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Original Research

OPTIMIZING THE SIMULATION OF CONVEYOR SYSTEMS THROUGH DIGITAL SHADOW INTEGRATION TO INCREASE ASSEMBLY PROCESS EFFICIENCY

OPTYMALIZACJA SYMULACJI SYSTEMÓW PRZENOŚNIKÓW POPRZEZ INTEGRACJĘ CYFROWEGO CIENIA DLA ZWIĘKSZENIA WYDAJNOŚCI PROCESU MONTAŻU

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Abstract

In today's highly competitive industrial environment, continuous improvement of efficiency and optimization of processes is crucial. This paper presents an approach to the optimization of conveyor systems that uses the concept of a digital shadow. A digital shadow, as an exact digital replica of a physical conveyor system, enables detailed simulation and analysis of real operational data, providing a basis for in-depth analysis and identification of areas for improvement. The aim of this approach is not only to improve the understanding of the dynamics and performance of existing conveyor systems, but also to increase the overall efficiency through predictive simulations and optimization algorithms. In this work, we demonstrate how the integration of a digital shadow into the simulation process can contribute to a better reaction to changes in the production environment, to the reduction of downtime and to the optimization of production flows. Our methodology combines data collection / analysis, and enables the creation of accurate and flexible models of conveyor systems. These models are then used in simulations that help identify optimal settings for different production scenarios and predict potential problems before they occur. The results of applying our approach on a test laboratory line show a significant improvement in efficiency and a reduction in operating costs. This study provides important insights and practical guidelines for engineers and production managers focused on the use of digital shadow to increase the efficiency of conveyor systems. It also contributes to the development of intelligent production technologies in the era of Industry 4.0.

Keywords: conveyor system, simulation, digital shadow, efficiency

Streszczenie

W dzisiejszym wysoce konkurencyjnym środowisku przemysłowym kluczowe znaczenie ma ciągła poprawa wydajności i optymalizacja procesów. W artykule przedstawiono podejście do optymalizacji systemów przenośnikowych wykorzystujące koncepcję cyfrowego cienia. Cyfrowy cień, jako dokładna cyfrowa replika fizycznego systemu przenośników, umożliwia szczegółową symulację i analizę rzeczywistych danych eksploatacyjnych, dając podstawę do dogłębnej analizy i identyfikacji obszarów wymagających poprawy. Celem tego podejścia jest nie tylko lepsze zrozumienie dynamiki i wydajności istniejących systemów przenośników, ale także zwiększenie ogólnej wydajności poprzez symulacje predykcyjne i algorytmy optymalizacyjne. W tej pracy pokazujemy, jak włączenie cienia cyfrowego do procesu symulacji może przyczynić się do lepszej reakcji na zmiany w środowisku produkcyjnym, ograniczenia przestojów i optymalizacji przepływów produkcyjnych. Nasza metodologia łączy zbieranie/analizę danych oraz umożliwia tworzenie dokładnych i elastycznych modeli systemów przenośnikowych. Modele te są następnie wykorzystywane w symulacjach, które pomagają zidentyfikować optymalne ustawienia dla różnych scenariuszy produkcji i przewidzieć potencjalne problemy, zanim one wystąpią. Wyniki zastosowania naszego podejścia na linii laboratorium badawczego wskazują na znaczną poprawę wydajności i redukcję kosztów operacyjnych. Niniejsze badanie dostarcza ważnych spostrzeżeń i praktycznych wskazówek dla inżynierów i kierowników produkcji skupiających się na wykorzystaniu cyfrowego cienia w celu zwiększenia wydajności systemów przenośników. Przyczynia się także do rozwoju inteligentnych technologii produkcyjnych w dobie Przemysłu 4.0.

Słowa kluczowe: system przenośników, symulacja, cień cyfrowy, wydajność

1. Introduction

In today's rapidly changing industrial environment, there is a constant need to increase efficiency and optimize production processes. One of the cornerstones of modern production systems is conveyor systems, which play a key role in automating and streamlining assembly lines. Thanks to their ability to efficiently move materials and components among different parts of the manufacturing process, conveyor systems are an integral part of industrial production. However, in order to achieve maximum efficiency and minimize outages, it is necessary to constantly monitor and optimize their performance Antosz et al. (2019).

