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Optimization of the Conveyor Line System Using Computer Simulation on the Example of a Modern Warehouse

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ABSTRACT

The paper presents a outline of a modern large-area warehouse of an enterprise engaged in the sale of, among others, food products, software, books, automotive components, and many others. The techniques, methods, research and design tools used were described. A control system was designed, its plan and network connections of control devices based on the characteristics of technological documentation. The design of logical structures controlling the conveyor line, network topology configuration and also the safety system was proposed. The performance and errors of the line were checked in the simulation process. The paper also includes the process of commissioning and testing an industrial PLC (Programmable Logic Controller) on a real object, which is a modern warehouse.

Keywords: conveyor, industrial automation, PLC, SCADA, modern warehouse.

INTRODUCTION

Nowadays, automation is a growing trend in enterprises, especially with use of dedicated systems [1]. It is a basic procedure very often requiring the adaptation of simulation systems and caused not only by economic but also by efficiency factors [2, 3]. This solution works well in large warehouses when transporting small and medium-sized products. Automation affects more accurate planning of the transport process, shortens the time of order preparation, and allows for greater product control during production and further storage [4–5]. It completely eliminates manual work and the use of, for example, forklift trucks, which reduces human error. The more complex processes are used, the more effective transport will be. The transport of goods can be expanded by tracking parcels, labeling or sorting on the basis of cameras and scanners [6–9].

Automation of transport in the warehouse sector allows you to increase the company's profits, transport efficiency, prevent the loss of parcels and avoid their damage. By additional automation of the stages of storage and shipping, employees can be relieved of monotonous activities during transport service, which will limit them only to supplementing the package with goods in accordance with the order, along with securing and packing the package for the time of transport [10–12].

There are some things you should pay attention to when designing transport by conveyors. The most important is the economic factor. Automation forces higher costs, which will pay off after an appropriate time with the assumed line efficiency, with lower costs may not pay off and it will be more economical to find other options [13–16]. In addition, taking into account the reliability of the control systems (e.g., through appropriate diagnostic techniques), a system with very high efficiency can be achieved [17–18].

Scanning, labeling or choosing the right destination of the parcel when subjected to automation can be excluded from the competence of employees. The fully automated system allows for monitoring all transport parameters through visualization using SCADA (Supervisory Control And Data Acquisition) supervision systems. Thanks to them it is possible to obtain supervision over failures, equipment errors, efficiency and information on line filling [19–21].

This requires the preparation of control logic. In the industry, the most often chosen for such tasks are industrial PLCs, which need communication with the executive and control devices to operate. The program needs to be tested already at the stage of simulation but also during start-up. This gives confidence that the system is completely safe for the environment, and also works as expected by the customer [22–26].

METHODOLOGY

The described control system was designed using TIA Portal V16 software. This software is used to create and test PLC (Programmable Logic Controller) program code in LAD (Ladder diagram) language. The code program was implemented in the S7–1500 CPU 1517F-3 controller by Siemens [27–28]. Another software for designing the control system is 'Emulate 3D'. This software allows you to virtually test the logic of the system's operation. Control simulation saves time before entering the construction site. It shortens the project's critical path as well as the total testing time. The program works with the rules of physics, so you can see every smallest error in the program.

At the beginning, before starting the design of the control system, it is necessary to configure the CPU (Central Processing Unit), i.e. to select the appropriate type of PLC controller (Fig. 1), and then map the Profinet network topology (Fig. 2).

Properly designed network topology in the software enables the correct exchange of signals between devices of the control system.

The next step is to create an appropriate program structure in the 'TIA Portal V16' software. To ensure transparency, the program is divided into sections, each of which is responsible for a separate control segment. The relationships between the program sections and the scope of their activities are presented in Figure 3.

The safety section protects the surroundings and people in the vicinity of the control system. The manufacturer of Siemens controllers has prepared additional modules to support this functionality. The system structure is based on a local solution, that secures the connection of power contactors in a local conveyor line, and a global solution, which includes dedicated Safety controllers that support the overall safety system in the enterprise and send the superior line readiness status defined in groups. Master controller groups are high when no safety switch is pressed.

The power section is responsible for servicing the condition and availability of Profinet devices, servicing the condition of electrical devices

