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ARCHITECTURE PROPOSAL FOR IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE ON CNC MACHINE TOOLS

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Abstract: Today, the emergence of new industrial values and the integration of advanced technologies have ushered in a significant evolution in industry through the implementation of Industry 4.0 strategies. As Taylor noted in 1911, a production system must be analyzed starting from its elementary processes. Building on this idea, this paper proposes a control system with artificial intelligence at a foundational level of production systems, specifically focusing on CNC machine tools. Two types of artificial intelligence control systems are proposed for manufacturing processes: one aimed at increasing processing accuracy and the other designed to reduce processing costs or enhance productivity
Keywords: Artificial Intelligence, AI, CNC, machine tools, Industry 4.0.

1. INTRODUCTION

In "The Principles of Scientific Management", was published the ideas of Winslow Taylor about the modern manufacturing model that he implemented in the manufactured of Ford, which remains rational and valid today. Analyzing the ideas that Taylor expressed, the manufacturing system development has the improvement of the elementary processes as a starting point "Analyzing the production activity on the elementary processes with these scientifically-based methodologies, creates a benefit in the economic efficiency of the enterprises and its workers" [1].

In recent years, the evolving industrial values have brought about a significant advancement known as Industry 4.0. Various steps are currently being taken to implement this new phase, which greatly impacts the industry by fostering the development of new products, with intelligent manufacturing, and quality services that can seamlessly integrate with the Internet of Things. The next evolutionary model in the industrial sector, referred to as Industry 5.0, is being proposed.[1] This new concept focuses on enhancing the workforce's capabilities and

protecting the environment, all while promoting efficient management practices [2].

In today's increasingly competitive market, companies aim to focus on developing new products and production systems that are more competitive than ever before. This intense competition leads to the introduction of new constraints in the daily operations of all departments. To address these challenges, companies need to implement systems capable of analyzing, managing, and continuously improving productivity, efficient management, and decision-making. This approach is essential for ensuring the sustainability and stability of the organization [2, 3].

The concept that Taylor articulated in 1911 remains relevant today: to enhance a production system, efforts must begin with the fundamental processes. To successfully embrace the Industry 4.0 paradigm in production workflows, it is essential to prioritize the development of machine tools that fully align with these innovative requirements. This foundational step will pave the way for enhanced efficiency and competitiveness in the manufacturing landscape. To achieve this, we propose a control system for these machine tools that incorporates artificial intelligence [1, 2, 3].

This paper proposes the implementation of a control system with artificial intelligence at a lower level of production systems, specifically on CNC machine tools. The starting point for this implementation is the fundamental processes that provide the greatest economic benefits for companies and create a significant competitive advantage.

2. INDUSTRY 4.0

In 2013, the German National Academy of Science and Engineering published a manifesto for Industry 4.0, which initiated the implementation of this concept. Industry 4.0 is structured into several workgroups: smart factory, environment, economic environment, human ergonomics, human factors and human work, and technological factors [1, 6].

The current IT infrastructure is designed to efficiently meet the implementation needs of Industry 4.0, aligning with higher expectation [2]. One of the significant challenges is finding human resources who are capable of developing and implementing the analytical algorithms required for self-learning intelligence.[7] These algorithms are essential for achieving the technological advancements necessary to adopt the paradigms of Industry 4.0.[8] Another challenge lies in the existing manufacturing infrastructure, which must be modified, adapted, and transformed to meet new requirements. For instance, machine tools need to be capable of integrating into a network using Internet of Things, so they can communicate with one another, facilitating autonomous decision-making. A major change resulting from the implementation of Industry 4.0 is the evolving relationship between humans and machines, which will lead to the development of new jobs [3, 4, 8].

The concepts of Industry 4.0 are based on three main dimensions: Horizontal and Vertical Integration within the company and End-to-end Engineering [1, 5, 9].

The implementation of Industry 4.0 represents a significant step toward creating a more sustainable and eco-friendly industry. This approach focuses on using resources, energy, and materials more efficiently to develop new products. It relies on intelligent modules that

create interconnected values across various processes [7].