Traditional methods of monitoring and optimization often rely on manual intervention and post-hoc analysis, which cannot adequately address the dynamic nature of production processes. In this context, the integration of the digital shadow, a concept based on the field of Industry 4.0, offers a revolutionary approach to the optimization of conveyor systems Kluz et al. (2019). The digital shadow, as a virtual replica of the physical system, records and analyzes data in real time, providing a comprehensive overview of the current state and performance of the conveyor system.

The use of digital shadowing in the context of simulation and optimization of conveyor systems enables accurate bottlenecks identification, prediction of potential problems and material flow optimization Husar et al. (2019) . This methodology makes it possible to create simulations that can predict system performance under different operating conditions and settings, leading to significant improvements in assembly efficiency and reductions in downtime and maintenance costs. At the same time, integrating a digital shadow into the optimization process allows changes to be made and their impact simulated in a safe, virtual environment, eliminating the need for costly and time-consuming real-world tests. This approach not only increases the adaptability and flexibility of production systems, but also enables faster implementation of innovations and improvements Malopolski et al. (2018).

In addition, the use of advanced analytics tools and machine learning algorithms within the digital shadow enables continuous optimization and learning from historical data, increasing the accuracy of predictions and the efficiency of decision-making processes. This approach supports the development of intelligent, self-regulating systems that can dynamically respond to changes in the operating environment and maintain a high level of performance without the need for external intervention. In this paper, we present a comprehensive overview of how digital shadow integration can radically change the approach to simulation and optimization of conveyor systems Van Vianen et al. (2016). We explore various strategies and technologies that enable effective use of digital shadowing to improve assembly processes, and discuss potential challenges and solutions in implementing these technologies in practice. The aim is to provide readers with an in-depth look at the benefits and possibilities that the digital shadow brings to industrial manufacturing and highlight its key role in the transformation towards more efficient and intelligent manufacturing systems Trojanowska et al. (2023).

1.1. Simulation of conveyor systems

Subsequently, we will focus on the importance and meaning of the conveyor systems simulation in the context of digital shadow integration, as a tool for improving efficiency and optimizing processes in industrial assembly. The simulation of conveyor systems is a critical step in the process of planning and optimizing production lines. Using digital modeling and simulation, various aspects of conveyor systems can be virtually tested and analyzed, including their configuration, capacity, speed and interaction with other components of the production process Kawa et al. (2016). This approach allows engineers and designers to identify potential problems and bottlenecks in the process before the system is physically implemented, greatly reducing modification costs and increasing the overall efficiency of assembly operations Graczyk-Tarasiuk et al. (2022).

Integrating a digital shadow into the simulation process brings another level of accuracy and detail to the analysis. Collecting real-time data from physical systems, the digital shadow provides up-to-date and accurate information on the health and performance of existing conveyor systems. This information is subsequently used in the simulation, which increases the relevance and applicability of the obtained results to real production situations Lazar et al. (2012). This synergy between digital shadowing and simulation makes it possible to create highly accurate models that can predict the results of changing configuration, workload or operational parameters with unprecedented accuracy.

In practice, the conveyor systems simulation enables a comprehensive assessment of various aspects of production processes. For example, it can help decide the optimal speed of movement on conveyor belts to maximize production capacity while minimizing equipment wear and energy consumed to operate it. Simulations can also reveal inefficient layouts of production lines, allowing them to be reconfigured for smoother material flow and reduced time lost in transportation among individual production sites Kolny et al. (2023).

Another key aspect is the ability to simulate conveyor systems to support predictive maintenance. Analysis of data from the digital shadow makes it possible to identify patterns that prevent component failures and wear. In this way, maintenance work and part replacements can be planned before they could cause serious production interruptions or expensive repairs.

