Applying machine learning techniques to waste classification: development and analysis of a mobile application

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Abstract. Modern society is facing a large-scale problem of waste disposal, which is attracting more and more attention from both researchers and the public. According to the United States Environmental Protection Agency (US-EPA), the total generation of solid household waste in the world is about 2,924 million tons, which is approximately 1,2 kg per person per day. Using the hierarchy analysis method, an analysis of current commercial solutions was performed. As a result of a comparative analysis of applications, it was found that the model of the developed application surpasses the considered analogues according to the stated criteria.

1 Introduction

Modern society is facing a large-scale problem of waste disposal, which is attracting more and more attention from both researchers and the public. According to the United States Environmental Protection Agency (US-EPA), the total generation of solid household waste in the world is about 2,924 million tons, which is approximately 1,2 kg per person per day [1]. The disposal of these wastes is a key task for sustainable development and preservation of the ecological balance. Many governments and organizations are actively looking for solutions to reduce the negative impact of waste on the environment. According to information from the World Bank, the volume of municipal solid waste (MSW) produced by humankind annually exceeds 2 billion tons. The increase in the world's population, the transition of the economy to digitalization, an increase in the volume of waste, limited land resources and regulatory standards serve as the basis for the development of intelligent technologies in the field of collecting secondary raw materials.

The number of mobile applications is increasing every year, but only a few of them integrate advanced machine learning and computer vision technologies that simplify daily tasks. In light of the ever-increasing volume of waste produced by people every day, it becomes important to have an easy-to-use and useful mobile application that effectively helps in the rapid recognition and accurate classification of a variety of waste.

In recent years, the complexity of waste disposal has increased significantly due to the widespread use of disposable products widely used in various industries, from bottled water

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to disposable coffee cups. Materials such as Styrofoam, medical waste, light bulbs and plastic bags have become commonplace. The main incentive for effective waste management is the preservation of the ecological balance of the planet, which humanity has significantly disrupted over the past two centuries.

Improper waste management and environmental problems have a serious negative impact on the economy, human health and the environment, which has led to increased interest in creating «smart» cities for effective urban waste management. Waste recycling also stimulates research and development, contributing to a sustainable business model. There are concerns about the need to sort waste according to its biodegradability and non-decomposition. An effective classification of waste based on its biodegradability contributes to its proper disposal and recycling. The modern era requires the development of intelligent waste sorting systems, which is becoming the focus of attention of researchers and scientists around the world, in response to the mentioned environmental challenges.

Such waste includes a variety of items, from cans, bottles, disposable cups and bags to food, furniture and electronic components. Both hazardous and safe, as well as disposable and reusable items fall into the category of solid household waste. Fig. 1 shows the characteristics of waste categories and their percentage in the total amount of waste for 2022-2023 according to US-EPA statistics [1].

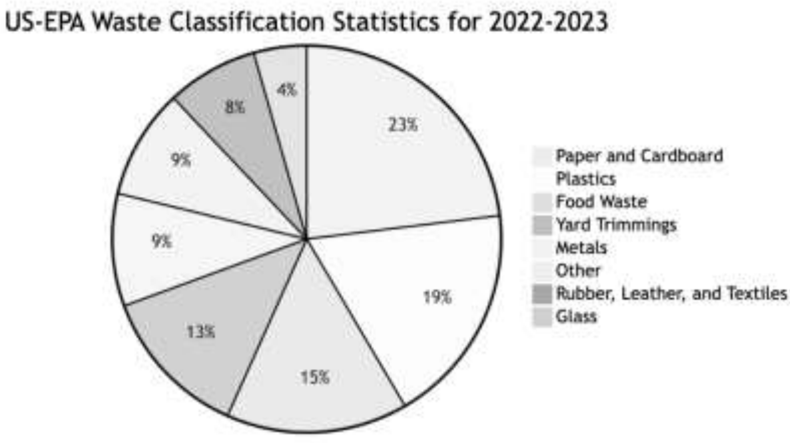

Fig. 1. Waste classification by type, according to the United States Environmental Protection Agency (US-EPA) 2022-2023.

Reducing human efforts and financial costs is at the center of automating the waste recycling process. The key element of such automation is the efficient separation of recyclable materials. One of the modern approaches to the classification of solid waste is the use of deep learning based on convolutional neural networks. Convolutional neural network is a deep learning model that is widely used to recognize objects in images [2]. The correct division and management of waste into categories, including recyclable, biodegradable, non-degradable, organic and hazardous, ensures their effective use and disposal. Computer vision offers cost-effective ways to recognize, classify and separate garbage in landfills. Modern advances in computer vision make it possible to sort waste using various object detection methods. The main goal is to replace manual labor in the waste sorting process with automated waste management systems. In these systems, waste will be determined using computer vision and classified using machine learning methods.