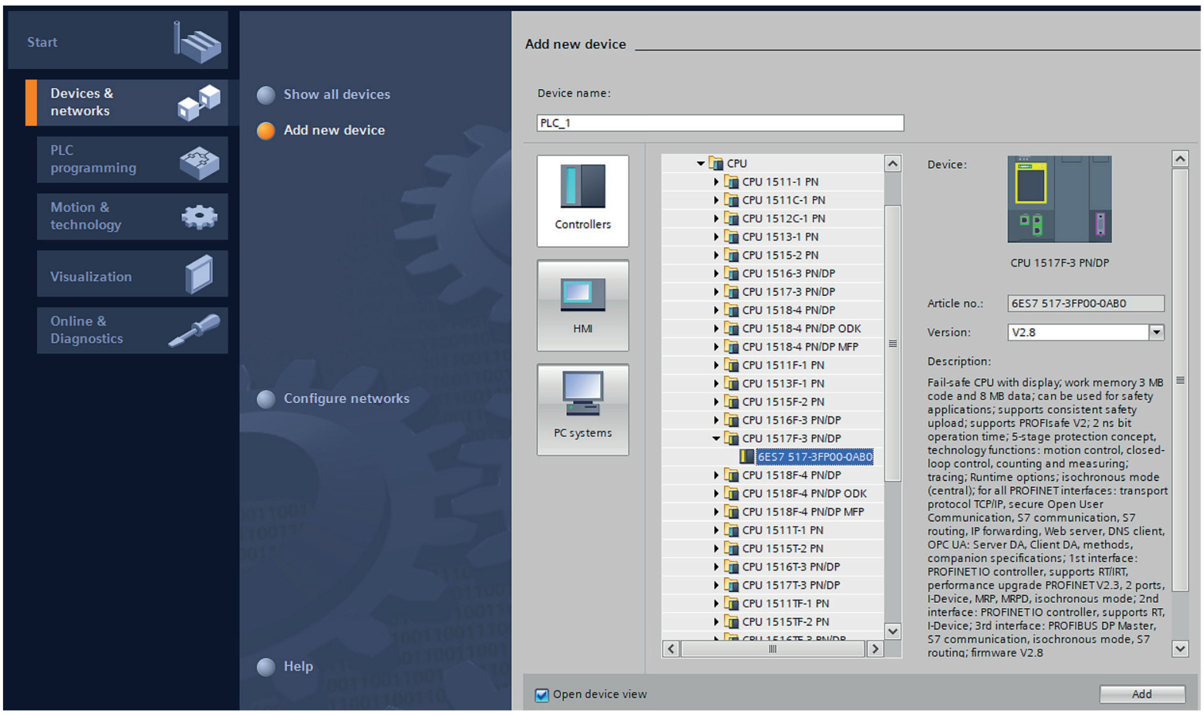

Fig. 1. Adding a controller to the project

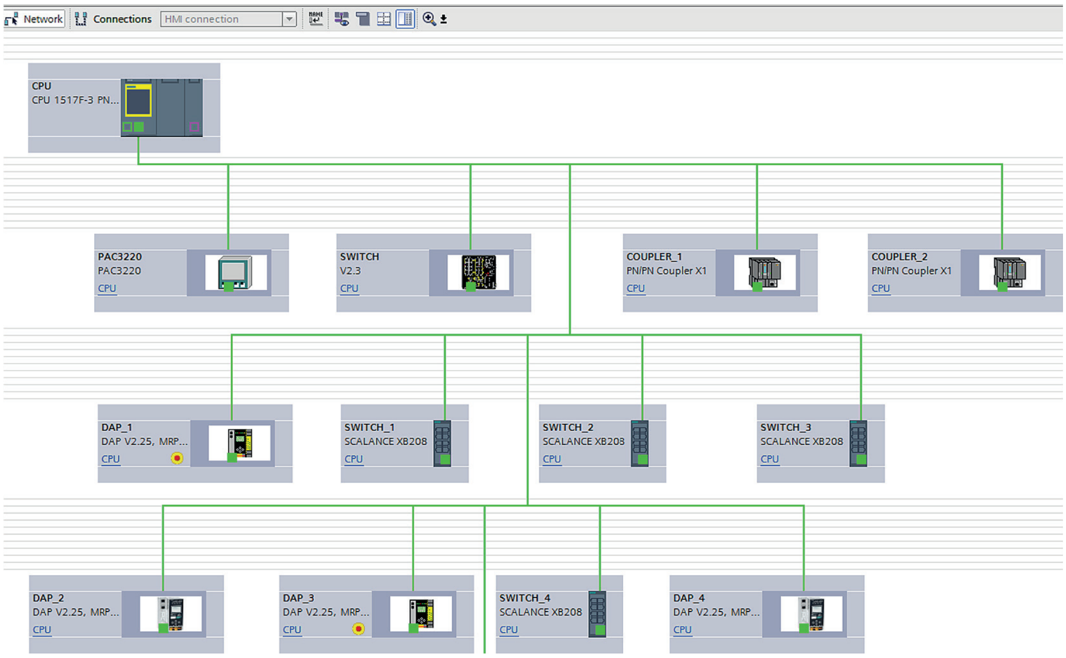

Fig. 2. Mapping of network topology by connecting devices to the appropriate ports

such as: surge arrester, network parameter meter, circuit residual current devices, error reset, start and stop. The system section is responsible for controlling the conveyors. It contains information on the operation of the conveyor, sensors and bits needed for data exchange between the conveyors of the system.

The recommended method of programming in SIMATIC S7 controllers is application block architecture, using the structure of OB (organization block), FB (function block), DB (data block) program blocks, FC (function) and their instances, as this method allows a clearer view of the process control and allows for faster and more efficient testing of individual components process, also allows the resulting structures to be reused in another project after prior configuration. An additional advantage of such architecture is the ability to divide the program into functions and sub-functions to be able to use them repeatedly changing only the input parameters. This is especially effective in for repetitive control tasks. The program should also be divided into sections, i.e. program blocks that will concern individual process fragments and allow you to quickly locate program fragments responsible for controlling individual processes / devices. Structures such as data blocks and FB block instances can be arranged separately directories. It is not recommended to use a linear architecture based on a program written in one block "line by line" because the control implemented in this way makes the program less transparent, more difficult to edit and modify, and additionally the risk of making a mistake increases significantly. The manufacturer of the SIMATIC 7 software recommends the use

