AUTOMATION OF TRANSPORT AND WAREHOUSE OPERATIONS BASED ON THE DEVELOPMENT OF ADAPTIVE SYSTEM TO REDUCE RISKS FOR MANAGING WAREHOUSE LOGISTICS AT AGRICULTURAL ENTERPRISES

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Abstract

Digital transformation is a comprehensive approach. The processes of transforming the enterprise functioning through the business procedures digitization and the automation of implementation and management of specialized software for internal and external interactions as part of the country's digital ecosystem form the basis of the approach. In this regard, as well as in the conditions of ensuring import substitution against sanctions policy, the most pressing issue is the development of domestic software for managing the domestic enterprises at various levels and agro-industrial spheres (AIC). It is the production process of agricultural enterprises, to a greater extent than enterprises of other industries, that is influenced by various risks caused by climatic, technological, biological, etc. factors. The article examines the provision of automation of transport and warehouse operations when managing logistics processes at an agricultural enterprise through the development of special software. A block diagram of the control process automation is presented, taking into account the level hierarchy, the architecture of the process control automation system, individual elements of the developed software product (the algorithm of the program for controlling an automatic pallet stacker, the visualization system: the push-button screen for information support and the main screen of the operator's touch panel). A mathematical model for a program to lay non-standard workpieces (packages) on a pallet with the optimization of their placement has been generated. The calculation of the project implementation economic efficiency is suggested. The payback period is five months, provided the operator has got the necessary competence level. The article concludes that a similar management system can be implemented at various enterprises with warehouse space (industrial, agricultural, service industries, cargo transportation, etc.) in order to reduce risks (related to technological, man-made and human factors) during loading and unloading of packaged raw materials and products, and considered as innovative resource-saving technology as well as the part of import substitution and adaptation of software when managing logistics processes in the context of digital transformation.

Keywords: management system, decision making, digitalization, production, agricultural enterprises, transformation, transport and warehouse equipment

I. Introduction

Currently, much attention is paid to improving management processes at enterprises. This is due to the widespread introduction of methods and means that allow the decision maker (DM) to optimize the management procedure. Digitalization of the economy favourably contributes to this process, and the unstable geopolitical situation boosts the development of domestic software for implementation at all levels of organization and industrial management of enterprises. Let`s take for example the industrial sector, where the production of bulk materials such as cement, soda, and lime occupies one of the leading roles now. As for the agro-industrial complex, a lot of manufacturing and food processing enterprises make a significant contribution to ensure the economic security of the country. At the present stage of development, they all need digital technological innovations [1]. The installation of automatic systems related to the transportation and storage of goods [2], the mobile microprocessor systems for automating transport and warehouse operations [3], etc., which increase management efficiency and, ultimately, production volume while reducing costs (thereby contributing to an increase in income), is currently a relevant issue, especially in the context of economic processes digitalization. Similar operations are carried out in agricultural enterprises during transport and warehouse operations in grain production, dairy farming, etc. Moreover, when loading and unloading packaged raw materials or finished products, various risks arise (including those depending on the human factor), including a violation of the container when falling, injury to workers, failure of the packaging composition by date of production, etc. In this case, automation of process control will reduce the likelihood of a risky situation, including technological or man-made ones (for example, when transporting fertilizers or pesticides), thereby eliminating an increase in costs. In addition, the seasonality of agricultural production, the influence of weather and climatic factors affect the uneven workload of employees throughout the year, therefore, automation of a number of processes reduces the cost of additional hiring during certain time periods.

The object of the research is the automated process control system with a pallet stacker in the context of optimizing the organization of transport and warehouse operations when managing logistics processes at the agricultural enterprise. For clarity, we will consider this equipment using the example of stacking single packages on a pallet (for other types of packages it is the same). Until recently, these operations were performed manually, the productivity of such work was about 50 packages per hour. Modern equipment allows for stacking at a speed of up to 3000 packages [4]. The choice of the research issue is substantiated by the importance to consider the problem of introducing automatic palletizers from the viewpoint of package placement optimization, as well as in the context of reducing risks and introducing energy and human resource-saving processes.