Furthermore, Industry 4.0 helps achieve sustainable industrial growth across economic, social, and environmental dimensions [6]. The concept of Industry 4.0 presents opportunities for companies, categorized into new business models and value creation networks [10]. From a micro perspective, Industry 4.0 presents various opportunities with a focus on the following key areas: Product: Products should be designed with a sustainable focus, aiming for a closed-loop life cycle that enables reuse and remanufacturing. Process: Processes should adopt a holistic approach to efficiency, utilizing resources intelligently and incorporating technologies that adapt easily and communicate efficiently. Equipment: Machine tools need to integrate communication capabilities and demonstrate higher efficiency. Human: The human element remains essential as the creator of the value chain. Organization: Organizations should maintain a strong focus on developing and implementing sustainable practices and efficient resource management with a dynamic approach [9, 10].

Industry 4.0 significantly impacts various areas within industry, including: Business Models, Profitability, Communication, Production Efficiency, Machine Tools and Human Safety, Product Lifecycles, Product Design, Sustainability, Education, IT Security, Socio-Economic Improvement. These changes signify a shift toward a more connected, efficient, and sustainable industry landscape [11].

3. SMART MANUFACTURING

Smart manufacturing utilizes advanced data analytics and modern IT technologies to improve system performance and facilitate decision-making [12].

According to Wang et al. (2018), the growing use of sensors and the implementation of the Internet of Things (IoT) have resulted in an exponential increase in the volume of production data [13]. Data analytics has an essential role in managing this information by evaluating and processing it effectively. Smart manufacturing seamlessly integrates advanced information and

communication technologies with cutting-edge facilities, driving transformative benefits across the entire organizational structure and fostering enhanced efficiency and innovation. The data gathered from sensors is diverse in source, semantics, and format, originating from manufacturing systems, intricate processes, production lines, and personnel. This rich variety not only enhances our understanding but also empowers us to make informed decisions that can significantly improve operational efficiency and productivity [14].

In their 2021 paper, Wang et al. perform a comparative analysis of two terminologies: Intelligent Manufacturing (IM) and Smart Manufacturing (SM). These two paradigms appear to have developed independently but are closely related [12]. The literature reviewed indicates that the term Smart Manufacturing is often associated with the concepts of Industry 4.0. Common emerging technologies that are relevant to both SM and IM include Cyber-Physical Systems (CPS), the Internet of Things (IoT), Big Data (BD), Digital Twin (DT), Cloud Computing (CC), Artificial Intelligence (AI), and Machine Learning (ML) [14].

Bi et al. characterize smart manufacturing (SM) as a transformative manufacturing paradigm that significantly enhances system intelligence, driving innovation and efficiency in production processes [16]. This approach utilizes digital technologies to empower physical items involved in product manufacturing, enabling access to virtual assets through networks. This expanded production capability supports data-driven decision-making across all domains and levels of manufacturing operations [14]. Additionally, it allows for the reconfiguration of systems to adapt to changing customer needs when producing products.

Kusiak, in 2018, highlights that data modeling and analysis are crucial for smart manufacturing, facilitating the management of large data volumes and enabling real-time data processing [15].

Smart manufacturing encompasses various components, including databases (often referred to as Big Data), essential features, supporting technologies, and key implementation pillars.

Smart Manufacturing approaches these concerns by integrating into every stage of product lifecycle, advanced product design and manufacturing capabilities with digital technologies [17]. The advent of digital technologies has facilitated the developing of cyber-physical systems, which enhance interoperability among various systems within an enterprise [18].

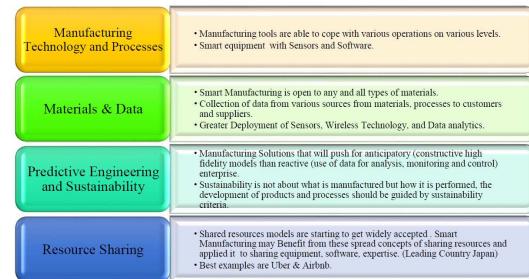


Fig.1. Smart Manufacturing Pillars [16].

