A survey on detection, identification, and classification methods and algorithms for automatic trash sorting.

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***Abstract*—This paper aims to survey the literature and compare different methods and algorithms of detection, identification, and classification of trash in the intelligent trash sorter systems. Scholarly articles have reviewed in this survey. Several methods and algorithms such as K-NN, RPN, R-CNN, Binarizing, and optimization are discussed and analyzed to find out the state-of-the-art in this field. The paper also addresses some of the challenges of trash sorting algorithms. After mentioning what has been done and evaluation of previous studies, the paper addresses what hasn't been done and what needs to be done in future researches. In general, if the state-of-the-art in the neural network is trained meticulously, the problem of trash sorting can be solved.**

Keywords—Waste sorting, Waste classification, Binarized trash image, Autonomous waste sorter, Convolutional neural network in trash sorting, mixed-type trash sorting.

I. INTRODUCTION

In the modern world, garbage has become a prominent issue that is increasingly having adverse effects on the environment. It affects humans and ecosystem enormously. A research from Grow NYC indicates that 80% of the world's waste is produced in the United States [1]. About 70% of its trash only used once and 45% burnt and buried [2]. One way to counteract this issue is to recycle the trash we dispose of. These days there are a lot of ongoing efforts to separate trash. To effectively do this, it is necessary to properly sort the trash to make it ready for processing. However, there is often a lack of proper sorting. Having mixed-type trash in containers make the recycling process more difficult and costly because a separation process is needed, which can be avoided. At this point, governments prefer to burn or bury the trash instead of spending a lot of money to separate and then recycle waste [3]. In this condition, the increasing need for raw materials from one side and the pollution of trash from another side threaten society and the ecosystem. One of the traditional ways to separate trash is using different containers for each kind of trash, but there is always a possibility of human errors. Another traditional way is to separate different types of trash after gathering from houses, which is very costly and challenging [3]. There are a few automatic systems that can separate a few types of trash. In general, these automatic trash sorters have a main container. Trash will be detected, identified, and classified using different methods. Then waste will be led to a proper sub-container. A functional block diagram of a basic automatic trash sorter is given in figure 1.

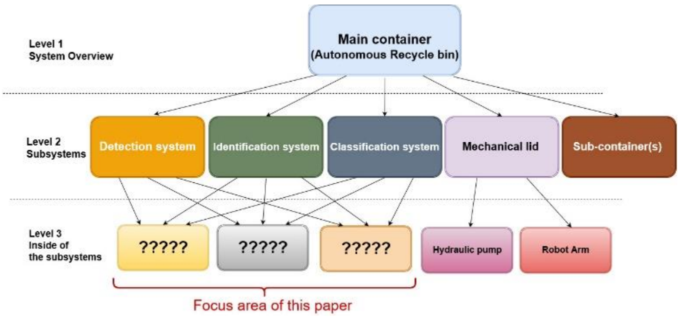

Figure 1. Functional block diagram of a trash sorter system

The user in this autonomous system is just throwing the waste in the main container, and the machine will do the sorting autonomously. Figure 2 shows the basic use case diagram of this system.

