Beverage Container Collecting Machine Project

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Abstract The article describes an integrated project for the collection and recycling of beverage containers (aluminum cans and plastic bottles) in a big city. Collection is proposed to be carried out with the help of a reverse vending machine (RVM). A RVM is a machine where people can return empty beverage containers, such as bottles and cans, for recycling. The installation of RVMs for collecting beverage containers faces difficulties in the Russian Federation due to the contradictions in the Act of the manufacturers’ extended responsibility. We offer a solution for automatic recycling of plastic and metal waste in combination with another mechanism of economic motivation of end users – a system of discounts and bonuses in large retail chains. The machine recognizes containers with a conventional camera, which allows reducing costs. Then special workshops produce more accurate sorting of containers and transfer them to processing companies for further disposal. Secondary raw materials can be reused, namely in the building and repair of automatic machines for beverage containers (internal aluminum structures and plastic parts printed on a 3D printer). This approach can significantly improve the economic efficiency of the project.

1. Introduction
The volume of waste generation is growing rapidly year by year; it has increased by 43.7% [1] over the past ten years. The problem of environmental pollution from production and consumption waste is a significant challenge which requires an integrated approach [2]. Waste sorting lines extract up to 5% of contaminated secondary resources, which are almost impossible to send to further recycling without a prior expensive pretreatment. The recycling problem in Russia, the implementation of the state policy in the field of processing of different types of waste is difficult to resolve for several reasons:

• Imperfection of the regulatory framework;
• Unfair execution and low level of control over the implementation of laws and regulations already in force;
• The lack of an integrated state database on types of waste, which significantly impedes making the right decisions on the ground;
• Inadequate funding for waste collecting and sorting.

Recently, Russia began to realize the urgency of the waste disposal problem, so the country is gradually increasing funding for projects and programs aimed at the waste management system [1].
In addition to increasing subsidies, the government began to provide opportunities to encourage people to make rational use of packaging materials. Implementation of separate waste collection in different cities of the country showed that people are ready for the initiatives. The willingness of people is caused by enhanced public awareness about the health hazards of waste and an increase in charges for waste disposal; thereby it increases public attention to the issue of consumer waste.

In 2019, the Russian government pay special attention to the problem of collecting and processing solid municipal waste. The accumulated experience of foreign countries encourages companies to replace manual labor with modern automated and mechanized processes in the waste collection and sorting system.

The federal law No. 458-ФЗ is aimed to urge production and import companies to maximize the volumes of recycled and reused goods while to minimize the amount of general waste. Enterprises begin to install machines for receiving secondary raw materials (a reversible vending machine).

2. A Reverse Vending Machine
A reverse Vending Machine (RVM) is a machine where people can return empty beverage containers, such as bottles and cans for recycling. Reverse vending machines are especially common in regions with beverage storage laws (where you get money for returning certain containers) or mandatory recycling legislation. Machines recognize each type material, then separate and process them without contamination. Reversible vending machines are a key part of container storage systems in Europe and the United States, which include from 70 to almost 100% of all beverage containers returned for recycling [3].

The global market for the production of reverse vending machines is very concentrated. Most of the market is divided between a Norwegian company Tomra Ltd, a German company Diebold Nixdorf and an American company Envipco [4]. Tomra Ltd is a market leader with a 65% of the market share [5]. Table 1 presents the analysis of RVM for collecting PET bottles.