The main characteristics of smart manufacturing, as identified by Deloitte in 2021, include: connectivity, optimization, transparency, proactivity, agility [17].

The solutions offered by Industry 4.0 are flexible enough to support customized configurations and developments tailored to the unique needs of various industries, including the automotive sector, which covers a wide range of products. As a result, dynamic manufacturing networks create opportunities for managing supply chains and business models [19].

4. INTELLIGENT MANUFACTURING SYSTEMS

A new era started with the implementation of the Industry 4.0 concept, especially in production systems, through the implementation of Smart Manufacturing Systems (SMS), which can easily adapt to market needs [20].

The Industry 4.0 revolution demands a strong focus on flexibility and reconfigurability in manufacturing systems, along with the advancement of control architectures. The emergence of cyber-physical systems (CPS) has significantly enhanced their flexibility and integrated capabilities, enabling a decisive shift from centralized control to heterarchical (decentralized) control architectures. This

transition is not just a progression; it is a transformation that takes us from traditional manufacturing systems to sophisticated, intelligent systems [21].

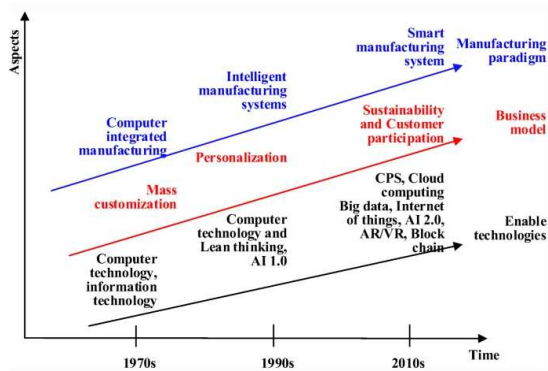


Fig. 2. The evolution of Smart Manufacturing Systems [20].

Qu et al. in 2019 reviewed the fundamental definition of intelligent manufacturing systems from an engineering perspective. They define an intelligent manufacturing system as one that can respond to real-time demand for new products, facilitate the rapid manufacturing of those products, and optimize the manufacturing and supply chain network in real-time [20].

Intelligent manufacturing systems are flexible systems that utilize intelligent products [17]. These systems can adapt to both predictable and unpredictable changes in production. There are two levels of flexibility: Resource flexibility: This refers to machines and robots that can process new types of products, allowing for variability in the sequence of operations performed on a given product; Material flow flexibility: This involves manufacturing equipment that can carry out multiple operations, which means that the pathway taken by the processed products can vary.

Overall, the ability to adjust to changes makes intelligent manufacturing systems more efficient and responsive.

Functional requirements are analyzed from the perspective of autonomous SMS (Smart Manufacturing Systems) analysis capabilities. This includes the ability to capture information and data from intelligent equipment, adapt to dynamic requirements and activities, and self-optimize. The autonomous functions include

Self-optimization by: detection, adaptation, organization, and decision. The basic requirements of SMS include physical layers such as multi-agent systems and intelligent cells. Intelligent manufacturing cells are equipped with sensors, actuators, and communication technologies. This includes robots, smart machines, smart meters, and other infrastructures that can interconnect through intelligent modules. To maintain the high performance required by today's manufacturing systems, it is essential to employ methods and tools for managing performance throughout the system's life cycle [15]. During the design phase, these methods and tools are utilized to model, analyze, and test the system, allowing for the investigation of anticipated manufacturing needs and operational environments before the system is constructed. In the operational phase, methods and tools are applied to ensure that the system maintains the planned performance by monitoring and evaluating performance while responding appropriately to any deviations [16].

To ensure the effectiveness of manufacturing systems, three key aspects must be considered: Performance measurement, analysis, improvement, and measurement.

5. ARTIFICIAL INTELLIGENCE SYSTEM FOR MACHINE TOOLS

Industry 4.0 is a transformative advancement in industrial development, characterized by the integration of emerging technologies that redefine efficiency and drive innovation. Several models have been introduced to explain Industry 4.0 and its applications. Most of these models adopt a maturity evolution perspective, outlining the expected progression of technology implementation [20].