The paper describes waste treatment technologies such as: biogas plants, composting and plastic recycling, and the use of machine learning to optimize these processes.

The authors propose an application model that allows users to easily scan waste requiring disposal and follow the suggested instructions for their correct processing.

The application is a useful and convenient tool for the entire population of the globe, especially for residents of countries with strict waste classification standards. The developed system, capable of classifying different types of waste, was created for devices based on the iOS operating system, using the Core ML framework [3]. Core ML is optimized for performance on the device, which allows you to use the minimum required amount of memory and efficient power consumption of the model. The operation of the machine-learning model strictly on the device also ensures the security of user data, and the application works even in the absence of a network connection.

2 Materials and methods

The study used data from the Department of Nature Management and Environmental Protection of Moscow, as well as international sources such as the United States Environmental Protection Agency (US-EPA) and the World Bank.

Research and analysis of the problem: Assessment of the relevance of the waste classification task, learning of existing solutions and market alternatives. The analysis was conducted through a literature review and market data.

Developing a waste classification model: Creating and training a machine-learning model using a dataset containing images of various types of waste. Image augmentation and strategies to prevent overfitting of the model were carried out.

Mobile application integration and development: Development of the user interface of the mobile application for iOS, enabling the functions of uploading waste images and obtaining classification results. Integration of the model using Apple Core ML technology.

The waste image dataset used was taken from the platform Kaggle (waste_pictures) [4]. The dataset consists of photos of waste of various categories in different places. The dataset contains 17,872 images of waste from 34 classes ('bandaid'; 'battery'; 'bowlsanddishes'; 'bread'; 'bulb'; 'cans'; 'carton'; 'chopsticks'; 'cigarettebutt'; 'diapers'; 'facialmask'; 'glassbottle'; 'leaflet'; 'leftovers'; 'medicinebottle'; 'milkbox'; 'nailpolishbottle'; 'napkin'; 'newspaper'; 'nut'; 'penholder'; 'pesticidebottle'; 'plasticbag'; 'plasticbottle'; 'plasticene'; 'rag'; 'tabletcapsule'; 'thermometer'; 'toothbrush'; 'toothpastetube'; 'toothpick'; 'traditionalChinesemedicine'; 'watermelonrind'; 'XLight'). Each class contains from 34 to 934 images.

During the development of the application, a comparative analysis was carried out with analogues available in App Store – Deep Waste AI [5] and Recyclist [6].

Each application under consideration has its advantages and disadvantages, in order to choose the best mobile application for classifying recyclable waste, we use the hierarchy analysis method [7-8]. (**Table 1**).

Table 1. Comparison criteria

Goal	**Choosing the best mobile app for classifying recyclable waste**
Criterias	K1 – Number of waste categories
	K2 – Variety of disposal recommendations
	K3 – Application Size
	K4 – Classification speed
	K5 – Russian language support
	K6 – Availability of additional functions
Applications for	A1 - waste

classification of recyclable waste	A2 - Deep Waste AI
	A3 - Recyclist

3 Results

The main results of the study show that the use of machine learning and computer vision technologies allows not only to classify waste, but also to optimize its recycling processes. The developed mobile application promotes the generation of resources from waste, contributing to the transition to a cyclical economy. Research in the sphere of analyzing the role of information technology for waste classification through the prism of machine learning (development of a mobile application for waste classification) to following key results: When comparing the waste application proposed by the authors with two analogues available in the App Store – Deep Waste AI and Recyclist, the following results were obtained.

The developed waste mobile application has similar functions, providing the user with the opportunity to classify recyclable waste based on their visual analysis. With its help, you can easily determine the type of waste and get information about proper disposal. A special feature of waste is its intuitive interface and high classification accuracy due to the use of its own machine-learning model based on the framework Core ML.

Table 2 is a matrix of priorities for three different applications, which are considered in terms of six criteria. Each criteria has its own weight, reflecting its relative importance in making a decision. Application scores for each criterion are presented as numbers from 0 to 1, where closer to 1 means a higher score.

Table 2. Global Priority Calculation

Criterias	K1 – Number of waste categories	K1 – Number of waste categories	K1 – Number of waste categories	K1 – Number of waste categories	K1 – Number of waste categories	K1 – Number of waste categories	Global priority
Weights of criteria	0.09	0.06	0.16	0.41	0.24	0.04	
A1 - waste	0.63	0.30	0.79	0.64	0.31	0.08	0.5371117
A2 - Deep Waste AI	0.06	0.06	0.07	0.31	0.05	0.77	0.18496705
A3 - Recyclist	0.30	0.63	0.15	0.05	0.64	0.16	0.26963228

The calculation of priority is calculated for each alternative and consists of the sum of the normalized indicators multiplied by the coefficient of this indicator (Table 2). The developed «waste» application is recognized as the best, which received the highest global priority value based on the calculation results, is recognized as the best. Fig. 2 shows a graphical representation of the calculation results.

