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Utilizing digital technologies for waste management

Aziz Sadinov[1] *and *Sherzod* Rajabov[1]

[1]Tashkent State University of Economics, Islam Karimov street, 49, 100066, Tashkent, Uzbekistan

Abstract. This article is aimed at applying a new mechanism for improving an automated control system through methods for creating useful products from waste and developing innovative projects in a digital economy.

1 Introduction

The world's growing population, urbanization and changes in lifestyles are generating an unprecedented amount of waste in the world, for example in 2016 there was 2.01 billion tonnes waste generated globally [1]. Waste management is not only a problem in developing countries, but also in developed countries. Waste management has a direct impact on people's lifestyles and well-being, the environment, and many other industries. Current waste management methods are not advanced enough to achieve an efficient and sustainable waste management chain. For this reason, the waste management chain needs new, innovative, and smart solutions to reduce the amount of waste generated and to improve recycling, making the chain more efficient and significantly more environmentally friendly [2].

The goal of this report is to find ways to utilize robotization, automatization, artificial intelligence, and other digital technologies for waste management. The focus is on finding front line solutions, i.e., digital technologies that are approximately no older than five to ten years old and have the possibility to improve waste management, sustainability, and circular economies. The topic of the work has been formatted based on the AWARE (Against Waste: Activate Research & Education) project, which aims to raise public awareness of the economic potential of recyclable waste and the serious environmental threats in the region of Saint Petersburg and Leningrad [3].

2 Background on digital technologies

This section presents the theoretical background for the digital technologies on which the solutions considered in this work are based on. The chapter covers artificial intelligence and machine learning as well as the Internet of Things. In addition, the chapter introduces the concept of smart city and its key features.

* Corresponding author: azizsadinov@gmail.com

One of the best-known ways to take advantage of weak artificial intelligence is to set the machine to learn directly from the data provided - this is known as machine learning. The concept was defined as early as 1959, when Arthur Samuel described machine learning as a field of research that allows a machine to learn without having to be explicitly programmed for a specific task (Wall 2018). Machine learning can be more precisely defined as the field of computer science, in which operating methods are studied, i.e., algorithms and techniques that can be used to automate the handling of complex problems that are difficult to solve with traditional programming methods. Traditionally, there is a need to create a detailed plan for the program first, which tells what the program is expected to do. After that, the plan should be turned into a working program in a language the computer can understand. In practice, such an approach can be quite challenging despite a clear plan. In machine learning, on the other hand, algorithms do not need a detailed plan, as they learn from a given training data that illustrates the operation of the program using examples. The problem solving of these algorithms is based on an indirect method in which they aim to create a model from the given training data that they can also utilize in processing the new data. The accuracy of machine-learning algorithms depends on the size of the given training data, as the larger the amount of data used in a training situation, the more accurate the algorithms will give [4]. Additionally, the skills of people implementing machine learning algorithms affect the accuracy of the solutions as choosing the right algorithm to train has significant effects on the accuracy.

3 Internet of things

Internet of Things, IoT, refers to digital devices, technologies, and software that each have their own identity and are connected to the Internet. With an Internet connection, devices can exchange information with each other and with different systems without human having to be involved in the process [5, 6]. If IoT is properly used, it can help decrease the amount of waste and support sustainability things are connected to the Internet and to make informed decisions. With IoT, it is possible to control devices from anywhere in the world, the only requirement being that the device and both the controller are connected to the Internet. IoT can be used in Smart City, for example, to monitor energy consumption, for example. However, this work examines how IoT can be used, for example, in smart bins to monitor their occupancy rate wirelessly.

4 Smart city

The concept of smart city has different meaning depending on whether it is from human or technology perspective. The reason for this is the different goals and perspective of countries when they set the goal of creating smart cities. In other words, a precise definition of smart city has not yet been created, and it is difficult to define a standard, a globally used meaning for its concept. [7] Intelligence in an urban context refers to the ability to learn from previously collected data and thus make better decisions and get better results. So, cities can become smarter when they intelligently integrate city events and data in one integrated solution [8].

Caragliu et al. [9] discuss that city performance is a synthesis of physical infrastructure as well as social infrastructure. According to them, human and social capital are crucial factors for urban competitiveness. They believe the city is smart when investing in human and social capital, traditional (transport) and modern (information and communication) communication infrastructure, promotes sustainable economic growth, a high quality of life and wise management of natural resources through inclusive governance. From the human capital perspective, it is important understand what motivates people to engage in a variety of activities that are important for a cleaner, safer, and more socially friendly environment. [10] Smart city can also be seen as a solution for responding in a timely manner, facilitating services, and improving the quality of city life. This is based on smart devices around the city that can monitor the urban environment in real time, respond in a timely manner, and collect data for intelligent decision making. [11] According to Kitchin [12], a smart city is a city that monitors and integrates all its critical infrastructures, such as roads, bridges, tunnels, and electricity and water networks. In this way, it is possible to better.

