ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024

THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY

VOLUME-5, ISSUE-5

A MATHEMATICAL MODEL DEVELOPMENT FOR AN AUTOMATED CONTROL SYSTEM FOR PACKAGING AND SORTING PRODUCTS CLOSED AREA

Svitlana Maksymova [1], Mohammad Hamdan [2], Vladyslav Yevsieiev [1], Amer Abu-Jassar [3]

[1]Department of Computer-Integrated Technologies, Automation and Robotics, Kharkiv National University of Radio Electronics, Ukraine

[2]Department of Cyber security, College of Information Technology, Amman Arab University, Amman, Jordan

[3]Department of Computer Science, College of Information Technology, Amman Arab University, Amman, Jordan

ABSTRACT

The article considers an approach to a mathematical model development for an automated control system for packaging and sorting products closed area. The features of such systems functioning are analyzed and the main parameters that affect their efficiency are determined. Proposed mathematical model takes into account dynamic changes in the production process, optimization of product flows and minimization of downtime.

The developed approach allows increasing the accuracy of control, adaptability to changes in production conditions and reducing energy and time costs. The model is implemented in the form of algorithmic support, which allows conducting numerical experiments to determine the optimal parameters of the system. The operation of a closed area is simulated taking into account various scenarios, which confirmed the effectiveness of the proposed solutions. The results obtained can be used to improve automated production lines, increase their productivity and reduce the impact of the human factor.

Keywords: Automated Control, Mathematical Model, Packaging, Sorting, Optimization, Production Line, Dynamic Processes, Closed Area, Industry 4.0.

INTRODUCTION

Automation of production processes is a key direction in the development of modern industrial enterprises, as it allows to increase the efficiency, productivity and quality of products [1]-[18]. One of the important elements of such processes is automated control systems for closed areas for packaging and sorting products, which ensure continuity, accuracy and speed of operations.

In the conditions of the growing need for flexibility of production, minimization of losses and optimization of resources, the development of a mathematical model of such a system is an urgent task. The introduction of mathematical apparatus allows formalizing control processes, developing optimization algorithms and simulating the operation of the system for various production scenarios.

This will contribute to improving the adaptability and reliability of automated complexes, reducing operating costs and increasing the level of automation of production. In particular, mathematical modeling allows taking into account dynamic changes in input parameters, predicting possible deviations and timely adjusting the operation of the system.

The feasibility of conducting the study is due to the need to increase the efficiency of closed areas of packaging and sorting, which is critically important for enterprises that strive for automation and digitalization of production [19]-[33].

The results of the study can be used to develop intelligent control systems that provide adaptive adjustment of operating parameters in real time, which corresponds to modern trends of Industry 4.0.

Different methods and approaches can also be used here [34]-[50].

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5

LITERATURE REVIEW

A huge number of scientists and developers are involved in the creation of automatic control systems. Such systems are completely different and are used in absolutely different areas. Let us consider several works on the creation of such systems.

Lin, Z., & Xu, F. in [51] construct the robot automatic control model, and design the action and path planning of the bionic robot. The simulation results show that the proposed algorithm can obtain the optimal path of the whole motion at a faster convergence rate.

Authors in [52] discuss the automatic control system of balcony agriculture stereoscopic cultivation based on wireless sensor network. A distance-based routing algorithm is designed to realize the networking of wireless sensor networks, and the network simulation is carried out with TOSSIM.

In the paper [53] there is considered the antilock braking system. There is presented an automatic control system, especially the effectiveness of smart hybrid antilock braking system in automobiles.

Wang, J., & Jiang, C. in [54] designed an intelligent control system for seed pelletizing coating machine aiming at the problems of low degree of automation in seed pelletizing coating, poor pelletizing coating quality, and backward pelletizing process,

Ajagekar, A., & You, F. in [55] consider deep reinforcement learning based automatic control in semi-closed greenhouse systems. They propose a novel deep reinforcement learning (DRL) based control framework for greenhouse climate control. This framework utilizes a neural network to approximate state-action value estimation.

Researchers in [56] propose to use fuzzy logic algorithm for automatic temperature and humidity control system for tarantula terrarium using. They try to create a system that can solve this problem with the use of fuzzy logic. Incorporating fuzzy logic can help in controlling the parameters as consistent as possible. They use fan, water pump and heatlamp with DHT11 as a sensor for temperature and humidity. Without fuzzy logic, the system might flood the terrarium or heat too much that would kill the tarantula inside.

So, we see that automatic control systems are widely used in various fields of science. Further in this article we will propose mathematical model development for an automated control system for packaging and sorting products closed area.

THE STRUCTURE DEVELOPMENT FOR AN AUTOMATED CONTROL SYSTEM FOR PACKAGING AND SORTING PRODUCTS CLOSED AREA

The structure development for an automated control system for packaging and sorting products closed area is an important task, since such a system allows ensuring high efficiency and quality of the production process. Automation of this area is an integral part of modern production systems operating within the framework of the Industry 4.0 concept. The main goal is to integrate all stages – from product loading to its sorting and shipping – into a single closed system that minimizes human participation and optimizes resource use. Such a structure should ensure continuity and consistency of operation of all components: conveyors, robotic manipulators, quality control and labeling systems. This will allow to achieve not only high productivity, but also to ensure the versatility of the system for working with different types of products. Particular attention should be paid to the distribution of functions between system elements, the creation of adaptive control algorithms and ensuring flexibility for adapting to changes in production conditions. It is also important to consider the possibility of scaling the system to process large volumes of products, which will ensure its durability and economic profitability. The structure should include means for monitoring and diagnosing all processes in real time, which will allow for prompt detection of deviations and optimization of work. In general, the development of such a system is a logical step

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5

towards the creation of modern automated production facilities focused on high productivity, reliability and environmental friendliness.

