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MODELING OF THE AUTOMATED COMPLEX COMPONENTS FOR SEGREGATED RESIDUES GATHERING OF OPERATIONAL PRINTING

Tetyana Neroda[1], Dmytro Storozhuk[2]
[1,2]Ukrainian Academy of Printing, Lviv, Ukraine
ORCID: [1]0000-0002-5728-7060, [2]0009-0003-5011-6407
E-mail: [1]tetyana.neroda@uad.edu.ua, [2]100dimitras@gmail.com

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Abstract. *An overview of the printing industry primary measures regarding the balanced implementation of the sustainable development goals at the regional level was carried out. Based on the latest works analysis in the direction of the enlargement of branch waste management systems, the solutions insufficiency for the limited financial situations of small businesses is revealed, and the relevance of finding optimal means of gathering segregated waste and their temporary storage at the enterprise is shown. The criteria have been established and the stratification of typical categories of orders the operational printing has been carried out according to print run and rest volume. The requirements for the collection and storage of waste raw materials and consumables have been clarified and expanded, in particular regarding the provision of microclimatic conditions. In order to model effective business processes of production residues management, the construction of a universal complex for target cumulative of pre-segregated substrate scraps in the form of a smart container with a weighing terminal is substantiated. For flexible allocation of corporate flows, the hardware part is implemented from measuring, supervisory and communication blocks depending on their purpose in the automated microprocessor platform. The researched printing waste types the built algorithm of the life cycle of their cumulating made it possible to draw up an architectural diagram of segregator system and determine the main components hierarchy of printing waste receptacle when order manufacturing. As a result, analytical models were built and the modeling of automated complex of segregated residues gathering in operational printing was carried out based on created microcontroller system for monitoring of mass and climate control of cumulated surpluses to maintenance proper conditions their subsequent recycling.*

Анотація. *Виконано огляд першочергових заходів поліграфічної галузі щодо збалансованої реалізації цілей сталого розвитку на регіональному рівні. На основі аналізу останніх праць у напрямку розробки галузевих систем управління відходами виявлено відсутність рішень для обмежених фінансових ситуацій малого бізнесу та показано актуальність пошуку оптимальних засобів збору сегрегованих відходів і тимчасового їх зберігання на підприємстві. Обумовлено критерії та здійснено стратифікацію типових категорій замовлень оперативної поліграфії за накладом та обсягом залишків. Уточнено та розширено вимоги до збору та зберігання відходів сировини і витратних матеріалів, зокрема щодо забезпечення мікрокліматичних умов. Для моделювання ефективних бізнес-процесів управління виробничими залишками обґрунтовано конструкцію універсального комплексу цільового накопичення попередньо сегрегованих обрізків субстрату у вигляді смарт-контейнера з вагoтермінaлом. Для гнучкого виділення корпоративних потоків апаратну частину реалізовано з вимірювального, супервізорного та комунікаційного блоків залежно від їх призначення в автоматизованій мікропроцесорній платформі. Досліджені види поліграфічних відходів та побудований алгоритм життєвого циклу їх накопичення дали змогу скласти архітектурну діаграму сегрегаторної системи та визначити ієрархію основних компонентів збірника поліграфічних залишків при виконанні замовлення. В результаті побудовано аналітичні моделі та виконано проєктування автоматизованого комплексу роздільного збору відходів оперативної поліграфії на базі розробленої мікроконтролерної системи моніторингу маси та клімат-контролю накопичених залишків для підтримання належних умов їхньої наступної утилізації.*

Ключові слова: оперативна поліграфія, бізнес-процес, промисловий інтернет речей, обчислювальна платформа, автоматизований комплекс, сегрегація залишків, цілі сталого розвитку.

Keywords: operational printing, business process, computing platform, industrial internet of things, automated complex, rest segregation, sustainable development goals.

Introduction

In recent years, the printing industry has undergone fundamental changes. Displacing the classical industry, operational printing, however, takes on long-standing problems that require immediate solutions to ensure the Sustainable Development Goals of responsible consumption and production and the protection and restoration of terrestrial ecosystems [1].

Automation of technological processes of operational printing involves full or partial replacement of mechanical components to ensure faster, optimal functioning of the equipment [2], which generally guarantees an improvement in the quality of regulation and control of existing machinery park devices and production lines [3]. However, engineers and designers pay insufficient attention to the automation and digitization of the life cycle of gathering, storage and disposal of printing production waste.