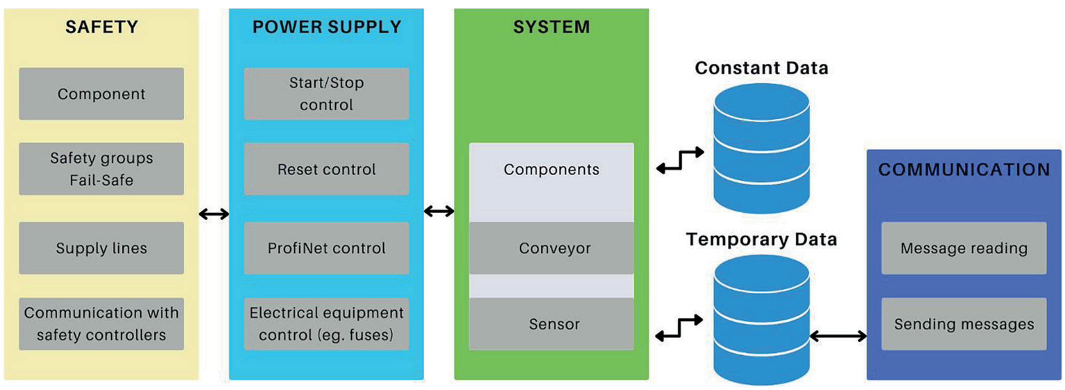

Fig. 3. Structure of the control program and its dependencies

of block architecture properties such as the ability to use organizational blocks.

Then the control system is simulated. This process is based on simulating the operation of the system in real time, taking into account the physics of objects and interactions between the elements of the system. The 'Emulate 3D' software allows you to import the CAD (Computer Aided Design) model of the conveyor lines, simulating the signals of the devices in the system, which are then processed by the controller. The use of a 3D model provides realistic feedback on the course of processes in the control system. The control system simulation is used for the purposes of:

- Reducing the commissioning time, hence faster implementation time and lower costs,
- Checking whether the required parameters have been met by the control system,
- Verification of the correctness of the displayed SCADA system messages,
- Detection of errors in the program such as wrong naming of variables, incorrect placement of them or much more serious problems that result from wrong assumptions or incorrect logic when writing the program,
- Testing various software solutions without being on a physical site. This allows for a reliable verification of program assumptions and the transformation of the program if necessary. Such testing gives much more confidence when starting the system, which allows you to find electrical or mechanical problems,
- Checking the operation of the system in extreme conditions, which are difficult to obtain in a real system. Such situations may only occur when operating at full capacity of the system, but achieving such conditions actually involves high costs. To create such conditions, a large number of people are needed to deliver and receive transport units such as containers or parcels of various sizes, which takes many hours. In the event of an error, the entire process should be repeated which takes a few more hours. Repeating the situation is not a problem during the simulation, and it also takes a few minutes.

To run the simulation a PLC of the same type as selected in the project is needed. Use the IO-Supervisor computer to load the program into its memory. It has the TIA Portal software through which it manages the project and introduces changes. The programmable controller communicates with a computer containing the Emulate 3D simulation program, which simulates the signals used in the control system (Figs. 4, 5) [29].

The next and final stage of commissioning is about the automation process. After completing this stage, the control system is collected by the customer and operated. During this stage, the correctness of the program operation, the device configuration and the safety of the control system for the operators are verified.

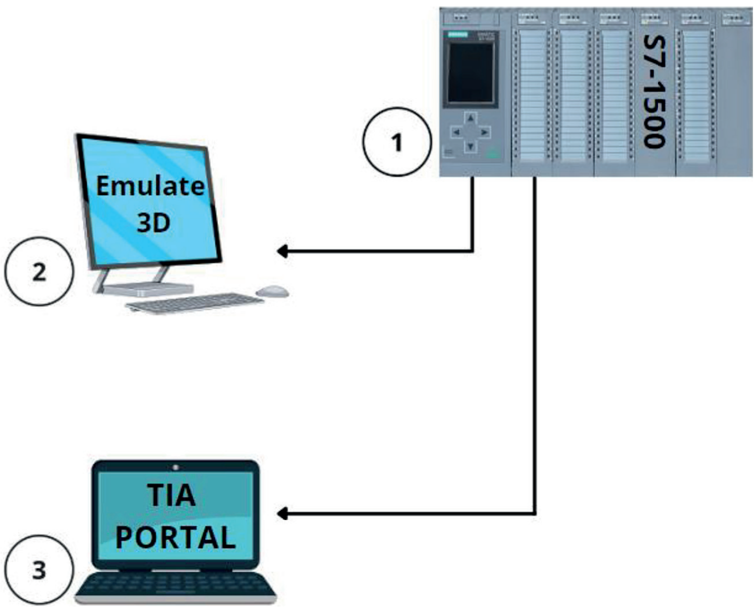

Fig. 4. Diagram of the simulation stand: 1 – S7–1500 PLC controller, 2 – computer with Emulate 3D program, 3 – IO-Supervisor laptop