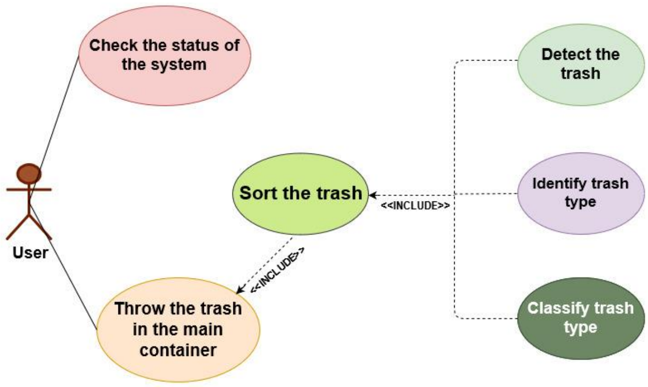

Figure 2. Use case diagram of an automatic trash sorting system

These systems, nevertheless, have different efficiencies and effectiveness. Some of them can sort trash into two or three types which establish the need for further sorting and some are highly dependent on humans for maintenance, and some are very expensive [4]. The most important part of an autonomous garbage separator system is the detection, identification, and classification of the trash type [4]. Different methods and algorithms have applied for detection, identification, and classification. Apart from the tools required for detection, identification, and classification, various algorithms are employed to make the result more accurate and broader for more types of waste. By having a proper, reliable, and efficient autonomous trash detection, identification, and classification algorithm, it is possible to elevate the efficiency and performance of automatic trash sorter systems and as a result

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increase recycling and reproduction massively and decrease the need for raw materials, together with diminishing garbage pollution and providing additional jobs in this field [5-6]. In this survey paper, there is an attempt to evaluate the efficiency of different garbage Detection, identification, and classification methods and algorithms in automatic waste sorting systems. After introducing the problem, a literature review is conducted to find out the state-of-the-art in this subject. It helps to become familiar with the body of knowledge that has been created by other expert researchers in this field. The data that has been made by others is the data that will be analyzed in this survey paper in section III. The current state-of-the-art will be evaluated and will be compared with what hasn't been done to conclude this research paper.

II. LITERATURE REVIEW

The first attempts of separating trash for recycling happened to salvage reusable materials such as paper, metal, and wood, while it was highly dependent on humans [7-8]. It is crucial to propose a method that can sort waste and avoid human errors as much as possible. An attempt for intelligent waste classification in 2010 was based on pattern recognition; Bayesian framework [9]. This methodology while lacking good automation, has a well-documented mathematics background and is very good in object recognition literature [10]. Another attempt was using a convolutional neural network that is called Smart Trash Net [11]. This method requires meticulous techniques to make a reliable dataset. This study is a benchmark in showing the efficiency of linearities. The most significant step of this work is the detection of recyclable material and non-recyclable ones. Data set for this work was gathered at Stanford University [12]. It also has a metal detector and works with a switch that triggers by weight. This paper is using the Faster R-CNN method to share full-image convolutional features with the detection network. Faster R-CNN has a proposal network, which is a type of convolutional neural network that can calculate object bounds at each position. Region proposal network (RPN) is generating high-quality region proposal by being trained end-to-end. Figure 3 demonstrates the architecture of R-CNN.

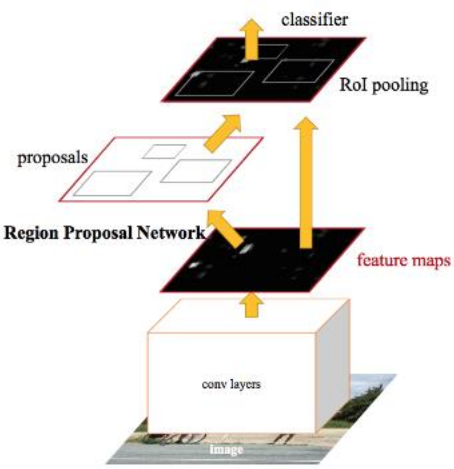

Figure 3. R-CNN architecture [11]

