ISSN 2464-4617 (print)
ISSN 2464-4625 (online)
Computer Science Research Notes - CSRN 3301
http://www.wscg.eu
WSCG 2023 Proceedings

The use of artificial intelligence for automatic waste segregation in the garbage recycling process

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ABSTRACT

The problem of recycling secondary raw materials remains unresolved, despite many years of work on this issue. Among the many obstacles that arise is also the difficulty of sorting individual waste fractions. To facilitate this task and help solve this problem, modern computer vision and artificial intelligence techniques can be used. In our work, we propose constructing an intelligent garbage bin containing a camera and a microcomputer along with software that uses these techniques to sort waste. The role of the software is to recognize the type of waste and assign it to one of five main categories: paper, plastic, metal, glass and cardboard. The proposed method uses image recognition techniques with a convolutional neural network. The results confirm that using artificial intelligence methods significantly helps in sorting waste.

Keywords

recycling; environmental protection; artificial intelligence; computer vision; intelligent garbage bin.

1 INTRODUCTION

Out of all the materials that flow through the Polish economy, only one-tenth are recyclable, indicating the low circularity of the economy [Pace22]. This situation needs to change as soon as possible, both from economic and environmental perspectives. To address this, experts from the Polish Institute for Innovation and Responsible Development of Innowo, the Norwegian strategic agency Natural State, and the Dutch non-profit organization Circle Economy have undertaken the ambitious task of estimating the extent to which the Polish economy operates as a closed circuit. Their work is summarized in the "Circularity GAP Report Poland," which is funded under the EEA and Norway Grants programs. This report is the first of its kind on the Polish economy [Eurostat22, Stat21]. They discovered that the economy utilizes a total of 610 million tonnes of materials per year, with the consumption of virgin raw materials amounting to 520 million tonnes or 14 tonnes per person per year. Consequently, only 10% of the materials are recycled.

To improve this situation, modern image processing techniques supported by artificial intelligence can be used. The article proposes using these methods to develop an intelligent waste bin that supports waste sorting and recycling.

Our main contribution to the work is the proposal of a waste recognition method that, when combined with a microcomputer and camera, can be an element of an intelligent waste bin.

2 RELATED WORKS

Almost all countries have recognized the issue of waste management and are taking the problem seriously [Han13]. When designing smart cities and promoting sustainable urban development, designers and scientists put a significant effort into building efficient Waste Management Systems (WMS). The demand for creating effective waste management systems is high, as it has a significant impact on protecting the environment and public health [Bag19]. Currently, the focus is on using cutting-edge technologies to improve and automate services, such as the Internet of Things (IoT), information technology, and Machine Learning (ML) [Bob13]. These technologies have drastically improved the efficiency of various WMS processes, enabling the forecasting of waste, collection, transport, sorting, and recycling [Now20, Ko22].

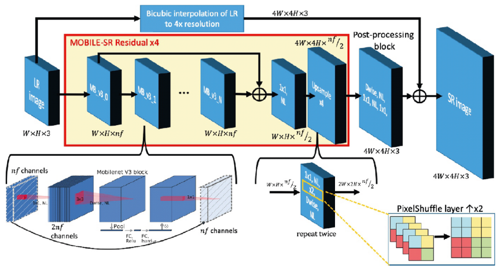

Figure 1: The structure of MobileNet-V3 [How19]

Several pre-existing CNN networks, such as ResNet-50 [Ma22], YOLO [Val19], MobileNet-V2 [Zio20], and a Hybrid of CNN and multilayer perceptron, have been used for waste classification tasks. Waste classification is an essential activity that separates different types of waste and dramatically improves the recycling process's efficiency. A project offers a waste bin equipped with a camera, microcontroller, and servo motor to separate various types of waste. The bin hardware is controlled by non-standard software based on the ResNet-34 algorithm [Ko22]. DL methods significantly impact the recycling process by detecting different types of materials and items for segregation, making the recycling process more efficient in recovering materials.