II. Methods

Methods of the systems approach, logical analysis and synthesis, optimization modeling and algorithmization were used while researching the issue.

There are robotic palletizers and palletizers of a continuous type on the market. The former are used for the workpieces of different volumes and shapes. Mechanical arms, suction cups and other tools allow you to grab and place any objects. At the same time, robotic palletizers have limited productivity, while palletizers of a continuous type allow stacking from 600 to 3000 packages per hour. The former are more flexible and at the same time quite compact, while the latter are massive, but at the same time have greater productivity. Palletizing robots are mainly used in pharmaceuticals and logistics. At enterprises producing products in bottles, bags and bags, belt (continuous type) palletizers are used [5, 6]. They have a wide range of designs and are used in various fields of production: textile, food or industrial.

Overview of palletizers

I. Manual palletizers are practically no longer used due to low productivity and the risk of human error.

II. A large number of Russian enterprises are equipped with the latest automatic equipment. However, Industria 4.0 has not yet reached everyone. As for the pallet stacker, there are still quite a few enterprises that use semi-automatic installations [7]. Such palletizers are less productive. In addition, there is a need to employ people as duty personnel (at least 4 people, since the installation operates around the clock). And these are additional wage costs. Operator`s work is monotonous, which increases the risk of human error. Semi-automatic pallet stackers are not always equipped with a monitoring and control system: an operator touch panel, a program for a specialist's automated workstation (AWS), a SCADA system.

III. Digitalization has affected almost all areas of human life including industry. The main advantage of the industrial enterprises` digital transformation is the increase in productivity as the product development, production, packaging and logistics take much less time, and production costs are reduced [8, 9].

The operation of equipment using sensors without human intervention according to a specially written algorithm means stability and safety. In addition, the introduction of digital technologies allows you to interact with machines using visualization systems and automated workplaces.

Analyzing various enterprises, we can safely say that the use of semi-automatic equipment in modern production is economically unprofitable [10]. If we consider new enterprises or those where complete re-equipment is planned, then for them it is most advisable to use automatic pallet stackers. However, at the moment, enterprises in which a semi-automatic unit operates dominate [11]. Buying a new one is a very expensive decision, and the payback period is not quick. In this regard, the question arises of digital transformation of the technological process through full automation of the palletizer using modern high-quality equipment with the ability to work around the clock without human intervention. Therefore, the purpose of this work is to develop a control system for a semi-automatic pallet stacker when it is converted into an automatic one.

III. Results

Automation system development

We have developed a block diagram for automating the process of managing transport and warehouse operations at enterprises using a pallet stacker. Figure 1 shows the hierarchy of its levels with the corresponding components. The scheme fully corresponds to the sequence of logistics process management stages implementation. The decision maker is equipped with an operator's workstation and an HMI panel (upper level), used as a graphical process control panel. Thanks to this electronic installation, which facilitates the visualization of information received from devices, the performance of the technological control object is analyzed (lower level) and further work is adjusted taking into account the controller data (middle level). Operational remote control, using support for selected protocols, allows you to implement the interaction of peripheral equipment at the field level and optimize the control procedure to select relevant management actions.

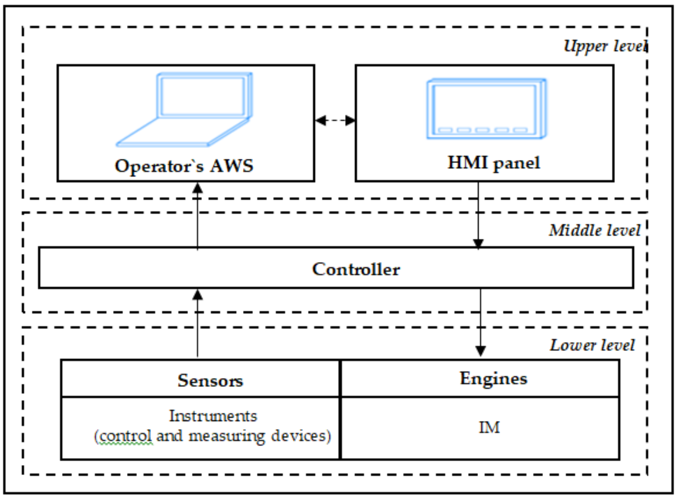


Figure 1: *Block diagram of automation of the management process*

Based on the block diagram, the architecture of the process control automation system was built (Figure 2).