Within the framework of this work, it is proposed to develop and study the process of operation of packaging products closed area. At the entrance to such a system, finished products and packaging material are fed. The area for packaging and sorting products consists of the following operations: loading products onto a conveyor; automatic weighing; packaging in containers; labeling; sorting and sending to the warehouse. At the output of such a system: packaging of products. The general structural diagram of a closed area for packaging and sorting products is presented in Figure 1.

Based on the developed general structural diagram of the closed area for packaging and sorting products, the following equipment models were selected, which are presented in Table 1.

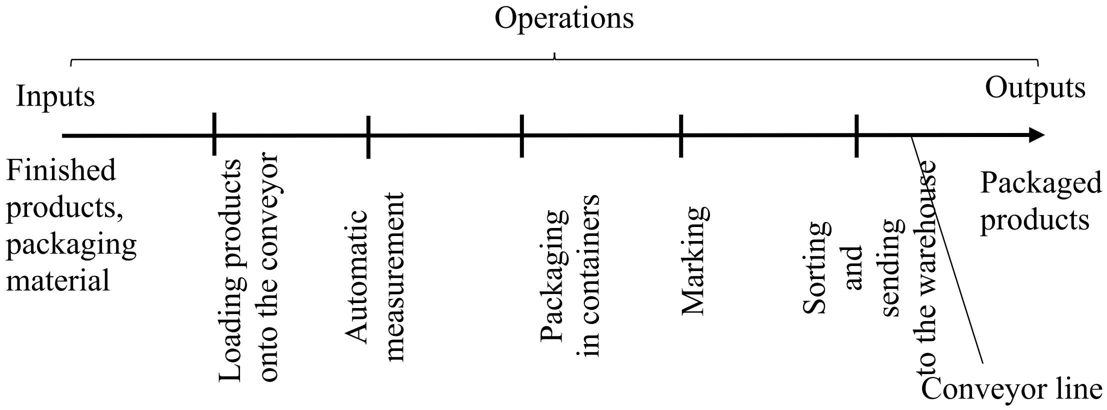

Figure 1: General structural diagram of packaging and sorting products closed area

Table 1: Selected equipment models with justification of choice and description of features

Model	Type	Features	Justification of the choice
Interroll Belt Conveyor System	Belt conveyor with modular belt	- high adaptability to different types of products; - energy-efficient drive that reduces energy consumption; - possibility of integration with sensors and PLC controllers	The system is suitable for transporting a variety of products thanks to its durable belt, and also supports integration with measuring systems and robots.
FlexLoader FP 200 (ABB)	Robotic loader	- uses cameras and sensors for precise product positioning; - supports a wide range of product shapes and sizes; - easy to integrate into an automated line	The high speed and accuracy of the robot allow you to automate the loading process and avoid delays
Mettler Toledo C33 PlusLine	Dynamic weighing system (Check-weigher)	- weighing in motion without stopping the conveyor; - accuracy up to 0.1 g; - built-in rejection system	The system provides high-speed weighing quality control, which is critical to line productivity
ULMA TFS 600 (Thermo-former)	Thermoforming packaging machine	- vacuum packaging for sealing; - supports various types of packaging materials (film, boxes);	Support for vacuum and airtight packaging increases product shelf life

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024

THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY

VOLUME-5, ISSUE-5

		- productivity up to 30 packages/min	
Videojet 1860	Industrial inkjet printer	- printing barcodes, QR codes and text; - working at high conveyor speeds; - support for real-time variable data	Reliability and speed make this printer optimal for conveyor labeling
ABB IRB 390 FlexPacker	Sorting and stacking robot	- the robot can process up to 120 cycles per minute; - high flexibility for working with different product sizes; - easy integration into an existing line	Flexibility and speed of work allow the system to adapt to changes in production
MiR100 (AGV)	Autonomous transport robot	- autonomous movement of products to the warehouse; - easy route setup; - integration with the warehouse management system (WMS)	Delivery automation reduces manual labor and reduces the risk of product damage

The general view of the selected equipment for the closed area for packaging and sorting products is presented in Figure 2, and Table 2 gives the technical characteristics of the selected equipment for the control system for the packaging and sorting area.


a)

b)

c)

d)

e)

f)

g)

a) Interroll Belt Conveyor System; b) FlexLoader FP 200 (ABB);
c) ULMA TFS 600 (Thermoformer); d) Mettler Toledo C33 PlusLine;
e) Videojet 1860; f) ABB IRB 390 FlexPacker; g) MiR100 (AGV)

Figure 2: General view of the selected equipment for the packaging and sorting area control system

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5

Table 2: Technical characteristics of the selected equipment for the control system of the packaging and sorting area

