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Implementation of Automated Lines for Sorting and Recycling Household Waste as an Important Goal of Environmental Protection

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Abstract:

The principles of selection and creation of rational methods of disposal and recycling of wastes are based on the fact that the problem of waste is an interconnected environmental-economic and technological problem, and the waste itself should be considered as technogenic raw materials of complex organo-mineral composition. Therefore, the main purpose of the work is to define methods for recycling waste and their environmental aspects. To achieve this goal, the methods of analysis, spectroscopy were used. It is determined that the final treatment of waste, to date, means either their disposal in a landfill or incineration, which adversely affects the environment. Methods for identifying the material of the object, as well as algorithms for the selection and recognition of objects by processing data from the computer vision system are considered. High accuracy is shown in 94.12% identification of plastic polymers.

Keywords: plastic polymers; material oxidation; waste management; environmental standards.

JEL Classification: Q20, Q50.

Introduction

The economy of most countries is based on the use of minerals and other natural resources as primary raw materials. In fact, what was created by nature during geological eras, i.e. over millions of years, it has been consumed over several decades, transforming in a short time into solid, liquid and gaseous wastes that pollute the environment (Chadès et al. 2017; Schwarzböck et al. 2016).

Uncontrolled and ill-considered waste management can lead to serious environmental consequences and poses a threat to the very basis of human existence (Hoag et al. 2018). The issue of recycling household waste recently arises in the world more and more often. The problem of complete destruction or partial utilization of household garbage is relevant, first of all, from the point of view of the negative impact on the environment. For any city and settlement, the problem of disposal or neutralization of solid household waste is always primarily an environmental problem.

The market currently presents two main types of complexes for the sorting of municipal solid waste: automated and using manual sorting (Hooper et al. 2017). The division into automated and manual ones is conditional here, since in both cases, manual labor is used, but at different scales. The main difference is the use of manual sorting at the stage of selection of useful fractions (paper / cardboard, plastic, wood, textiles, glass, metals), which can be recycled and are valuable in terms of profit and the possibility of building a business in the field of solid waste sorting (Paulraj et al. 2016; Bakirova 2011).

Waste treatment is based on changes in the physicochemical characteristics of the waste prepared for use as a fuel (Zhenikhov 2013). For example, the grinding of waste (using crushers, shredders) can be carried out to obtain the required particle size (Rigamonti et al. 2016; Sarra et al. 2017). Another example is the separation of impurities by mechanical processing and grinding. Fuel output may vary due to humidity and ash (Ferrarini et al. 2015; Kiziloz and Kupatadze 2015; Patriota et al. 2016; Nuñez-Hernandez et al. 2017; Costa and Rocha 2017).

The sorting lines on the market have an identical design: a conveyor belt, to which waste distributed in one layer is fed. Above the tape is an optical system that recognizes the substances that make up the waste elements. At the end of the conveyor belt, air nozzles are installed, transporting the recognized waste elements to different containers using a stream of compressed air (Wienke et al. 1996; Rinnan et al. 2009).

1. Material and Methods

The key parameter for successful recognition of a substance is the signal-to-noise ratio received by the receiver of the sum signal. The following factors significantly affect this parameter:

- Stickers on the bottles. The thickness of the walls of various plastic containers is usually about 0.3 mm and the radiation of the near infrared range (NIR) penetrates through, forming a high-quality reflected signal. Stickers, often made from another material, have a thickness of 0.01-0.02 mm. The radiation passes through them, with the result that the reflected signal is a mixture of signals from the sticker and from the container itself. This mixture can vary greatly in proportions, depending on how tightly the label fits to the surface of the container. For reliable recognition of materials in such cases, requires a high signal-to-noise ratio and special processing algorithms that allow you to select a useful signal.
- Multilayer bottle walls. The next factor – the multilayer walls of the bottles, has a much greater impact on the quality of recognition of substances. In the manufacture of containers with multilayer walls, polyamide sheets placed between two PET layers are most often used. The peculiarity is that these sheets have a thickness of 0.02 mm and are under the surface of the material. A similar factor is the use of mixtures of two different polymers for the manufacture of containers. Both cases are extremely difficult to recognize and at the moment there is no industrial technology for sorting such materials that provides an acceptable result.
- Plastic films. Films are the main area in which it is possible to achieve higher levels of recycling. The most commonly used materials for their manufacture are polyethylene, polypropylene and polyvinyl chloride. The thickness of the films is usually from 10 microns to 15 microns and most often they are folded and dirty. Polymer films are sorted in two stages, first the films themselves are separated from the total waste stream, and then separated by substances: polypropylene and polyvinyl chloride should be separated from polyethylene. Since these materials are very light, to ensure high sorting performance, they need special sorting lines. For example, films should be distributed over a very large area of the conveyor and pressed against its surface by a stream of air.
- Biological waste. Organic or food waste is not the scope of NIR-sorting methods. Water in large quantities is part of the organic, actively absorbs infrared radiation. Therefore, the analysis of such objects as vegetables or fruits, with a water content of more than 50% is difficult. To ensure IR transparency, the food industry uses

another part of the near infrared range: from 700nm to 1100nm. At the same time, for the further processing of organic waste in bioreactors and methane production, low content of paper in them is necessary.

- Paper. Mostly paper is made from cellulose, but other formulations are also found. Different types of paper differ in the content of lignin (in the mechanical, or chemical processing of raw materials for paper production), the content of fillers (waxing, changing the brightness and color of the paper in the mass), as well as the content of surface dyes and inks. For example, oil inks for offset printing, or water-based for flexographic printing.
- The tree. Wood has the same chemical composition and must be separated from the paper. Moreover, natural wood is more valuable than processed wood, which includes components such as varnishes, paints and adhesives.

In this area, the most popular method is spectroscopy. Spectroscopy is the science of the interaction of electromagnetic radiation with various substances. In this method, there are several main areas (Ball 2001):

- optical spectroscopy (OS);
- infrared spectroscopy (IR);
- ultraviolet spectroscopy (UFS);
- terahertz spectroscopy (THzS);

Since in the near infrared region the most powerful radiation in the infrared range, this method is suitable for the analysis of complex organic molecules. The radiation source is usually a halogen lamp with a tungsten filament.

2. Results and Discussion

2.1 Features of waste management in the world

Waste generation is a serious environmental issue. For example, overseas landfills and landfills do not attach serious importance, since they are considered as temporary measures before the construction of industrial enterprises for their processing. For example, in Japan, landfills and landfills are eliminated (Formalev *et al.* 2015; Formalev *et al.* 2017). All household waste is neutralized and disposed of at specialized enterprises. In Russia, solid household waste is mainly stored in country landfills. It has been established that no European country recycles as much waste as Germany. In Germany, the share of garbage return to the net turnover is 66 percent, while the average for Europe is 46 percent.

According to the study, Austria, Belgium and the Netherlands are also among the leaders in waste recycling in Europe: in these countries the share of waste collection is more than 50%. In the middle of the ranking are Sweden (48.9%), France (41.7%) and Spain (29.7%). The list closes the list of Greece and Romania – here for recycling send 17% and 13.3% of waste, respectively. At the same time, Malta has the worst performance: the share of garbage collection in the country is only 7.1% (Kunychka *et al.* 2017). For example, the recycling of household waste in Germany is presented in Table 1.

Table 1 - Recycling of raw materials from household waste in Germany

Material	1991	2013	2014	2015	2016
Tin-plate	34%	97%	96%	93%	93%
Aluminum	5%	91%	89%	88%	88%
Glass	54%	90%	91%	86%	86%
Paper	28%	81%	82%	81%	81%
Plastics	3%	56%	58%	52%	53%

Source: Formalev *et al.* 2018

The main method of waste disposal in Russia is burial. About 92% of waste is disposed of at specialized landfills and dumps, where it is simply buried in the ground, thereby getting rid of raw materials suitable for recycling, and only about 8% of the waste is recycled and incinerated.