| Company                                         | Producer      | Max productivity\(^a\), units/min | Capacity\(^b\) | Price in thou rubles\(^b\) | Rewards                                      |
|------------------------------------------------|---------------|-----------------------------------|----------------|---------------------------|----------------------------------------------|
| Tomra Ltd                                      | Norway        | 30/40                             | 200/450 units  | no data                   | no data                                      |
| Diebold Nixdorf                                | Germany       | 40/60                             | \(\frac{h}{d}\) | no data                   | no data                                      |
| Envipco Holding N.V.                           | USA           | 40/42                             | 300/2333 units | 388 – 905                | no data                                      |
| Loetec Elektronische Fertigungssysteme GmbH    | Germany       | \(\frac{h}{d}\)                   | 0,43 m\(^3\)   | \(\frac{h}{d}\)            | Cash, coupons, mobile phone account          |
| “RICH”, Ltd.                                   | Russia        | 15                                | Up to 1 m\(^3\) (20–40 kg of PET bottles) | 350 | Coupons, utility bills, mobile phone account |
| PANDA-MAT                                      | Ukraine       | 12                                | 300 units      | 125                       | Cash                                         |
| Zhengzhou Honest Machinery CO., Ltd            | China         | 30/50                             | 400 units      | 388 – 646                | Coupons, mobile phone account                |
| INCOM TOMRA Recycling Technology (Beijing) co., Ltd | China       | 15                                | 335 units      | 518 – 972                | Coupons                                      |

\(^{a}\)Technical characteristics differ from the model;  
\(^{b}\)Prices are based on the exchange rate in March, 2019.
The table points to the conclusion that the identification and acceptance of PET bottles depend on the price of the machine. The volume of accumulated PET bottles is determined by the volume of the storage container and, consequently, the size of the RVM.

Today, RVM are widely used for sorting and collecting a large range of secondary raw materials. Automation of processes provides many advantages; the main ones are related to saving resources, including labor costs [6].

Whereas there are positive sides in the implementation of RVM for collecting and sorting waste, there are negative aspects that hinder their implementation:

- Financing plays a primary role at the initial stage of PET bottles collection. It is economically inexpedient to install one machine as in a pilot project, while the purchase of hundreds of machines amounts to around ten million rubles. Such investments with 5-6 year payback period [7] can be provided only by municipal or federal programs with state budget funding;
- Limitation in the types of collected containers. In most cases, RVM accepts 1-2 types of packaging: PET bottles and aluminum cans. Glass bottles are also collected, but less frequently;
- RVM location. Using the machine 24 × 7 does not apply to all models. The range of weather conditions for RVM is different and not all machines are designed to work outdoors;
- Payment method. Difficulties are associated with the appropriateness of a particular type of encouragement and mentality of the population.

This article develops an integrated approach to the solution in the field of beverage containers collection (aluminum cans and plastic bottles).

In the exchange of used packaging consumers may receive monetary rewards in combination with other economic motivation mechanisms. For example, a system of discounts in large retail chains, bonuses for a subway ticket, donations to charitable foundations. Thus, each recycled beverage container may provide a non-monetary opportunity for a user. RVM running also requires involvement of local authorities as an RVM owner’s profit is measured by the cost of recycled plastic or metal and is very low due to the high logistic costs.

The main piece of RVM is the recognition system. Proper packaging identification and fraud prevention are ensured by the application of several safety procedures:

- The control of a container material (for example, using an IR spectrometer);
- The control of a container shape;
- The barcode control.

These three main control procedures can prevent fraud. At the same time, it makes RVM too expensive (a machine costs £ 7,000 + VAT) [8]. Modern computer vision technology allows the development of another effective and inexpensive RVM with the same functions and high protection against fraud.

A user places an empty bottle or a jar in the receiving opening; the horizontal feed system allows the user to insert containers one by one. RVM scans and identifies a bottle / a can (maps it to a database) as a participating container. Foreign machines can use material recognition scanner together with a barcode scanner along with the online or local barcode database.

The recognition process begins with placing a container in the gutter to direct it to the conveyor belt which delivers it to sort. Then, the conveyor belt scrolls the container until the Raspberry Pi camera identifies its barcode. During the process, the container is backlighted with lamps of the opening supply in order to minimize reflections from its surface to the cameras [5].

This principle was used in most RVM until Tomra Ltd developed Tomra flow technology. The system recognizes beverage containers with cameras by reading the barcode printed on the label. A distinguishing feature of the technology is the location of cameras around the recognition block, which increases the speed of container detection as there is no need to rotate it (Figure 1) [5].