Together, simulation and the digital shadow provide the basis for creating adaptive and intelligent manufacturing systems. These systems are able to dynamically respond to changes in demand, material flows and operating conditions, thereby increasing their efficiency and flexibility. The practical implementation of these technologies means for industrial enterprises not only an improvement in performance, but also an increase in competitiveness on a global scale. However, despite these advantages, the integration of digital shadow and simulation of conveyor systems presents some challenges. These include ensuring data quality and integrity, processing huge data volumes in real-time, and creating accurate models that adequately reflect reality. In addition, there is a need to overcome cultural and organizational barriers that may hinder the adoption and effective implementation of these advanced technologies Kawa et al. (2016). The conveyor systems simulation with digital shadow integration opens up new possibilities for optimizing and streamlining industrial assembly lines. It offers in-depth insight into operational performance, enables predictive maintenance and supports fast and informed decision-making. With appropriate investments in technology and a change in mindset, this integration can significantly contribute to achieving higher levels of industrial efficiency and adaptability in an ever-changing global economic environment.

1.2. Literature review

Optimizing the simulation of conveyor systems through digital shadow integration can increase assembly efficiency. By creating digital twins or digital shadows of production systems, companies can limit physical test runs and reduce costs Kassen et al. (2021). These digital twins can mirror the current stage of the physical pallet transportation process and predict transportation times, allowing for optimized product scheduling and resource allocation Raileanu et al. (2019). Implementing range-inspection control (RIC) in automated conveyor systems can further optimize their operation within the smart manufacturing framework Wang et al. (2022). Model-based design and simulation can be used to achieve optimal efficiency of conveyor belts, improving productivity in advanced manufacturing environments Salawu et al. (2020). Virtual commissioning and simulation tools like Siemens Tecnomatix Process Simulate can be used to design and test control systems for conveyors, increasing efficiency and reducing the risk of damage to functional parts Ruzarovsky et al. (2018).

Simulation of conveyor systems through digital shadow is a valuable tool in the design and optimization of conveyor control systems. By creating a virtual model of a real conveyor, engineers can test and evaluate different scenarios without the need for physical intervention or potential damage to functional parts Mikušova et al. (2019). This approach allows for the integration and testing of control systems through simulation before the physical construction of the conveyor, saving time and resources Li et al (2011). The use of simulation language and regression models further enhances the ability to test proposed changes and improve the functionality of the conveyor in real-world operations Pathak et al. (2021). The combination of digital technology and traditional shadow puppets has also been explored, allowing users to manipulate and control digital shadow props in a user-oriented and interactive manner Tri handoyo at el. (2010). Overall, simulation and digital shadow techniques offer significant benefits in the design, optimization, and performance of conveyor systems.

2. Methodology

The digital shadow creation of the conveyor system is based on the concept of the SmartTechLab laboratory for Industry 4.0 shown in Figure 1. The selected laboratory is located at the Faculty of Manufacturing Technologies, located in Prešov, Technical University of Košice. This laboratory is focused on industry 4.0 and smart technologies Kovbasiuk et al. (2023).

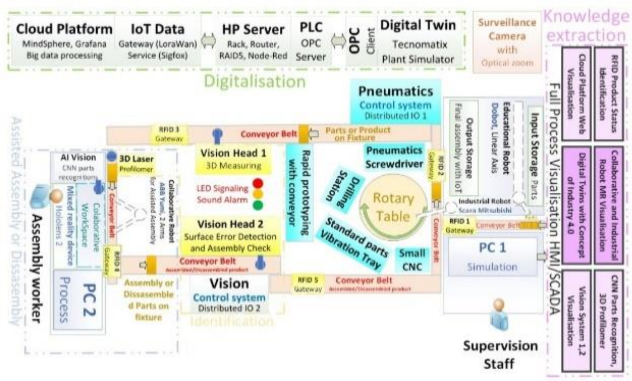

Fig. 1. SmartTechLab concept for industry 4.0

As can be seen from the picture, the system arrangement principle consists of 4 conveyors arranged in a closed cycle. There are 6 conveyors, 3 conveyors with a width of 20 cm and 3 conveyors with a width of 8 cm. Control of the electric motors is provided by frequency converters for speed control connected to a central PLC that performs complex logic operations and controls various aspects of the conveyor operation, such as speed, direction and coordination between multiple conveyor segments. In the presented article, we created a layout model in the 2D interface of the simulation tool Tecnomatix Plant Simulation Židek et al. (2021).