5 Household waste

In 2018, household waste accounted for 8.2% of all waste in the EU Although the share of household waste in total waste is small, new solutions are needed for its processing and management. (Eurostat 2021) Urbanization, the circular economy, climate change and people's expectations all influence the introduction of digitalisation in waste management [13]. While it may be generally thought that when we talk about household waste, we only mean how households produce and can regulate their own waste production, it is also necessary to look at what kind of innovation has taken place before the products reach consumers. Also, the supply chain of the products should be considered, because the journey between factory and households can produce a lot of emissions, especially now during the Covid-19 pandemic, when the amount of online shopping has increased significantly [14].

The development of products and materials can have a significant impact on the amount of waste that will become waste in the future, for example in terms of recyclability and recyclability [15]. The problem, however, is that product designers may not have any knowledge of which material choices would best support recyclability and how the products themselves can be made as recyclable as possible. However, this could be remedied by providing information to manufacturers in digital form. For example, AI can also help design better products using historical and real-time data, which then can be used to make the products even better and more recyclable [16]. Also, some universities offer courses in sustainable choices. In addition, legislation, for example, can influence how well products can be recycled or how much packaging materials each company uses. [17] According to studies carried out in five European countries (Italy, Belgium, Netherlands, Germany, and France), packaging materials and paper waste account for 40-65% of the total cost of waste treatment and collection.

6 Packaging waste product design solutions

The University of Göttingen has developed a new material made of popcorn to replace Styrofoam as an insulator. The material can also be used to replace the use of Styrofoam as a packaging material. The advantage of the material is that it is completely biodegradable and non-toxic, so that it can even be fed to animals as feed after use. Styrofoam is a plastic-based material and generates a huge amount of waste in packaging use, while the use of a popcorn-based material facilitates recycling and reduces carbon dioxide emissions. Another advantage of the material made of popcorn is that it is also fire resistant [18, 19].

7 Different types of innovations for managing the household waste

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There has been introduced many different innovations that help managing and reducing the household waste. Some of the methods that are being introduced next require a lot of capital and planning whereas some of the innovations and technologies could be implemented quickly anywhere in the world.

8 Automated vacuum collection

An automated vacuum collection system has been developed [20]. The system works by collecting different household waste on the street at a specific pick-up location in sacks of different colors. The underground piping system sucks the garbage bags into a central location where waste is easy to collect. Waste can be tracked using RFID tags as well as a scale, providing fully real-time data on waste volumes. According to the manufacturer, this innovation will make it possible to change consumer behavior and improve the recycling rate.

This system allows waste to be retrieved centrally from a single location and areas do not need to be designed to accommodate all large areas for rubbish and garbage trucks. In addition, the amount of waste can be reduced when people see in real time how much waste

This system is already in use in about 600 different places in the world and affects the daily lives of 3 million people. The advantage of the system is that it uses existing technologies that have been proven to be good and reliable, so that its operation can be assumed to be certain. This kind of systems can be especially beneficial in countries where space is limited, and population density is very high. Many cities in Asian countries fall in this category.

9 AI chatbot service

Today, there are also various artificial intelligence-assisted chat bots that city residents can ask about, for example, waste sorting. (Berg et al. 2020, p. 32) For example, an image can be sent to the system stating where the product in question should be sorted, and it can be used to show residents frequently asked questions and answers to them. The biggest advantage of the system is that it significantly improves waste sorting by raising public awareness if the system is well received by residents. In addition, artificial intelligence solutions can be developed so that they continuously learn to better identify different waste types. The downside, however, is that not everyone wants to contact a customer service representative who is just a robot. There has also been a problem in some places that decision-makers in waste companies fear that contact with customers will be lost when robotic servers are used.

10 Household waste management using smart dust bins

Dubey et al. (2020) have designed a waste collection system for households and residential areas that utilizes the Internet of Things and artificial intelligence for waste sorting. The solution proposed by the researchers is in two stages: the first stage involves the collection of waste from individual households and the second stage involves the sorting and treatment of waste at community / residential level. Artificial intelligence is used in the solution to generate various alarms by monitoring data from three different sensors, such as the amount of biowaste and mixed waste and the concentration of hazardous gases in the waste container. (Dubey et al. 2020, p. 1950)

In the first phase, household bio-waste and mixed waste are collected separately, and in the second phase, artificial intelligence is used to separate the different types of waste from

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mixed waste. In the second stage, biowaste is also composted. The process works so that the waste bin detects when someone is approaching it and opens the door automatically. Once the waste has been placed in the container, the user presses either the red or green button, depending on whether the user puts mixed waste or biowaste in the container. According to the user's choice, the device rotates the drum inside so that the waste goes to either a bio-waste container or a mixed waste container. If toxic gases are detected in the container or it is full up to a certain point, a message will be sent to the waste container manager. The container is then moved to be emptied and once emptied, returned to its place. (Dubey et al. 2020, pp. 1953-1954).