This method uses a pre-made dataset of mixed-type trashes to try to identify them. A python code has written to remove extra data of the dataset and speed up the image processing. By doing this, a new dataset that has 10000 images of piles of trash was made. This new dataset has split train, validation, and test data around 6000, 2000, 2000, respectively. This research also downplays the feasibility of using optical sensors due to labels and curvature of the glass and plastic. In contrast, it recommends using pressure sensors; however, it's not part of their final solution. A British company called reverse vending produces a machine that separates aluminum cans, empty glass bottles, and plastic drink containers [13]. This machine, which is called Reverse vending machine [RVM], uses a conveyor belt to take in the trash. There are three sensors during the conveyor path, which each of them is set to find either glass, aluminum, and plastic. The producers maintain separation doesn't rely on human so it can be more precise. A group of students at the University of South Florida created and developed an autonomous recycling robot with the ability to separate plastic, glass, and aluminum [14]. Their method is working with using optical sensors that can detect size, position, color, and shape. After detection, a mechanical system, controlled by a computer, uses compress air to lead the trash into a proper container. This system uses an item locator sensor which has a range of 2 cm to 3 cm of detection. It detects garbage type by sending an ultrasonic ping. This sound goes toward the object and bounces back to the sensor after hitting it. When the echo-back is detected, an output pulse will be provided to the system using a processor. Figure 4 shows the installation of the ping sensor of the robot.

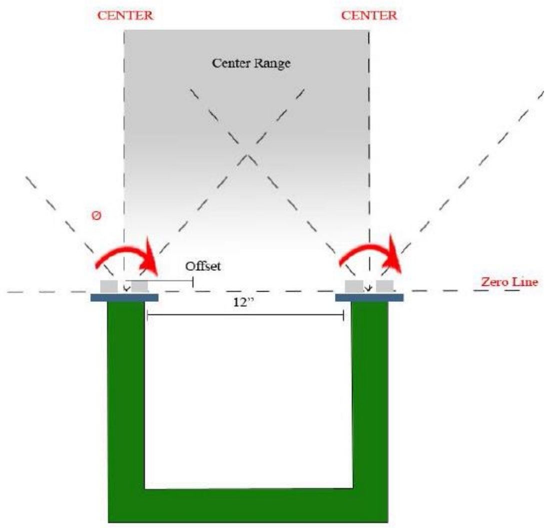

Figure 4. Ping sensor of IWS [14]

This detection method is one of the best methods that has been used so far, but the ping is stationary. As for identification, this system is using different sensors for each type of trash. Since it sorts aluminum, glass, and plastic, it has three different sensors. Another separate weight detector sensor is used to trigger other primary identifier sensors. In paper [15], which is called Trash Net (Recycle Net), the focus is on the classification of selected classes of common waste material. It gives a solution for the detection of glass, paper, cardboard, plastic, and metal. The data set of Trash Net incorporates six classes of recycled objects [12]. Every image has resized to 512*384 pixels. There are 2527 materials with training, validation, and test percent for each of them. A deep neural network is used to solve the inaccuracy problem. This research paper maintains the Dense Net family of neural networks achieves the ideal classification performance when its pre-trained with the dataset. This method is, however, slightly slow in prediction time. Decreasing the number of skip connections is a modification for the problem that is done by this equation [15].

$$x_l = H_l([x_{l-1}, x_{l-m-1}, x_{l-2m-1}, x_{l-3m-1}, ..., x_0]),$$

Equation 1. Dense Net equation

X1 is output, and H1 is the composite function of the operation. Trash Net also suggests having M=2 is ideal for this equation. Different optimization algorithms such as Adam and Ada Delta have used to deliberately search for a global minimum and explore the most optimize approach. To improve generalization in the neural network, a simple data augmentation methodology has applied. Horizontal flip, vertical flip, and random rotation, to name but a few. Trash Net concluded that waste could be defined as a shape-shifting material. Figure 5 shows the accuracy of the best result.