The rational accumulation of waste received from the production of order in operational printing is of great importance for their safe preservation, transportation or disposal, as well as, if necessary, for complete and irreversible ecological destruction [1]. Such a conscious approach will satisfy at least three Sustainable Development Goals of the UN Summit, adopted for the period 2015-2030. In particular, within the framework of the presented project, the problems of the development of industry, innovation and infrastructure, aspects of the implementation of responsible consumption and production, the issue of protection and restoration of terrestrial ecosystems were considered [4]. Measures for the balanced implementation of such goals begin with activities at the regional levels [5].

Analysis of the last research and problem statement

The development of waste management systems is currently receiving close attention of the world community. Professionals in various industries are actively evaluating the impact of industrial wastes such as used tires, slag, ocher, shavings, steel wool and other iron-based wastes, brick and ceramic wastes, wear wastes in concrete, solid wastes, etc.

The negative impacts of the generation of plastic waste and construction-oriented solutions for their transformation are considered in [6]. The original method of analyzing mixed industrial waste by volume [7] makes it possible to determine the hidden potential for resource regeneration to optimal utility and value. The use of encapsulation technologies in the transformation of industrial food waste [8] is intended to stabilize food security for a sustainable circular economy. Measures for the getting rid of industrial waste materials through joint processing in a cement kiln [9] lead to the need to predict the choice of services using the theory of the random utility model. Ordered approaches to the selection of industrial waste management techniques applied in nonlinear Diophantine fuzzy sets [10] are considered as potential directions in the steel industry in the context of the growing shortage of energy, materials and environmental crisis.

In our country, the evaluation of the real situation in the field of waste management [11, 12, 13] led to the approval of the procedure for the creation and administration of the information system of waste management, which since the beginning of 2024 has been actively used by domestic entrepreneurs. This decision is maintained in the form of an electronic database in order to ensure proper accounting, reporting, summarization and analysis of information in the field of waste management, provision of electronic public services, maintenance and placement of registers and provision of information interaction between subjects in the field of waste management. However, none of the considered areas of research pays due attention to the implementation of measures of automated processing and storage of waste in conditions of limited financing of small businesses, which in particular includes the market niche of operational printing. Therefore, the designing of microcontroller complex for the gathering of waste received during the production of a printing order is timely and relevant.

Purpose, objectives and methods of research

Purpose and objectives of the research were to develop a supervisory system for the segregation of the remains of the printing industry. The object of research of the presented scientific project is the substrates of operational printing during the execution of an order. The subject of the research is the conditions for proper provision of physical properties and chemical composition of various types of substrates in the environment of the supervisory system for segregated residues from the printing industry. To review the latest global research and thematic publications, the methods of scientific generalization were applied, which made it possible to single out the most significant achievements in the direction of optimizing the processes of optimal preservation of waste for further recycling. The method of the least squares was used to select parameters to best match the converting model to approximate measurements. The methods of modeling theory were applied to build an algorithm for gathering and processing residues and drawing up an architectural diagram. The methods of the theory of simulation modeling and the methods of the designing theory were applied in computer drawing of circuit and wiring diagrams and the mechanical and electronic components development for segregation container.

Deployment of the business process to gathering and storage of printing waste

Currently, operational printing is in quite high demand in the field of business and marketing strategies. This market niche allows effectively communicating with consumers and promoting products and services. When considering the amount of waste generated in different types of operational printing, it is necessary to take into account such factors as material type, printed product size, printing technology, inks used, and other factors that affect the waste creation. Typically, orders with larger final product dimensions or more complex specifications may have more waste.

The printing industry uses various materials as substrates for printed products (Fig.1). The most common substrate for printing orders is ***paper***: offset, glossy, matte, coated, etc. Paper is often used for printing postcards, brochures, posters, flyers and other types of printing products. A thick and strong substrate used for the manufacture of soft covers, packaging, leaflet, folders, paper boxes and other products — ***cardboard*** can have different densities and corrugated depending on its purpose. Various types of ***films*** are also used in printing, such as polyethylene, polypropylene, polyester, etc.; these substrates are commonly applied for printing labels, packaging, business cards, transparencies, and so on (Fig.1). Other types of plastic and polymers, such as polyvinyl chloride, polycarbonate, polystyrene, are used for printing on cards, IDs, packaging and other printed products of higher rigidity. Plastic can have different thicknesses and physical properties, which allows it to be flexible or resistant to wear, depending on the needs [4].

