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ADVANCEMENTS IN CNC MACHINERY: A COMPREHENSIVE REVIEW IN INDUSTRY 4.0 (2024)

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ABSTRACT

Advancements in CNC Machinery: A Comprehensive Review in Industry 4.0 is a detailed examination of the latest technologies and methodologies that are shaping the CNC machinery industry, in line with the core principles of Industry 4.0. This review compendium includes a range of research papers covering precision engineering, automation, integration with smart technologies, real-time data processing, and sustainability practices within the CNC machinery domain. By studying the evolving landscape of CNC machinery through the lens of Industry 4.0, the report aims to show how these advancements are helping to improve intelligent manufacturing processes, increase capacity and promote sustainability initiatives. This comprehensive review has been created by thoroughly analyzing and synthesizing existing literature, and will be an invaluable guide for researchers, practitioners, and industry stakeholders who want to harness the full potential of CNC machinery in the industry 4.0 paradigm shift.

Keywords: Artificial Intelligence, Automation, CAD/CAM Technology, CNC, Human Machine Integration, Industrial Internet of Things, PowerMILL, RFID, Robotics, Speech Recognition.

1. INTRODUCTION

The onset of Industry 4.0 marks a significant change in manufacturing, where digital technology is now blended with traditional manufacturing processes. Computerized numerical (CNC) machinery plays a crucial role in this evolution by providing precision, automation, and interoperability in today's

manufacturing industry. This comprehensive review explores the dynamics of CNC machines, their adaptability to smart manufacturing principles, and highlights topics such as automation, integration with smart technologies, real-time data processing, and sustainability. The review title examines key aspects of CNC machine development, shedding light on their roles in supporting intelligent manufacturing processes, capacity building, data analytics, and sustainability practices. It focuses on the Industrial Internet of Things (IIoT), highlighting how CNC machines are connected and how artificial intelligence penetrates, emphasizing their transformative effect on production. Through critical research and thematic analysis, the review aims to provide a general understanding that advanced CNC machinery not only increases productivity and reduces downtime but also enables change in the dynamic Industry 4.0 environment. The subsequent identification of existing gaps and suggestions for future research are valuable resources for researchers, practitioners, and industry stakeholders navigating the evolving CNC machining landscape in the industry 4.0 era.

2. LITERATURE SURVEY

Mohsen Soori, Behrooz Arezoo, Roza Dastres [1], This paper is a comprehensive review of how machine learning and artificial intelligence are integrated into computerized numerical control (CNC) machine tools. It focuses on various applications, techniques, and recent developments of machine learning and AI applications that are used to enhance the spreadability of CNC machine capabilities. This advanced technology contributes to the overall productivity, efficiency, and automation of CNC machines. The content of the paper includes a discussion of applications where machine learning and AI techniques have been successfully applied to enhance CNC machining processes. This includes a range of applications from predictive maintenance to quality control to machining. The study also examines the challenges of advances in this technology and shows how they have adapted to meet the specific requirements and challenges of the CNC industry. In addition to the positive aspects highlighted, the paper acknowledges the challenges associated with implementing machine learning and AI in CNC environments. This includes considerations such as data quality, model interpretation, and integration of this technology into existing workflows. Providing a balanced approach, the paper not only demonstrates the potential benefits of integrating machine learning and AI into CNC machines but also provides valuable insights into the barriers that must be overcome. Overall, this paper aims to contribute to a greater understanding of the impact of machine learning and artificial intelligence on machine tools and the ability to determine the future of precision manufacturing.

Samuel Lee, Jeng-Dao & Tsai-Lin, Cheng-Wei & Lee, Yi-Cheng & Liu, Min-Che & Chen, Li-Yin. [2], The trend of customized manufacturing is on the rise due to changes in consumer habits, leading to a shortened product life cycle. To address the need for greater efficiency and flexibility in automated production, many countries are looking towards Industry 4.0 as a pivotal goal. One of the essential initial steps in this industrial evolution involves the development of an automatic loading and unloading CNC machining system with vision inspection capabilities as discussed in this paper. The CNC controller serves as the central command unit, coordinating the actions of the robot, conveyor, and other associated equipment. The system incorporates machine vision technology to detect the material's position on the conveyor and the machining material's edges. Open CNC and SCADA software are integrated to allow real-time monitoring, remote control system operation, email notifications for alarms, and the collection of critical parameters. To further enhance efficiency, RFID technology has been introduced for employee classification and management. The innovative concept of machine handshaking is introduced, successfully enabling automatic vision detection, edge tracing measurements, machining operations, and the collection of system parameters. This holistic approach aims to achieve seamless industrial automation system integration with real-time monitoring and comprehensive data analysis capabilities.