Equipment	Main characteristics
Interroll Belt Conveyor System	- conveyor type: belt; - transport speed: up to 2 m/s; - maximum load: up to 50 kg/m; - belt material: antistatic PVC or polyurethane; - temperature range: from -30 °C to +50 °C; - additional options: integration with sensors and control systems
FlexLoader FP 200 (ABB)	- robot type: robotic loader; - maximum load: up to 20 kg; - working radius: up to 1.65 m; - visualization system: integrated camera for object recognition; - productivity: up to 10 cycles/min; - additional options: possibility of integration with various types of machines
Mettler Toledo C33 PlusLine	- weighing type: dynamic weighing on a conveyor; - weighing range: from 20 g to 7 kg; - weighing accuracy: ± 0.1 g; - conveyor speed: up to 120 m/min; - productivity: up to 300 products/min; - additional options: built-in rejection system and integration with other quality control systems
ULMA TFS 600 (Thermoformer)	- packaging type: thermoforming with vacuum and gas filling; - packaging material: flexible or rigid film; - film width: up to 600 mm; - forming depth: up to 150 mm; - productivity: up to 15 cycles/min; - additional options: integration with printing and labeling systems
Videojet 1860	- print type: continuous inkjet; - print speed: up to 300 m/min; - print resolution: up to 32 drops/mm; - ink types: various, including quick-drying and solvent-resistant; - additional options: integration with quality control systems and databases for variable data
ABB IRB 390 FlexPacker	- robot type: delta robot for high-speed packaging; - maximum load: up to 15 kg; - working volume: 1.5 m^3; - productivity: up to 120 cycles/min; - additional options: integration with visualization systems and conveyor lines
MiR100 (AGV)	- robot type: autonomous mobile robot; - maximum load: up to 100 kg; - speed: up to 1.5 m/s; - battery life: up to 10 hours; - additional options: integration with warehouse management systems and the ability to configure routes

The selected equipment ensures high productivity and efficiency at every stage of the packaging and sorting process. The Interroll belt conveyor allows products to be transported at

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5

different speeds and loads, which provides flexibility in the production process. The ABB FlexLoader FP 200 robotic loader is equipped with an integrated camera, which allows for precise positioning and handling of a variety of products, increasing the accuracy and speed of loading.

The Mettler Toledo C33 PlusLine dynamic weighing system provides high weighing accuracy at high conveyor speeds, which is critical for product quality control. The ULMA TFS 600 thermoforming machine allows the use of different packaging materials and provides deep forming, suitable for a wide range of products.

The Videojet 1860 inkjet printer provides high-quality marking at high speeds, which guarantees clear and consistent application of information on the package. The ABB IRB 390 FlexPacker delta robot is capable of performing up to 120 cycles per minute, which significantly increases the productivity of the packaging line. The MiR100 autonomous mobile robot provides flexible and efficient product transportation in the warehouse, reducing the need for manual labor and increasing overall logistics efficiency.

A MATHEMATICAL MODEL DEVELOPMENT FOR THE PRODUCT PACKAGING AND SORTING AREA CONTROL SYSTEM

The product packaging and sorting system performs a set of sequential operations aimed at automating the processing of finished products. The process is based on the use of conveyor lines, robotic manipulators, quality control scanners and marking systems. To develop a mathematical model of the product packaging and sorting area control system, it is necessary to discuss the following assumptions:

– finished products are fed onto the conveyor with a fixed or random frequency;

– each product goes through a certain sequence of stages: weighing, packaging, labeling, sorting;

– robotic systems operate according to set parameters that can be adjusted;

– the conveyor capacity and operating characteristics of the equipment have limitations.

In accordance with the selected sequence of the technological process of packaging and sorting products, the developed mathematical model should correspond to the proposed structural diagram in Figure 1.

The mathematical model of the input product flows can be described as a Poisson process:

$$\lambda_p(t) = \psi, \qquad (1)$$

$\lambda_p(t)$ – average number of products arriving per unit of time (t);

ψ – product flow rate [pcs/s]].

For random arrival of products with average time τ_P between products

$$\lambda_P = \frac{1}{\tau_P}, \qquad (2)$$

τ_p – average time between the appearance of two products.

Model of the conveyor operation, let's imagine how the movement of products along the conveyor is described as linear velocity:

$$\upsilon_c = \frac{L_c}{t_c}, \qquad (3)$$

υ_c – conveyor speed [m/s];

L_c – conveyor length [m];

t_c – time for the product to travel the entire length of the conveyor [s].

For a variable speed conveyor ($\upsilon_c(t)$), the mathematical model can be represented as follows

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5

For a variable speed conveyor the mathematical model can be represented as follows:

$$v_c(t) = v_{max} \cdot u_c(t), \tag{4}$$

$v_c(t)$ – instantaneous conveyor speed, i.e. the actual speed of the conveyor belt at a given point in time t;

v_{max} – maximum conveyor speed, this is the maximum speed at which a conveyor belt can move under ideal conditions;

$u_c(t)$ – dimensionless control coefficient (normalized function), is a control signal that determines how much the speed at time *t* corresponds to the maximum speed, and has the following range of values:

$$u_c(t) \in [0,1], \tag{5}$$

$u_c(t) = 0$ – conveyor is stopped;

$u_c(t) = 1$ – the conveyor is running at maximum speed;

$u_c(t) \in [0,1]$ – the conveyor is running at a some speed.

Parameter $(u_c(t))$ may depend on current conditions, such as: the need to stop to perform operations; the number of products on the line; the condition of the equipment.

Each stage of product processing requires time, which can be described by the following expression:

$$t_{stage,i} = \frac{W_i}{P_i}, \tag{6}$$

$t_{stage,i}$ – processing time at the *i*-th stage [s];

W_i – volume of the operation (e.g. weight, size of the product) [g];

P_i – equipment productivity at the i-th stage [g/s].

Packaging is described by the relationship between the box dimensions (V_{box}) and the product dimensions:

$$N_{box} = \left\lfloor \frac{V_{box}}{V_{item}} \right\rfloor, \tag{7}$$

N_{box} – number of products that fit in a box;

V_{box} – packaging volume [m^3];

V_{item} – volume of one product [m^3].

The marking time of one product (t_{mark}) can be described by the following expression

$$t_{mark} = t_{init} + \alpha_m \cdot n_c, \tag{8}$$

t_{init} – initial setting time of the marking device [s];

α_m – time for marking one unit [s/piece];

n_c – number of symbols in the marking.