In some cases, ***textiles*** are used to fulfill orders in operational printing. For example, when making flags, tents, umbrellas or advertising banners, textile materials are often used. Some types of technical fabrics, such as polyester fabrics with waterproof or flame retardant properties, can be used for printed products that require special characteristics, such as outdoor advertising banners or stage decorations.

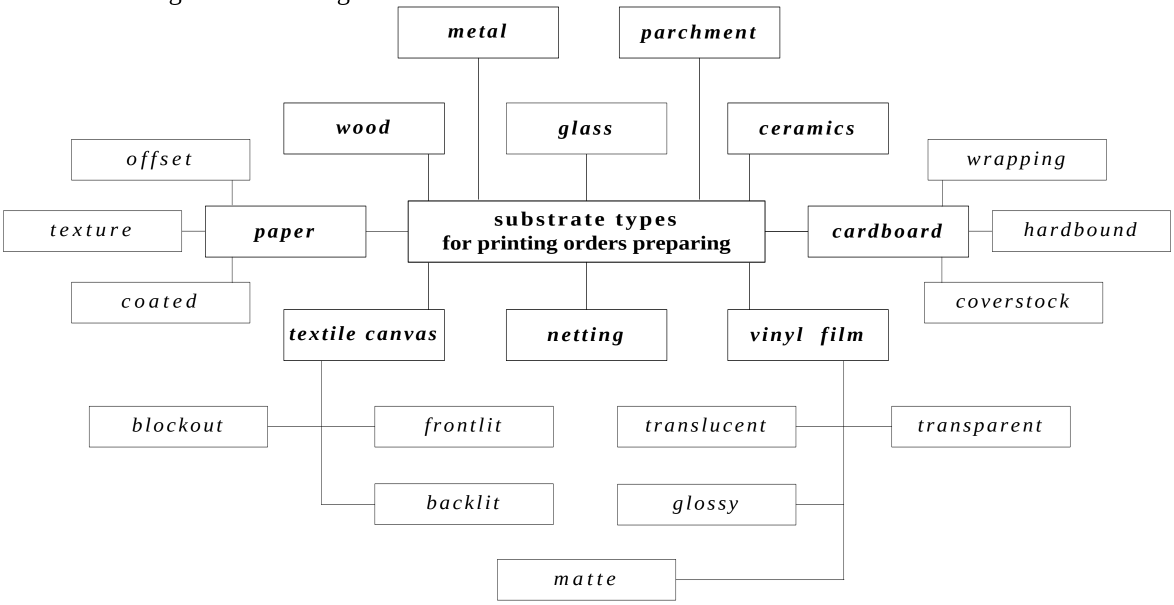

Fig. 1. Stratification of printing substrate types

Also, special printed products can be making ready on ***metal*** substrates such as aluminum foil or steel plates. These substrates are used for the production of metalized labels or packaging with high requirements for strength and durability. Fancy printed products such as plaques, awards, business cards and signs can be printed on ***glass***. Glass substrates can be transparent or have a foil backing, which allows creating spectacular designs. ***Wood*** substrates such as plywood or medium density fiberboard can be used for printed object such as posters, panneau, signs and other decorative products. Printing on ***ceramics*** allows creating unique items such as mugs, plates, tiles and other decorative products. The substrate in this case is the ceramic surface itself.

Such a variety of substrates causes increased attention to the correct disposal or burial of raw material residues and defective products. In the context of growing interest in sustainable development, brands that pay attention to waste disposal and reducing their impact on the environment can gain a positive reputation among consumers. Sustainability and environmental responsibility are becoming important factors of choice for many purchasers.

For the efficient disposal of substrate residues, it was decided to install smart containers at the printing plant as a sorting system for separate gathering of different types of substrates, which facilitates their temporary storage for further recycled. The designed industrial segregator technology, being located at an operational printing company, ensures the reuse of substrates and can help reduce the negative impact on the environment.