The area of landfills and landfills for waste disposal has already reached 107 thousand hectares, while it is increasing annually by 2.5 – 4 percent, and the area of disturbed lands has already exceeded 1 million hectares. The identified landfills are located in the zone of settlements (58%), in water protection zones (16%), on agricultural land (15%) and forest land – (8%). The shortage of polygons is observed in 45% of the subjects of the Russian Federation, but in fact this value is even higher (Gordetsov 2010).

Currently, the absolute leaders in the number of unauthorized dumps are the Central and North-West federal districts, in which the rates of accumulation of solid waste per capita are among the lowest in the country: 285 kg / person. year and 235 kg / person. year, respectively, while the average rate in Russia is 310 kg / person. year.

The practice of waste disposal at landfills is applied in other countries. For example, in the UK 90% of waste is exported to landfills, more than 60% in the USA, and 97 percent in the CIS. However, in foreign countries the problem of waste disposal is solved at the state level. In many countries, the disposal of waste at landfills is permissible only in cases where none of the known technologies can handle them. For example, in the Netherlands such a rule has been in effect since 1997.

In Europe, the principle of preventing or minimizing the generation of waste through the introduction of low-waste technologies is applied. And this is a direct savings in waste management activities. One of the ways to solve the problem of waste treatment is the organization of an effective system of separate collection and recycling of waste, as is done in Europe, where up to 50% of waste is processed.

The situation is completely different in the leading European countries. For example, in Sweden the proportion of waste disposed is less than 3%, while the rest is recycled in accordance with the highest environmental standards and norms (Figure 1).

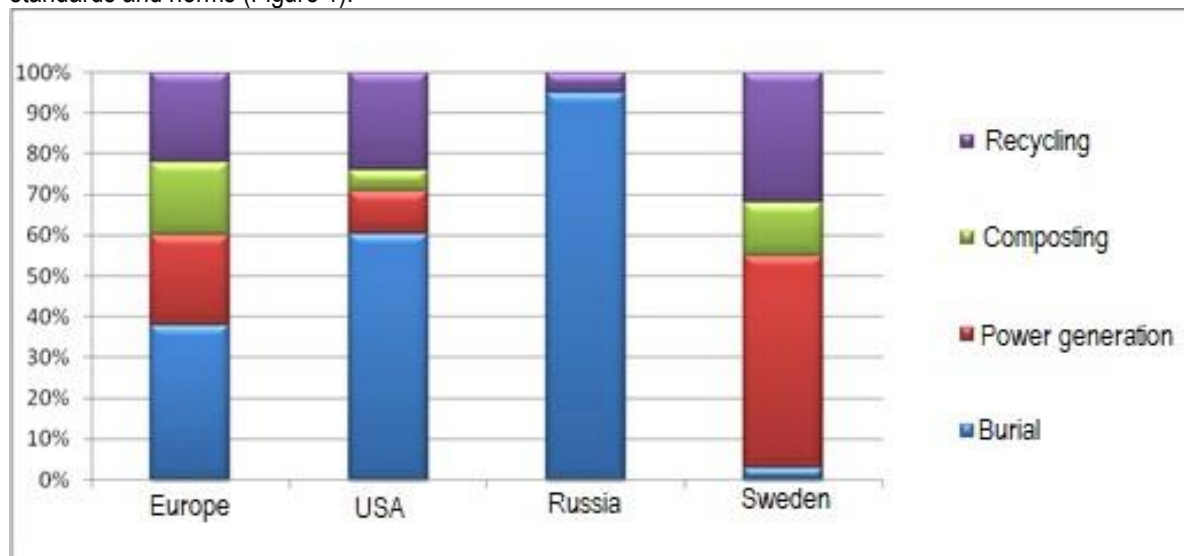


Figure 1 - The structure of waste management in Russia and foreign countries

In many ways, such striking differences between countries are explained, on the one hand, by the lack of national infrastructure and technological backwardness of Russian waste disposal enterprises, on the other hand, by the strong backlog of Russia from leading countries in terms of legislative regulation of waste treatment and secondary resources. The ecology of Chinese cities is under threat. Environmentalists are sounding the alarm, as about two thirds of Chinese cities "have taken in a blockade" heaps of garbage. According to experts, approximately 6 billion tons of household garbage has accumulated in the cities of the country for 20 thousand hectares of land, and this "mountain" is growing by 4.8 percent per year. Waste not only fills the places that can be used for agricultural purposes, but also contribute to environmental pollution.