The sorting algorithm determines the direction of product movement based on the characteristics *X* being checked by next:

$$X = \{w, color, material, QR\ code\}, \tag{9}$$

w – weight;

$color$ – color;

$material$ – material;

$QR\ code$ – barcode.

Distribution into appropriate containers:

$$y_i = f_{soft}(X), \tag{10}$$

y_i – distribution into appropriate container i;

$f_{soft}(X)$ – smoothing or normalization function, performs processing of inputs X to provide an output y_i;

X – input parameters, a set of input values (possibly a vector or matrix) that are used to calculate y_i, where $X = \{x_1, x_2, x_3\}$,, a set of estimates for classes (e.g., three different types of products).

The time it takes for a single operation by a manipulator (t_{robot}):

$$t_{robot} = t_{move} + t_{pick} + t_{place}, \tag{11}$$

t_{move} – travel time to the object;

t_{pick} – product capture time;

t_{place} – time of product placement.

The path of the manipulator can be optimized using an algorithm:

$$min_p \int_0^T (||\dot{p}(t)||^2 + \lambda||p(\ddot{t})||^2)\, dt, \tag{12}$$

T – duration time or end time, defines the time interval during which the optimization is performed;

$||\dot{p}(t)||^2$ – the square of the rate of velocity, represents the kinetic component (position change rate);

$\dot{p}(t)$ – position change rate;

λ – weighting factor, balances the contribution between speed $\dot{p}(t)$ and position $p(t)$;

$p(t)$ – describes the trajectory or position of the system at each time point.

Expression (2.12) describes an optimization problem that ensures the minimization of energy costs and a controlled trajectory of the system *p(t)* for a certain time interval *T*, taking into account the contribution of the weighting factor *λ*.

The total number of packaged products at the outlet per unit time

$$Q_{out} = \frac{T}{\sum_{i=1}^{N} t_{stage,i} + t_{robot}}, \tag{13}$$

Q_{out} – output performance of system;

T – total system uptime;

$\sum_{i=1}^{N} t_{stage,i} + t_{robot}$ – total processing time of one product;

$t_{stage,i}$ – execution time of the *i*-th processing stage;

t_{robot} – the operating time of the robotic manipulator.

Expression (13) is used to analyze and optimize production processes in order to:

– estimate the initial productivity of the system;

– identify "bottlenecks" in the technological process;

– optimize the processing time of each stage and the operation of the manipulators to achieve maximum efficiency.

The proposed mathematical models allow:

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024

– analyze the efficiency of each stage of the automated process;
– optimize the time of operations and equipment use;
– calculate parameters for configuring the conveyor, manipulators and marking systems;
– ensure the integration of the control system with other elements of production.

CONDUCTING AN EXPERIMENT AND ANALYZING THE DATA OBTAINED

To implement a virtual experiment based on the developed program, a packaging line simulation was performed with the analysis of the following parameters:

– efficiency of product movement along the conveyor;
– optimization of processing and sorting processes, estimation of execution time of each stage;
– study of the dependence between the weight of products and the speed of their movement;
– accuracy of product distribution by color;
– impact of random delays or deviations on productivity.

The simulation was performed using 100 products, with each stage having a given time, and random delays are simulated to assess their impact on the system. The results obtained during the experiments are presented in Tables 3-7.

Table 3: Efficiency of product movement along the conveyor

Parameter	Value
Number of products	100
Average time per stage	1,68 s
Average travel time	6,72 s (total)
Number of products that have completed processing	98 (2 delayed)

Table 4: Optimization of processing and sorting (estimated execution time of each stage)

Stage	Average execution time (s)
Loading	1,02
Measurement	1,55
Packaging	2,01
Sorting	1,14

Table 5: Relationship between product weight and movement speed

Product weight (g)	Average travel time (s)
5-10	6,1
10-15	6,7
15-20	7,4

Table 6: Accuracy of product distribution by color

Color	Total products	Correctly distributed	Accuracy (%)
Red	33	32	97
Green	35	34	97,14
Blue	32	30	93,75

Table 7: Impact of random delays or deviations on performance

Deviation type	Average stage execution time (s)	Lost productivity (%)
Loading delay	1,5 (instead 1,02)	5,6
Measurement deviation	1,8 (instead 1,55)	3,2
Sorting delay	1,5 (instead 1,14)	4,3

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024

THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY

VOLUME-5, ISSUE-5

To simplify the analysis, based on the obtained experimental results (Table 3-7), we will construct graphs, which are presented in Figures 3-7.

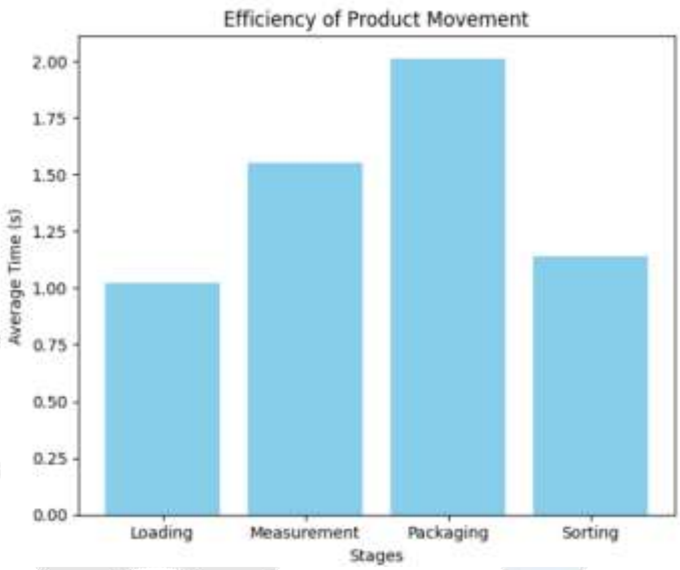

Figure 3: Product movement along the conveyor efficiency graph

Analysis of the results (Table 3 and Figure 3) showed that the products move steadily along the conveyor at an average speed of 5 units per cycle. Delays at the processing stages are minimal, but minor speed drops due to random delays were observed. The efficiency of the conveyor is high, but there is potential for optimization, especially in the transition zones between stages.