Fig. 2. Marking of industrial waste gathering containers

The requirements for the storage and disposal of printing waste contain a set of rules and recommendations aimed at ensuring safety, environmental protection and compliance with regulatory requirements. The main requirements relate to the processes of gathering, storage, transportation and disposal of waste. As for gathering, waste should be separated and excluded immediately after its generation, establish an internal waste collection process, including its regular removal from the workplace. Also, after gathering, waste should be placed in special containers for each type with labels indicating the type of waste and meeting safety requirements (Fig.2).

Regarding storage, it can also be added that waste must be stored in accordance with safety requirements, including avoiding potential fires, emissions and other hazards. Also, if it is waste that can be used for further recycled, it should be stored in appropriate microclimatic conditions so that it does not lose its properties and can later be used as secondary raw materials. In particular, in order for the paper not to lose its properties, it needs air humidity not higher than 60% and a temperature regime of 15°C÷20°C. But such humidity will be too high for cardboard. It needs no more than 40% humidity for normal storage.

The disposal and recycling of waste such as paper, cardboard and ink is an important step in the management of operational printing waste. These materials have a significant impact on the environment, so proper handling of them is extremely important. First of all, the available waste must be sorted among them by type. Collected paper and cardboard can be used as raw material for the production of new paper. The recycling process involves shredding the waste, removing impurities and bleaching to produce new paper. Non-recyclable paper and cardboard can be used for other purposes, such as packaging and thermal insulation. Used ink can be sent to specialized enterprises for safe disposal. It involves neutralization of the chemical composition of the ink, or its safe burial. Some dyes can be reused or disposed. For example, several of them are recycled to make new raw materials or are implemented in other fields, such as art and design. Based on the analysis of raw materials (Fig. 1), a decision was made to develop a universal complex for the most efficient cumulating and storage of pre-segregated printing waste (residues and scraps of the substrate). In the presented study, it was decided to implement an optimized algorithm for the industrial residues gathering, built on the basis of surveys and wish to employees from several local enterprises of operative printing (Fig. 3).

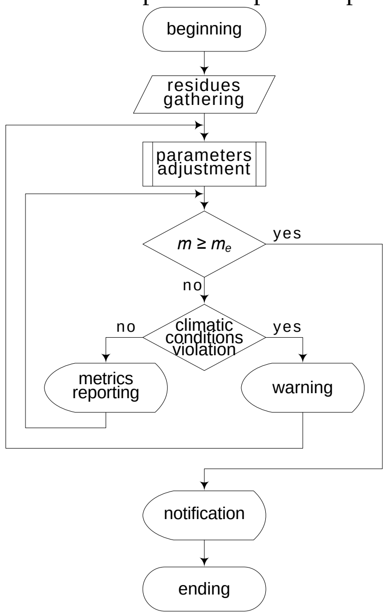

Fig. 3. **Life cycle of gathering and automatic telemetry for industrial residues**

One of the main components of the complex is the casing, the rational design of which will help maintain raw material residues in proper condition. Physical characteristics of the receptacle must correspond to the volume of production, take into account the material of the used substrates and the specifics of its life cycle. It is proposed to assemble the casings of receptacles of individual categories of waste in the form of a parallelepiped without an upper face, which will be close to a rectangle. The approximate dimensions of the casing are offered ~ 50×100×50 cm. The frame is welded from a profile pipe with a wall thickness of 3 mm. The walls are sheathed with aluminum sheets and with the constructive possibility of opening one of the walls to remove the gathered waste. This could be implemented through loops to which one of the faces of the prism would be attached.

Assembling the casing from scratch and purchasing materials for this turned out to be impractical, given the cost and range of ready-made solutions. Therefore, the criteria were substantiated and an analysis of several types of receptacles distributed on the domestic market was carried out (Table 1).

Table 1 – Comparison of several receptacle options

Name	Volume, ℓ	Material	Cost, ₴
"EcoSort" can	50	plastic	2370
"STEFANPLAST" container	50	plastic	650
"Europlast" tank	120	polypropylene	1330
Unknown company container	90	plastic	888

Consequently, the option with the "EcoSort" can is not suitable, because it has a rather small volume, while the price is the highest among the others studied. The only thing is that it has a convenient form factor. The "STEFANPLAST" container has the lowest price, but the quality of the plastic is quite poor and the volume is small. The "Europlast" tank has large dimensions, best plastic among those presented, a moderate price, and another rather big advantage is the presence of wheels, which makes transporting a full receptacle more convenient. Accordingly, for the designed complex, this casing is most suitable to gathering of paper and vinyl residues.