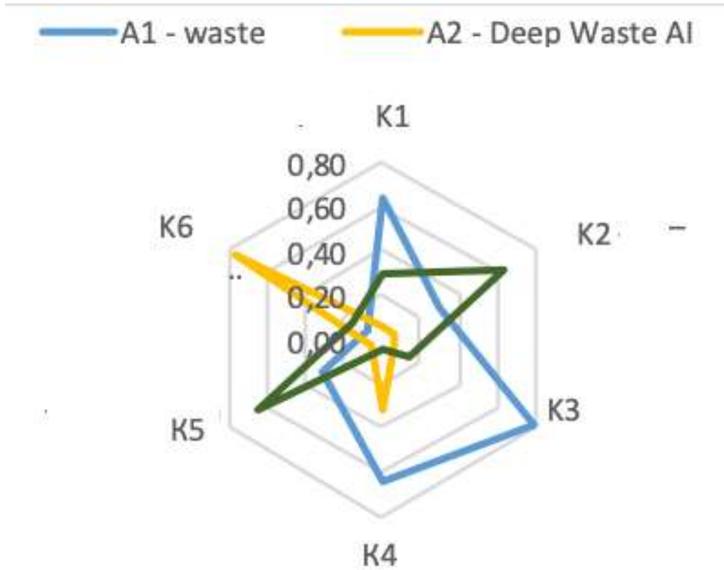

Fig. 2. Graphical representation of the results of comparing alternatives to mobile applications for waste classification using the hierarchy analysis method

As a result of the analysis of the comparison of analogues according to the specified criteria, it can be concluded that the A1 (waste) Application has a high score according to the K1 (Number of waste categories) and K4 (Classification rate) criteria, which makes it a strong option for processing a large volume of diverse waste with high accuracy and speed. It also has good support for the Russian language (K5) and an average application size (K3). However, the ratings for K2 (A variety of disposal recommendations) and K6 (Availability of additional functions) are lower, which may indicate more limited capabilities compared to other applications. The A2 (Deep Waste AI) application has the highest score in K4 (Classification Speed) and K6 (Availability of additional functions). This makes it a good option for users looking for high-speed waste classification and additional features. However, estimates for other criteria are significantly lower, especially for K1 (Number of waste categories) and K3 (Application size), which indicates limitations in waste categories and the possible large size of the application. Russian Russian Language Support A3 (Recyclist) application has high ratings for K2 (A variety of recycling recommendations) and K5 (Russian language Support), which makes it attractive to users looking for a wide range of recommendations and support for the Russian language. In addition, it has strong ratings for K3 (Application size) and K6 (Availability of additional functions). However, the estimates for K1 (Number of waste categories) and K4 (Classification Rate) are significantly lower, which may indicate limitations in processing a large number of waste categories and classification speed.

Based on the data obtained, it can be concluded that the A1 (waste) application has the highest global priority with an estimate of 0.5371117. This means that, taking into account all the criteria, the waste application has the highest overall rating and is probably the best choice among the applications under consideration. It is followed by Appendix A3 (Recyclist) with a score of 0.26963228, which indicates its relatively good performance. Application A2 (Dee Waste AI) has the lowest global priority with a score of 0.18496705, which indicates its lower attractiveness compared to other applications. It is important to note that an application with a lower global priority is not necessarily bad or inefficient. The choice of the application depends on the individual needs and preferences of the user. The developed application is the best among analogues for the stated criterias.

4 Conclusions

Using the hierarchy analysis method, an analysis of current commercial solutions was performed.

Based on the analyzed data, it can be concluded that the A1 (waste) application occupies a leading position with a global priority rating of 0.5371117. This implies that, taking all the criterias, the waste application has the highest overall rating, which makes it the most preferred option among the analyzed applications. Next comes the A3 (Recyclist) application with a rating of 0.26963228, reflecting its relatively high characteristics. The A2 (Deep Waste AI) application with a rating of 0.18496705 has the lowest global priority, which indicates its lower attractiveness compared to other applications. Note that the lower rating of the application does not mean its inefficiency or poor quality. The choice of the application depends on the unique requirements and preferences of the user. In this context, the model of the developed application surpasses the considered analogues according to the stated criterias.

These results highlight the potential and effectiveness of the developed application in the context of waste classification, and highlight the importance of using appropriate machine learning and data processing techniques to achieve sustainable development goals.

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