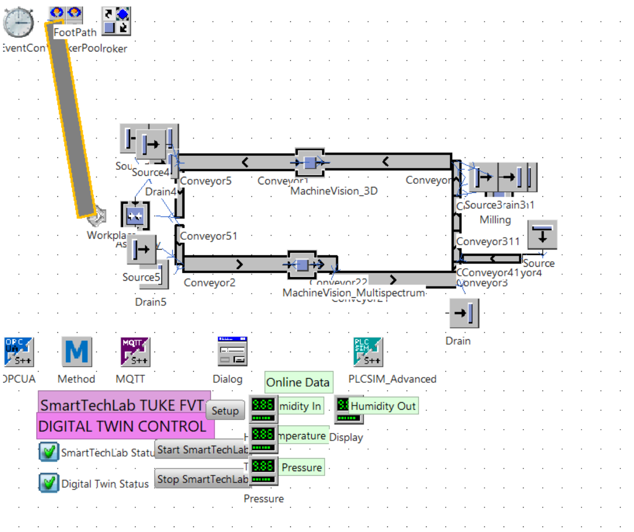

Fig. 2. 2D model of conveyor system

Tecnomatix Plant Simulation provides robust conveyor system modeling benefits that are key to optimizing and analyzing manufacturing processes. With its advanced simulation capabilities, it enables users to efficiently model and simulate complex conveyor systems, reducing the need for physical prototypes and shortening the time needed for experimentation. Tecnomatix Plant Simulation supports a detailed analysis of material and information flow, enables accurate prediction of the various scenario impacts on the overall efficiency of the production system. This ability to predict and optimize the performance of the conveyor system before its physical implementation significantly reduces production costs and increases productivity. In addition, the flexible and user-friendly Tecnomatix Plant Simulation platform supports rapid adaptation to changes in projects, thereby improving the ability to respond to dynamic market demands and increasing the competitiveness of manufacturing companies.

Based on the disposition model of Fig.3, a digital shadow was subsequently created.

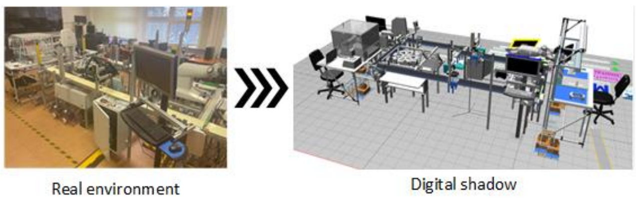

Fig. 3. SmartTechLab concept for industry 4.0

In the digital shadow, users can customize a wide range of conveyor settings, including conveyor speed, capacity, type (belt, roller, chain), movement direction, accumulation method, start and stop conditions, as well as interaction with other objects and response to disturbances.

These settings are crucial for accurate modeling and simulation of conveyor systems, enabling efficient layout planning, optimization of material and information flow, as well as realistic simulation of work cycles and responses to unexpected events. This detailed level of customization supports in-depth analysis and production process improvement.