However, regardless of the chemical composition of the raw materials, a basic structure is proposed for such a segregation container (Fig.4). It is planned to make a double bottom in the casing. Lower part is welded to the casing, and between the upper and lower parts of the bottom, a strain gauge is installed, which is attached to the "upper bottom", and this entire component must be movable for measurement accuracy. The main primary transducer for informing about the fullness of a smart container is a *weighing terminal* based on a conditioned strain gauge. A *computing platform* that processes data on the current mass of waste is used as a weighing processor. Strain gauge will connect to the computing node board and send the received data for further processing. Another signal — about the *climatic* conditions in the container — is provided by a combined sensor of temperature, humidity and gas contamination.

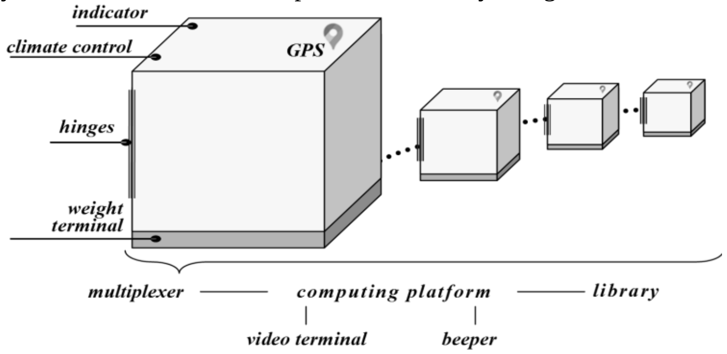

Fig. 4. Structural diagram the projected segregators array of industrial raw material

Multiplexer polls the subsystems on a timer and reports the telemetry of a specific container to the platform. The computing node organizes the received information and outputs the current displays to the *video terminal*. Also, the analytical apparatus of the platform detects deviations from the specified conditions: for this purpose, the node's memory provides a *library* with the limit values of the storage conditions for raw material residues of a specific material. In case of such a deviation, the *beeper* emits a warning signal, and the *indicator* lights up on the container to draw attention to the need to remove waste, access to which is provided thanks to the *hinges* on the front face.

For the further allocation of corporate information flows, it was decided to implement the hardware part of the waste gathering complex in operational printing from measuring, supervisory and communication blocks, depending on their purpose in the automated system. Next, need to decide on the computing platform node (Fig. 4), since it is the main electronic component of the designed complex. The telemetric part of segregation containers to waste raw gathering in operational printing enterprises for control node requires a computing platform that will be optimal in terms of price/functionality/support ratio. Operational printing establishments belong to small businesses, therefore they are limited in their financial capabilities with the uncontrolled expansion of the hardware base and the maintenance of service personnel on permanent terms. Thus, it is necessary to carefully approach the choice of brands for projects of machine park modernization and technological processes. The main competitive computing platform manufacturers in the electronics market are BeagleBone, Raspberry Pi and Arduino, compared in many thematic blogs. All of them are considered a reliable basis for numerous projects, regardless of their bigness.

Belonging to the class of microcontrollers, Arduino is suitable for simple projects where there is no need to hire professional programmers and circuit engineers. The platform is aimed specifically at beginners, so it is intuitive to configure, use and connect to external components. Arduino is best suited for single-purpose projects where there is interaction with a physical object. However, the boards of this manufacturer do not have a large computing power. Also, they don't have a native GUI to help with using this board. But Arduino and its programming language are open source, which is why it can easily connect this platform to almost anything, which means great freedom of action, flexibility and elasticity in debugging and use for almost any purpose. Arduino is the most accessible low-cost option, optimal for small business capacity expansion: with low power consumption, they are extremely attractive in integration and ideal for small-scale process automation in IIoT deployments. Manufacturers and enthusiasts also provide a large number of interoperable expansion boards, so it is easy to find the target peripheral.

Raspberry Pi already belongs to the class of microcomputers and runs Linux from an SD card, which allows running a variety of innovative projects. Raspberry Pi has two USB ports, an Ethernet port and an HDMI port, so it is possible to connect the classic peripherals of a personal computer, expanding the functionality of multimedia systems. A relatively cheap platform that allows to change the operating system according to the project. However, unlike the discussed Arduino, the Raspberry Pi microcomputer is difficult to integrate into projects where it is necessary to interact with external sensors and buttons. That is, it is clearly not suitable for the control unit of the telemetry installation.