The severity of the impact of the treatment and disposal of waste on the environment depends on the volume of waste produced, their composition, the amount of illegally disposed waste, the amount of waste disposed at the landfill and standards in waste treatment plants. The future impact of the waste management process will depend on how these factors change. Final waste treatment, today, means either their burial in a landfill, or incineration, and these two types of final treatment have a different, but in both cases a negative, environmental impact. When burning different types of garbage, harmful gases appear. Placing waste in landfills leads to the release of methane, one of the greenhouse gases and hazardous chemicals that have a harmful effect on the environment.

Incineration of waste leads to the release of gases from the pipes of the plants burning them. These gases contain hazardous chemicals such as cadmium, mercury and lead. The toxicity of heavy metals when they are isolated on a warm-blooded organism has been studied extensively. It is known that when they enter the body, they can affect the function of blood formation, cause changes in the morphological composition of peripheral blood, block sulfhydryl groups, pose a danger, contributing to the development of carcinogenic, genetic and other remote biological effects. In addition, the environment is affected by the release of biogas – methane, oxygen, carbon dioxide, the content of which can be tens of percent. These values exceed sanitary standards and can cause suffocation of a person. Biochemical decomposition and chemical oxidation of the landfill material may be accompanied by the formation of heat release foci with an increase in temperature up to 75 ° C spontaneous

combustion is possible. The rotting of MSW material is accompanied by the spread of odor over a distance of more than 1 km. A negative factor is the removal from use of large areas occupied by authorized and unauthorized landfills.

Particularly hazardous to the environment and human health waste, which for various reasons cannot be disposed of with household garbage, is called special waste, which includes approximately 600 highly hazardous substances. Municipal solid waste in cities contain a significant amount of a variety of toxic substances and materials. Approximately 4% of waste is toxic. 100 items of toxic compounds and among them – dyes, pesticides, mercury and its compounds, solvents, lead and its salts, drugs, cadmium, arsenic compounds, formaldehyde, radioactive waste, etc.

Government policy should be aimed at developing a set of legislative measures, measures of economic support, including the creation of incentives among the population to sort household waste. This policy should be based on such principles as maximum processing of secondary material resources, minimization of environmental damage and costs, should be consistent, comprehensive and well-defined. For example, several years ago, containers for separate garbage collection were already installed in one of the major cities of Russia. Residents even began to use them correctly: glass in one compartment, plastic in another, etc., until they saw what happens next with this garbage. A car arrives, takes the tanks and safely dumps all this carefully separated garbage into one big spacious body.

After receiving the spectrum of the detected object, the initial filtering of the FIR filter is performed using the moving average method and the determination of the extremum. The wavelength corresponding to the extremum of the spectral density of the reflected signal corresponds to a certain type of material. The spectrometer used in this work is a small-sized spectrometer DLPNIRnano, manufactured by Texas Instruments. Unlike many other spectrometers, this model is not built on a linear, but on a matrix detector, i.e. a two-dimensional image is obtained at the sensor output. The detector has a high sensitivity in the range from 900nm to 1700nm. Spectrum measurement was carried out through the DLP NIRscan Nano GUI application and then saved to CSV (Comma-Separated Values) files.

For the analysis of the spectral density of the reflected signal in the near infrared zone, samples were taken of various plastic materials (HDPE, PP, PET, PS, PVC), paper / cardboard, wood and textiles.

2.2 Definition of material features

As arguments for the classification of materials using the principal component method, we use the values of the frequencies corresponding to the found extremums of the absorption spectral density in the near infrared zone. As can be seen from the analysis of the obtained spectral densities of the reflected signal, all materials are characterized by the presence of two frequencies and areas around them with characteristic distinctive features. However, due to the inhomogeneity of the relief of the samples, scanning is performed at an arbitrary angle of incidence of the emitter, in the spectral density there are noises (false extremes), the presence of which significantly complicates further processing and increases the number of false alarms of the peak detector.