An IR spectrometer, a barcode scanner and associated electronics increase RVM price. Daily database synchronization to process new container bar codes from thousands of suppliers complicates the recognition process. We have developed another identification method which recognizes object
neural networks (NN) with a tiny IoT control device (Raspberry PI 3) [9, 10]. It has a screen, a camera and some sensors. The cost of the system is less than $100.

![Image of cameras location in the identification block of RVM](image)

**Figure 1.** Cameras location in the identification block of RVM [5]

This approach is independent of the database upgrades; NN studies the forms of cans and PET bottles and determines the main characteristics necessary for classification. This NN feature can identify any new PET bottle image as an aggregate class of PET bottles, if the beverage packaging has appropriate characteristics. A can is handled in the same way and can be identified as an aggregate class of cans, even if the beverage container is stuck and twisted. We also teach NN to detect fraud (including glass bottles), hands, and fire in the opening to avoid the inclusion of a transport servo. Thus, the system is autonomous and can handle any type of containers.

A beverage container is retrieved from an aperture into the corresponding basket by the servo-driver. In one of our RVM models, a disposable packaging is fixed and shredded to reduce its size, to avoid spillage and to increase storage capacity. RVM is equipped with a feedback system for notifying the logistics center about the receiver stuffing and security events.

When a container is identified and processed, RVM offers a user to choose a bonus from the list on the screen. The choice is converted into a QR code, which the user can scan on their smartphone with the corresponding application. Thus, top-level operations are delegated to a smartphone, including user authentication, logging into the trading network web portal for requesting bonuses, and others. In this way, we divide and distribute functionality and reduce a user interaction with RVM. The main advantages of the system are user authentication and data exchange security, independence for RVM from GPRS / 3G connections, absence of inconvenient sensors or physical keyboards on the front panel of RVM.

The deep learning approach is the most advanced level of neural networks. Modern researchers can design powerful specialized equipment with a large amount of data to perform machine learning. It creates more opportunities to train networks with dozens of hidden layers that are capable of hierarchical learning. In these models, simple concepts are learned at lower layers while more complex abstract patterns are performed at upper layers of the network. The most effective NNs are convolutional neural networks (CNN) which automatically memorize discriminatory patterns (filters) from images by sequentially superimposing convolutional layers on each other. In many applications, powerful image classifier and is currently responsible for advancing the modern level in the computer vision subfields that use machine learning [11, 12].

Machine learning algorithms are divided into two types: uncontrolled and semi-controlled. In a controlled case, CNN is provided with a set of inputs and target outputs. The algorithm then tries to learn patterns that can be used to automatically match the input data with their correct target output:
the machine learning algorithm tries to guess the correct answer, and in case of failure the teacher guides it to a more accurate guess. Thus, the goal of CNN in classifying images is to take sets of images and identify patterns that can be used to distinguish different classes of images (shapes of objects) from each other.

LeNet based on the Keras and Tensorflow frameworks was chosen for our project [11–13]. This network automatically memorizes discriminatory patterns (filters) from images by sequentially stacking convolutional layers on top of each other to get more accurate recognition accuracy. Each input image in the learning set is resized to 28 × 28 pixels and then passes through several hidden layers. So, the vector of objects has a length of 784 (28 × 28). This is the number of nodes in the input layer. Hidden layers are an uncontrolled limited Boltzmann machine where the output of each RBM in a hidden layer is used as input for the next [14].

The visible output layer contains the output probabilities for each class label. The output node that produces the highest probability is selected as a general classification. We can sort the output probabilities and select all the class labels that lie within a certain range close to the highest probability, so that we can find the most likely class labels and make soft decisions.