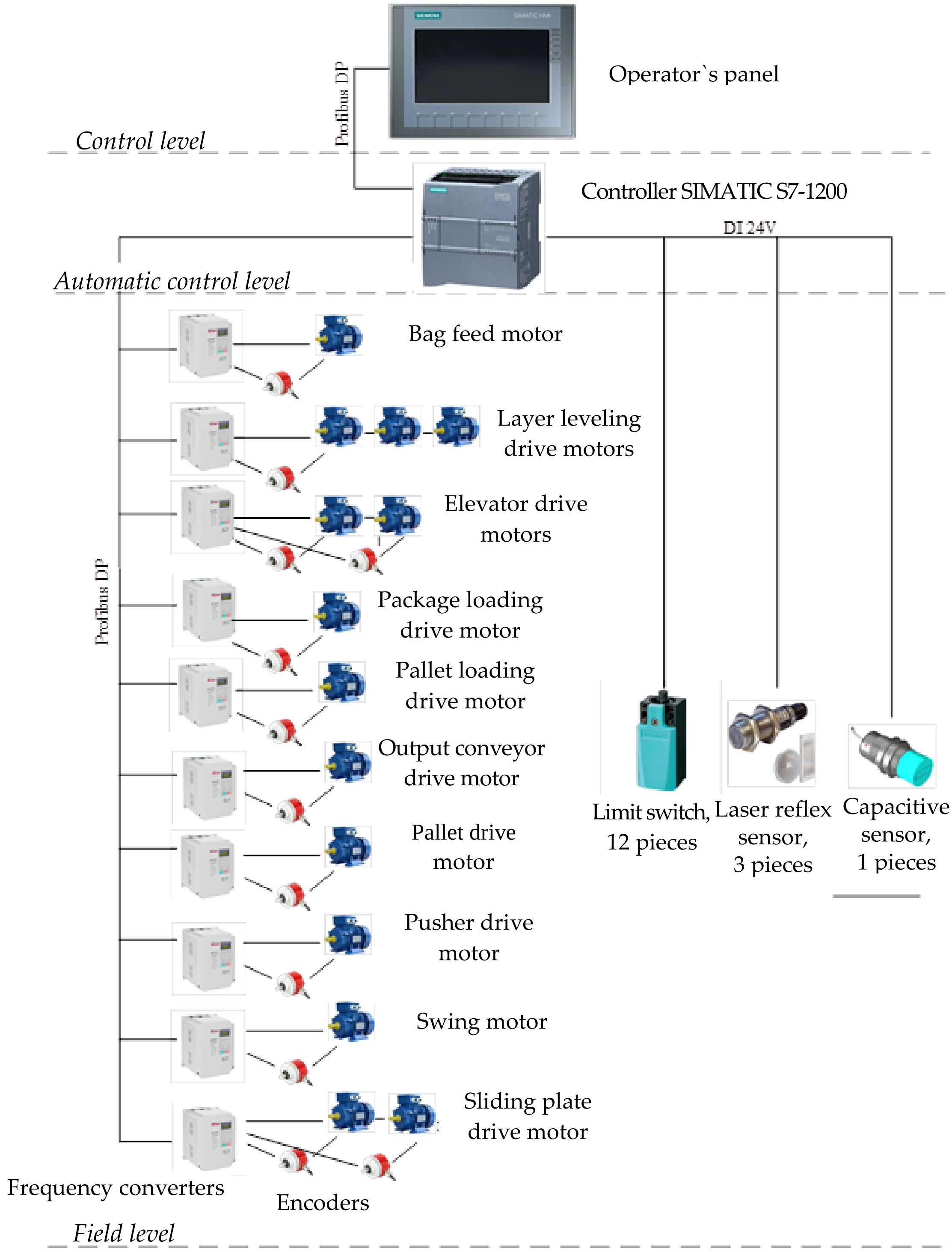


Figure 2: *Architecture of a process control automation system*

The field level consists of two limit switches, one capacitive and three laser reflex sensors. Also, in addition to sensors, the field level includes 14 asynchronous motors and 10 frequency converters, each controlling the speed of the drives of individual actuators. An encoder is connected to each frequency converter to provide speed feedback.

The field level is followed by the automatic control level, which consists of a programmable logic controller (PLC). All frequency converters are connected