To achieve Industry 4.0 goals, enhancing production system performance is essential. This enhancement is closely related to technological advancements and how these technologies can be introduced and implemented in production processes. A high-performance production system that meets the criteria for both vertical and horizontal integration must be capable of responding effectively to market demands. Additionally, it should be able to adapt swiftly

to meet requirements for productivity, quality, and cost efficiency [18, 19].

The level of performance of machine tools is one of the most fundamental factors in a production system that contributes to the dynamism and efficiency of manufacturing processes. This performance is determined by several factors, including the degree of automation of the equipment, the flexibility of the process, the precision and quality of the process, as well as the complexity of the manufactured products and the associated production costs. Consequently, there is a continuous and dedicated effort within the machine tool development industry to enhance technical capabilities [1].

When it comes to manufacturing parts using machine tools, the current trend focuses on optimizing technical objectives - such as precision, quality, and production capacity - as well as economical goals like minimizing processing costs and increasing productivity. Reaching these objectives is possible only through the use of intelligent control systems, commonly known as artificial intelligence (AI). These systems can adapt and control work process parameters in real-time by utilizing predefined algorithms tailored to specific conditions, ultimately aiming to optimize various criteria.

Artificial intelligence systems function as internal optimization tools that enhance machining processes by utilizing data and information related to process disturbances. Consequently, machine tools equipped with artificial intelligence control systems can operate autonomously, but at the same time they can be integrated into product data management systems (PDM) [1].

Manufacturing processes using machine tools are inherently complex because of the wide range of controllable and random factors that can influence the correct functionality of the machining process over time. As demand for productivity, precision, quality, and cost-effectiveness continue to rise in production systems, particularly in mechanical machining, there is a constant interest in finding ways to meet these needs and requirements.

Concerns generally focus on both the managerial aspects of organizing, controlling, coordinating, and correlating industrial activities, at the same time as on technical and economic factors. These elements are regarded as priorities because they are essential for achieving optimal performance in the effective use of technological tools, machine tools, and equipment.

In a unified vision, various aspects that characterize production systems—especially when examined through the lens of automation—need to be structured in a cohesive and hierarchical manner. This approach ensures that they are compatible and connected with a flexible and efficient information system. In other words, it is essential to maintain a continuous integration of material flows with information.

A manufacturing process system using machine tools has a hierarchical aspect that is established by using a flexible system. This flexibility refers to the manufacturing system's ability to adapt to various tasks based on productivity, quality, and economic conditions. Automation and robotization play a key role in achieving this adaptability. The level of automation significantly affects the flexibility of a production system, which needs to have the capacity to quickly respond to various changes in production tasks. To effectively adapt to new challenges arising from these diverse variations, the manufacturing system must adjust each component in its structure, including machine tools, transport systems, handling processes, and storage solutions.

Modern concepts of production, rooted in Industry 4.0 system, emphasize an integrative approach that considers management, production, economic, and psychosocial aspects equally. A thorough and comprehensive analysis requires a unified perspective that accounts for all the connections and correspondences among various factors that define the manufacturing process [1].

The efficiency of a production system is closely linked to the optimization of parameters that influence quality, productivity, and manufacturing costs. Therefore, a variety of algorithms have been developed to manage these

parameters. The construction of machine tools, as well as the design and functionality of the control systems, must meet specific requirements. To fulfill these requirements, we can consider two major perspectives: Machine tools loading degree, Machine tools utilization coefficient

To achieve those essential objectives, the manufacturing process must be supported by a coherent technological framework. Thus, optimization algorithms focused on quality and economic criteria will be employed, and these models will invariably incorporate terms that address the aforementioned requirements.

Optimizing technological processes, especially those involving machine tools, is a complex task due to the multitude of factors that must be considered—both internal factors, linked to the machine tool, and external ones. Internal factors primarily arise from the elastic structure of the technological system, which includes components such as the cutting tool, clamping device, and machine tool itself, along with their interconnections in the processing workflow. Most phenomena that occur during the technological process can lead the system into a nearly constant state of imbalance. This imbalance can pose challenges in producing parts with uniform surface quality, particularly when they are manufactured under varying conditions that demand different levels of precision, quality, and productivity.