As a result of the peak detector operation, the radiation wavelengths corresponding to the extremes of material absorption were determined for the spectral densities of the reflected signals of the selected samples, the found points can be used to reduce the sample for further processing by the principal component method (Figure 2).

As a result of decomposition of the input signals by the principal component method, clustered clusters are obtained, which correspond to a certain type of material. For classification, i.e. determining whether a sample of a given spectral density belongs to a particular class, a method can be used based on the Euclidean distance (if the classes are circles) to the center of the class or the Mahalanobis distance, which takes into account the elliptical form of the class.

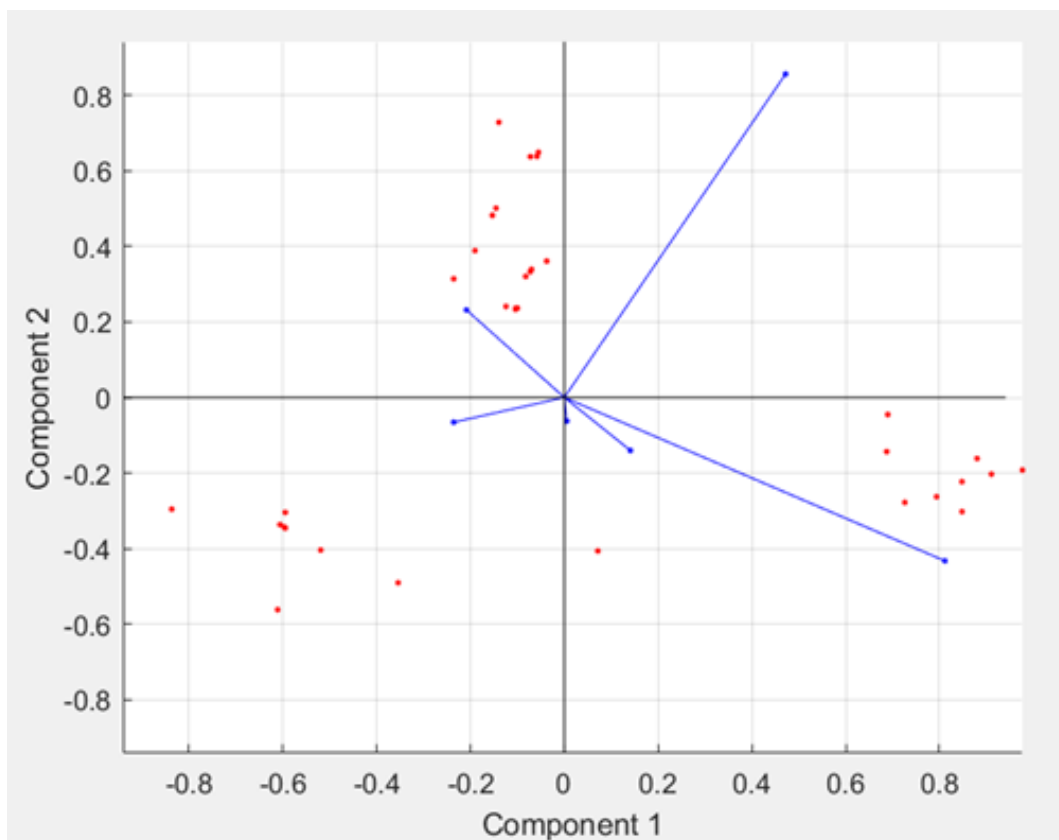


Figure 2 - Decomposition of plastic polymers in two main components

2.3 Algorithm to recognize the characteristics of the material

We use hardware artificial neural networks to recognize signals. The neural network architecture is a convolutional neural network with the following parameters: number of layers (5); number of inputs (227); number of Outputs (8); number of neurons (50).

We will also study the effect of the number of neurons in the hidden layer on the accuracy of recognition.

