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INNOVATIVE DESIGN OF WASTE PROCESSING TECHNOLOGIES

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Abstract

Designing modern waste recycling systems is an urgent problem. The experience of attracting masters from two leading Russian universities in organizing interaction and cooperation in the development and implementation of waste sorting complexes is considered. Faculties of Russian Academy of National Economy and Public Administration and Moscow Institute of Physics and Technology held a project session for developing and launching innovative technological projects on the market called “Techno marketing”. The developed methodological base made it possible to combine educational and entrepreneurial tasks and ensure the promotion of student technological projects. As a result of the conducted project session, a project on the use of computer vision systems for sorting waste was developed, the competitive differences of the project and its technical and economic indicators were presented. The mechanisms for the implementation of an innovative waste sorting project have been determined. Despite being twice as expensive, the waste sorting machine is able to fully pay off 3 times faster than manual sorting, justifying further investment in the project.

Keywords: waste sorting, computer vision, NIR, educational project

1. INTRODUCTION

The rapid development of technology in all fields and sectors of the national economy, the pace acceleration of scientific and technological progress, the digitalization of the economy, all of these factors form a multi-tasking environment for the development of modern business and define technological entrepreneurship as the driver of social development. A key role in the development of competencies for the implementation of innovative technology startups belongs to universities, whose graduates must have working skills in the new market conditions.

The solution to the problem of training students and bachelors with maximum

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efficiency can be achieved with the joint participation of universities in various industries and activities. At the XI Congress of the Russian Union of Rectors, which was held in April 2018 in St. Petersburg, Russian President Vladimir Putin suggested that the best conditions for technological startups should be built on the basis of Russian universities, which should further create successful high-tech companies. According to the president, it is necessary “to build regional models of interaction between innovators, high-tech companies, and enterprises. And, of course, this can be done on the basis of Universities.” (Putin, 2018).

Modern mechanisms of entrepreneurship have been further developed through inter-university cooperation in a project implemented by the Moscow Institute of Physics and Technology (MIPT) and the Russian Presidential Academy of National Economy and Public Administration (RANEPA) (Kosareva & Safronova, 2016). The participants of the project were the Masters of the Department of Technological Entrepreneurship at the Moscow Institute of Physics and Technology, led by the head of RUSNANO A.B. Chubais, on the part of the RANEPA were third and fourth year students of the Faculty of Market Technologies of the Institute of Industrial Management. The goal of the joint project of the two universities was to train young technology entrepreneurs who are able to work in a multi-tasking environment and to form a community of future market leaders.

The joint work on innovative projects of students of two universities contributed to the immersion of specialists in various fields in the conditions of the modern market environment, the formation of not only a new innovative product, but also the calculation of financial indicators, its competitive positioning in the market, the development of marketing solutions to ensure successful introduction of the product to the market and the development of promotional methods and tactics. As a result, the students had the opportunity to carry out the technological development of the project as well as position it on the market.

According to the famous researcher of the business environment, professor Shirokova G.V. University initiatives, those that aim at development of human and social capital, have a positive effect on the scale of students' entrepreneurial activity (Shirokova, 2015).

2. MATERIALS AND METHODS

At the end of 2019, the departments of the two largest Russian universities organized a competition of technological projects, which were the results of the work of mixed student’s teams from both universities. In total, ninety students and masters took part in the competition. The competition was preceded by a project session on the development and marketing support of eleven technological projects, of a various orientation: from the automation of the development of chat bots and hydrophones, to post-quantum data protection technologies and gamified scholar training applications. The projects represented both the ideas, which require a further development and real technologies and products, ready to enter the market. Within the framework of the project development, each project team solved the following tasks: studying the potential consumer of the innovative product and his problems and which of them the proposed product will solve; preparation of a brief description of the product from the user’s perspective; testing a prototype for potential consumers, determining material and financial resources, sources of replenishment, calculating project financial indicators.

During the project session, the roles of interaction were established between the technological entrepreneur, i.e. the customer of the solution of the project task, the university and the student team.

The development of methodological support for organizing and conducting the project session was carried out at the Department of Business Process Management of the Faculty of Market Technologies of the Institute of Industrial Management and the Department of Technological Entrepreneurship of the Moscow Institute of Physics and Technology. The main stages of the project session and their contents are shown in table 1.