A machining system on machine tools is inherently interdependent and acts as a dynamic system that is continuously undergoing disturbances. By integrating control mechanisms based on artificial intelligence, we can continuously (and sometimes discretely) adjust the parameters that are responsible for introducing disturbances in the technological process. This adjustment, supported by mathematical algorithms, helps eliminate imbalances and stabilize the production process. Based on classical principles of machine tool automation, we propose a concept for implementing artificial intelligence, which can be illustrated in the accompanying diagram.

The block diagram illustrates that various factors influence the mechanical processing process. These factors can be divided into controllable and disruptive categories, both of

which impact the output values that contribute to the objective function.

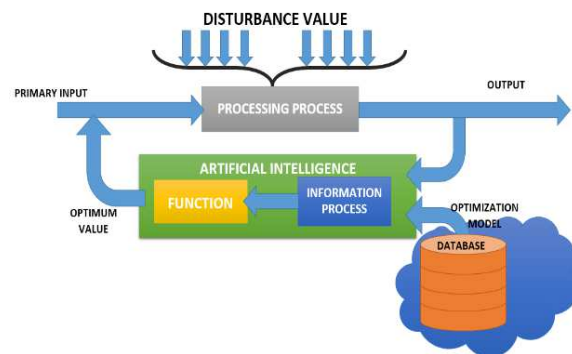


Fig. 3. The proposed architecture of artificial intelligence system [1].

When the input and output values establish a stabilization relationship aimed at satisfying specific conditions or achieving an objective function—such as productivity, precision, or economy—this interaction can be represented by a physical quantity that serves as an input value. This relationship allows the process to achieve the goal function over time without requiring human intervention, which is characterized as a self-control of the processing method.

Using interdependent relationships, as shown in Figure 4, a mathematical algorithm is designed to optimize the objective function. The schematic block representation of the processing structure derived from manufacturing processes, depicted in Figure 5, powerfully highlights the critical factors that influence these processes and specifies the input and output parameters that define them.

The primary components essential for ensuring the objective function in the manufacturing process include several key elements: machine tools, devices (such as tooling and clamping devices), cutting tools, semi-finished materials, and the technological environment. The manufacturing process occurs under the influence of primary parameters that generate mechanical, chemical, and elastic phenomena.

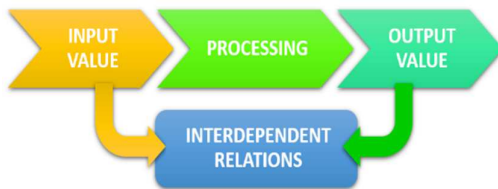


Fig. 4. Interdependence relations [1].

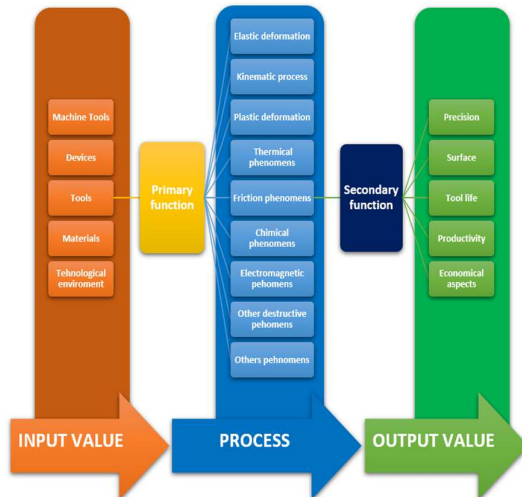


Fig. 5. The schematic representation of the processing structure [1].

The relationships among these elements define the primary function, while the secondary function is determined by the link between the manufacturing process and secondary parameters. These secondary parameters can be quantified through metrics like machining accuracy, surface quality, machining process stability, cutting tool life, productivity, and economic considerations. During the conceptual and detailed design stages of a product, primary parameters are identified and modeled by selecting the appropriate machine tool, cutting tool, machining method, and more. In machining processes on machine tools, parameters such as machining efficiency and performance can be evaluated using analytical, quantitative, and qualitative methods. This evaluation is based on measurable output parameters, including productivity, quality, and production costs. To maximize machining efficiency on machine tools, it is essential to establish optimal conditions by considering as many input parameters as possible. This includes determining the optimal cutting regime and accounting for factors that affect the machining process, such as elastic and thermal plastic

deformations. Understanding these interdependencies and influences is crucial for improving overall machining performance.