Fig. 4. Setting the conveyor's basic parameters

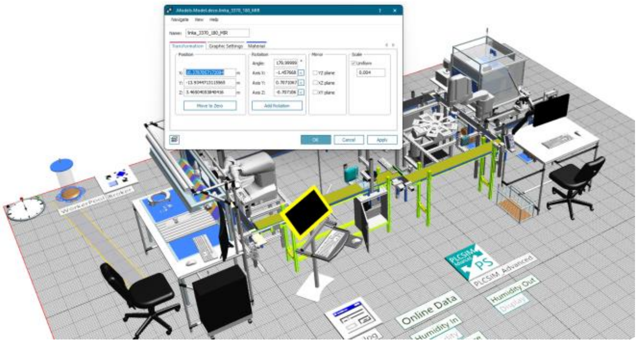

Fig. 5. Setting the conveyor's dimensional parameters

The presented digital shadow is a universal tool for simulating the selected transport system. In addition to conveyor parameters, it is also possible to edit objects moving along the conveyor. As already mentioned, the conveyor systems are 20 cm and 8 cm wide, therefore, for our needs, a preparation of a handling pallet with dimensions of 18 x 7.5 cm was created. The universal handling pallet is an innovative solution, designed to adapt to different sizes and shapes of loads, thereby increasing the efficiency of handling materials and optimizing the use of warehouse space. This flexibility is crucial in dynamic manufacturing and distribution environments where the requirements for transporting and storing materials are constantly changing. The universal handling pallet enables quick and efficient configuration changes as needed, which reduces the time required for load preparation and minimizes the need for different specific pallets for different types of products.

Thanks to its modularity and adaptability, the universal handling pallet can support a wide range of loads – from small components to large and heavy objects – ensuring stable and safe storage and transport.

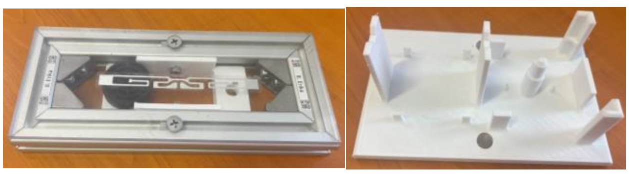

Fig. 6. Universal palette and preparation for handling

This type of pallet often includes adjustable or replaceable components, such as sidewalls, space dividers or customizable mounts, which ensure that it can effectively serve a wide range of applications regardless of the load specifics. Such versatility and adaptability make the universal handling pallet a valuable tool for lines looking for ways to improve their logistics operations while reducing costs and environmental impact by minimizing the need for multiple types of packaging materials.

3. Results

In the article, we present a digital model of a conveyor line on which all parameters can be modified according to real data obtained by observation and measurement. In our model, we included several operations with a specific time and we gradually added to the empty pallet in the model the preparation, plastic components that were put together in the assembly workplace to form the final product representing the cam switch.

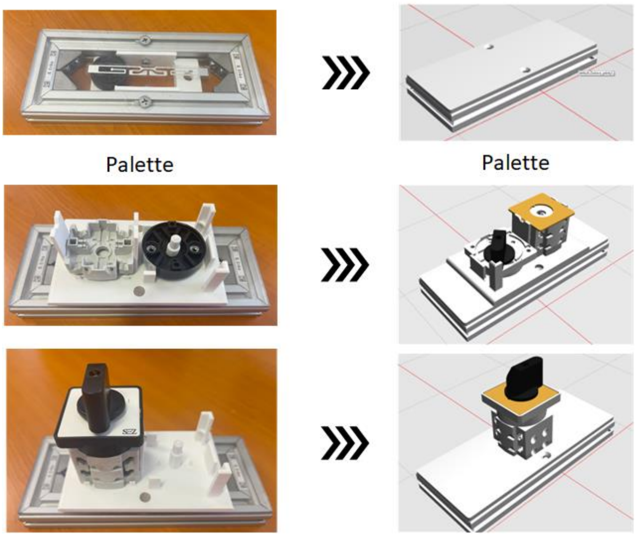

Fig. 7. A view at real components and elements for simulation / digital shadow

In order to increase efficiency, we gradually began to optimize the cam switch assembly process. As part of the simulation, we gradually changed the amount of products in the production batch in the range of 10 pcs to 100 pcs available in 10 pcs increments. In doing so, we analyzed the ratio of performed operations to transport and storage. From the obtained results, it is obvious that the processes did not change, but with a larger number of pieces, the ratio of total transportation began to decrease from 70% to 60%, which represents a saving of 10% of the total time. In the model proposed by us, downtime and blocking times of individual operations have been eliminated. In our case study, in the next steps we optimized the speed of the conveyors in the simulation model, we implemented the optimization of the times of the components placed on the stage, and we also tried to optimize the individual operations activities using robotic workplaces.