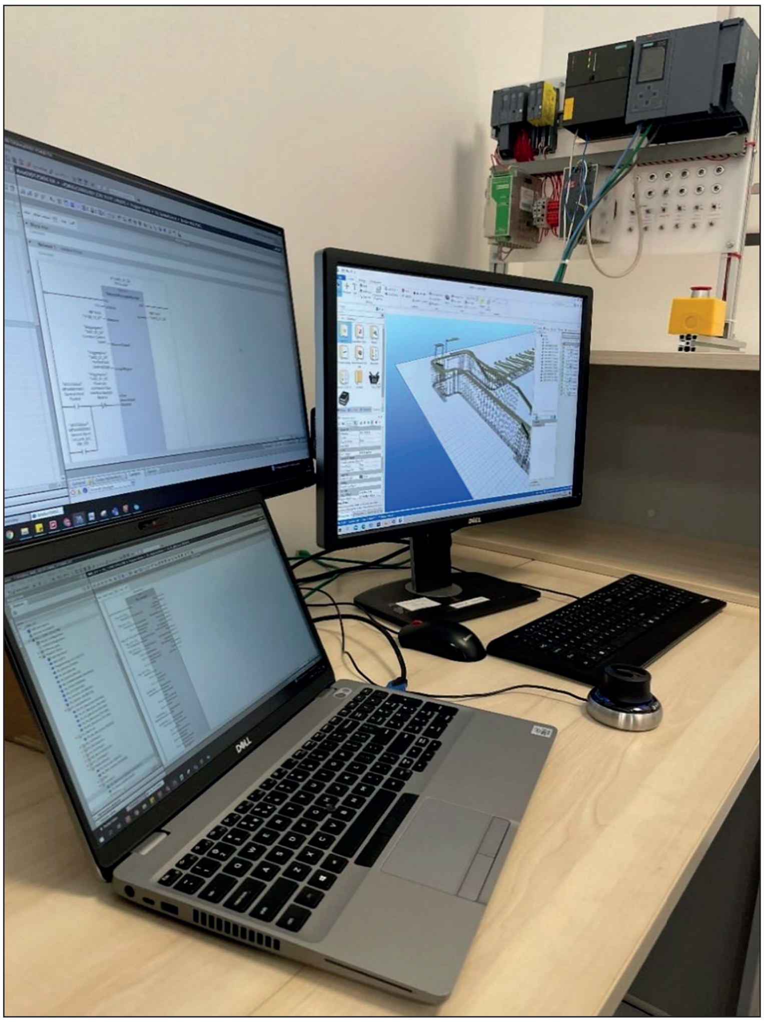

Fig. 5. Simulation station

The basic thing that should be checked immediately after uploading the program to the PLC controller is the diagnosis of connections of Profinet devices:

- are the devices available,
- are they working properly,
- whether they are properly connected.

Then, diagnostics of connections of Pro fi net devices should be carried out through the 'TIA Portal V16' or 'Proneta' software. These software will show the correctness of the IP addresses of the individual devices as well as the card ranges of the input and output modules. In case of any irregularities, the Pro fi net network devices will report problems.

The control system has a "Safety" system. By controlling the switching of the coils of the power contactors, it provides protection of the power supply to the main voltage lines. According to the written logic, "Safety" groups come from superior PLC controllers responsible for safety in a given area. They support emergency stops that decide which contactor coils are to be closed. It should be checked whether the conveyors located in the area of a given emergency stop switch lose power when the appropriate contactor is turned off (Fig. 6).

Then the optical sensors should be checked and correctly set up (Fig. 7). Each of the optical sensors shall be set to receive a reflection signal from the mirror. The last and important step is to tighten the fastening screw firmly, because the conveyor generates high vibrations during operation, which may, in the case of insufficient tightening, lead to loosening of the screw and loss of signal. In the control system, each conveyor has one optical sensor.

The next step is to check the conveyors and their parameterization. Their parameters should be verified and compared before uploading to their memory in accordance with the documentation of the conveyors, which contains their

Fig. 6. Contactors supplying the respective conveyors

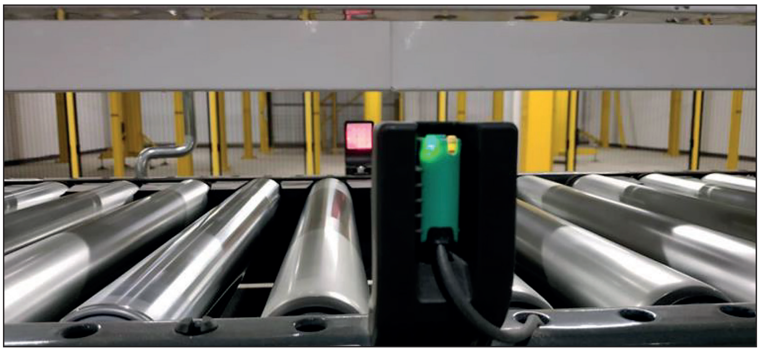

Fig. 7. Correct setting of the optical sensor

detailed values. Values such as speed, acceleration, power and rated current, among others, must be the same. The parameters are uploaded using the 'Nordcon' program (Fig. 8). Additionally, the frequency inverters are parameterized using device pins that correspond to the drive power.