A representative of the class of single-chip systems, the BeagleBone platform performs all computing tasks of a computer using a compact node. A significant number of BeagleBone interface options are due to two contact fields with 46-pin connectors, supporting a number of operating systems and, in principle, not requiring a display for configuration. Although these points are rather disadvantages for our project, because they require highly qualified specialists for support.

Performed analysis allows us to come to the conclusion that it will be most appropriate to use computing platforms of the ARDUINO line, because, foremost, they are not so expensive compared to competitors; in addition, they fully satisfy all the requirements set to the analytical apparatus of the telemetry system raw material residues in the smart container form factor at operational printing enterprise. A further researching of the available models of the ARDUINO family in terms of price/functionality/expansion/support showed that among other devices (Table 2) for controlling the presented supervisory complex, the ARDUINO LEONARDO model based on the ATmega32U4 microprocessor, which has a directly built-in USB controller and flashed bootloader, is optimal. Such a solution allows implementing a flexible hardware-constructive interface and significantly reduces the cost of the project due to the absence of an additional processor, external programmer and original power supply unit.

Table 2 – Comparative characteristics of the Arduino line microcontrollers

Characteristic	**Adruino Uno**	**Adruino Leonardo**	**Adruino Nano**
Microcontroller	ATnega328P	ATmega32U4	ATmega328P
Number of digital pins	14	20	14
Number of analog pins	6	12	8
Frequency, MHz	16	16	16
Flash capacity, KB	32	32	32
SPAM capacity, KB	2	2.5	2
Built-in functions	—	HID devices, USB series	—
Dimensions, mm	53,4 × 68,6	53,3 × 68,6	18 × 45

To clarify the components of automated complex for printing residues cumulating and the sequence of its further designing, an architectural diagram was drawn up (Fig.5). This made it possible to formalize the hierarchy of the main units, to determine the features of their interaction for coordinated functioning.

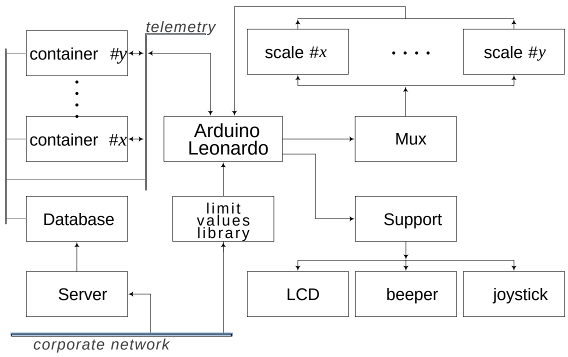

Fig. 5. Architectural diagram of the segregator complex

Data cycle in the automated system of segregator smart container begins with receiving the strain gauge *telemetry metrics*. A multiplexer as *MUX*, located on the diagram in the region of the measuring unit, is introduced into the control system to connect the signal amplification boards from the strain gauges.

When the strain gauge calibrating, the method of least squares was used to select coefficients to best match the model of converting mass *m* into voltage *U* to approximate measurements (1):

$$m = k \cdot U + b \tag{1}$$

where: *k* is scaling coefficient (in kilograms per volt);

b is displacement (in kilograms) for compensation of the zero point.

Now, after performing n measurements, it is necessary to minimize the sum of the squared deviations (2) between the actually measured values of the cumulated residues mass m_i and the results predicted by the model (1):

$$f_{min}(k,b) = \sum_{i=1}^{n} (m_i - (k \cdot U_i + b))^2 \tag{2}$$

The smaller of the obtained function value, the closer proposed model correspondence to observe data and the more reliable the voltage measurements from the strain gauge under different loads. After calculating the optimal parameters (*k*, *b*), model (1) can be used to predict voltage values from the strain gauge under any load with high accuracy. Thus, the linear model helps not only to get the current state of the system, but also to predict how it may react to future changes, which allows making informed decisions about managing processes and responding to events. This is especially useful in the context of an automated complex of temporary storage of substrate scraps, where it is necessary to respond to changes in real time.