The developed algorithm showed recognition accuracy of 94.12% by the criterion of "plastic – not plastic", while 10 neurons in the hidden layer are enough, which is a good indicator for ensuring high computing performance of 0.68 ms using the Intel Core i7-6700HQ processor. The probability of recognition of various types of plastics is presented in Table 2. The recognition accuracy of individual types of plastics is more than 90%, and the probability of PVC extraction is 100%, which positively affects the safety of further recycling (Figure 3).

Table 2 - The probability of recognition of various materials

Material	Recognition accuracy
HDPE	93.33%
PP	92.50%
PET	92.31%
PS	94.44%
PVC	100.00%
Paper / cardboard	90.00%
Textile	86.67%
Wood	85.00%
Plastic polymers (medium)	94.12%
Non-plastic materials (medium)	87.27%
Overall	92.14%

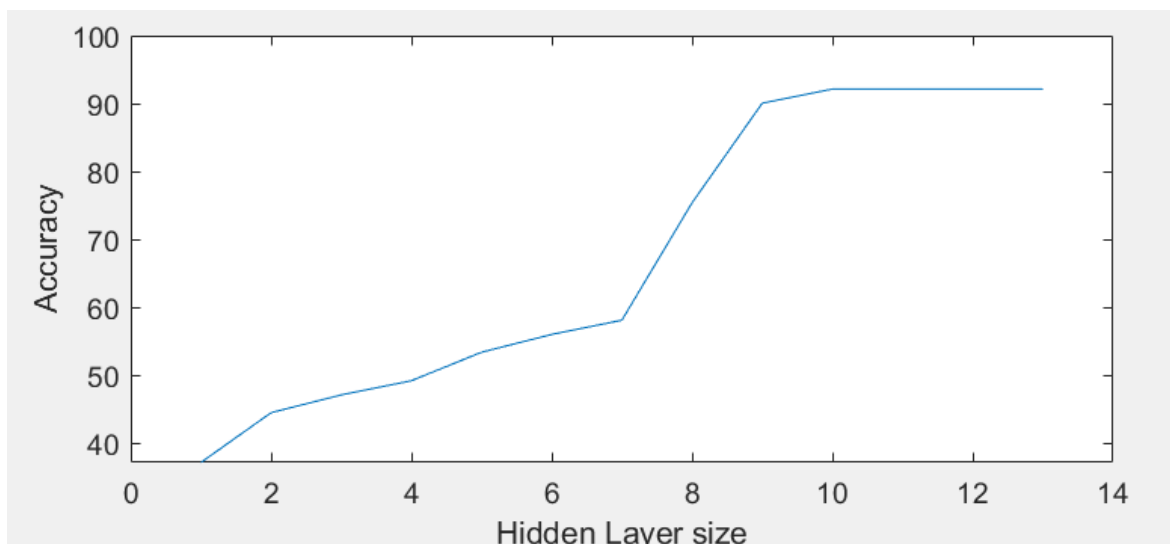


Figure 3 - The influence of the dimension of the hidden layer on the overall recognition accuracy

Conclusion

Thus, at the heart of the implementation of the concept of integrated management of household waste, the public plays a key role. At the present stage of solving the problem of sorting and further processing of household waste, the formation and improvement of the sorting culture of solid household waste becomes of key importance. The basis of this process is the creation of necessary conditions on the part of the state and society. After all, it is easier to control what goes to the landfill than waste decomposition products migrating from the landfill to the environment.

As shown by the results of the analysis of the spectral density of the reflected signal, the sensor used is sufficiently sensitive to analyze and recognize parameters using the second harmonic of the reflected signal.

The developed material classification algorithm is intended for processing the data of the combined machine vision system as part of software and hardware solutions as part of an experimental sample of a robotic sorting node (EO RSU). The developed robotic sorting node is intended for further use in the tasks of automating the processes of sorting operations with objects that have several (more than one) characteristics (properties of objects that are important for their classification and / or sorting operations). In the future, the developed solutions should find their application, above all, when conducting sorting operations with components of municipal solid waste at the stage of the waste sorting process cycle for the selection of useful fractions.