Table 1. Description of the project session stages, 2020

Stages	Tasks
Stage 1. Participant testing and team building	– selection of participants in the project session; – testing; – analysis of the results; – team building.
Stage 2. Presentation of the case (business tasks) by the customer (owner)	– presentation of the case (tasks) by representatives of the customer's organization; – statement of a specific task for each team participating in a social experiment; – the beginning of the interaction of team members in the process of solving a business problem.
Stage 3. Planning and organizing the work of project teams	– decomposition of the goals and determining the order of work execution; – drawing up a plan, a work schedule; – distribution of work between team members; – review and study of sources of information on the topic of business – tasks.
Stage 4. Question and answer session with the customer	– brainstorming session to form a list of questions to the customer; – determination of the need for additional information for the development of the project; – formulation of questions in order to obtain the information necessary to solve a business problem; – interaction of teams and the customer; – clarification of the conditions for the implementation of business - tasks; – testing of possible solutions to business – tasks.
Stage 5. Business Solution	– formation of a list of possible solutions; – assessment of the necessary resources for the implementation of the task; – development of alternative solutions; – assessment of decisions; – coordination of opinions by team members; – selection of the final solution; – finalization of the solution of the business task; – design and visualization; – team performance preparation.
Stage 6. Business task defense	– presentation of a business-task solution to the relevant organizations of the customer. Getting feedback and project evaluation; – defense of a project for solving a business task during the question session; – analysis of questions and comments; – assessment of the work of the team by independent experts.
Stage 7. Exam	– If required by the curriculum;
Stage 8. The sum up of the business task solutions	– examination of business task solutions; – determination of the winners of the competition in nominations (stages); – rewarding the winning teams; – analysis of the results of the project session.

Let us have a look at a project of environmental orientation developed by the students and passed by a team of experts of the competition, composed of representatives of venture capital businesses, universities and public organizations. As a result of the competition all teams presented their economically proved projects. One of the presented projects was “Development of the waste sorting technology based on Artificial Intelligence”.

3. RESULTS

3.1. Waste sorting problem and a demand for recycled materials

Waste is a massive problem: the world generates more than 1.3 billion tons of waste each year (Ijjasz-Vasquez et al., 2018). By 2030, this number is expected to hit 2.59 billion tons (Fig. 1).

Unfortunately, the global recycling efforts aren’t helping as much as assumed. To prove that, only 14 percent of plastic is recycled globally. In the U.S., roughly a third of all waste is recycled and the figure has remained static for a decade. (Environmental Protection Agency, 2017)

Through effective waste recycling, any country will benefit from reduced landfilling and will also save money. In addition, the manufacturing of one ton of paper from recycled fiber is estimated to save approximately 17 trees, 3.3 cubic yards of landfill space, 360 gallons of water, 100 gallons of gasoline, 60 pounds of air pollutants, and 10,401 kW of electricity (West, 2020).

Conventional sorting machines have improved the recycling process, but that does not seem to be enough. Sorting machines identify waste particles through infrared cameras using optical sensors, then mechanical sorters, such as blowers, arrange the garbage. But even after this process, recycling workers are still required.

The future of smart recycling is looking brighter. Spider-like robotic arms, guided by cameras and artificial intelligence (AI) make up the facial-recognition technology for garbage and are able to help make municipal recycling facilities run more efficiently.