The analytical modeling of these independencies involves considering as many influencing factors as possible, typically expressed through constant or experimentally determined values. This approach aims to meet the objective function and ultimately defines the algorithm that is the basis of the manufacturing process. Artificial intelligence used to control manufacturing processes on the machine tools relies on algorithms that modify the system in real-time. By adjusting processing parameters in real-time, the system can steer the manufacturing process toward the desired outcome without requiring external human intervention. Two types of controls utilizing artificial intelligence are proposed: one aimed at increasing processing accuracy and the other aimed at reducing processing costs while enhancing productivity.

By implementing artificial intelligence, we can benefit from adaptive management due to its structure and functionality, which are based on defined parameters and values. Figure 6 illustrates the functions of artificial intelligence related to the collection, storage, comparison, processing, and transmission of information through electrical signals.

The control block ensures the integrity of the processing processes by utilizing input parameters. These parameters can be influenced by disruptive factors that correspond to accompanying phenomena. Achieving optimal conditions is closely linked to the constant monitoring of output variables, which is facilitated by the sensor block. Several parameters have been identified based on the intended purpose and can be quantified through measurement and evaluated quantitatively. Examples include cutting force, energy consumption, temperature, and various vibrations. These parameters can be detected and measured through the sensor block.

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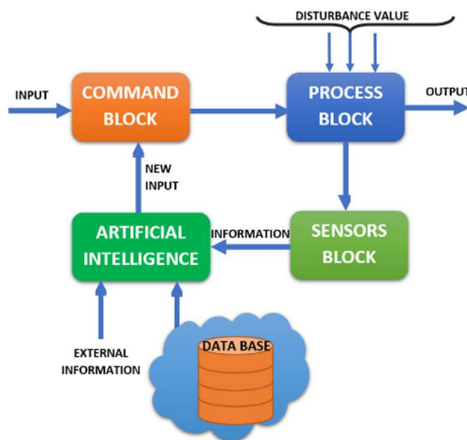


Fig. 6. The block diagram of process using artificial intelligence [1].

The computing block within the artificial intelligence system is responsible for processing the information received from the control block. This includes data obtained from the sensor block, as well as information received from neighboring systems. The artificial intelligence analyzes, calculates, and compares this information in real time with data from the database. The results are then transmitted to the control block to reconfigure the processing process and manage it effectively, making the necessary adjustments to achieve the desired function.

6. CONCLUSION

Recently, the industrial sector has faced intense competition due to globalization and the demand for new products that are easy to customize. The key principles of Industry 4.0 include the interconnection of equipment, information transparency, decentralized decision-making, and real-time technical assistance for human operators. All components

of the manufacturing system must be interconnected and utilize shared data models. Consequently, manufacturing processes need to be digitalized, and simulation techniques are leading to the development of the "digital factory" [22]. A significant challenge within Industry 4.0 systems is identifying individuals who possess the expertise, talent, and skills required to design and implement the cutting-edge algorithms that drive artificial intelligence. Addressing this gap is crucial for harnessing the full potential of technological advancements in the industry. Perhaps even more crucial is creating models for implementing learning systems, particularly for human resources at the lowest levels of the manufacturing process, leveraging the existing infrastructure. The shift toward Industry 4.0 in industrial production unlocks remarkable opportunities for creating sustainable and resilient manufacturing processes by harnessing the extensive capabilities of information and communication technology (ICT). Additionally, the integration of artificial intelligence systems allows for the advanced programming of numerically controlled machine tools, enabling them to be seamlessly incorporated into a production system or employed independently. Embracing these innovations is essential for any organization seeking to thrive in the future of manufacturing.