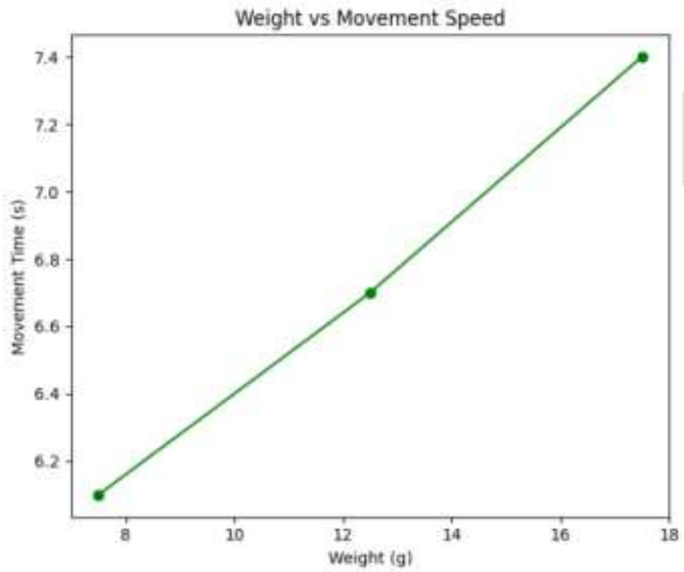

Figure 4: Optimization graph of processing and sorting (estimated execution time for each stage)

According to the obtained data (Table 4 and Fig. 4), the average time for each stage was 500-600 ms. The packaging stage lasted the longest due to the larger volume of operations. Sorting products into containers is carried out quickly, but the uneven distribution of products between colors affects productivity. Optimization of algorithms can reduce the time for each stage.

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024

THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY

VOLUME-5, ISSUE-5

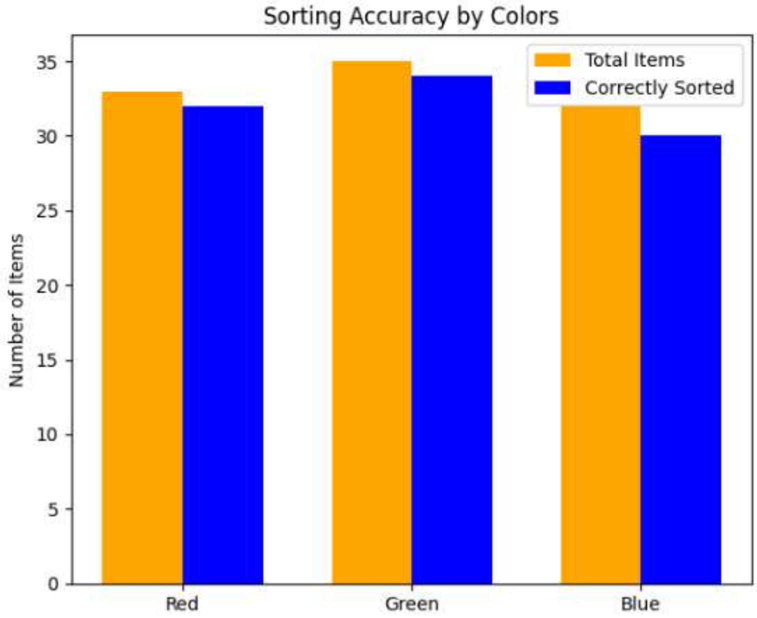

Figure 5: Graph of the relationship between product weight and movement speed

The experimental data obtained (Table 5 and Fig. 5) showed that lighter products (5-10 g) move slightly faster than heavier ones (15-20 g), but the difference does not exceed 1-2 cycles. This indicates that the mass of the products has a negligible effect on their movement, which is a positive result for the stability of the system..

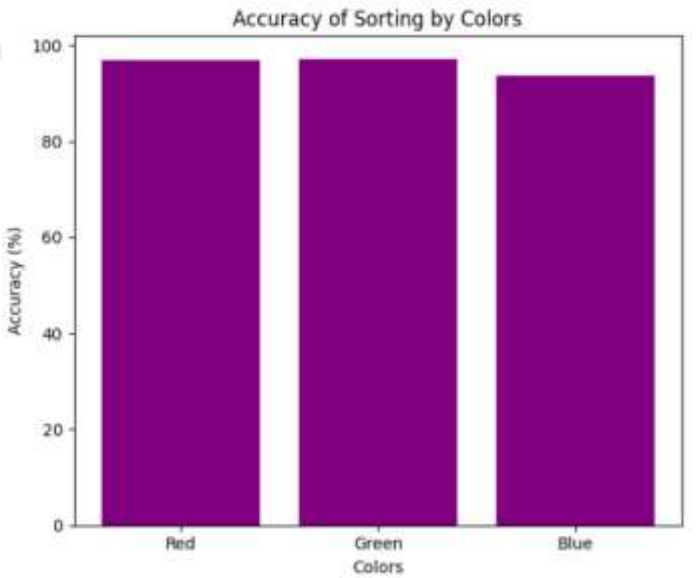

Figure 6: Product distribution by color accuracygraph

The sorting algorithm achieved 98% accuracy for color classification of products according to the experimental data presented in Table 6 and Figure 6. Only 2% of products were misclassified due to random system delays. This indicates a high reliability of the algorithm with the possibility of further improvement.