Further discretization of the received analog voltage level U_i takes place, taking into account the ATmega32U4 bit depth (*N*=8) and the conversion error. The discrete value will be closer to the percentage signal if rounding to the nearest whole number (3) is used:

$$D_i = \left\lfloor \frac{U_i}{U_{ref}} \times 2^N \right\rfloor \qquad (3)$$

where: U_{ref} is the reference voltage of the platform microcontroller.

This model takes into account the principles of sampling, including scaling the analog signal to the range of values of the platform's analog-to-digital converter using a reference voltage. Thus, the discretization of the instantaneous voltage values from the minimized sum of squares allows obtaining real-time digital mass data that can be used for further analysis or control.

Since the ATmega32U4 operates in fixed-point form, the absolute value of the machine image of the received telemetry (3) lies within (4):

$$\begin{cases} 2^{-N} \le |D_i| \le 1 - 2^{-N} & \text{for fractions ,} \\ 2^{0} \le |D_i| \le 2^{N} - 1 & \text{for integers .} \end{cases} \qquad (4)$$

The average absolute submission error is defined as the arithmetic mean between the minimum number and its error, that is, as half of the least significant bit (5):

$$\begin{cases} \Delta D_c = 2^{-N} / 2 & \text{for fractions ,} \\ \Delta D_c = 2^{0} / 2 & \text{for integers .} \end{cases} \qquad (5)$$

At the same time, the relative error of presenting the maximum accumulated mass D_i of substrate residues with the lowest density at average compaction in the specified container (Fig. 1: $\rho_{cardboard}/2 \approx 0.36$ g/cm3) for a byte microcontroller with a fixed point based on models (4), (5) is calculated as follows (6):

$$\delta D_i = \frac{\Delta D_c}{D_i} \qquad (6)$$

Calculations and comparisons have shown that the relative error for the format, with the point fixed in the most significant digit, is smaller than the format with an integer number, making it more accurate for data processing on the ATmega32U4 microcontroller.

Another node in the diagram is a *database* with each residues type characteristics. For accompanying information, a liquid crystal display as *LCD*, a piezoelectric *beeper* for audio accompaniment and a *joystick* as a manipulator for feedback are provided. A multiplexer as *MUX*, located on the diagram in the region of the measuring unit, is introduced into the control system to connect the signal amplification boards from the strain gauges. For wireless data exchange in the communication block, synchronization of standard shields was performed.

Results and discussion

The construction of the circuit diagram of the project based on the assembled architectural diagram was carried out in the KiCad open source for electronic design automation environment. In view of the determined components of the microcontroller complex (Fig. 4, 5), target software free libraries were included. Next, in fig. 6 shows the basic set of electrical circuit components. Since the designed microcontroller complex is modular, all peripheral components can be changed and added, expanding the presented solution. This is a necessity in this project, as for each type of waste (Fig. 1) there may be different parameters of their storage. Thereof, it should be taken into account, and due to the easy feasibility of replacing components, it is possible to combine target control boards for different specializations of segregators' smart containers.

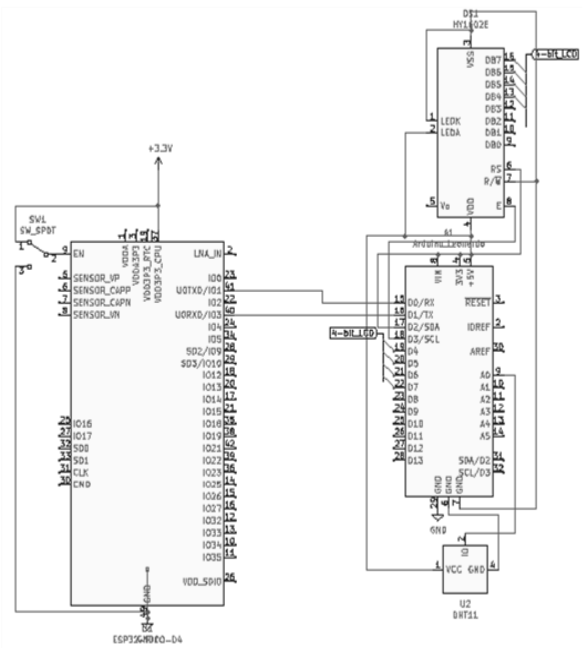

Fig. 6. The basic set of circuit diagram for the segregator complex

When assembling the wiring diagram of the microcontroller complex (Fig. 7), the strain gauge was connected through the amplifier module. This arrangement of the pre-calibrated strain gauge and amplification board increases the accuracy and sensitivity when measuring the weight of the accumulated residues. And these aspects are quite important in our complex, and especially when it comes to a small initial volume of waste.