We tested images of several components on different types of models. To obtain data and subsequent results, we used the following image sample for the test: 5 photos of bottles (samples No. 1–5), 5 photos of cans (samples No. 6–10) and 5 photos of other objects (samples No. 11–15). The "%" columns indicate the percentage of network trust to its response. One of the models contained 6 classes: "PET bottles", "Cans", "Glass bottles", "Fire fraud", "Male hand" and "Other fraud". We assume that the recognition accuracy will be better, if we manually divide all possible objects into classes that are as diverse as possible.

Another option is to design paired models for LeNet CNN, each of which is trained in two classes: "PET bottles / not PET bottles" and "Cans / not cans" (Figure 2). We can run two Python scripts for the respective models at the same time and get results from the output layers. This type of recognition processing meets perfectly our goals: the developed RVM has two openings for PET bottles and cans, respectively. If we place PET into the can opening, it should be identified as an unacceptable fraud and removed.

![Figure 2](image.png)

**Figure 2.** "Cans – not cans" system

The next step was to improve efficiency by changing the visual qualities of the training sample: to increase contrast (can_c, pet_c), illumination (can_l, pet_l), clarity (can_s, pet_s). The test sample images were not modified.

Experiments with the training sample that recognizes cans showed that when image settings were changed, the result improved significantly. Since the main problems on the previous stages were related to the identification of cans, the resulting network could significantly improve the overall recognition efficiency of two-network system. The effect on the training sample in the network that
recognized bottles degraded the results. A similar test with a 6-class network also showed a decrease in the overall percentage of correct recognition.

Thus, the best network of the 6th grade is 6cl_56 (3 errors). To determine the best two-network system, combinations of errors have to be taken into account, since these networks will work simultaneously. Therefore, it is best to use the can_s and pet_56 networks. This dual LeNet application shows better results than LeNet from 6 classes on the same test samples (Table 2).

Table 2. Results of LeNet Testing with 2 Models

| Model name: | can_sharpen.model | pet_56.model |
|-------------|-------------------|-------------|
| Parameters  | Correct class %   | Correct class % |
| PET #1      | Correct 98        | Correct 91  |
| PET #2      | Correct 96        | Correct 76  |
| PET #3      | Correct 96        | Correct 69  |
| PET #4      | Correct 91        | Correct 67  |
| PET #5      | Correct 58        | Correct 99  |
| Cans #6     | Not correct 84    | Not correct 70 |
| Cans #7     | Not correct 99    | Correct 92  |
| Cans #8     | Correct 99        | Correct 64  |
| Cans #9     | Correct 88        | Correct 88  |
| Cans #10    | Correct 74        | Correct 58  |
| Other #11   | Correct 72        | Correct 98  |
| Other #12   | Correct 99        | Correct 99  |
| Other #13   | Correct 96        | Correct 98  |
| Other #14   | Correct 99        | Correct 98  |
| Other #15   | Correct 99        | Correct 98  |
| Correctness | 87%               | 93%         |

3. Recycling

The updated federal law No. 458-ФЗ delegates the responsibility to comply with the standards for waste management to industrial companies. They are accountable for the entire product life cycle, including its return, recycling and final disposal. However, the law does not stipulate how companies should fulfill their waste management obligations.

One option is when companies can independently recycle using their own infrastructure. If they choose this option, they have to collect, deliver, recycle the relevant waste; disclose information on waste collection points. Most of these waste management actions require a manufacturer or an importer to have a license.

Another option is when a manufacturer or an importer enters into a contract with a waste management operator or a regional recycling operator who will deal with specific wastes.

Under the existing waste management regulation, the implementation of manufacturer’s extended responsibility is hardly achievable. This is due to the contradictions in the legislation and other things. First, when a company concludes the contract with a regional operator, it transfers the waste ownership to them. But according to the law a producer is still responsible for waste disposal. In other words, a producer is responsible for something they do not own. Secondly, the environmental fee, which a manufacturer is obliged to pay, is included into the product cost. This is a consumer who pays this fee, not a manufacturer. In fact, a consumer when buying goods pays to the regional operator for both: waste from the use of goods and the negative impact on the environment.