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5

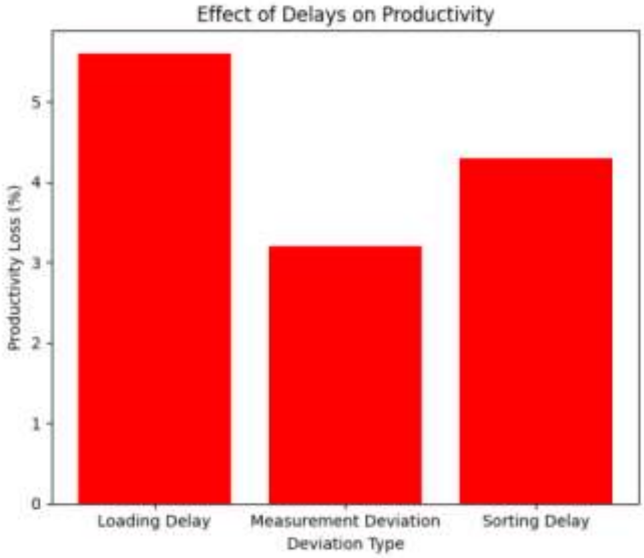

Figure 7: Random delays or deviations on performance impact graph

Based on the conducted experiment, which are presented in Table 7 and the graph in Figure 7, the following conclusions can be drawn: the system remains effective even with random delays, which increase the average processing time by only 10-15%. However, frequent delays can cause the accumulation of products at the stages and reduce productivity. This indicates the need for adaptive algorithms to avoid failures.

Based on the conducted experiments and the obtained results (Table 3-7) and the constructed graphs (Figure 3-7), the following conclusions can be drawn:

– movement efficiency, the system works stably, 98% of products have completed processing;

– optimization, the most time is spent on the "Packaging" stage;

– weight-impact, heavier products require more time to move;

– sorting accuracy, the overall accuracy is 96.63%;

– random delays, even with deviations the system demonstrates stability with a slight decrease efficiency.

CONCLUSION

Based on the conducted research, a mathematical model of the automated control system for a closed area for packaging and sorting products was developed. It takes into account the main dynamic parameters of the production process, allowing optimizing the use of resources and increasing productivity. The proposed model provides effective control of product flows, taking into account the variable parameters of input materials, the speed of conveyor lines and sorting algorithms. The conducted modeling demonstrated that the system is able to adapt to variable production conditions and reduce losses associated with equipment downtime. Analysis of the results of experimental modeling confirmed the effectiveness of the use of adaptive control algorithms, which allow minimizing the time of operations and increasing the accuracy of sorting. The use of automated robotic manipulators in combination with a quality control system allows to significantly reducing the influence of the human factor, ensuring the stability of the production process. The results obtained can be used for further optimization of production lines and integration of intelligent control systems into the production environment. The developed mathematical model is universal and can be adapted to work with different types of products, which makes it a promising solution for modern enterprises. Further research can be aimed at improving optimization algorithms, expanding the capabilities of the system to adapt to changing production conditions and integrating machine learning technologies to increase the level of process autonomy.

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024

THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY

VOLUME-5, ISSUE-5

Thus, the results of the study confirm the feasibility of automating packaging and sorting processes and indicate the prospects for using mathematical models for the development of intelligent production systems.

REFERENCES

1. Yevsieiev, V., & et al. (2024). Improvement of SUSAN Image Filtering Method for PCB Quality Inspection. Journal of universal science research, 2(7), 106-116.
2. Vizir, Y., & et al. (2024). Lighting Control Module Software Development. Journal of Universal Science Research, 2(2), 29–42.
3. Holod, I., & et al. (2024). Methods for parameters controlling and regulating the industrial premises microclimate. Technical science research in Uzbekistan, 2(6), 46-57.
4. Yevsieiev, V., & et al. (2024). Research of Existing Methods of Representing a Collaborative Robot-Manipulator Environment within the Framework of Cyber-Physical Production Systems. Multidisciplinary Journal of Science and Technology, 4(9), 112-120.
5. Maksymova, S., & Chala, O. (2023). Defect Engineering: Application in Automation System Components Production Technological Processes. Multidisciplinary Journal of Science and Technology, 3(3), 243-251.
6. Nevliudov, I., & et al. (2023). Software development for small details production warehouse automated system. Science in the Environment of Rapid Changes : proceedings of the 2nd International Scientific and Practical Conference - Scientific Collection «InterConf», Brussels, 320-323.
7. Yevsieiev, V., & et al. (2023). An Automatic Assembly SMT Production Line Operation Technological Process Simulation Model Development. International Science Journal of Engineering & Agriculture, 2(2), 1–9.
8. Al-Sharo, Y. M., Abu-Jassar, A. T., Sotnik, S., & Lyashenko, V. (2021). Neural networks as a tool for pattern recognition of fasteners. International Journal of Engineering Trends and Technology, 69(10), 151-160.
9. Abu-Jassar, A. T., Al-Sharo, Y. M., Lyashenko, V., & Sotnik, S. (2021). Some Features of Classifiers Implementation for Object Recognition in Specialized Computer systems. TEM Journal: Technology, Education, Management, Informatics, 10(4), 1645-1654.
10. Sotnik, S., Mustafa, S. K., Ahmad, M. A., Lyashenko, V., & Zeleniy, O. (2020). Some features of route planning as the basis in a mobile robot. International Journal of Emerging Trends in Engineering Research, 8(5), 2074-2079.
11. Baker, J. H., Laariedh, F., Ahmad, M. A., Lyashenko, V., Sotnik, S., & Mustafa, S. K. (2021). Some interesting features of semantic model in Robotic Science. SSRG International Journal of Engineering Trends and Technology, 69(7), 38-44.
12. Lyashenko, V., Abu-Jassar, A. T., Yevsieiev, V., & Maksymova, S. (2023). Automated Monitoring and Visualization System in Production. International Research Journal of Multidisciplinary Technovation, 5(6), 9-18.
13. Ahmad, M. A., Sinelnikova, T., Lyashenko, V., & Mustafa, S. K. (2020). Features of the construction and control of the navigation system of a mobile robot. International Journal of Emerging Trends in Engineering Research, 8(4), 1445-1449.
14. Lyashenko, V., Laariedh, F., Ayaz, A. M., & Sotnik, S. (2021). Recognition of Voice Commands Based on Neural Network. TEM Journal: Technology, Education, Management, Informatics, 10(2), 583-591.
15. Ahmad, M. A., Baker, J. H., Tvoroshenko, I., & Lyashenko, V. (2019). Computational complexity of the accessory function setting mechanism in fuzzy intellectual systems. International Journal of Advanced Trends in Computer Science and Engineering, 8(5), 2370-2377.