The architecture of the proposed system is relatively straightforward. One major drawback is the large amount of data that needs to be processed quickly for real-time adjustments to the operational process. For example, let's examine a calculation that encompasses several key components: accurately determining the composition of the processing force. This can be effectively achieved by measuring the power, highlighting the intricate relationship between force and energy in our processes. Additional errors can be introduced, such as fluctuations in electric current. It's important to note that variations in power can arise from factors beyond just the tangential force component and speed, such as efficiency.

One example of applying artificial intelligence is in situations where a CNC machine tool is operating at maximum load and reaches the minimum feed rate. An AI system

can optimize the process by dividing the cutting depth into multiple passes. While NC programming using CAM software offers many advantages, it also has inherent limitations related to the programming method itself. This type of programming is known to be a priori stable and external, meaning it cannot account for the complexities of the manufacturing process. Consequently, this limitation impacts the performance metrics of the machine tools. CAM systems for generating NC programs have a notable disadvantage: the programming of the part is mainly done outside of the machine tools. Often, the programmer responsible for creating the manufacturing technology is not situated in the same location as the production system and lacks knowledge of the machine tool's history. This method of programming can lead to significant issues, one of the most common being the improper selection of cutting modes. Such incorrect choices can result in the introduction of numerous errors.

Currently, the most widespread model in use is the integration of the numerical control (NC) system with data management systems (PDM). By combining artificial intelligence with access to these data management systems, the limitations of numerical programming can be expanded. This integration allows artificial intelligence to receive external data related to the manufacturing process, enabling it to modify the NC program in real-time. This system not only addresses the complete technological setup of the CNC machine tool but also significantly enhances communication with adjacent machine tools, ensuring a seamless and efficient technological workflow.

The key role of numerical control (NC) systems is to expertly manage the machining process on machine tools, guaranteeing that every dimension of the part strictly conforms to specifications. This precision not only enhances the quality of the final product but also boosts overall efficiency in manufacturing. In contrast, artificial intelligence (AI) systems come into play when the manufacturing process is unstable and external factors disrupt the machining process. These disturbances can negatively impact machining efficiency, quality, and precision. Simulations and experiments that

have integrated AI systems with numerically controlled machine tools demonstrate their effectiveness. These systems can boost productivity by up to 50% while also reducing processing costs by as much as 33%.

7. REFERENCES

- [1] Stef, D., Draghici, G. *Manufacturing Processes Automation and Their Intelligent Monitoring*. In: Draghici, A., Ivascu, L. (eds) *Sustainability and Innovation in Manufacturing Enterprises. Advances in Sustainability Science and Technology*. Springer, Singapore, 2022.
- [2] Stock, T., Seliger, G., *Opportunities of Sustainable Manufacturing in Industry 4.0*, 13th Global Conference on Sustainable Manufacturing – Decoupling Growth from Resource Use, Procedia CIRP, pp. 536-541, 2016.
- [3] Kagermann, H., Lukas, W., Wahlster, W., *Abschotten ist keine Alternative*. In: VDI Nachrichten, Issue 16, 2015.
- [4] Plattform Industrie 4.0: *Industrie 4.0 Whitepaper FuE-Themen*. Plattform Industrie 4.0, February 2020, 2015.
- [5] Kagermann, H., Lukas, W., Wahlster, W., *Industrie 4.0 - Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution*. In: VDI Nachrichten, Issue 13, 2011.
- [6] Spath, D., Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., Schlund, S., *Produktionsarbeit der Zukunft – Industrie 4.0*. Fraunhofer IAO, Fraunhofer Verlag, 2013.
- [7] Perez-Lara, M., Saucedo-Martinez, J., Marmolejo-Sacedo, J.A., Salaris-Fierro, T., Vasant, P., *Vertical and horizontal integration systems in Industry 4.0*, Springer Nature, 2018.
- [8] Stock, T., Seliger, G., *Opportunities of sustainable manufacturing in Industry 4.0*. Procedia CIRP, 40(Icc), 536, 2016.
- [9] Swat, M., Brünnet, H., Bähre, D.: *Selecting manufacturing process chains in the early stage of the product engineering process with focus on energy consumption*. In: *Technology and Manufacturing Process Selection: The*