Shuling, Cao and Guan Jinbiao [3], This paper delves into the CNC machining of complex parts, with a particular focus on the essential role of cutting simulation and subsequent program processing that relies on CAD/CAM technology. The study highlights the use of powerMILL, a powerful software solution that

is widely recognized for its excellence in CAM (Computer-Aided Manufacturing). The powerMILL plays a crucial part in the CNC machining process by facilitating cutting simulation and post-program processing, which leads to improved accuracy and efficiency. Cutting simulation is an essential aspect of CNC program inspection, and powerMILL effectively conducts this task by ensuring meticulous examination of tool paths and program accuracy. Further, powerMILL seamlessly integrates subsequent program processing, including the adjustment and refinement of tool paths, into the workflow. This feature provides a valuable supplement to the CAD/CAM programming function. The research emphasizes the significance of powerMILL in advancing the CNC machining of surfaces with intricate designs. The paper aims to provide insights that not only enhance the quality and efficiency of the manufacturing process but also showcase the specific capabilities and advantages brought about by the utilization of powerMILL in conjunction with CAD/CAM technologies. Through a detailed exploration of powerMILL's features and functionalities, the study aims to provide a comprehensive understanding of how this software enhances CNC machining processes for intricate surfaces, ultimately optimizing precision and productivity in the manufacturing domain.

Omkar Govind Borawane, Shreya Mangesh Deshmukh, Mansi Pandurang Malekar, Prof.Gajanan Arsalwad [4], This paper explores the increasing trend of people using robots for various tasks due to their versatility, accuracy, reliability and efficiency in reducing human efforts. The study focuses on the development of a programmable robotic arm, similar to a human arm, to help physically handicapped individuals write and integrate home automation features for speech-based commands like turning on lights and fans. The innovative mechanism includes a speech recognition system that allows users to articulate commands verbally, which are then translated into written text or used for home automation tasks. The robotic arm's primary objective is to transcribe spoken words into written form, equipped with a pen. Additionally, the arm can draw small sketches. Besides facilitating writing operations, the system is designed to be a low-cost device, providing programmable functionality to enable individuals with physical challenges to write. The integration of home automation features enhances the user experience, allowing voice commands for tasks like controlling lights and fans. This paper aims to highlight the potential of robotic technology in aiding those with physical limitations, emphasizing its cost-effectiveness and adaptability for a broader user base.

M. Norda, C. Engel, J. Rennies, J. -E. Appell, S. C. Lange and A. Hahn [5], Automatic Speech Recognition (ASR) is now a common feature in everyday consumer devices like cars, mobile phones, and smart home gadgets. However, integrating voice control into industrial Human-Machine Interfaces (HMI) presents unique challenges due to the specific operating conditions in industrial settings. This paper aims to optimize diverse HMI scenarios by introducing or complementing voice control alongside existing touch interactions, recognizing voice control as a natural and efficient communication method. This paper focuses on addressing the complexities of industrial operations, particularly in the context of commands issued to CNC milling machines and industrial robots. These commands are analyzed and categorized based on their complexity, taking into account factors such as menu levels and required interactions. The objective is to understand how voice control can enhance the efficiency of these interactions. The findings of the study reveal that incorporating voice control into industrial HMIs can result in significant time efficiency benefits. This is particularly evident in commands that require navigating through additional menu levels or multiple touchscreen interactions. In instances where commands are more intricate, the time efficiency advantage of utilizing voice control can be as high as 67%. This highlights the substantial potential of voice control in not only simplifying command sequences but also improving operator training times. By shedding light on the advantages of voice control in industrial settings, this research contributes valuable insights into the design and optimization of Human-Machine Interfaces. The study emphasizes the practical benefits of leveraging voice as a complementary interface alongside traditional touch interactions, paving the way for more streamlined and efficient industrial operations.

Adam, Anbia & Sam, Toong Hai & Latif, Kamran & Yusof, Yusri & Khan, Zohaib & Memon, Danish & Saif, Yazid & Hatem, Noor & Iliyas Ahmad, Maznah & Abdul Kadir, Aini. [6], The next generation of Computer Numerical Control (CNC) aims to incorporate key elements like interoperability, openness, and flexibility, aligning with the requirements of Industry 4.0. However, the inherent nature of

traditional CNC software systems often poses challenges for users seeking to enhance and modify them to meet the evolving demands of contemporary technology. To address this limitation, extensive research has been conducted over the years, as highlighted in the review presented in the paper. Based on the trends revealed in the review, it becomes apparent that approximately 80% of the advanced CNC systems use ISO 14649 as the preferred ISO data environment. This preference is rooted in the interoperability offered by ISO 14649, which facilitates seamless information exchange between Computer-Aided Technologies (CAx). The study also indicates that a significant majority, accounting for 35%, prefer Windows as their Operating System. This choice is attributed to the inherent flexibility of Windows, which enables the development of modules and programs that support the CNC machine. The flexibility of the chosen operating system plays a pivotal role in accommodating the dynamic requirements of CNC systems and their compatibility with evolving technologies. Essentially, the ongoing efforts in CNC research underscore a commitment to overcoming the limitations of conventional CNC software systems. By prioritizing interoperability and flexibility, researchers aim to ensure that CNC technology remains adaptable to the demands of Industry 4.0, fostering a more responsive and versatile manufacturing environment.