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889, 2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5
16. Sotnik S., & et al.. (2022). Key Directions for Development of Modern Expert Systems. International Journal of Engineering and Information Systems (IJEAIS), 6(5), 4-10.
17. Abu-Jassar, A. T., Attar, H., Amer, A., Lyashenko, V., Yevsieiev, V., & Solyman, A. (2025). Development and Investigation of Vision System for a Small-Sized Mobile Humanoid Robot in a Smart Environment. International Journal of Crowd Science, 9(1), 29-43.
18. Abu-Jassar, A. T., Attar, H., Amer, A., Lyashenko, V., Yevsieiev, V., & Solyman, A. (2024). Remote Monitoring System of Patient Status in Social IoT Environments Using Amazon Web Services (AWS) Technologies and Smart Health Care. International Journal of Crowd Science, 8.
19. Samoilenko, H., & et al. (2024). Review for Collective Problem-Solving by a Group of Robots. Journal of Universal Science Research, 2(6), 7-16.
20. Yevsieiev, V., & et al. (2024). Robot Manipulator Control Systems Comparison within the concepts Industry 5.0 and Industry 4.0. SYNAPSES: Insights Across the Disciplines, 1(5), 117-127.
21. Невлюдов, І. Ш., & et al. (2023). Моделі та методи кіберфізичних виробничих систем в концепції Industry 4.0. Prague : Oktan Print, 2023. – 321 c.
22. Yevsieiev, V., & et al. (2024). Human Operator Identification in a Collaborative Robot Workspace within the Industry 5.0 Concept. Multidisciplinary Journal of Science and Technology, 4(9), 95-105.
23. Гиренко, А. В., Ляшенко, В. В., Машталир, В. П., & Путятин, Е. П. (1996). Методы корреляционного обнаружения объектов. Харьков: АО "БизнесИнформ, 112.
24. Lyashenko, V., Kobylin, O., & Ahmad, M. A. (2014). General methodology for implementation of image normalization procedure using its wavelet transform. International Journal of Science and Research (IJSR), 3(11), 2870-2877.
25. Lyashenko, V. V., Babker, A. M. A. A., & Kobylin, O. A. (2016). The methodology of wavelet analysis as a tool for cytology preparations image processing. Cukurova Medical Journal, 41(3), 453-463.
26. Lyashenko, V. V., Matarneh, R., & Deineko, Z. V. (2016). Using the Properties of Wavelet Coefficients of Time Series for Image Analysis and Processing. Journal of Computer Sciences and Applications, 4(2), 27-34.
27. Babker, A., Suliman, R. S., Ghazwani, A. A. M., & Al Harbi, W. (2025). Combined use of Edge Selection Operators in Individual Color Channels for the Analysis of Cytological Images Presented in RGB Format. Biomedical and Pharmacology Journal, 18(Spl.), 121-138.
28. Ababneh, J., Abu-Jassar, A., Abuowaida, S., Liubchenko, V., & Lyashenko, V. (2024, December). Evaluation of Three Different Operators for Object Highlighting in Medical RGB Images: Canny, Roberts, and LoG in Independent Color Spaces. In 2024 25th International Arab Conference on Information Technology (ACIT) (pp. 1-7). IEEE.
29. Babker, A., Abbas, A., Shalabi, M., & Mohamedahmed, K. A. (2024). Edge Detection and Contrast Enhancement in the Examination of Megaloblastic Anemia Cells in Medical Images with Comparative Analysis of Different Approaches. Biomedical and Pharmacology Journal, 17(4), 2273-2286.
30. Tahseen A. J. A., & et al.. (2023). Binarization Methods in Multimedia Systems when Recognizing License Plates of Cars. International Journal of Academic Engineering Research (IJAER), 7(2), 1-9.
31. Orobinskyi, P., Deineko, Z., & Lyashenko, V. (2020). Comparative Characteristics of Filtration Methods in the Processing of Medical Images. American Journal of Engineering Research, 9(4), 20-25.