- Product Life Cycle Perspective, Springer, 2014.
- [10] Uhlmann, E., Fürstmann, P., Rosenau, B., Gebhard, S., Gerstenberger, R., Müller, G., *The Potential of Reducing the Energy Consumption for Machining TiAl6V4 by Using Innovative Metal Cutting Processes*. In: Proceedings of the 11th Global Conference on Sustainable Manufacturing GCSM2013, 2014.
- [11] Larsson, T., Larsson, A., Leifer, L., Kobayashi, H., *Design for Wellbeing*. www.designforwellbeing.org, Accessed October 16th, 2015.
- [12] Wang, B., Tao, F., Fang, X., Liu, C., Liu, Y., Freiheit, F., *Smart Manufacturing and Intelligent Manufacturing: A Comparative Review, Engineering*, Volume 7, Issue 6, pp. 738-757, 2021.
- [13] Wang, J., Ma, Y., Zhang, L., Gao, R.X., Wu, D. *Deep learning for smart manufacturing: Methods and applications*, Journal of Manufacturing Systems, Vol. 48(C), pp. 144-156, 2018.
- [14] Kusiak, A., *Smart Manufacturing*, International Journal of Production Research, Vol. 56, (No. 1-2), pp. 508-517, 2018.
- [15] Bi, Z., Zhang, W.J., Wu, C., Luo, C., Xu L.. *Generic Design Methodology for Smart Manufacturing Systems from a Practical Perspective. Part I-Digital Triad Concept and Its Application as a System Reference Model*, Machines 2021, 9(10), 207, 2021.
- [16] Helu, M., Morris, K., Jung, K., Lyons, K., Leong, S. *Identifying performance assurance challenges for smart manufacturing*, Manufacturing Letters 6, 2015.
- [17] Lee, E.A., *Cyber physical systems: Design challenges*. In: Proceedings of the 11th IEEE Symposium on Object/Component/Service-Oriented Real-Time Distributed Computing; Orlando, FL, USA. Piscataway: The Institute of Electrical and Electronics Engineers, Inc., 2018.
- [18] Papakostas, N., Efthymiou, K., Georgoulas, K., Chrysosolouris, G., *On the Configuration and Planning of Dynamic Manufacturing Networks*. In: Windt K. (eds) Robust Manufacturing Control. Lecture Notes in Production Engineering. Springer, Berlin, Heidelberg, 2013.
- [19] Qu, Y.J., Ming, X.G., Liu, Z.W., Zhang, X.Y., Hou, Z.T., *Smart manufacturing systems: state of the art and future trends*. Int J Adv Manuf Technol 103, pp. 3751-3768, 2019.
- [20] Boccella, A.R., Centobelli, P., Cerchione R., Murino, T., Riedel, R., *Evaluating Centralized and Heterarchical Control of Smart Manufacturing Systems in the Era of Industry 4.0*, Applied Sciences, 10(3), 755, 2020.
- [21] Romero, M., Guedria, W., Tanetto, H., Barafort, B., *Towards a characterization of smart systems: A systematic literature review*. Computers in Industry, Volume 120, September 2020, 103224, 2020.
- [22] Stef, D., *Dezvoltarea produsului in contextul Fabricii Digitale*, PhD. Thesis, Ed. Politehnica, Timisoara, 2012.

Propunere de arhitectură pentru implementarea Inteligenței Artificiale pe mașini-unelte cu CNC

În prezent, apariția unor noi valori industriale și integrarea tehnologiilor avansate au dus la o evoluție semnificativă în industrie prin implementarea strategiilor Industrie 4.0. După cum a observat Taylor în 1911, un sistem de producție trebuie analizat pornind de la procesele sale elementare. Pornind de la această idee, această lucrare propune un sistem de control cu inteligență artificială la un nivel de bază al sistemelor de producție, concentrându-se în special pe mașinile-unelte CNC. Pentru procesele de fabricație sunt propuse două tipuri de sisteme de control prin inteligență artificială: unul care vizează creșterea preciziei prelucrării și celălalt conceput pentru a reduce costurile de procesare sau a spori productivitatea.

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