to the PLC via the ProfibusDP protocol. Limit switches and sensors are connected directly to the PLC.

The automated operator workstation consists of an HMI panel, which is also connected to the PLC via the ProfibusDP interface.

All drives as well as the control panel are connected to a programmable logic controller (Figure 3).

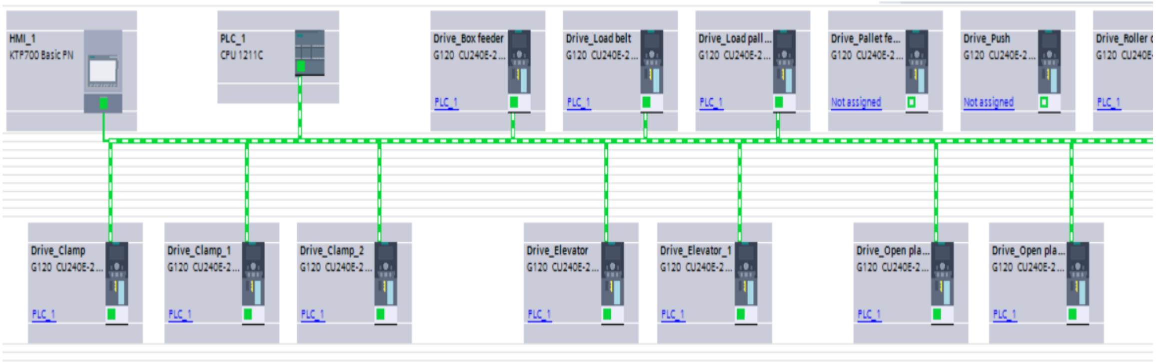
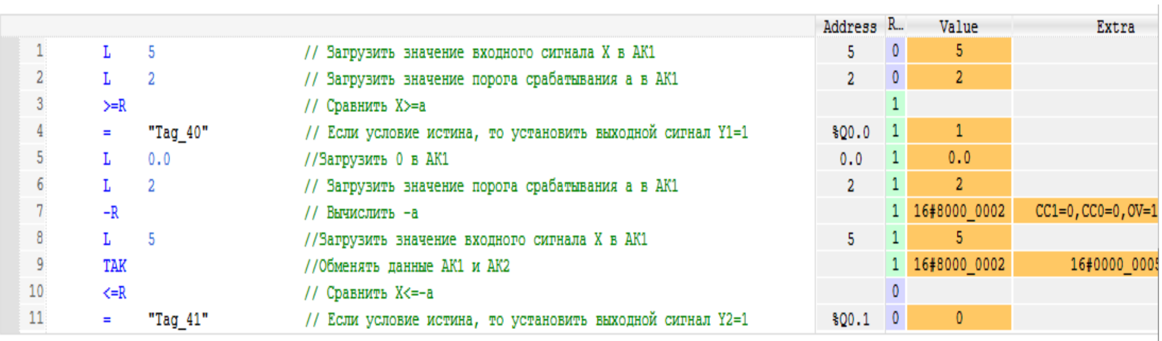


Figure 3: *Link with the controller*

All elements of the automation system architecture form a single automated system and provide a solution to all assigned automation tasks at this level.