Then, the current state of the conveyor input signals should be verified. If they are powered with voltage and correctly parameterized, they emit a "ready" signal. If this input signal is not exposed, the electrical connections should be checked. Checking the signals of the transporters

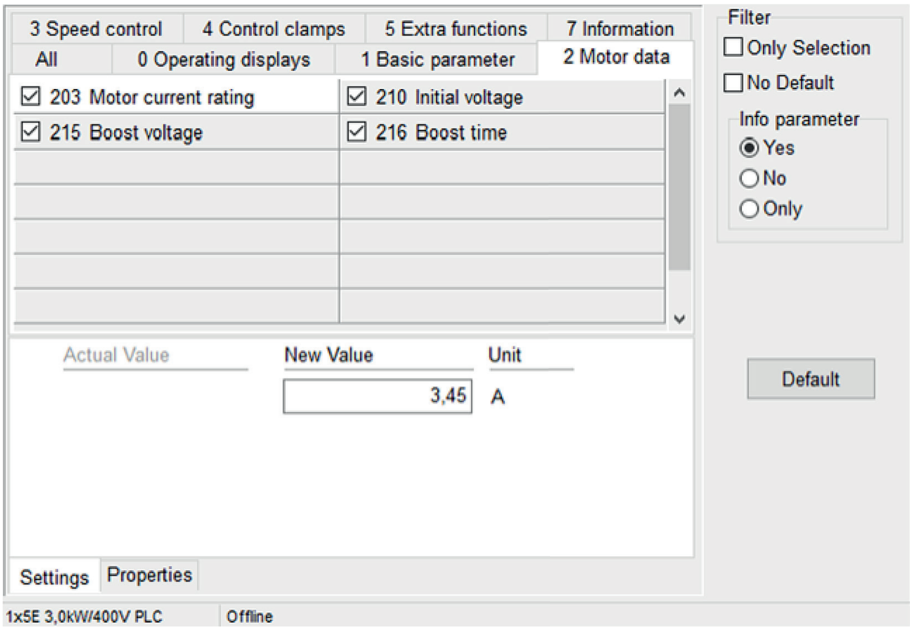

Fig. 8. Setting the rated current for the conveyor

is done through the "watch table". This table is created in the 'TIA Portal' program and the variables responsible for the readiness and operation of the conveyor are entered into it.

The next step is to switch the conveyors into manual mode and check their speed one by one using a device such as a tachometer (Fig. 9). If the speed is consistent with the list of conveyors, the transporter can be switched to automatic mode.

The last step is to verify of the SCADA (Supervisory Control And Data Acquisition) system correctness. For it to work properly, check that all signals have been properly connected to the appropriate graphics. The proven SCADA system allows to quickly find the error. Trought the above, when testing lines on site, it is easy to diagnose and locate faults that need to be solved (Table 1).

RESULTS AND DISCUSSION

The simulation process contributed to many changes in the program code. In addition to excluding errors such as typos in variables or incorrectly used addresses, it contributed to logic transformations as well as to writing new lines of code to correct imperfections in transporting boxes (Fig. 10).

A problem with the drives turning on too late, causing boxes to stick together has been noticed. This issue has been resolved by using an earlier optical sensor to wake the conveyor.

Another problem was the bad positioning of the box at the exit. Bad positioning caused the board to hit the board, so the box did not move completely onto the main line. This resulted in the box jamming and blocking the main line. This problem was solved by writing an appropriate algorithm for positioning. An input has been drawn from the algorithm where the distance from the previous optical sensor in millimeters is adjusted (Fig. 11).

The final problem was that incorrectly matched conveyor speeds could cause collisions. If the upstream conveyor has a higher speed than the upstream conveyor, it hits it. Such work ceases to be smooth, and thus the control system may not achieve the assumed performance. This problem was solved by changing the speed in the code (Fig. 12).

The maximum speed of the roll is 60 m / min. Speeds of 45m / min and 46m / min were used for smooth driving. Control system tests performed on the simulation prove that the changes made had an impact on the correct operation of the system. The transport capacity that was measured during the simulation is a maximum of 2615 units per hour, while the required number is only 2100 units per hour. After the value obtained in this way, it can be concluded that the performance test on the real object will be passed (Fig. 13).

Comparing the simulation to the real system, it can be said that the simulation is a great simplification of the actual operation of the system. Pro fi net devices or signals from electrical devices

Fig. 9. Tachometer for checking the conveyors speed

Table 1. Basic status symbols in the control system (own elaboration)

Color	Significance
	Disabled / inactive
	E-STOP / device failure
	100% Full
	25–75% Full
	Active / working
	Active / not working
	Energy save mode
	Service / manual mode

are forced to work properly. Optical sensors do not need an appropriate setting to work properly, and the settings of the inverters, electrical connections or communication with another PLC controller are not mapped in the simulation. The security system is also not mapped and is ignored for proper operation. The number of boxes on the line is generated continuously, at a certain time that will be set in the generator, in this case every 1 second. In fact, the number of boxes depends on the person who is feeding them per line.

Summing up, the simulation will not fully replace the actual commissioning process, but it is definitely a great convenience. Thanks to it, errors found on the programming side have an impact on reducing the runtime on the real object.

CONCLUSIONS

In the paper, the authors presented the methodology of creating a control system for conveyor lines. Several programming languages of industrial controllers were used to achieve the assumed goal. Due to the applied control and executive elements, the performed works met the assumed goals.

Through the simulation stage, the correct operation of the system control logic was checked and errors were eliminated, thanks to which the functioning of the system was improved. This resulted in a reduction in the time to start up the physical facility. During the commissioning phase, it was found that the simulation is not a perfect representation and cannot be fully relied upon, but is inherent in the entire process.

