurate in separating and shifting the detected garbage to the appropriate bin that takes less than a second.

6. Conclusions and Future Scope

The proposed system effectively detects the garbage in the sightline of the camera. It also identifies the different categories of recyclable waste and segregates it using the robotic arm's reach. Multiple types of waste are detected simultaneously and the co-ordinates transmitted allow the robotic-arm to queue the segregation of these objects.

The pre-trained tiny-YOLO model allows the testing of the model on a small embedded processing unit such as the Raspberry Pi. However, the much larger version of YOLOv3 with 74 layers instead of 25 would be beneficial if more memory space and GPU is available.

Further improvement can be made to the accuracy of the model by the adding a new feature that would allow real time dataset creation. If the software could add more items to its training set with each iteration and detects an unknown object. This will make the model learn with new real time data set and also can detect that in turn can improve the accuracy.

This work can be also be implemented with the conveyor belt. Objects can be kept on a conveyor belt and transported to the system which detects and picks out the recyclable items and lets the decomposable objects to move through the belt to the decomposable bin. The recyclable objects that are collected in a bin can be further divided to separate categories and sent to its respective recycle stations.

With a more accurate model and a scalable hardware this model may be implemented at both household/residential locations as well as garbage segregation centres for larger quantities of waste. Automating this process would benefit the streamlining of disposal in urban as well as rural areas.

Nomenclatures

Abbreviations

YOLO	You Only Look Once
CNN	Convolutional Neural Network
mAP	Mean Average Precision
IOU	Intersection Over Union
JESTEC	Journal of Engineering Science and Technology

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