A Deep Learning Based Multiclass Segregation of E-waste using Hardware Software Co-Simulation

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Abstract. Today, the advancement in technology has potentially changed the lifestyle of all the people. Though this innovation is beneficial, it has quite adverse effects on both human health and environmental health. One of the main causes is ‘E-Waste’ produced by electronic gadgets. Globally, the usage of electronic gadgets has increased the quantity of “e-waste” or electronic waste and it has now grown a major problem. An unproper disposal of e-waste is now becoming an environmental and public health issue, as this kind of waste has become the most rapidly increasing segment of the municipal waste stream in the world. But this ever-increasing waste is very complex in nature and is also a rich source of metals such as Neodymium, Indium, Palladium, Tantalum, Platinum, Gold, Silver, Aluminium and Copper which can be recovered from these wastes and brought back into the production cycle and day to day utilization. Hence, there is a need of proper e-waste segregation and management to recover the precious materials from these kinds of wastes. In this project, a Deep learning model implemented using NVIDIA’s Jetson Nano development kit has been proposed, to classify the waste components into two categories based Precious or Non – Precious metals present in the waste. The prototype model developed in turn segregates the waste with good accuracy and less time consumption.

1. Introduction
Object recognition is one of the major applications on every industry, while talking about real time object recognition using camera, the first factor coming to the mind is computational Power, there are lot of options to use real time application on various hardware. [10] Among that list, GPU-based hardware is used widely and has high computational power when compared to CPU. On that factor by having price also as consideration, the low-cost GPU device by NVIDIA, Jetson Nano is most popular hardware which uses GPU with low cost. In terms of classification, Artificial Intelligence (AI) plays a vital role. In earlier days, classification kind of application can be done with the help of only image processing algorithm. However, on those algorithms the features of the object that need to be classified should be handcrafted and given by the users, which also has less accuracy. On using Deep learning, features are extracted automatically from the image in the dataset. Deep learning requires more dataset to have better accuracy. In Deep learning algorithms, Transfer learning is one of the major applications which is easy to train the deep learning model for the custom dataset by using the pretrained model trained with another existing dataset. By loading the weights of transfer learning model, current model acquires capability for classification. Alternate way for this classification is to design a neural network...
from the scratch. Through the use of Jetson Nano development kit, a neural network application can be deployed easily in the hardware. Since Jetson nano is a GPU enabled device, frame rate of the processing camera feed and classification is high. For E-waste segregation, deep learning plays an important role because it eliminates the need for manual operations. Manual operation requires human interference, and the chemical components present within the wastes can be potentially harmful. This project overcomes these issues and ensures the accurate classification.

2. Literature Review

For E-waste segregation and classification, solutions like addressing the safe disposal of domestic waste, provide appropriate framework for recycling process and extraction of required material from the wastes, promotes adequate ESM technologies for recycling, tax incentives for scrap dealers [3]. Metal is the major constituent of E-waste which is about 60% and plastics is about 20% approximately. Non-precious metal: Iron (Fe), Copper (Cu), Aluminium (Al) and precious metals like Silver (Ag), Gold (Au), Palladium (Pd), Iridium (Ir) and rare earth metals like Neodymium (Nd), Yttrium(Y) etc., India disposes E-waste by the means of Incineration Landfill and Acid-Etching. Hence, there is a need for the implementation of waste separation techniques as precious and non-precious and the process of recycling should also be done [1]. By mechanical pre-treatment and pyrolysis method Iron, Zinc, Magnesium can be recovered. The recovery efficiency of Zinc is over 99% on a waste battery [2]. Automatic waste segregator (AWS) and monitoring system was proposed to overcome the disposal of waste. The wastes are sorted into three categories: metallic, organic and plastic. Segregated waste is passed through the conveyor belt which is operated with the help of DC motor. Lightweight materials are separated with the help of blower. The robotic arm with an electromagnet separates the metallic substances. This overall process is controlled by ARDUINO UNO. Separated wastes are collected in Bins where ultrasonic sensors are used to monitor the level of bin. When the bin is full, a message is sent to the operator by GSM module [4]. Most of the household electronic gadgets are working with the help of primary and secondary batteries which have shorter lifetime. The recycling of primary battery (zinc, carbon) is done with pyrolysis method. The steel shell (outer layer of the battery) mainly consists of Iron. By mechanical pre-treatment and pyrolysis method Iron, Zinc, Magnesium was recovered. The recovery efficiency of Zinc is over 99% on a waste battery [5]. The main purpose of using CNN algorithm is for its wide use in image identification, segmentation and detection. Support vector machine and convolution neural network with six layers was used for classification of E-waste. The accuracy rate for SVM is 68% and CNN is 23% [6]. In [7], the use of TensorFlow and camera to automatically sort the waste like recyclable and hazardous is proposed. A digital image object detection and recognition system using neural network is used for classification. [7]. Phoneme recognition is done using Time-Delay neural network which characterizes 2 properties [8]. One is for simple computation using 3-layer arrangement which learns through error back propagation and the other one is that the time delay neural network arrangement helps to find the acoustic-phonetic features and the relations which is independent of position with respect to time and it’s also not blurred by the shifts in the input. For recognition, several phonetic circumstances are taken to compare with several hidden Markov model to achieve the outcome. An accuracy of 97.5% accuracy by over 1946 testing tokens is achieved.
3. Materials and Methods