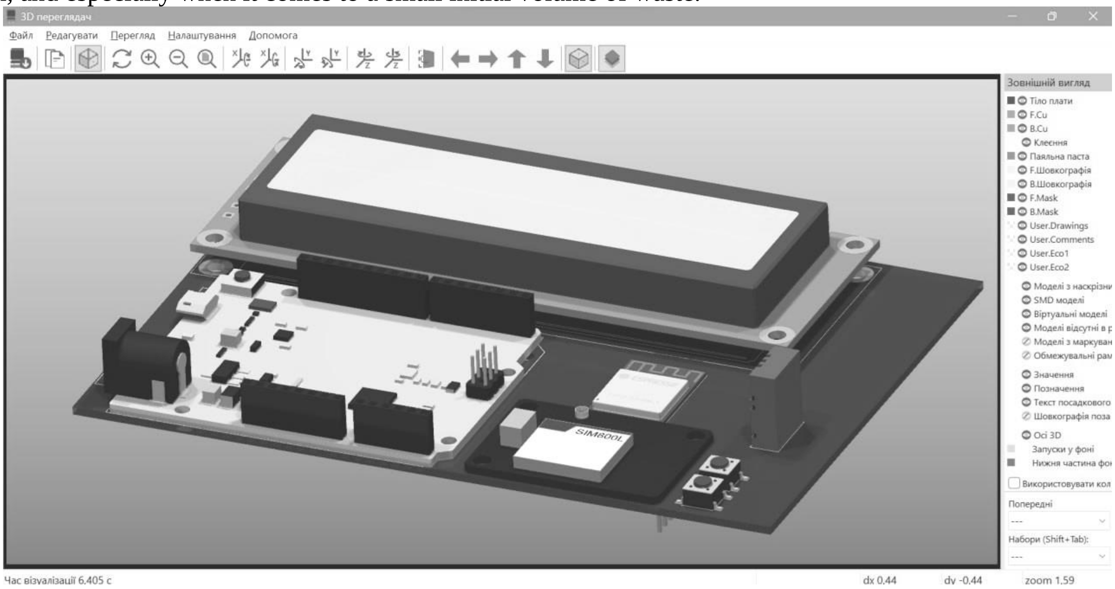

Fig. 7. 3D visualization of designed microcontroller platform for monitoring of mass and climate control

Hereby, the mass of waste creates weight due to gravity on the strain gauges implemented by the Wheatstone bridge. This weight is converted into a potential difference coming from opposite points of the warped plate bridge to load amplifier. It should be noted that in the case of using the multiplexer for sampling a specific strain gauge from containers array, there is no need for the amplification board, which is shown in Fig. 7. In any case, the c computing platform reads the enhanced weight metric and converts it to value of waste mass in kilograms with accuracy to the hundredth. The wireless module transmits the received telemetry through the server and can broadcast the analytics in real time in the web panel interface [14].

Conclusions

The availability of an array of the presented smart containers at branch productions organizes the industrial waste total volume and guarantees optimal conditions for their temporary storage in accordance with raw material type. The determined hardware base for the projected segregation complex for waste gathering in operational printing is sufficient and does not foresee a particular increase in the financial costs of a small enterprise. Instead, it qualitatively coordinates the work of the relevant firms on recycling of secondary raw materials. To increase functionality, the project is suitable for expansion. Thus, in order for the presented project to function effectively and bring profit, the assistance of owners and employees of printing establishments is needed. Consequently, among classic business processes the printing industry — pre-printing, actual printing, post-printing and product distribution it is time to introduce an important process class of environmentally sustainable and safe temporary storage of segregated residual raw materials and consumables.

Subsequently, installed sensors to monitor metrics of the quantity and quality of waste collected are also useful in determining the effectiveness of the segregation program and can drive improved results over time. Partnership with companies specializing in the processing of printing waste will help ensure that the residues gathered in smart containers based on an automated microcontroller complex will be sent for processing in a timely and targeted manner. Further research is planned in the direction of deploying adequate machine learning systems in the receptacle of each category to ensure the quality of the available remains and timely inform about parameter deviations.

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