3. COMPARATIVE ANALYSIS OF LITERATURE REVIEWS

Table 1: Comparison study of papers

Paper Title	Authors	Comparative Study
Machine learning and artificial intelligence in CNC machine tools, A review	Mohsen Soori, Behrooz Arezoo, Roza Dastres	This paper examines how machine learning and AI enhance CNC machine tools, covering applications from predictive maintenance to quality control. It highlights both the benefits and challenges of integrating these technologies, offering insights into their impact on precision manufacturing's future.
Fully automatic CNC machining production system	Samuel Lee, Jeng-Dao & Tsai-Lin, Cheng-Wei & Lee, Yi-Cheng & Liu, Min-Che & Chen, Li-Yin.	The paper discusses the rise of customized manufacturing driven by changing consumer habits and the need for greater efficiency in automated production, with Industry 4.0 as a key focus. It examines the development of an automatic loading and unloading CNC machining system with vision inspection capabilities, aiming for seamless industrial automation and comprehensive data analysis.

Paper Title	Authors	Comparative Study
CNC Machining Process and Programming Technology of Complex Parts Based on PowerMILL	Shuling, Cao and Guan Jinbiao	This paper explores the CNC machining of complex parts, focusing on the role of cutting simulation and program processing using CAD/CAM technology, particularly emphasizing the use of powerMILL software. It highlights powerMILL's significance in improving accuracy and efficiency through cutting simulation, program inspection, and subsequent processing, ultimately optimizing precision and productivity in CNC machining for intricate surfaces.
Automated drawing and writing machine and home automation	Omkar Govind Borawane, Shreya Mangesh Deshmukh, Mansi Pandurang Malekar, Prof.Gajanan Arsalwad	This paper explores the use of robotic technology to assist physically handicapped individuals with writing tasks and home automation through a programmable robotic arm. It integrates speech recognition for verbal commands, enabling transcription and home automation functionalities like controlling lights and fans. The study emphasizes the cost-effectiveness and versatility of robotic technology in aiding individuals with physical limitations.
Evaluating the Efficiency of Voice Control as Human Machine Interface in Production	M Norda, C Engel, J Rennies, J E Appell, S C Lange and A Hahn	This paper investigates integrating voice control into industrial Human-Machine Interfaces alongside touch interactions to enhance efficiency in CNC milling machines and industrial robots. Findings show significant time efficiency gains, particularly in complex commands, highlighting the potential of voice control to streamline operations and improve operator training in industrial settings.

Paper Title	Authors	Comparative Study
Review on Advanced CNC Controller for Manufacturing in Industry 4.0	Adam, Anbia & Sam, Toong Hai & Latif, Kamran & Yusof, Yusri & Khan, Zohaib & Memon, Danish & Saif, Yazid & Hatem, Noor & Iliyas Ahmad, Maznah & Abdul Kadir, Aini.	This paper reviews the challenges faced by traditional CNC software systems in adapting to Industry 4.0 requirements and highlights research efforts to overcome these limitations. Findings indicate a preference for ISO 14649 for interoperability and Windows as the preferred operating system for flexibility, reflecting a commitment to ensuring CNC technology remains adaptable to evolving manufacturing demands.

4. CONCLUSION

The review report titled "advancements in CNC machinery: a comprehensive review in industry 4.0" highlights significant progress in computer numerical control (CNC) technology. The survey of literature shows that researchers are making a concerted effort to achieve key elements essential for Industry 4.0, such as interoperability, openness, and flexibility. They are also addressing the limitations of traditional CNC software systems to align with the demands of the next industrial revolution. The integration of the latest technologies like machine learning, artificial intelligence, and advanced CNC controllers indicates a commitment to improving productivity, efficiency, and adaptability in manufacturing processes. The emphasis on automation, precision, and the use of sophisticated software solutions in CNC machining positions the industry at the forefront of innovation. As CNC machinery evolves to meet the challenges and opportunities of Industry 4.0, it is vital to embrace intelligent systems, automation, and open-source solutions. This journey towards a more interconnected, intelligent, and adaptable manufacturing environment sets the stage for continued advancements.

5. STATEMENTS AND DECLARATIONS

Author contributions: Every author contributed to the research topics by conducting a thorough analysis of all relevant research papers through a comprehensive literature review. The tasks of data collection and analysis were executed by NS, NP, RR, and TS, under the supervision and guidance of LG and MV. The first draft of the manuscript was written by RR and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript**.**

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