In the second stage, the biowaste and mixed waste are separated and the biowaste is composted together with the leaves, etc. collected from the green areas of the residential areas. Metals, plastics and wood and the rest of the waste are separated from the mixed waste, leaving only the waste that cannot be separated by the system. The separation of metals is handled by means of induction sensors and the separation of plastic and wood is handled by means of capacitance sensors. When the amount of waste that cannot be further separated rises to 90%, it will be notified to the waste facility and will be emptied. The accuracy of the machine learning model developed was 93.3 percent and the system allows waste to be separated as close to the point of origin as possible. (Dubey et al. 2020, pp. 1954, 1958) This could also be accomplished by pre-using different containers for different wastes, but such a system is much easier for residents when only biowaste must be separated from other wastes separately. In addition, this system allows the waste facility to be notified when it is time to empty the waste bins, so that the emptying routes can be optimized as well as possible without unnecessary driving.

11 Household electronic waste collection system using IoT

Electronic waste is one of the fastest growing types of waste, and electronic waste, especially generated by households, only 40% of that waste has been recycled in the EU. (European Parliament 2020). Most electronic waste is generated in Asia. Kang et al. (2020) investigate how the recycling of household electronic waste in Malaysia can be improved through smart electronic waste management systems. The solution has been sought by offering customers collection boxes with mobile application and data server systems for bringing mobile phones and other small waste and attaching smart features to them via the Internet. Mobile phone applications make it easy to provide people with recycling instructions for different products to increase recycling activity, and RFID tags and scales can be used to inform service providers that a collection container is filling up (Satyamanikanta & Naraynan. Proposed solution from Kang et al. (2020), however, was as follows: the collection boxes include an ultrasonic sensor, an Arduino circuit board, and a Wi-Fi module. With the help of these three components, it is possible to determine the filling level of the collection container and information about the filling levels of the different containers goes to the cloud database. In Figure 1 is illustrated how the waste e-waste disposal process works. By default, the collection box is in sleep mode and can be activated for five minutes by reading the QR code, and at the same time you can be sure that the user is throwing electronic waste into the box and nothing else. Once the QR code has been read, the box will get wake-up signal from the server and its ultrasonic sensor checks every three seconds what level the surface of the collection box is at and forwards the information to the server. The system runs until the sensor detects that the distance from the surface of the container has changed, i.e., the user has thrown electronic waste into the container or until the five-minute threshold has been reached. When the system was tested, the cost of all components was about $ 37.59 and the energy cost of one collection box is about $ 0.7 per month (Kang et al. 2020, p. 4)

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The mobile application and the Wi-Fi module are connected to the cloud database. When the container is 80% full, the system sends an e-mail message to the container emptying party, allowing the container emptying route to be optimized. With the help of the mobile application, the system is activated, but it also allows the user to find, for example, the nearest collection point. To use the system, users must be registered and logged in to the service. When a user then wants to recycle electronic waste, the user uploads a picture of it into application and selects what is being recycled. This can also be used to monitor how well people know how to recycle and that waste that does not belong there is not put in the bins. To get people to use such smart apps, in Malaysia the app was gamified. Each time.

12 Organizational waste

Nowadays, many organizations are striving to find more environmentally friendly and efficient solutions for waste management, as both various environmental laws and directives and organizations' stakeholders create social pressure to look for less environmentally burdensome solutions in the organizations' operations. Thus, this chapter of the report looks at how different organizations such as companies and universities are using advanced digital technologies as a part of their waste management (Figure 2).

13 Construction industry

According to Ali et al. (2019), the construction industry accounts for 35% of the world's waste and being the most common source of solid waste. The industry is a major user of natural resources, and it is not possible to make full use of these resources, which generates so-called construction waste.

Fig. 1. Heavy Picker by ZenRobotics. 1. Sensors 2. Control unit 3. Industrial robot 4. Recovered fractions (Lukka et al. 2014).

There are several impacts and benefits to utilizing robotics in CND waste sorting. Lukka et al. (2014) state that robotics is feasible for waste sorting and mention that robotics can significantly reduce costs for companies, as the amount of manual work is reduced and the work cycle can be increased from, for example, two-shift to three-shift work, which also improves overall efficiency. In addition, they mention that once robotics is established, waste management can be optimized around robotics, which improves the functionality and automation of processes. Ahmed & Asadullah (2020) emphasize the ability of robots to constantly learn new things and adapt to the new environment. The robot improves performance, quality and provides reliable and consistent results for the job. In addition, they mention that robotics is a major security enhancer as waste streams, conveyors and various waste handling equipment create an environment where working is dangerous and can cause health hazards.