At the stage of starting the system, the system of transporters was prepared for operation and use. The key problem was the inability to position the box at the exit, which caused constant blockages. It took a few minutes to fix the bug, which caused the line to drastically reduce its performance. This situation is unacceptable from the point of view of the transport of the boxes. This problem was solved by writing an appropriate algorithm for positioning. This algorithm caused the package positioning to work correctly and excluded the repeat of this error.

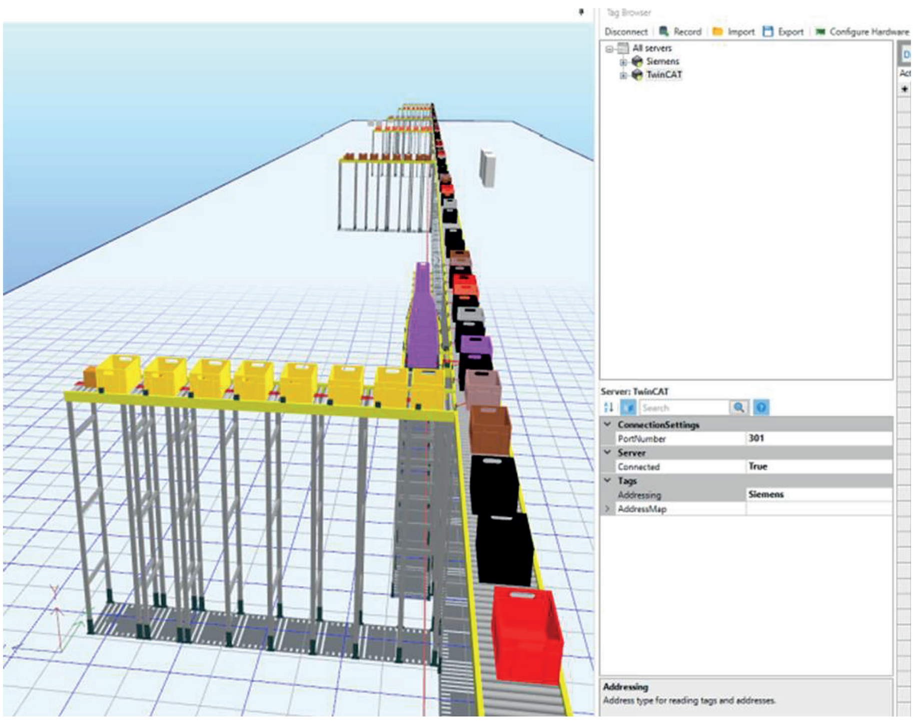

Fig. 10. Screenshot of emulate 3D

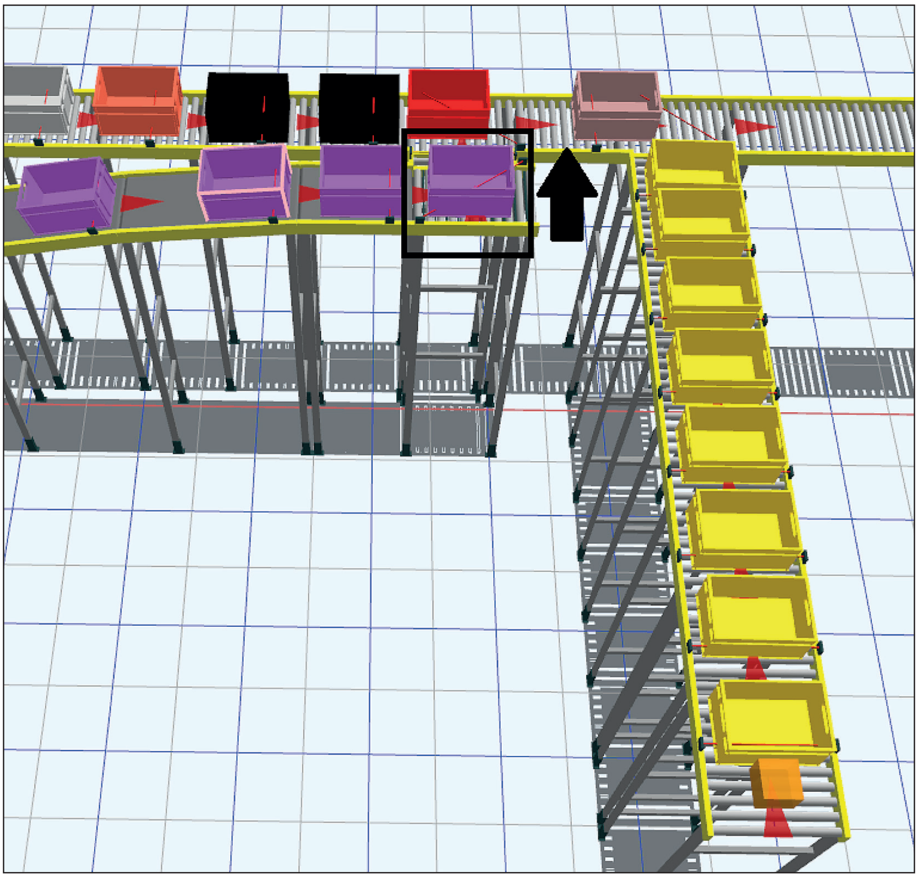

Fig. 11. Correct positioning of the box

		Name	Data type	Default value
79		Constant		
80		cSpeed_46m/min	Real	0.77
81		cSpeed_45m/min	Real	0.75