Figures 4 and 5 show screenshots of the written pallet stacker control program.



				Address	R...	Value	Extra
1	L	5	// Загрузить значение входного сигнала X в АК1	5	0	5	
2	L	2	// Загрузить значение порога срабатывания a в АК1	2	0	2	
3	>=R		// Сравнить X>=a		1		
4	=	"Tag_40"	// Если условие истина, то установить выходной сигнал Y1=1	%Q0.0	1	1	
5	L	0.0	//Загрузить 0 в АК1	0.0	1	0.0	
6	L	2	// Загрузить значение порога срабатывания a в АК1	2	1	2	
7	-R		// Вычислить -a		1	16#8000_0002	CC1=0,CC0=0,OV=1
8	L	5	//Загрузить значение входного сигнала X в АК1	5	1	5	
9	TAK		//Обменять данные АК1 и АК2		1	16#8000_0002	16#0000_000
10	<=R		// Сравнить X<=-a		0		
11	=	"Tag_41"	// Если условие истина, то установить выходной сигнал Y2=1	%Q0.1	0	0	

Figure 4: *Reading signals from sensors*

Development of an adaptive system for searching the optimal location of non-standard workpieces.

The pallet stacker control program includes a special function for optimal placement of workpieces on a layer. This approach allows to place on pallets not only identical packages with strictly defined dimensions, but also completely different ones in shape and size. Such an adaptive system is especially important in the logistics of large enterprises that produce related products with different package dimensions on adjacent conveyor lines.

To perform this task, the following variables have been added to the program: L – length of the workpiece; S – is the area of the next layer; N – number of blanks. It is necessary to obtain m different types of workpieces with either length L_i or area S_i, where i is the type of workpiece ($i = 1, 2, ..., m$). The number of workpieces of the i-th type in the layer is known, i.e. the number of blanks that is necessary to form one layer – b_i. The total number of blanks produced by the enterprise is denoted by k. The arrangement of workpieces on a layer can be done in n ways. Then a_{ij} is the number of workpieces of the i-type, obtained by the j-method ($j = 1, 2, …, n$). The unused area in the j-method is C_j. It is necessary to arrange the workpieces in such a way that C_j (the total area of the gaps between the workpieces) is minimal. Let us denote by x_j the number of units of blanks cut by the j method. Find x_j>0 that satisfy the following restrictions.