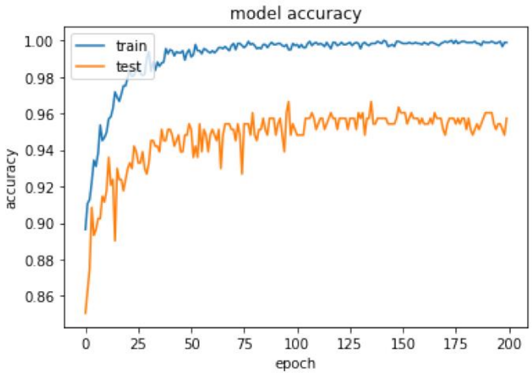

Figure 5. The accuracy of the best-gotten result [15]

It emphasizes that when the state-of-the-art convolutional neural network is trained, the method can produce industrial-grade results [15]. Another paper that was evaluated is Intelligent waste sorter (IWS) [16]. It works for aluminum, plastic bottle, and plastic cutlery. It suggests a broader solution for detection, identification, and classification. The whole system triggers by a touch screen. There is a webcam to measure the RGB image of the waste shape. The identification of waste is split into image processing, characteristic extraction, and machine learning. Every object is evaluated by each of these three steps to increase the preciseness of the solution. As for the image processing part, the RGB image is converted to grayscale and then binary to remove unnecessary features from the image. The grayscale conversion algorithm is given in figure 6.

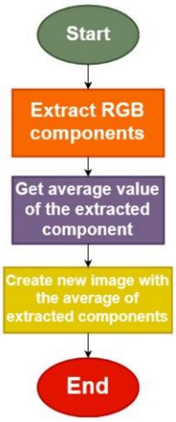

Figure 6. Grayscale conversion process

The algorithm used for binarizing images is given in figure 7.

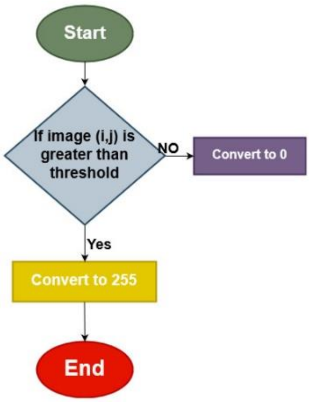

Figure 7. Binarization process

Figure 8 shows the difference between these images.

Figure 8. RGB image Grayscale image Binarized image [16]

The global properties of the images have used instead of local properties. HU approach, which was a first huge step on the utilization of moment invariants for image analysis and object representation, is used for image analysis and object representation [16]. The solution uses an invariant moment.

$$m_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^p y^q f(x,y)\,dx\,dy.$$

Equation 2. Invariant Moment

f(x,y) represents the discrete representation of image and X,Y are width and height coordinates of the image. As for training, an algorithm called K-NN is used. However, it searches for the nearest training item. In fact, K-NN is a lazy algorithm [18]. In case of any ties, that two or more classes collected the same number of votes, the class of the nearest neighbor can be chosen. With a relatively small training set, object classification can be started. IWS uses 20 samples of each class of waste to train the system.

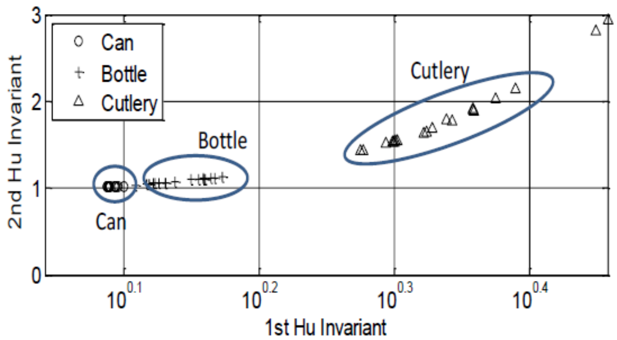

Figure 9. Classification of training set [16]

Figure 9 shows the outcome of the classification. In general, the classification for the given samples was successful. However, as can be seen, some bottles may be classified as can or vice versa. If the user throws two pieces, it classifies them as one piece. The IWS is unable to identify deformed objects and highly relies on the original shape of the trash. Paper [21] suggests not only the shape but also the color and texture of waste particles can be analyzed for waste sorting. It introduces an Optical sensor and a laser beam for scanning. This sensor is capable of measuring 3D visual parameters, positions, and colors of waste. 3D acquisition for this method is based on a triangulation scan. This type of scanning is shown in figure 9.