Fig. 12. Correct speed settings

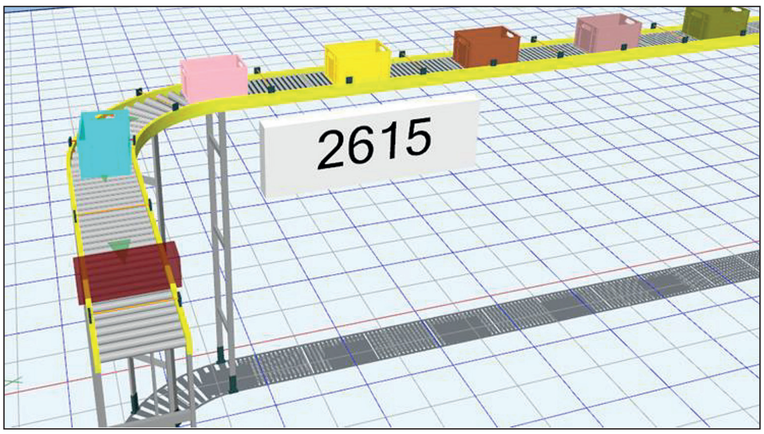

Fig. 13. Measured transport efficiency in Emulate 3D

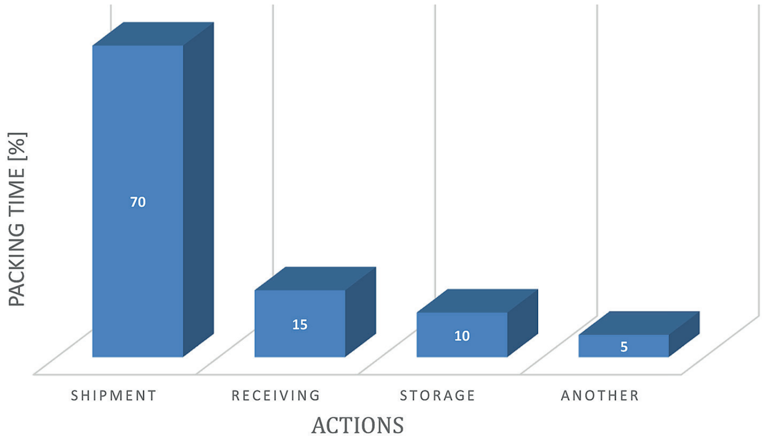

Fig. 14. Percentage share of the total time for individual stages responsible for completing the article

Fig. 15. Efficiency comparison between an automated process and an employee

In modern times, companies in industry are increasingly opting for the automation process. This process, despite high costs, increases work efficiency, lowers labor costs, reduces or completely excludes monotonous and tedious manual tasks, improves employee safety and also improves the quality of products. This article has shown that the longest stage in a modern warehouse is the goods movement stage (Fig. 14). Automating this process, despite high costs, increases work efficiency (Fig 15), lowers labor costs, reduces or excludes monotonous and tedious manual tasks, improves the safety of employees, and also improves the quality of products. Further research can be conducted based on the mathematical feedback correction in the PLC and also, it is needed to improve system reliability [30].

REFERENCES

1. Sika R., Rogalewicz M., Popielarski P., Czarnecka-Komorowska D., Przestacki D., Gawdzińska K., Szymański P. Decision Support System in the Field of Defects Assessment in the Metal Matrix Composites Castings. Materials 2020; 13: 3552. https://doi.org/10.3390/ma13163552
2. Ignaszak Z., Popielarski P. Sensitivity Tests of Simulation Models Used in Chosen Calculation Codes on Uncertainty Of Thermo-Mechanical Parameters During Virtual Mechanical Stress Estimation For Ferrous Alloy Castings", Defect and Diffusion Forum 2011; 312–35: 758–763.
3. Hajkowski J., Sika R., Rogalewicz M., Popielarski P., Matysiak W., Legutko S. Material Databases and Validation in Modelling the Structure of Castings Using the Cellular Automaton Method, Materials 2021; 14(11). DOI: 10.3390/ma14113055
4. Shcherbovskykh S., Kozlowski K., Pazderski P. Evaluation of Integral Anti-Windup Feedback Coefficient for PI Regulator, 2018 IEEE 9th International Conference on Dependable Systems, Services and Technologies (DESSERT) 2018; 74–77. DOI: 10.1109/DESSERT.2018.8409102
5. Araujo A.F., Varela M.R.L., Gomes M.S., Barreto R.C.C., Trojanowska J. Development of an Intelligent and Automated System for Lean Industrial Production, Adding Maximum Productivity and

Efficiency in the Production Process, Lecture Notes in Mechanical Engineering, Advances in Manufacturing (Manufacturing 2017), Springer 2017; 131–140.