In order to detect and identify each component in the MSW stream and type of secondary raw materials, different methods and types of sorting are used. Each method has its own advantages and disadvantages, which must be taken into account when analyzing materials and choosing the most optimal one for a particular waste composition of a given climatic zone. Given the heterogeneity of waste, it is recommended to use a combination of methods that will allow to achieve high-quality selection of materials.

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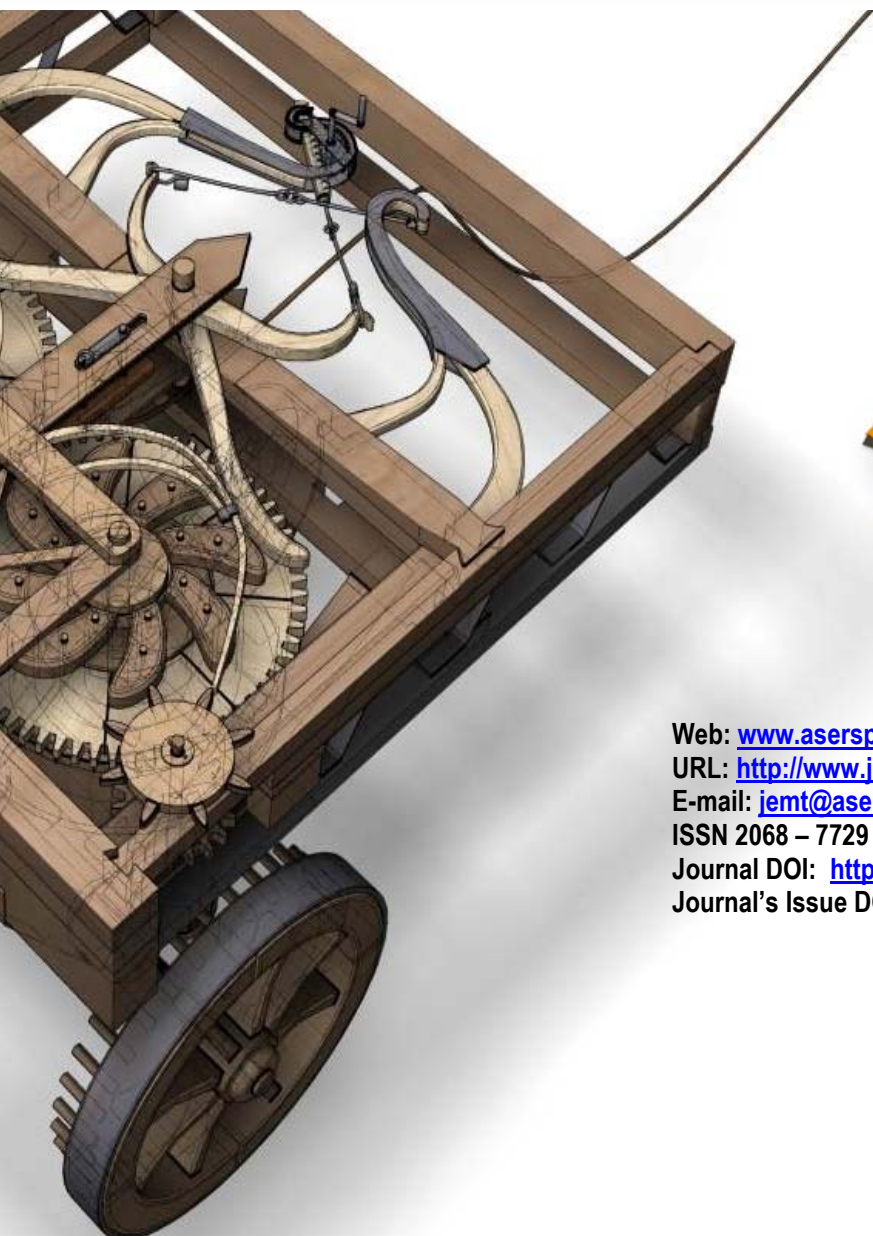
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