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ARTIFICIAL INTELLIGENCE AND CNC MANUFACTURING

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Abstract: The integration of artificial intelligence into CNC (Computer Numerical Control) manufacturing is one of the key development directions within the concept of Industry 4.0. Modern manufacturing systems increasingly rely on intelligent algorithms that enable dynamic process adaptation, increased precision, cost reduction and better quality control. This paper analyzes the application of artificial intelligence in the field of CNC manufacturing, with a focus on machine learning, predictive maintenance, optimization of cutting parameters, and automation of the programming process. Special attention is paid to the possibilities offered by systems based on real-time data, as well as the integration of sensor and diagnostic technologies to improve the reliability and productivity of the manufacturing system. Based on theoretical and empirical analysis, the aim of the paper is to point out the prospects for the transformation of traditional CNC production into intelligent and self-adaptive production systems of the future, as well as a general overview of the situation in Serbia when it comes to this topic.

Keywords: artificial intelligence, CNC manufacturing, machine learning, Industry 4.0, automation, predictive maintenance.

1. INTRODUCTION

The modern era is characterized by the accelerated digitalization of production processes, aimed at achieving greater efficiency, flexibility and adaptability to an increasingly demanding market. Within the concept of Industry 4.0, which involves the integration of intelligent technologies into all segments of industrial production, a special place is occupied by the application of artificial intelligence in the management of machine processes. With the advent of Industry 4.0, CNC machines are no longer isolated systems, but

become part of intelligent networks in which artificial intelligence plays a key role in automation, adaptive control and predictive maintenance of production [1]. One area in which the impact of these technologies is particularly pronounced is CNC (Computer Numerical Control) production, as the foundation of modern machining.

CNC technologies enable automated control of machine tools based on digitally defined parameters, thereby ensuring high precision, reliability and reproducibility in material processing. However, with the introduction of artificial intelligence, CNC production is moving to a new technological level — from traditional

automation to an intelligent and self-managing system. Thanks to machine learning algorithms, neural networks and real-time data processing, AI allows CNC machines to analyze operating conditions themselves, optimize processing parameters, predict failures and adapt to new requirements without human intervention.

2. THEORETICAL FRAMEWORK

2.1. Development of CNC technologies

CNC is a computer-controlled machine tool technology that has significantly improved the precision, reproducibility, and automation of manufacturing processes over the decades. In addition, CNC systems are an essential part of modern manufacturing technology, enabling high accuracy, repeatability, and control over complex machining processes [2]. Unlike traditional hand-operated machines, CNC machines perform tasks according to digital instructions, usually written in G-code. The application of CNC technology has enabled the production of complex geometric shapes with minimal deviation, which is essential in industries such as the automotive, aerospace, medical, and precision engineering industries.

The development of CNC technology has enabled the introduction of intelligent control systems that increase the precision and automation of manufacturing processes in the mechanical engineering industry [3].

The evolution of CNC systems from pneumatic and electromechanical controls to computerized systems has also followed the growth of market needs for greater flexibility and faster adaptation to serial and individual production. In the last decade, the development of the Internet of Things (IoT), cloud technologies and sensor networks has laid the foundation for further digital transformation of production in the direction of so-called smart factories.

2.2. The foundation of artificial intelligence

Artificial intelligence represents the ability of computer systems to simulate the processes of

human intelligence, such as learning, reasoning, decision-making and adapting to new conditions. Artificial intelligence-based approaches allow CNC processing systems to dynamically adjust cutting parameters, optimize tool trajectories and anticipate maintenance needs, significantly improving production efficiency [4]. Within the framework of technical disciplines, machine learning (ML) is of special importance, as a subdiscipline of AI, which allows systems to recognise forms from large amounts of data and automatically improve their performance. Typical applications of AI in industry include intelligent process control, anomaly detection, predictive diagnostics, visual inspection of products and optimization of production parameters. The combination of AI with sensory and Big Data systems enables the implementation of advanced concepts such as self-sustaining production systems and adaptive production cells.

3. PREDICTIVE ANALYTICS AND QUALITY MANAGEMENT IN CNC MANUFACTURING SUPPORTED BY AI

The integration of artificial intelligence into CNC manufacturing is one of the most important steps towards realizing the concept of a smart factory and improving the competitiveness of modern industrial systems. The introduction of AI technologies into the control of CNC machines enables automatic adaptation and optimization of the machining process, which results in improved product quality, reduced costs and reduced production time. The application of artificial intelligence in the quality management of CNC manufacturing contributes to the reduction of errors, increased precision and optimization of the control process in real time [5]. On the other hand, machine learning, as a subdiscipline of artificial intelligence, provides the opportunity to develop algorithms that, based on large data sets, can recognize patterns and predict system behavior. In CNC manufacturing, these algorithms analyze data obtained from sensors that monitor parameters such as cutting speed

and force, tool temperature, vibration and other factors that affect the quality and efficiency of the process. Based on this information, the system can automatically adjust cutting parameters in real time, thereby achieving optimal productivity and reducing tool wear.

One of the most important applications of AI in CNC systems is predictive maintenance. Instead of routine or reactive maintenance, AI allows monitoring the condition of machines in real time and predicting potential failures before they occur. This approach significantly reduces downtime, increases reliability and extends the life of equipment, which represents significant financial and operational benefits for manufacturing companies.

In addition, traditional CNC machine programming requires expertise and time to create precise instructions in the form of G-code. With the introduction of AI, systems are being developed that can automatically generate and optimize G-code based on CAD models, thereby reducing production setup time and reducing the possibility of human error. These systems can also adjust programs according to changes in material, operating conditions or quality requirements.