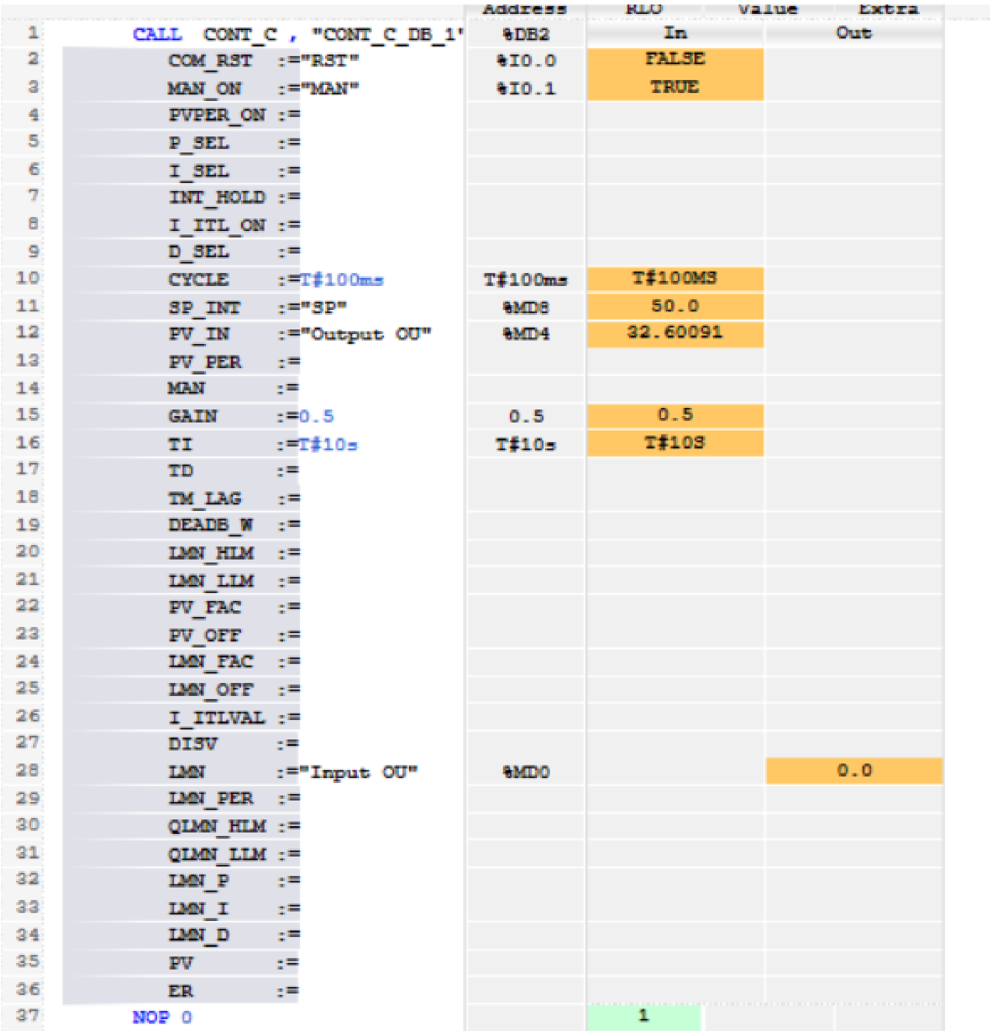


Figure 5: *Calling and setting up the control loop regulator*

Restriction on the number of blanks:

$$\sum_{j=1}^{n} x_j \leq N. \tag{1}$$

Production plan limitation:

$$\sum_{j=1}^{n} a_{ij} \cdot x_j = b_i, \quad (i = 1, \ldots, m). \tag{2}$$

This is exactly how many blanks of the i-type are obtained for all cut options. Based on the completeness condition, we obtain the following restrictions on the production plan:

$$\sum_{j=1}^{n} a_{ij} \cdot x_j = d_i \cdot k, \quad (i = 1, \ldots, m). \tag{3}$$

The total area of the gaps between the workpieces should be minimal, then the goal function will take the form:

$$\sum_{j=1}^{n} \mathrm{C}_j \cdot x_j \to \min. \tag{4}$$

The value of the variables responsible for the number of blanks must be integer. To prevent the numbers with fractional parts, the program contains a solution to the linear integer programming problem, based on the following: it is necessary to calculate a value $X = (x_1, x_2, ..., x_n)$, for which the linear function:

$$Z = \sum_{j=1}^{n} c_j \cdot x_j \tag{5}$$

takes the maximum or minimum value subject to restrictions:

$$\sum_{j=1}^{n} a_{ij} \cdot x_j = b_i \quad (i = 1, ..., m); \tag{6}$$

$$x_j > 0, \quad (j = 1, \dots, n); \tag{7}$$

$$x_j \; - \; \text{целые числа}. \tag{8}$$

Thus, the program calculates an option in which the maximum number of required blanks will be placed on the pallet with minimal gaps between each other.

IV. Discussion

Software development

The software under consideration is recommended to be installed on an automated workstation.

When launching the application, the following button form opens (Figure 6).

Figure 6: *Switch board "Information support for automated process control system of pallet stacker"*

This form contains a specific list of possible application working modes:

– requests for access to operational information;
– receiving a report – shift log;
– information about the developer.

The option to exit the application is provided.

Automation program development

To control an automatic pallet stacker, a program [12] is written in the visualized LAD language. The program assumes fully automatic operation without human intervention.

The operating algorithm is presented in Figure 7.