We hope that the mentioned contradictions in the law will be resolved in the nearest future and our integrated solution will find the place in the waste management system. The machine for receiving containers will allow obeying the priority directions of state policy specified in Federal Law No. 89-ФЗ. RVMs are designed to collect aluminum cans and plastic bottles. There are two containers
for separate collection inside the machine. All the collected bottles and cans are transported to a workshop for sorting and recycling (WSP). The work can be divided into two stages (figure 3).

**Figure 3.** Processing of aluminum cans and plastic bottles

For aluminum cans:
1. Final sorting: removal of contamination (obtained there by mistake or with a can) from the sample for further processing (washing in a chemical bath, crushing and pressing in a special briquette);
2. Processing: aluminum cans are melted to produce metal for secondary production or sold in the form of pellets for other industries.

For PET bottles:
1. Final sorting: removal of contamination (got there by mistake or with a bottle) from the sample, washing in a chemical bath, sorting bottles by color and preparation for different purposes:
   1.1. Grinding and pressing in a special briquette;
   1.2. Cutting into tapes of fixed sizes;
2. Recycling: unlike aluminum cans, plastic is more versatile and can be used for many purposes:
   2.1. PET bottles are melted to obtain plastic mass for secondary production or sold as pellets for another secondary production;
   2.2. Melting of PET bottles with special additives for formation of high strength building blocks (these blocks are well suited for temporary construction);
   2.3. On a broaching machine tapes of a fixed size can be formed from either reinforced (for the production of enclosing mesh structures – fences) or unreinforced (for the production of various lines or wires) plastic beams;
   2.4. Plastic fibers the furniture and textile industry can be produced on a broaching machine at other settings;
   2.5. PET and PETG filament for 3D printers can be made from fixed-size tape.

Secondary raw materials can be reused e.g. to build and repair automatic machines for the reception of beverage containers (internal aluminum structures and plastic parts printed on a 3D printer). This approach can significantly improve the economic efficiency of the project.

0.5 liter bottles are often used in school canteens. The average weight of such a bottle is 28 grams. By cutting such a bottle into tapes of fixed sizes you can get up to 20 grams of material for
the production of PET yarn. A more sophisticated machine allows to get 28 grams by pulling the thread from the bottle molten mass (Table 3).

Table 3. Results of LeNet Testing with 2 Models

| Type of the machine             | 1 bottle (0.5 liters) weight | # of bottles to produce 1 kilogram |
|---------------------------------|------------------------------|-----------------------------------|
| Based on fixed-sized tapes      | ~ 20 g                       | ~ 50 bottles                      |
| Based on molten mass            | 28 g                         | ~ 36 bottles                      |

According to the survey, a buffet sells from 20 to 40 0.5 liter bottles every day. Half of the bottles sold can produce 1 kg of PET yarn in 2-5 working days. The average retail price of 1 kg of PET filament is 2,000 rubles. This amount of plastic is sufficient for printing 80 test ships (Figure 4) with a length of 60 mm (the weight of the printed model with a filling of 20% is 12.5 g).

4. Conclusion

The integrated solution proposed by the authors of the article can significantly improve the process of beverage container (aluminum cans and plastic bottles) collection and make it more efficient. This project is not able generate large profits due to the large investments in the RVM network, special workshops and logistics. However, this project can perform an important educational function by teaching residents to sort out waste. Other positive outcomes include visibility of the packaging collection offered by RVM – providing educational institutions with a thread for 3D printing, participation in municipal projects for the improvement of public services and amenities in the city (replacing old bus stops, building fences for individual construction and dangerous areas).

To date, the authors have already developed the machine and are building its first prototype. Trial placement of RVM in educational institutions and grocery supermarkets is going to be carried out in the nearest future, which will create public awareness of the project. Statistics will be collected on the results of the performance within first months, which will facilitate to evaluate the quantity and quality of beverage containers (aluminum cans and plastic bottles). Based on the obtained data, the specialization of the workshops will be determined.

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