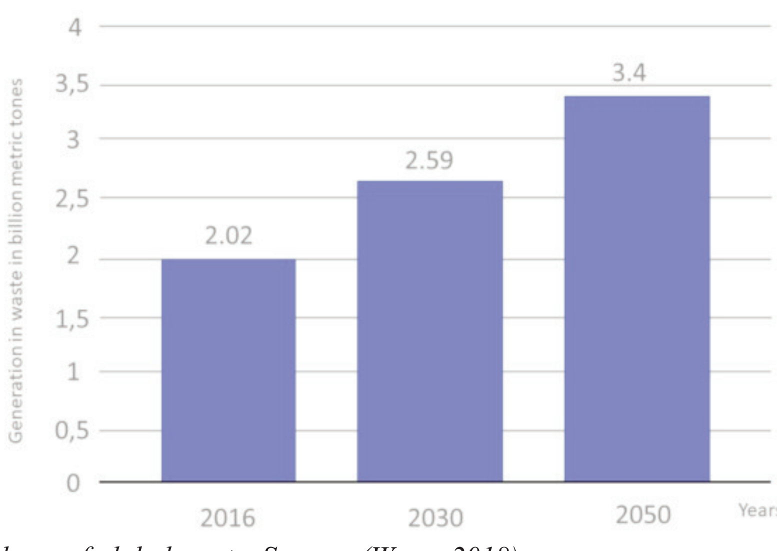

Fig. 1. The volume of global waste. Source: (Wang, 2018)

3.2. Existing waste sorting technologies

There are two types of waste sorting systems: manual and automated. In many countries, waste is sorted using a manual sorting system. Automated sorting systems offer significant advantages over manual sorting systems in terms of human health, speed, and accuracy.

All sorting technologies can be broken down into several types, such as size separation, gravity/density separation, metal separation, optical/sensor separation and manual separation, the disadvantages of which has been described above (Trine, 2013).

In this paper, we will have a closer look at sorting technologies, which use an optical or sensor separation method.

Optic sensor separation includes the following techniques: NIR Infrared, Colour Line Camera or X-Ray Fluorescence. The optic sensor equipment separates materials as paper, cardboard, wood, glass, electric scrap, minerals as well as individual plastic polymers (as PE (LDPE, HDPE), PP, PVC, PET, EPS and ABS) and colors. Black items can normally not be separated due to no reflection (Trine, 2013).

Usually, The NIR infrared equipment includes an acceleration conveyor, illumination and optical sensors (photo diodes) and an extraction unit with pressurized air (Fig. 2).

3.3. Development of the waste sorting machine based on Artificial Intelligence

Following topics are to be covered: the techniques behind the waste sorting machine using Artificial Intelligence, the economic effects of this waste sorting, and its advantages.

The technology proposed in the paper uses the same NIR cameras, which are already being using in waste recycling plants, but with a different approach to the sorting process.

The waste sorting machine (Fig. 3) is based on a Near Infrared Spectroscopy (NIR) scanning camera. It distinguishes almost all objects located on a moving conveyor belt with dimensions of more than 7 sq./cm at a speed of up to 2.5 m/s. Overall, the system

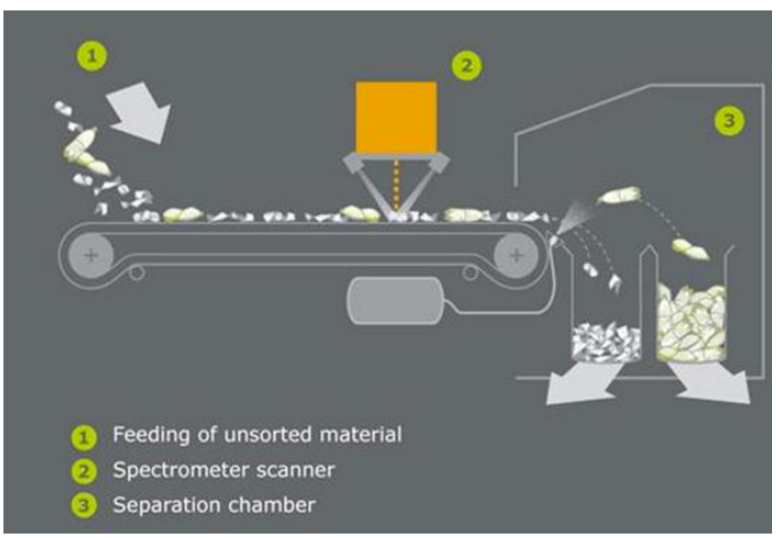

Fig. 2. Near Infrared Spectroscopy sorting (NIR). Source: (Trine, 2013)