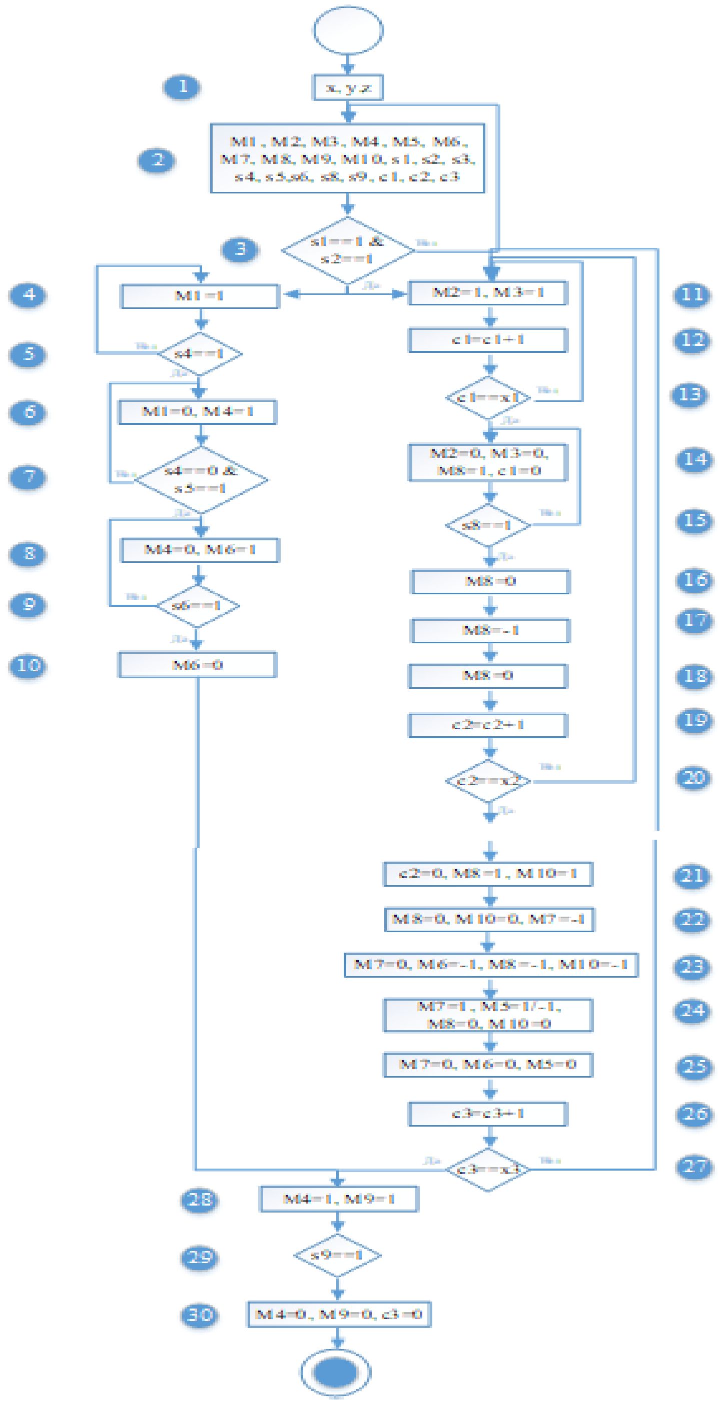


Figure 7: *Algorithm of the program for controlling an automatic pallet stacker*

The letter M denotes the corresponding drive, c – counter, s – sensor.

The program code provides for the main non-standard situations for displaying notifications and errors on the operator panel, which allows to quickly identify and eliminate the malfunction.

Visualization system development

A touch panel has been developed to visualize and control the technological process. It contains two screens. The first (Figure 8) is the main one, displaying the entire technological process; it is created directly for the operator's interaction with the automated system. The second screen displays diagnostic data.