3.1. AI-powered quality control

The integration of intelligent systems into CNC manufacturing enables adaptive process control and real-time decision-making, which is the essence of the digital factory concept [6]. On the other hand, the integration of AI into quality control systems allows the use of sensor data, images, and video for automatic detection of defects and deviations. Machine learning and computer vision algorithms enable fast and precise inspection of parts, which increases the reliability of control and reduces the need for manual inspection. Within the framework of the Industry 4.0 concept, CNC machines are becoming intelligent systems that use real-time data to optimize production processes and improve product quality [7].

4. ADVANTAGES AND CHALLENGES OF IMPLEMENTING ARTIFICIAL INTELLIGENCE IN CNC PRODUCTION

4.1 Advantages of applying artificial intelligence

Machine learning, as one of the key areas of artificial intelligence, allows systems to independently improve their performance based on data, which is of great importance for the automation of CNC manufacturing processes. [8] The application of artificial intelligence in CNC manufacturing brings a number of significant advantages that affect the improvement of productivity, quality and cost-effectiveness of manufacturing systems. The main advantages include: increased efficiency and accuracy, preventive and predictive maintenance, reduction of human error, flexibility of production, but also improvement of product quality.

Integrated inspection and quality control systems based on AI provide high accuracy in defect detection, thereby reducing the number of rejected parts and increasing end-user satisfaction.

4.2 Challenges of applying artificial intelligence

Despite its many advantages, the implementation of AI in CNC manufacturing also faces a number of challenges that may slow down or hinder its widespread application:

high costs of implementation and maintenance, technical complexity and integration, dependence on data quality and quantity, data security and protection, resistance to change, and personnel training.

Overall, although the application of artificial intelligence in CNC manufacturing carries significant potential for improving production capacities, its successful development and implementation depend on careful management of technological, organizational, and financial aspects.

5. EXAMPLES FROM PRACTICE IN THE REPUBLIC OF SERBIA

Although the application of artificial intelligence in CNC manufacturing in Serbia is still in its early stages, there are significant developments and concrete examples that indicate the growing interest and potential for digital transformation of the industry. The digitalization of production in domestic factories increasingly includes the application of automation and intelligent systems as a prerequisite for increasing efficiency and competitiveness [9]. The main challenges are focused on the modernization of the existing production base and the integration of intelligent systems into traditional production processes.

The Serbian automotive industry, with a large number of suppliers and small and medium-sized enterprises, has started to apply elements of AI in CNC manufacturing to improve quality and efficiency. Companies such as MK Grupa and Magna Petrovac are introducing machine condition monitoring systems based on sensors and software solutions that use elements of machine learning for predictive maintenance.

Some machine shops and factories in the Republic of Serbia, such as Potisje from Subotica and VISS Masina from Niš, are collaborating with technological faculties to develop AI models for optimizing metalworking processes. Within these projects, AI is used for automatic analysis of vibrations and heat during the operation of CNC machines in order to improve maintenance planning and reduce the risk of failures.

Technology incubators in Belgrade and Novi Sad, such as Startit Center and ICT HUB, support the development of startups working on integrating AI into industrial production systems, including CNC equipment. These projects include the development of software for intelligent quality control and automated programming, which is an innovative approach that is gradually being applied in practice.

In addition, industrial incubators play a key role in supporting innovation and digital

transformation of small and medium-sized enterprises in Serbia, thereby improving competitiveness in the modern market [10].

Although Serbia is in a phase of gradual digitalization, these examples indicate a positive trend in the adoption of modern technologies. Additional efforts are needed in the areas of education, financing and infrastructure to fully exploit the benefits that AI brings to CNC manufacturing.

6. THE FUTURE OF AI APPLICATIONS IN CNC PRODUCTION

Given the increasingly intensive digitalization of industry and global trends in the application of artificial intelligence in production processes, the Republic of Serbia is facing significant challenges and opportunities in the field of CNC production. In order to achieve a competitive position in the European and global markets, it is necessary to direct development towards several key directions, namely: strengthening scientific research and development infrastructure, encouraging digital transformation in enterprises, human resource development and education, but also improving infrastructure and digital security. Overall, focusing on these development directions will enable Serbia to build a sustainable and competitive industrial sector based on the most modern technologies, which will contribute to economic growth and improving the quality of production.

7. CONCLUSION

The integration of artificial intelligence into CNC manufacturing is a key step towards the digital transformation of industrial processes in accordance with the principles of Industry 4.0. The application of AI technologies allows for a significant increase in efficiency, precision and flexibility of production, as well as a reduction in maintenance costs and improvement of product quality. Machine learning and predictive maintenance contribute to greater reliability and continuity of CNC machines, while automation of programming and quality

control reduces human errors and speeds up production cycles. However, the successful implementation of AI in manufacturing systems requires overcoming numerous challenges, such as high implementation costs, technical complexity of integration, the need for adequate infrastructure, and the development of qualified personnel. In the Republic of Serbia, progress in this domain depends on strong cooperation between academic institutions, industry and state institutions, as well as systemic measures that encourage digitalization and innovation.

The future of CNC manufacturing in Serbia is closely linked to the adoption and further development of artificial intelligence, which will enable the creation of intelligent and self-adaptive production systems. With this approach, the domestic industry can strengthen its competitiveness in the global market and contribute to economic growth based on knowledge and technologies.

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