6. Nowakowski W., Łukasik Z., Bukalski W. Methods for Assessing The Safety of Industrial Automation Systems, Safety and Ecology 2018; 19(12). DOI: 10.24136/atest.2018.375
7. Acemoglu D., Restrepo P. Modeling Automation, AEA Papers and Proceedings 2018; 108: 48–53. DOI: 10.1257/pandp.20181020
8. Pryanichnikov V.E., Aryskin A.A., Eprikov S.R., Kirsanov K.B., Khelemendik R.V., Ksenzenko A.Y. Technology Of Multi-Agent Control For Industrial Automation With Logical Processing Of Contradictions. http://go.gale.com, Accessed 25.05.2022
9. Sujova E., Strihavkova E., Cierna H. An Analysis of the Assembly Line Modernization by Using Simulation Software, Manufacturing Technology 2018; 18(5): 839–845.
10. Desai N., Punnekkat S. Safety of fog-based industrial automation systems, IoT-Fog '19, April 15–18, Montreal, QC, Canada 2019; 6–10. 10.1145/3313150.3313218
11. Skoczylas A., Stefaniak P., Anufriiev S., Jachnik B. Belt Conveyors Rollers Diagnostics Based on Acoustic Signal Collected Using Autonomous Legged Inspection Robot. Applied Sciences 2021; 11(5): 2299. DOI: 10.3390/app11052299
12. Urinov S.R. Modeling and Control Methods Of Consistently Operating Conveyors of Mining Transport Systems, International Conference on Agriculture Sciences, Environment, Urban and Rural Development, Morocco, 30 December 2021.
13. Dager C. Smart Conveyors Streamline Wet Wipes Packaging Challenges, https://www.plantengineering.com/articles/smart-conveyors-streamline-wet-wipes-packaging-challenges/, Accessed: 12.05.2022.
14. Büchi G., Cugno M., Castagnoli R. Smart Factory Performance and iIndustry 4.0, Technol Forecast Soc 2020; 150: 119790.
15. Foster R. Automation, Production Systems and Computer-Integrated Manufacturing, Larsen and Keller Education Group, New York, USA 2019.
16. Fischer J., Vogel-Heuser B., Friedrich D. Configuration of PLC Software for Automated Warehouses Based on Reusable Components – An Industrial Case Study, IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA), 2015. DOI: 10.1109/ETFA.2015.7301414
17. Gordon R., Bejger A. Effect of Temperature Change on Acoustic Emission Signal in IGBT Transistors of Marine Propulsion System Converters. Energies 2020; 15(4276). DOI: 10.3390/en15124276
18. Gawdzińska K., Chybowski L., Bejger J.A., Krile S. Determination of Technological Parameters of Saturated Composites Based on Sic By Means Of A Model Liquid, Metalurgija 2016; 55(4): 659–662. https://hrcak.srce.hr/157391
19. Muthukumaraswamy S.A., Nadgauda N. Design and Development of Industrial Automated System using PLCSCADA, IEEE 1oth GCC Conference & Exhibition (GCC), 2019.
20. Setiawan,Sugeng A., Koesoema K.I., Bakhri S., Aditya J. The SCADA System Using PLC and HMI to Improve the Effectiveness and Efficiency of Producation Processes, IOP Conference Series: Material Science and Engineering 2019; 550: 012008.
21. Voytyuk I.N., Bolshunova O.M. Ensuring Energy Efficiency of The Belt-Type Conveyor Bolshunova Electric Motor Drive Operation Due to Noncontact Control of Mass Discharge of Cargo During Its Transport in Mining Condition, IEEE Conference Of Russian Pr Young Researchers In Electrical And Electronic Engineering, Elconrus 2019; 736–739.
22. Amin Al, Mridha M. A mini view of PLC, International Journal of Research in Advanced Engineering and Technology. Impact Factor: RJIF 2020; 6(2): 23–25.
23. Hulewicz A., Krawiecki Z., Dziarski, K. Distributed Control Systems DCS using a PLC Cotroller. ITM Web of Conference 2019; 28: 01041. DOI: 10.1051/itmconf/20192801041
24. Mazur P., Czerwiński R., Chmiel M. PLC Implementation in the Form of a System-on-a-Chip, Bulletin of the Polish Academy of Sciences Technical, 2020; 68(6). DOI: 10.24425/bpasts.2020.135386
25. Fu W. A Brief Analysis on the Application of Simens S7–1200 PLC in Sluice Gate Monitoring System of Hydro Power Station. Electric Drive Automation 2019; 41(1): 45–48.
26. Prajakta H., Nimish J., Pranav K., Amol K. Automatic Weighing and Packaging Machine, Internation Research Journal of Engineering and Technology (IRJET) 2019; 6(5): 2129–2138.
27. Oprzędkiewicz K. Real-Time Requirements Meeting in PLC Control System, State Higher Vocational School in Tarnów 2020; 5(2): 1–8. DOI: 10.5604/01.3001.0013.2568
28. Kazemi S., Kharrati H. Visual Processing and Classification of items on Moving Conveyor with Pick and Place Robot using PLC, Springer Singapore 2017; 3(1): 15–21. DOI: 10.1007/s40903–017–0071–3
29. Bambura R., Sujovâ E., Ĉierna H. Utilizing computer simulation to optimize furniture production system, BioResources 2020; 15(3): 6752–6765.
30. Lobur M., Shcherbovskykh S., Kozlowski K., Pazderski D. Experimental Analysis of Rotary Speed Observers for Electric Drive with Cascaded Control System, 2018 IEEE 13th International Scientific and Technical Conference on Computer Sciences and Information Technologies (CSIT) 2018; 125–128. DOI: 10.1109/STC-CSIT.2018.8526615