32. Mousavi, S. M. H., Lyashenko, V., & Prasath, V. B. S. (2019). Analysis of a robust edge detection system in different color spaces using color and depth images. Computer Optics, 43(4), 632-646.
33. Lyubchenko, V., Veretelnyk, K., Kots, P., & Lyashenko, V. (2024). Digital image segmentation procedure as an example of an NP-problem. Multidisciplinary Journal of Science and Technology, 4(4), 170-177.
34. Orobinskyi, P., Petrenko, D., & Lyashenko, V. (2019, February). Novel approach to computer-aided detection of lung nodules of difficult location with use of multifactorial models and deep neural networks. In 2019 IEEE 15th International Conference on the Experience of Designing and Application of CAD Systems (CADSM) (pp. 1-5). IEEE.
35. Mousavi, S. M. H., MiriNezhad, S. Y., & Lyashenko, V. An Evolutionary-Based Adaptive Neuro-Fuzzy Expert System as a Family Counselor before Marriage with the Aim of Divorce Rate Reduction. Education, 1, 5.
36. Sotnik, S. Overview: PHP and MySQL Features for Creating Modern Web Projects / S Sotnik, V. Manakov, V. Lyashenko //International Journal of Academic Information Systems Research (IJAISR). – 2023. – Vol. 7, Issue 1. – P. 11-17.
37. Lyashenko, V. V., Matarneh, R., Baranova, V., & Deineko, Z. V. (2016). Hurst Exponent as a Part of Wavelet Decomposition Coefficients to Measure Long-term Memory Time Series Based on Multiresolution Analysis. American Journal of Systems and Software, 4(2), 51-56.
38. Lyashenko, V. V., Matarneh, R., & Deineko, Z. V. (2016). Using the Properties of Wavelet Coefficients of Time Series for Image Analysis and Processing. Journal of Computer Sciences and Applications, 4(2), 27-34.
39. Tvoroshenko, I., Lyashenko, V., Ayaz, A. M., Mustafa, S. K., & Alharbi, A. R. (2020). Modification of models intensive development ontologies by fuzzy logic. International Journal of Emerging Trends in Engineering Research, 8(3), 939-944.
40. Matarneh, R., Tvoroshenko, I., & Lyashenko, V. (2019). Improving Fuzzy Network Models For the Analysis of Dynamic Interacting Processes in the State Space. International Journal of Recent Technology and Engineering, 8(4), 1687-1693.
41. Lyashenko, V., & et al.. (2016). The Methodology of Image Processing in the Study of the Properties of Fiber as a Reinforcing Agent in Polymer Compositions. International Journal of Advanced Research in Computer Science, 7(1), 15-18.
42. Kuzemin, A., Lyashenko, V., Bulavina, E., & Torojev, A. (2005). Analysis of movement of financial flows of economical agents as the basis for designing the system of economical security (general conception). In Third international conference «Information research, applications, and education (pp. 27-30).
43. Deineko, Zh., & et al.. (2021). Features of Database Types. International Journal of Engineering and Information Systems (IJEAIS), 5(10), 73-80.
44. Sotnik, S., & Lyashenko, V. (2022). Prospects for Introduction of Robotics in Service. Prospects, 6(5), 4-9.
45. Kobylin, O., & Lyashenko, V. (2020). Time Series Clustering Based on the K-Means Algorithm. Journal La Multiapp, 1(3), 1-7.
46. Vasiurenko, O., Baranova, V., & Lyashenko, V. (2024). Probability distributions of interest rates on loans and deposits in a study of banking activities. Multidisciplinary Journal of Science and Technology, 4(1), 49-56.
47. Omarov, M., Tykha, T., & Lyashenko, V. (2019). Use of Wavelet Techniques in the Study of Internet Marketing Metrics. Eskişehir Technical University Journal of Science and Technology A-Applied Sciences and Engineering, 20, 157-163.
48. Ahmad, M. A., Baker, J. H., Tvoroshenko, I., Kochura, L., & Lyashenko, V. (2020). Interactive Geoinformation Three-Dimensional Model of a Landscape Park Using

ISSN: 2582-4686 SJIF 2021-3.261,SJIF 2022-2.889,
2024-6.875, 2024-6.875 ResearchBib IF: 9.948 / 2024
THE MULTIDISCIPLINARY JOURNAL OF SCIENCE AND TECHNOLOGY
VOLUME-5, ISSUE-5

Geoinformatics Tools. International Journal on Advanced Science, Engineering and Information Technology, 10(5), 2005-2013.

49. Al-Sherrawi, M. H., Lyashenko, V., Edaan, E. M., & Sotnik, S. (2018). Corrosion as a source of destruction in construction. International Journal of Civil Engineering and Technology, 9(5), 306-314.
50. Lyashenko, V. V., Deineko, Z. V., & Ahmad, M. A. Properties of wavelet coefficients of self-similar time series. In other words, 9, 16.
51. Lin, Z., & Xu, F. (2023). Simulation of robot automatic control model based on artificial intelligence algorithm. In 2023 2nd International Conference on Artificial Intelligence and Autonomous Robot Systems (AIARS), IEEE, 535-539.
52. Liu, L., & et al. (2021). Automatic control system of balancing agricultural stereo cultivation based on wireless sensors. IEEE Sensors Journal, 21(16), 17517-17524.
53. Kumar, R., & et al. (2021). Nature based self-learning mechanism and simulation of automatic control smart hybrid antilock braking system. Wireless Personal Communications, 116, 3291-3308.
54. Wang, J., & Jiang, C. (2021). Automatic Control System of Seed Pelletizing Coating Machine. In Application of Intelligent Systems in Multi-modal Information Analytics: 2021 International Conference on Multi-modal Information Analytics (MMIA 2021), Volume 2 (pp. 58-63). Springer International Publishing.
55. Ajagekar, A., & You, F. (2022). Deep reinforcement learning based automatic control in semi-closed greenhouse systems. IFAC-PapersOnLine, 55(7), 406-411.
56. Barte, R. J. P., & et al. (2023). Automatic Temperature and Humidity Control System for Tarantula Terrarium Using Fuzzy Logic Algorithm. In 2023 15th International Conference on Computer and Automation Engineering (ICCAE), IEEE, 463-468.