3.1 Hardware Architecture

The Block diagram of the proposed system shown in Fig.1 consists of a conveyor belt for carrying wastes from one end to another end, An Embedded Processor for implementing Deep learning model, USB webcam for taking pictures of the waste components, and a rotating plate with bins for segregating the wastes and its collection.

USB webcam: The webcam used here is Logitech C615 with auto focus. It is a full HD webcam with 1080p resolution. Using this webcam object detection on a moving object is possible.

Processor: The Processor used here is NVIDIA Jetson Nano Developer Kit. It is an Embedded Development kit which is ideal for AI based applications. Jetson Nano also paves the way to robotics and deploying Deep Learning to the edge for real-time image classification, object detection, segmentation, speech processing, etc.[11].

Conveyor belt: It is made using plywood at a length of 80 cm and width of 4 cm. DC motor (3V-6V) and L293D motor controller is used to run the conveyor belt with a duty cycle of 200 sec and a delay of 0.5 sec.

Rotating plate and bins: It is done by making a circle shape cardboard with a radius of 20cm wherein two bins are placed above. One is for Precious metals and the other is for Non-Precious metals. Servo motor (SG90) attached to it helps to rotate the cardboard.

Figure 1. Block Diagram
3.2 Workflow of the proposed system
The following fig.2 shows the actual workflow of the proposed model.

![Flow Diagram](image)

**Figure 2.** Flow Diagram

A detailed illustration of the steps involved in this process are;

**Step 1:** The first step collection of wastes is a conveyor belt, wherein the speed of the belt is controlled by the processor which gives instruction to run in a given speed and gives command to start or stop the flow of the belt. E-wastes that are crushed are taken by the conveyor belt.

**Step 2:** The second step is to capture the image of the waste component using a USB camera.

**Step 3:** In the third step, the image captured by the camera is configured by the processor through ResNet18 Deep Convolutional Neural Network architecture (CNN), which classifies the component based on the type of material within it.

**Step 4:** In fourth step, based on information on the texture of the material, the segregator blocks the Component which is precious and allows the non-precious component to move through the end of the conveyor belt and collected in separate bin. This is done once when any of the classified waste is configured by the processor, instructs the segregator to separate the waste and drop it in the respected bins.

Same steps are repeated for other kind of E – waste components.
3.3 Image Datasets:
This paper mainly focuses on classifying E-waste into 8 classes. Approximately 1000 images of waste are collected and labelled into ten categories as shown in Table 1. The dataset consists of images of Resistor, Capacitor, IC voltage regulator, LCD, Relay, Circuit board, Node MCU, Battery which are very commonly disposed waste. This dataset is used for retraining a Neural Network. The Training and Testing folders both contains images of real-time components, which are captured using camera.