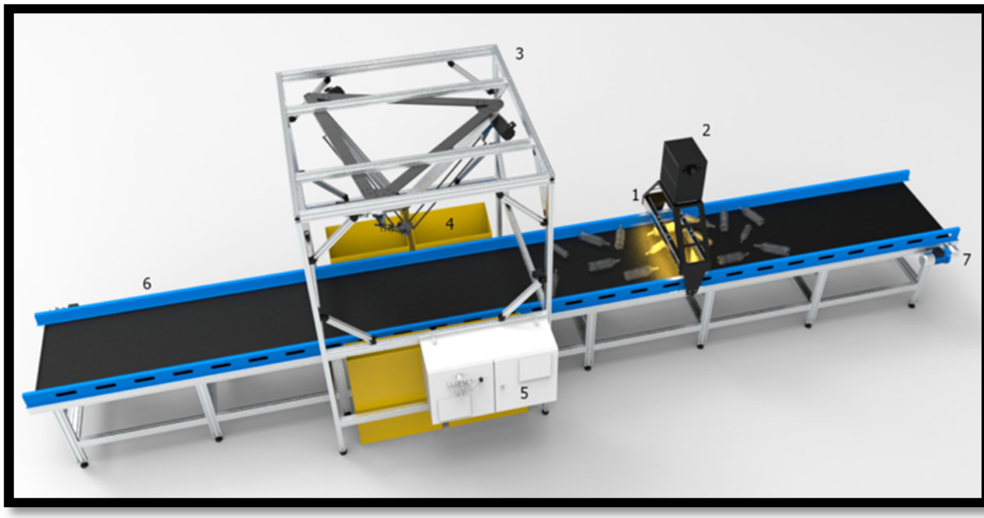

Fig. 3. The Near Infrared Spectroscopy (NIR) waste sorting machine

recognizes up to 20 types of plastics by their chemical composition and color during the movement of waste along the conveyor belt.

The high-speed manipulator1 (1 - robot arm) is equipped with a vacuum gripper, which allows it to sort plastic waste into bins with a speed of up to 60 objects per minute. The performance of the sorting machine is so high that one NIR camera can load up to 8 manipulators. As objects move, they cross a light beam, which analyzes the composition of the plastic, the calculator determines the material and the center of gravity of each object and transmits the corresponding control commands to the manipulator. This process takes about 250 m/s, its speed is determined primarily by the frequency and performance of the processor of the computer, controlling the system and recognizable types of materials are determined by software. This waste sorting machine (technology) is intended for integration into new or existing waste sorting and processing plants.

The machine consists of a light source, a NIR camera, a supporting frame, a robot arm with the FESTO control system, a suction device, sort bins, an automation cabinet, a conveyor (bulkhead table) and a conveyor tape drive (Table 2).

Although AI is still new to waste sorting, proponents believe it could be used for more than just for quality control.

4. FINANCIAL JUSTIFICATIONS

As it was mentioned before, waste management business is growing rapidly. The return on investment of the largest players in the global waste management market (including collection, removal, sorting and disposal) is illustrated by the SGI Global Waste Management Index, which is calculated by Société Générale Bank and Standard & Poor's agency. Over the past year, the index showed an increase of 12.4%, proving expediency of shifting the focus into said field.

The spreadsheet of costs necessary to carry out the project is illustrated below (Table 3).

Table 2. Project Specifications

Detail name	Description
Computer vision technology	a Near Infrared Spectroscopy (NIR) camera
Recognition material	20 types of plastics, more than 7 square meters. cm, at speeds up to 2.5 m / s. (optimum 40 cm / s)
Manipulator (a robot arm)	the FESTO tripod with a vacuum gripper
Compressed air source	oil-free air compressor
Sorting speed	up to 130 objects per minute
Number of working manipulators	Up to 8 simultaneously
Information transfer speed from the calculator to the manipulator	250 ms (varies relative to computer performance)
Power consumption	Up to 2 kW
Tape width	1200 мм

Table 3. Project Costs

Equipment	Price
Light source LED (2 pc)	1 000 rub
NIR Camera	325 000 rub
Support frame, robotic arm with FESTO control system, suction device	150 000 rub
Sorting bins	70 000 rub
Conveyor (bulkhead table and a belt drive)	577 850 rub
Automation cabinet	365 000 rub
Computer and software	200 000 rub
Total costs	1 688 850 rub

It is only logical to calculate the cost of a traditional waste sorting method, which is manual sorting (Table 4).