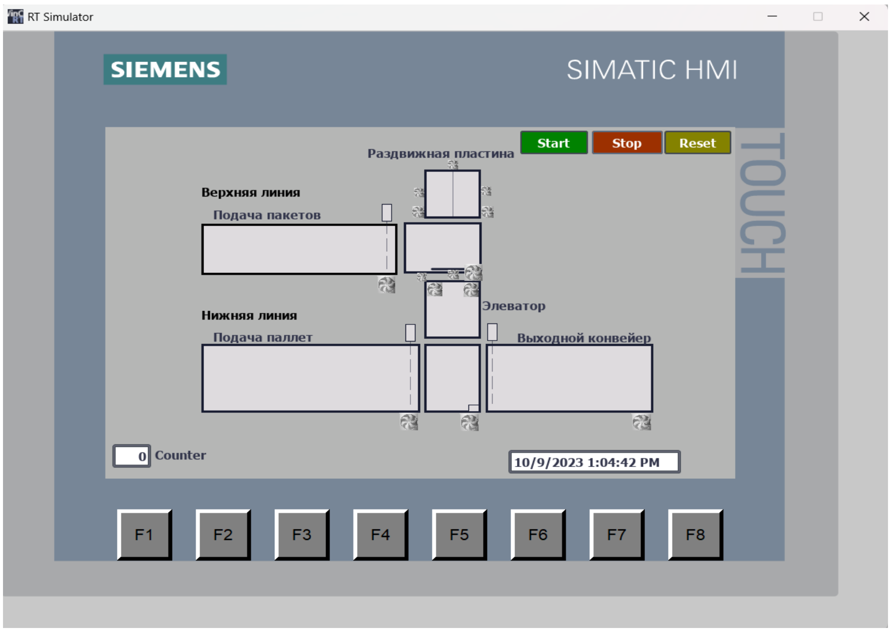


Figure 8: *Operator touch panel main screen*

The main screen contains three buttons for controlling the automatic palletizer: Start, Stop and Reset. These commands are duplicated with commands from the control cabinet. The F2 button scrolls to the second screen to view events that have occurred with the controller.

The tableau in the lower left corner displays the counted number of packages that have passed past the sensor installed on the conveyor feeding the packages.

The date and time are displayed at the bottom right.

The implementation of any innovation is known to require material and time costs. In addition, the level of competence of the specialist, who work on the new equipment, must meet the system requirements, otherwise, additional training costs will be required.

We have calculated the effectiveness of project implementation and the approximate payback period at one of the enterprises in AIC Orenburg region. Capital costs at the moment (capital costs mean the purchase of the necessary equipment for digitalization of the technological process and its installation) amount to 543,360 rubles, while profit from product sales will increase by 1,234,960 rubles.

The payback period of the project for the implementation of the developed control system for an automatic pallet stacker is calculated using the formula:

$$PP = \frac{I_0}{P}, \tag{9}$$

where PP is the payback period, months;

I_0 – initial investment, rub.;

P – net annual cash flow from product sales, rub.;

$$PP = \frac{543\ 360}{1\ 234\ 960} \approx 5 \text{ month.} \tag{10}$$

The payback period is quite short. The implementation of this project will significantly increase the enterprise competitiveness.

The presented project includes the purchase of new equipment and its installation. The experimental implementation of the developed product has proved that the supplementary operator training won`t be required.

The program for controlling the automatic pallet stacker can be used to organize the management of logistics processes within the framework of automation of transport and warehouse operations in the context of digital transformation at enterprises (with warehouse space) in a wide range of industries: in industry, in agriculture, in service sector, in the area of cargo transportation etc.

The developed control panel and software for the workstation displays the entire technological process and has all the necessary functions.

According to calculations, production volume will increase by 1.06%, and the profit from product sales will increase by 1.235 million rubles. The payback period of the project is about 5 months.

The developed automated system can be implemented both at a newly built enterprise and at the old one to replace outdated equipment. It is possible to modernize semi-automatic palletizers in order to fully automate them at the lowest cost.

This development contributes to the management processes digital transformation at the agricultural enterprise, which ultimately, together with the automation of technological processes and reducing risks (production, human, technological, etc.), will lead to increased production efficiency as a whole.

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