Table 1. Image Dataset

| No | Component     | Train | Test | Total | Metals Present       | Label Name |
|----|---------------|-------|------|-------|----------------------|------------|
| 1  | Resistor      | 135   | 15   | 150   | Carbon, Nickel, Chromium | resistor   |
| 2  | Capacitor     | 137   | 13   | 150   | Ceramic, Mica, Metals  | capacitor  |
| 3  | Regulator     | 140   | 10   | 150   | Zinc                  | regulator  |
| 4  | LCD           | 75    | 25   | 100   | Glass                 | led        |
| 5  | Relay         | 85    | 15   | 100   | Iron                  | relay      |
| 6  | Circuit board | 88    | 12   | 100   | Gold, Silver, Platinum| Circuit board |
| 7  | Node MCU      | 86    | 14   | 100   | Copper, Aluminium, Steel, Silver | nodemcu   |
| 8  | Battery       | 135   | 15   | 150   | Silver, Zinc, Lithium | battery    |
|    | Total         | 881   | 119  | 1000  |                      |            |

3.4 Transfer Learning

In Deep Learning algorithm, degradation problem occurs due to higher training error, which causes increase in network depth and the accuracy gets saturated which led to the discovery of Residual Networks (ResNet). To explicitly fit a residual mapping, desired underlying maps are directly fitted instead of hoping every stacked layer. Feed forward neural networks with shortcut connections are done which performs identity mapping and the outputs are added to the outputs of stacked layers. [10] In Transfer Learning, the network with pre-trained weights has already learned the characteristics of different large dataset. The same architecture is used for changing the initial and final layers of the network. The initial layer is replaced by an input layer which is going to train a new image dataset. The final layers of the network are replaced by FC layers with respect to number of classes in the dataset. The last layer is SoftMax layer which gives the output. SoftMax function that converts real values into probabilities that sum to one. It uses cross-entropy loss where the function is used to squash the raw class score into normalized positive values that sum to one. It gives output of numbers that represent probabilities, where the number value is between 0 and 1.

4. Results and Discussions
RESNET-18 algorithm takes an input image (using webcam), process it using the model with the processor and predict the categories of Resistor, Capacitor, Regulator, LCD, Relay, Circuit board, Node MCU, Battery.

The ratio of Training loss and Localisation loss express the different parameters of Overfitting, Underfitting and Just right of the images used for training.

- **Overfitting** – Training loss << Localisation loss
• Underfitting – Training Loss >> Localisation loss
• Just right – Training Loss ~ Localisation loss

The following observations are made from the working model.

I. When E-Wastes are made to flow in a conveyor belt, the processor predicts the output using ResNet-18 by the display captured through USB Camera.

II. After capturing the image, the processor processes and presents the object with a label name corresponding to it. The percentage value shows the accuracy of the component shown in the USB Camera in comparison with the original image used for training. Fig.4 shows the results obtained by classifying the components using ResNet18 algorithm.

III. After the detection the Jetson Nano Development kit sends information to the segregator of conveyor belt to separate Non-Precious metal and precious metal. The components are segregated and placed in the respective bins. Fig.5 shows that Battery is a component having precious metal (Ex: Silver) that is blocked by rotating plate or segregator whereas the LCD screen has non – precious metal and is allowed to be collected in separate bin.
Figure 4. Detected Components with accuracy

Figure 5. Segregation of the components
5. Conclusion

A pretrained model is trained for classifying wastes into eight categories. Using a pretrained network for training 1000 images requires small GPU and uses comparatively less time when compared to creating a network from scratch. Tensorflow with ResNet-18 model makes up the process and is an effective tool for machine learning and deep learning. Average accuracy of 93% is obtained using this method. Moreover, NVIDIA Jetson Nano is a powerful Embedded processor with 128 bits GPU and 64 bits Quad Core ARM Cortex 57 Processor. This makes it to be perfect tool for designing a Deep learning model and processing real time images. The proposed project helps to speed up the processing with other hardware components during the process of recognition. Further, it also helps to run multiple neural networks along with the parallel applications.

In future, a robotic arm with perfect precision - controlled mechanism can be used to separate the wastes at the end of conveyor belt. Miniaturized components in E-Wastes can be separated by using this technique.

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