3 PROPOSED METHOD

To develop a method of automatic waste sorting, we proposed using a neural network that would quickly and efficiently meet our expectations. We used a particular type of convolutional neural network because, in our opinion, it is the best proposal for recognizing this type of image. We chose the MobileNetV3 Large neural network due to its simple implementation and high efficiency.

The neural network based on mobile models was built on more efficient structural elements. MobileNetV3 uses a combination of convolutional layers as building blocks to build the most effective models. Layers are also updated with modified 'swish' nonlinearities. They use a sigmoid that can be inefficient for computation and questioning accuracy retention in fixed-point arithmetic. Therefore, it was replaced with a hard sigmoid [How19]. The construction of the MobileNetV3 network is shown in Figure 1.

Recognition of many objects in images is possible thanks to the YOLO network. YOLO is a method of identifying and recognizing objects in real-time in photos. It stands for You Only Look Once (YOLO) [Red16]. YOLO delivers state-of-the-art results by using an entirely new approach to object recognition, easily surpassing previous real-time object detection methods. The YOLO method divides the image into N grids, each having an equal SxS dimensional sector.

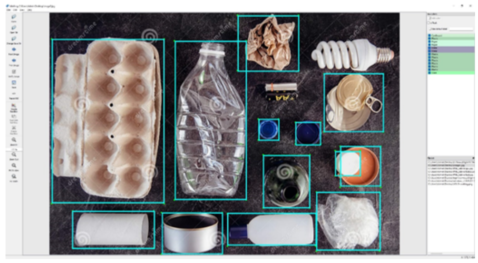

Figure 2: Scheme of forecasting and frame reduction [Red16].

Each of these grids N is responsible for detecting and locating the object it contains.

YOLO skips all bounding boxes with lower probability scores in attenuation. This is done by examining the probability scores associated with each option and selecting the highest score. This process continues until the repeating bounding boxes are removed.

We decided to use the YOLOv4 Tiny network. The Tiny version is less computationally demanding and works perfectly for our tasks. To prepare the training data, it was necessary to mark the waste on each image. For labelling, we used a specialized tool to mark objects and assign them to the appropriate classes quickly. An example of marking objects is shown in Figure 2.

In order to avoid incorrect assignment of objects to classes during recognition, we used two cameras positioned at different angles to the observed object, as in the case of the MibileNetv3 network.

4 EXPERIMENT

The input data is a set of photos showing the waste assigned to five classes: glass, metal, paper, plastic and cardboard. The data was divided in proportion to learning/testing: 90/10, 80/20, 70/30 and 60/40 per cent of all photos within each class. In each experimental case, 10% of the training data was extracted as validation data. This allowed for more precise observation of the learning process and the analysis of the possibilities of the trained network to work in real conditions.

4.1 Datasets

The problem with the input data for convolutional network training is that quite often glass is similar to plastic, cardboard may look more like a background (piece of furniture) than the actual internal appearance of the box, paper may show in the photo e.g. metal or plastic, etc. It is important to collect as many photos as possible in individual classes so that, despite the definitely long learning process, the accuracy of the already learned system is at an acceptable level. Preparing input data for the learning and testing phase is an essential element of the research process. For deep neural

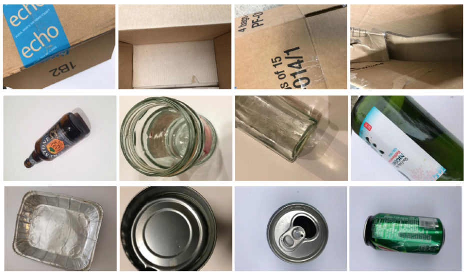

Figure 3: Sample images from dataset [Chan18]