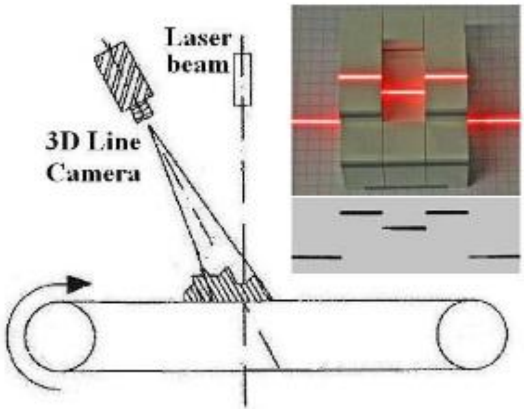

Figure 10. 3D Visual sensor installation [21]

It calls triangulate because lasers and cameras formed a triangle. This paper is also introducing 3D grayscale images processing and analysis. First, an image is captured from the object. Then it will be converted to black and white grayscale by software. Every object is higher than the surface is shown with a lower grayscale (lighter). it detects and identifies objects, but it needs a further localization process. So, the grayscale images are converted to binary. This method finds edges of objects. However, in grayscale, it's hard to find out the exact shape of the object. Figure 11 shows this difference.

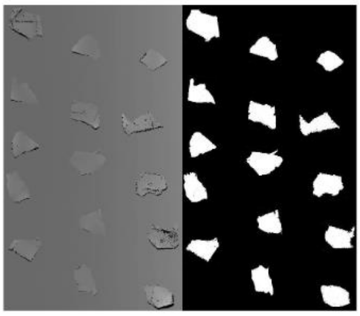

Figure 11. Binary image and edge segmentation of grayscale image [21]

In fact, the value one or the white parts means the object, and value 0 or the black parts means the area surrounding that object. As can be seen, it's risky to identify the shape of the objects.

III. ANALYSIS

After mentioning the body of knowledge that has been created by other researchers to inform the thinking, an analysis has done. First, the detailed version of the functional block diagram of the reviewed papers is given in figure 12, which is a complete version of figure 1.

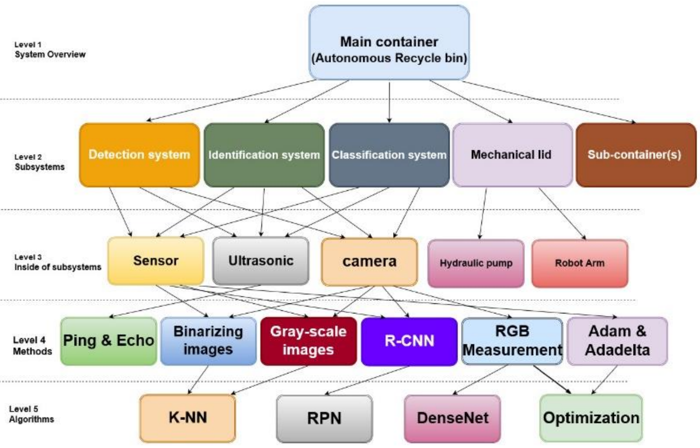

Figure 12. Functional block diagram of trash sorter systems in details

In [16], the focus is heavily on image processing, computer vision, machine learning, pattern recognition, and embedded systems. The complexity of the classification algorithm, however, depends on the training set. The classifier algorithm is simple and easy to use, but the distance among training set items and new ones should be calculated, which increases computational cost sharply. The problem will be more prominent when there is a larger dataset, so it needs a lot of time for rendering. Using the binarized technique is decreasing processing time very significantly because the dataset is only containing useful information, and all of the unnecessary features of images will be removed when binarizing. The current scheme can be validated with a comparison of other classification algorithms with the presented algorithm and can be improved. The method is useful for the selection of numerical attributes, which will be fetched from waste in order to do classification. The method works well; however, it has geometric distortions [17]. The IWS maintains that the system has an accuracy of 98.33%, but it must be considered that the number of samples threatens the feasibility of the approach. Apart from this, the system has some limitations. It can process a piece at a time. In [14], the ping is just a stationary sensor that gives limited field access. So, this detection method is for a tiny container and needs refinement for using in regular containers. Apart from that, the sound wave might be absorbed by trash. In [15], which is a perfect example of artificial intelligence in waste sorting, the focus is on deep learning algorithms. It gives an excellent level of accuracy, but the possibility of losing the best result should be considered. Figure 13 shows that this possibility.