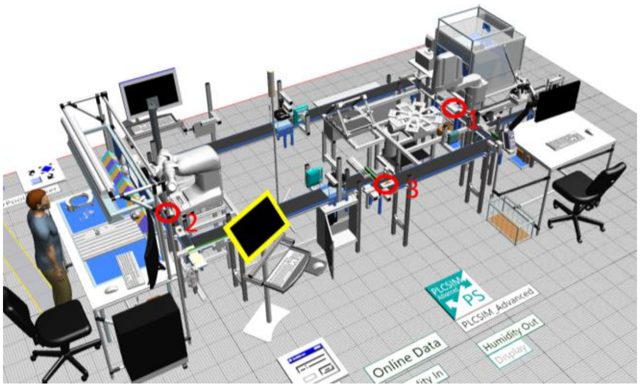

Fig. 8. Simulation model/digital shadow of a conveyor system with pallets

We can see 3 positions on the presented model. The first position represents the empty pallet arrival on which plastic components are gradually placed on a rotary table using the SCARA robot. The second position represents an assembly workplace with assisted assembly using the collaborative robot ABB Yuma and a human, and the third position represents the movement of a folded cam switch after exit inspection using a camera system directed to the exit warehouse. The movement of pallets is solved using the conveyor system described in chapter 2. The digital shadow represents an advanced digital replica of physical systems, allowing detailed monitoring, analysis and prediction of their performance based on real-time data collection and processing. In the context of our research, the digital shadow serves as the basis for the simulation and the conveyor system optimization used in the cam switch assembly process. Thanks to the integration of the digital shadow, we are able to virtually model the entire production process, adjust the simulation parameters according to real data and effectively optimize operations, thereby increasing the overall efficiency of assembly.

Our simulated model, including a digital shadow, allows detailed observation and modification of all relevant parameters. This approach not only increases the simulation accuracy but also provides valuable insight into possible optimizations. The optimization of the simulated model based on the digital shadow brought a significant improvement in the efficiency of the assembly process. Additionally, our case studies have shown that by optimizing conveyor speeds and component timing, we can further increase efficiency, while the integration of robotic workplaces into individual operations enables greater accuracy and assembly speed. The results of our study clearly show that the digital shadow represents a powerful tool for the simulation and production process optimization. Its ability to accurately reflect and predict the performance of physical systems opens up new possibilities for more efficient and flexible manufacturing operations. With this approach, it is possible not only to increase the efficiency of existing processes, but also to adapt to rapidly changing production requirements and ensure a competitive advantage in a dynamic industrial environment.

4. Conclusion

In a dynamic and constantly evolving industrial environment, the need to increase the efficiency of production processes becomes a focus for many organizations. Optimizing the conveyor systems simulation through digital shadow integration opens up new horizons for improving assembly efficiency. This approach, consisting of the connection of the virtual and physical world, brings significant benefits in the form of more accurate modeling, analysis and prediction of the conveyor systems performance. In the course of this article, we have explored how the integration of the digital shadow into simulations enables businesses to gain better understanding and control over their handling processes. Demonstrating a case study and theoretical concepts, we highlighted that the digital shadow offers a unique opportunity not only for monitoring and analyzing the current state of conveyor systems, but also for predicting future performance and possible problems. The key to success is the digital shadow's ability to acquire, analyze and apply real-time data, enabling a quick and efficient response to any changes or necessary adjustments.

This adaptive approach significantly reduces downtime, improves productivity and minimizes waste in assembly processes. In addition, the use of advanced machine learning algorithms and artificial intelligence within the digital shadow can further increase the accuracy of simulations and predictions, opening up new possibilities for optimizing production processes. In conclusion, the integration of digital shadow into the conveyor systems simulation represents a significant step forward in the field of industrial efficiency. It not only offers the opportunity to improve current operations but also provides a platform for innovation and improvement of future production processes. As we have shown, this approach has the potential to transform the way businesses approach the optimization of their production lines and has a significant impact on increasing assembly efficiency. Armed with this knowledge, businesses are better prepared to face the challenges of Industry 4.0 and take advantage of the opportunities that digitization brings.

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