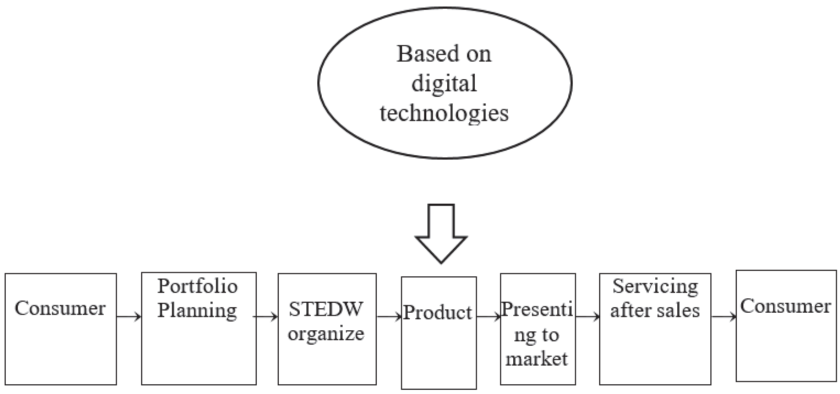

Fig. 2. STEDW process management mechanism.

14 Smart bins in organizations

The increased use of Internet of Things (IoT) technologies and devices has brought new opportunities to improve waste management (Cao et al. 2020). Several studies have presented IoT-based systems that improve sustainability and enable individuals and organizations to improve waste management. In this section, the work goes through IoT-based smart bin solutions that have been utilized by different organizations such as universities in their campus areas.

Cao et al. have developed a system called ZotBins that consists of intelligent waste bins and associated sensors that allow the system to collect and monitor data regarding waste collection. The system is built of three modules, which are 1) sensors and controller, 2) waste recognition framework and 3) user applications (Figure 3). First, the system has three sensors that measure the weight of the waste in the bins, the degree of filling of the bins (implemented with an ultrasonic sensor), the utilization of the waste bins (implemented with a break beam sensor) and a camera that stores images of the waste as training data for later use. Second, the waste recognition framework uses a barcode number to scan the product and a camera connected with convolutional neural network to identify the type of waste. Once the waste has been identified, the system can retrieve the corresponding disposal instructions from a specific database. Third, three user applications are available to support the use of ZotBins. One app supports the work of facilities management staff by allowing them to view bins' locations, statuses, and various related trends. Another application is a mobile application designed to support users in disposing of waste by showing, for example, disposal instructions and telling where the nearest trash bin is. The third application is a digital information board that is connected to the bins and conveys educational information about waste management (Cao et al. 2020).

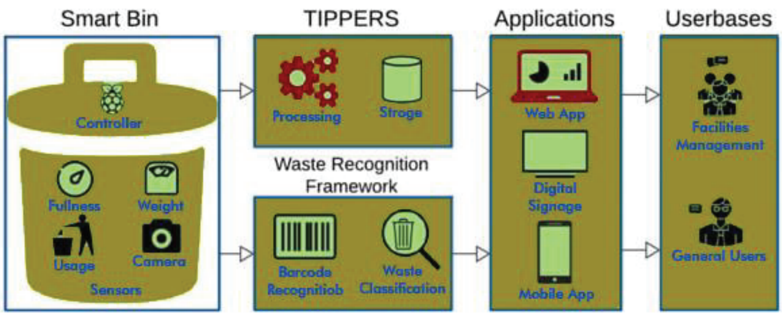

Fig. 3. Data flow in ZotBins system (Cao et al. 2020).

Similar research has been done by Anh Khoa et al. They have developed a waste management system that utilizes IoT and machine learning. The system consists of smart bins placed at the university, which are equipped with an ultrasonic sensor capable of measuring data about the volume and weight of the waste thrown in the bin. The sensor communicates with a server that collects data from the sensor, processes it, and uploads it to a server in the cloud. The cloud server communicates with a mobile application, which receives the data from the cloud, processes it, and creates visual information from the data. By applying machine learning and logistic regression to the data collected from the sensor, researchers have succeeded in modeling the probability of the need to empty the bin depending on the number of lectures given at the university on certain day. In addition, the algorithm operating in the system is able to create a model of the optimal waste collection order and path, taking into account the filling level of the bins, and present in on a mobile application. (Anh Khoa et al. 2020)

Kang et al. have further described the user interfaces in the context of IoT smart bin by developing a mobile application to facilitate electronic waste management. The mobile application acts as the main interface in the waste management process. The user creates an account and logs in to the application.

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