networks, collecting the largest amount of data for each defined class is necessary. Preliminary research showed that the minimum number of images per class should be greater than 500. All the collected photos showed objects classified into the five considered classes: paper, cardboard, glass, plastic and metal. These images come from the database Trashnet (2527 images) [Chan18], and their samples can be seen in Fig. 3. To increase the number of images in individual classes and obtain a similar number of images for each category, geometric transformations of images rotation, reflection and shift, were used. Such a set of data (about 1,000 simulated images per class) was enough to teach the prepared network structures properly. Objects causing the greatest difficulty in recognizing, i.e. transparent, textured and cardboard, were also selected for the experiment. The pictures were taken by placing the object on a white background and using natural light or bulb lighting. The pictures have been resized down to 512 x 384. The data acquisition process involved using a white posterboard as a background and taking pictures of trash and recycling around homes. The lighting and pose for each photo is not the same, which introduces variation in the dataset. Data augmentation techniques were performed on each image because of the small size of each class. These techniques included random rotation of the image, random brightness control of the image, random translation of the image, random scaling of the image, and random shearing of the image. These image transformations were chosen to account for the different orientations of recycled material and to maximize the dataset size.

4.2 Results

The learning process of the neural networks was carried out on a computer: AMD Ryzen 9 5950X 16-Core Processor 3.40 GHz, RAM 128 GB, NVIDIA GeForce RTX 3090 GPU. division of input data into training and testing. Four divisions were used: - 90% (training data) - 10% (test data), 80% (training data) - 20% (test data), 70% (training data) - 30% (test data) and 60% (test data) training data) - 40% (test data). The results of the experiments are presented in Table 4.1. Analyzing the obtained results, it can be seen that the MobileNetV3 network is quite good at recognizing objects with much greater use of training data concerning test data. The less training data, the more complicated the recognition process becomes, which illustrates the decline in the correct verification of objects. The advantage of this network is undoubtedly the learning time. Using two cameras and activating the network on each of the cameras allows you to avoid situations where, for example, an object on a newspaper presents a plastic bottle, and in fact, it is a newspaper, i.e. paper.

In the case of the YOLOv4 Tiny network, a much higher accuracy of correct object recognition can be noticed even with a reduced training data set. This is due, firstly, to a different approach to teaching the neural network and, secondly, to a relatively low threshold of object recognition, which with the standard settings of the YOLO network, is 25%. Increasing this threshold skips recognized objects but prevents misclassification. Unfortunately, the learning time of the network has increased significantly. Still, after learning the operation process runs without real-time delays, we can say that the FPS resolution is about 25 frames. MobileNetV3 performs better in processing, but our misuse of GPU computing may generate this data. That's why we didn't include the FPS scores in the table.
Our experiment results are similar to other methods using CNN - 96% in [Udd22] and [Gol19]. This confirms the validity of the idea of using artificial intelligence in the field of environmental protection and the usefulness of the presented method.

5 CONCLUSIONS

The obtained results show that our method copes quite well with a specific waste classification, especially when the training data are good examples. For bad patterns, it is necessary to increase the training data within each class and train the network with these bad patterns. The accuracy of the presented system at the level of over 96% for the YOLO4 Tiny network and over 94% for the MobileNetV3 network at the first assumed division into training and test data is acceptable for the proper functioning of the system and allows us to assume that the proposed method has a good chance of commercial use in real sorting plants waste. We are particularly pleased with the correctness of distinguishing waste by the YOLO network in a situation where there is more than one object within the camera's field of view.

6 ACKNOWLEDGMENTS

The project financed under the program of the Polish Minister of Science and Higher Education under the name Regional Initiative of Excellence in the years 2019-2023 project number 020/RID/2018/19 the amount of financing PLN 12 000 000.

No of division	Type of division	MobileNetV3 accuracy [%]	Training time [min]	YOLOv4 Tiny accuracy [%]	Training time [min]
1	90% - 10%	94,27	169	96.82	268
2	80% - 20%	89.14	164	96.25	224
3	70% - 30%	81.05	135	92.24	199
4	60% - 40%	74.65	122	90.09	183

Table 1: Results of experiment

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