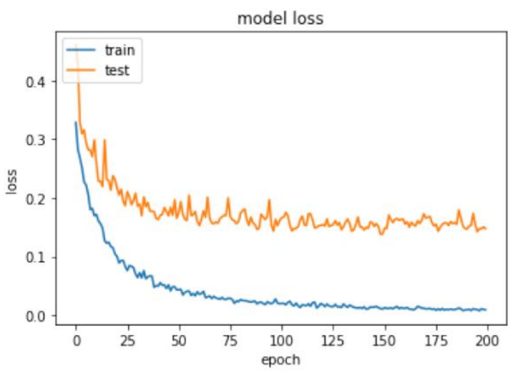

Figure 13. Loss of the best result [15]

It can, however, be experimented with a more sophisticated connection pattern and the use of optimization algorithms. Following the fact that the training set is quite small, it's hard to increase accuracy. If the training set is increased, it may work better. The main advantage of Recycle Net (Trash Net) over IWS is that it can easily be used for larger datasets without sacrificing rendering time. In [11], there is a trial and error. It also suggests using a conductivity sensor for identifying aluminum has a lot of shortcomings. The focus area of this paper is the classification. The solution requires a vast dataset (at least 10,000), which is not made. However, this dataset can be made and train the system for better results. The use of the different sensors for each type of trash makes the solution costly when using it for a lot of trash types. Apart from that, when there is a mixed-type trash like a banana peel in a plastic bag the sorting will fail. The paper [11] achieves an overall mean average of 0.6 in the classification of the trash images. The average precision (AP) value of different classes is shown in figure 14.

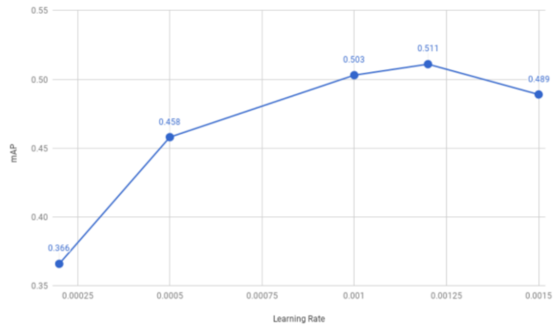

Figure 14. Average mAP scores over the three classes for different learning rates [11]

In [9], the Bayesian framework is very advanced in pattern recognition and gave a clue to other solutions. The main pitfall of this system was the need for hand-extracted features. This framework is also used for nuclear waste disposal [19]. All the training samples are minimal; therefore, there is no clearance of using the above-mentioned algorithms in real-world examples for waste. There is, however, no standardized dataset for everyone as a benchmark. Each solution is customized with its own dataset, which makes the dataset unusable for other studies. The latest advances in the convolutional neural network are not used for the paper [9], so a refinement in the architecture of the process is necessary to make it optimized and updated. IWS is the most efficient trash sorter because it has a machine learning feature to help training systems for different types of trash. It uses the Intel Atom processor with multimedia capabilities, which are very expensive but very efficient in real-time processing as well. Using Ultrasonic for detection of trash has both cons and pros. It is cheap, trustable, and easy to implement, but also it is very susceptible to noises, humidity, and distant [20]. The Ultrasonic cannot detect when the object is not exactly right in front of the trigger sensor. In fact, the Ultrasonic is a distant measurement tool rather than an object detector or identifier [20]. As for paper [21], it is the only study that explains the importance of localization, together with identification, and classification, when it comes to mixed-type trash. The identification algorithm which is using in this study can be used for more types of waste due to consideration of shape, color, and texture mapping that reduces the possibility of errors. It is also tested with five different types of waste. Non-ferrous metal, two kinds of polymer with different colors, bottles, and euro coins, are tested. The experiment showed that the method is not proper for black polymer because the color can absorb the laser beam. The paper [21] maintains the test was 90 % successful. However, it has some malfunctioning when the shape of the object is not the same as the original shape. In fact, when the shape of the waste is different than expected, the color sensor must identify the waste, but one factor is not enough for doing it. Table 1 and Table 2 are showing some more analysis of the above-mentioned algorithms.