Table 5 underlines the cost comparison between a traditional method of waste sorting and the waste sorting machine based on Artificial Intelligence.

At first sight, manual sorting is cheaper. Yet in order to see the whole picture it is mandatory to take a look at how long the payback period is in both cases (Table 6). The source of profit for waste sorting businesses is waste recycling factories, that purchase sorted waste in bulk. The purchasing price varies from 7 000 to 20 000 rubles.

Despite being twice as expensive, the waste sorting machine is able to fully pay off 3 times faster than manual sorting, justifying further investment in the project. In addition, the project eliminates human factor, which is strongly present in manual waste sorting, in return, producing "purer" and more expensive waste particles.

5. DISCUSSION

Craze for automation in sorting process has been an occurring trend for decades. For example, Faibish, S., Bacakoglu H., & Goldenberg A. (1997) came out with an automated recycling system in which ultrasonic sound is used to separate different particles of papers. Although, the system suffered image processing issues, such as non-uniform illumination, segmentation of dark objects with low reflectance (cloths), and detection of the bounds of the subframes.

Computer vision is far from being new to waste sorting field, even though it is not the first thing that comes to mind when talking

Table 4. Manual sorting costs

Equipment (employee)	Price
Conveyor (bulkhead table and a belt drive)	577 850 rub
Sorting bins	70 000 rub
Salary for 4 employees per month	114 400 rub
PPE and uniform	56 000 rub
Total costs	818 250 rub

Table 5. Cost comparison of manual waste sorting and the waste sorting machine

	Manual sorting (4 employees)	Waste sorting machine
Initial investment	818 250 rub	1 688 850 rub
Energy expenses	42 210,6 rub	23 105,3 rub
Rent, salary, repair costs	264 000 rub	160 000 rub
Raw material purchase costs	from 600 to 8 000 rub	
Total costs	1 124 460,6 rub	1 871 955,3 rub

Table 6. Payback period of manual waste sorting and the waste sorting machine

Technology	Manual sorting (4 employees)	Waste sorting machine
Material	Plastic bottles (1 piece - 41.2 g)	
Speed of sorting	12 objects per minute, 30kg per hour, 5.28 tons per month	60 objects per minute, 144kg / hour, 25.34 tons per month
Revenue per month	105 600 rub	506 800 rub
Payback period	11 months	4 months

about waste, but it hasn't been used in combination with fully automatic, robot-like sorting mechanisms, which are proposed in the project.

6. CONCLUSION

In conclusion, it is necessary to set educational tasks, create educational resources and improve educational technologies that provide solutions to disciplinary tasks and aid in forming competencies in the field of sustainable development of future specialists. The high pace of technology development dictated by industry 4.0 requires the organization of marketing support for technology startups in the early stages of developing an idea. The positive experience gained by MIPT and RANEPA allows us to recommend the proposed technology of inter-university project sessions for the development of technological entrepreneurship.

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ИНОВАТИВНИ ДИЗАЈН ТЕХНОЛОГИЈА ПРЕРАДЕ ОТПАДА

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Извод

Пројектовање савремених система за рециклажу отпада је ургетан проблем. Разматра се искуство привлачења мастера са два водећа руска универзитета у организовању интеракције и сарадње у развоју и имплементацији комплекса за сортирање отпада. Факултети Руске академије народне привреде и јавне управе и Московски институт за физику и технологију одржали су пројектну сесију за развој и лансирање иновативних технолошких пројеката на тржиште под називом „Техно маркетинг“. Развијена методолошка основа омогућила је комбиновање образовних и предузетничких задатака и обезбеђивање промоције студентских технолошких пројеката. Као резултат спроведене пројектне сесије, израђен је пројекат о коришћењу система компјутерског вида за сортирање отпада, представљене су конкурентске разлике пројекта и његови техничко-економски показатељи. Утврђени су механизми за реализацију иновативног пројекта сортирања отпада. Иако је дупло скупља, машина за сортирање отпада се у потпуности исплати 3 пута брже од ручног сортирања, што оправдава даља улагања у пројекат.

Кључне речи: разврставање отпада, компјутерски вид, НИР, едукативни пројекат

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