	Dataset scope	Trash recognition variety	Industrial Usage	Accuracy in testing
Waste Management [7]	NM*	NM	No	NM
Lithic [8]	NM	NM	No	NM
Bayesian [9]	Broad	10 types	Yes	44.6%
Smart Trash Net [11]	Limited-expandable	3 types	No	68.3%
RVM [13]	Broad	3 types	Yes	95%
Autonomous Recycling robot [14]	None	1 type	none	100%
Trash Net [15]	Limited-expandable	6 types	none	81%
IWS [16]		3 types	none	98%
Intelligent solid waste Processor [21]	Broad-expandable	5 types	none	90%

*Not Mentioned-Measurement needs more details

Table 1. Analysis of different method and algorithms (part 1)

	CPU/ GPU need	Time complexity	Human interference	Mixed-type trash sorting	Misshapen trash handling
Waste Management [7]	NM	NM	Yes	NM	NM
Lithic [8]	NM	NM	Yes	NM	NM
Bayesian [9]	NM	NM	Yes	No	Yes
Smart Trash Net [11]	NM	NM	No	No	No
RVM [13]	NM	NM	No	No	No
Autonomous Recycling robot [14]	Parallax Inc BS2-IC Basic Stamp2 20MHz	O(n2)	No	No	No
Trash Net [15]	Intel(R) Xeon(R) CPU @ 2.20GHz	NM	No	No	No
IWS [16]	Intel(R) Atom (TM) CPU E640 @ 1.00 GHz	NM	No	No	No
Intelligent solid waste Processor [21]	NM	NM	No	Yes	Yes

Table 2. Analysis of different method and algorithms (part 2)

IV. CHALLENGES

The real-world examples of waste detection, identification, and classification are a massive computer vision task. It is mainly because the key properties of the identification of the waste can be lost due to the shape-shifting of some waste types. The material is the same, but the key properties which are needed for pattern recognition are might lost after shape-shifting. This is the biggest challenge for researchers. Apart from this, basically, any object could be input for an autonomous waste sorting system, but the training samples are highly limited. It is understood that when the trash sorting system is facing mixed-type trash, a localization process is also needed in order to do the sorting properly. There is not a clear solution for the localization of trash in the above-mentioned researches. However, it is crucial when talking about mixed-type trash. Datasets which have been used in previous works are not following the standards of making dataset, and as a result, each solution had to make its own dataset.

V. CONCLUSION AND FUTURE RESEARCH

To sum up, with regards to the foregoing paragraphs, it can be stated that the methods and algorithms which are using for waste sorting are in early stages and primitive and far from being applicable in real-world use cases. In general, when the state-of-the-art in neural networks is trained very thoroughly, it can solve the problem of trash sorting. The binarized conversion is the most significant step in waste classification and identification algorithms, which increases the preciseness and decreases the dataset volume significantly. As for future research, evaluation of the localization algorithms for waste sorting can be done, together with object recognition algorithms for misshapen waste, and researching about a standard dataset to train waste sorting algorithms with.

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