



THE RELATIONSHIP BETWEEN AI AND CNC TECHNOLOGY

István György BURAI,¹ György CZIFRA²

¹ Óbuda University, Bánki Donát Faculty Of Mechanical and Safety Engineering, Institute of Mechanical Engineering and Technology, Budapest, Hungary, burai.istvan@bgk.uni-obuda.hu

² Óbuda University, Bánki Donát Faculty Of Mechanical and Safety Engineering, Institute of Mechanical Engineering and Technology, Budapest, Hungary, czifra.gyorgy@bgk.uni-obuda.hu

Abstract

Our research focuses on the applicability of artificial intelligence (AI) in the education of CNC programming. In this article, we present the current application areas of AI, focusing on its role in CNC technology. We define what the term artificial intelligence entails and briefly review its application areas. The acronym CNC is interpreted, and we summarize the history of CNC. We examine the potential of artificial intelligence, which we use to support CNC technology, and we present the application of AI in the context of Industry 4.0.

Keywords: *artificial intelligence, CNC, Industry 4.0.*

1. Introduction

Artificial intelligence (AI) is a set of computer algorithms that can mimic human intelligence in performing various tasks. Such activities include learning, problem solving, planning, natural language processing or image recognition. Artificial intelligence can reason and make decisions based on available data without human intervention [1].

Given the current state of development of artificial intelligence, one type is available, called Artificial Narrow Intelligence (ANI), also known as narrow or narrow AI. This type can only perform a specific task, which it can perform more efficiently than a human. It is the highest level of AI currently available. Examples include self-driving vehicles, facial recognition systems, digital personal assistants, language processing AI (Copilot, ChatGPT, Gemini, etc.), or for example a chess game [2].

The next stage of development is Artificial General Intelligence (AGI), which would not only specialise in a single task, but would be able to do complex thinking, learning and adapting in multiple environments. Such a system could understand problems and find creative solutions in a human-like way. AGI is still experimental and its development is a major goal of AI research.

The highest theoretical type is Artificial Super Intelligence (ASI), which would far surpass human intelligence not only in computational capacity, but also in reasoning, decision-making, and even emotional and social intelligence. The functioning of ASI would fundamentally change social and economic systems, but would also raise significant ethical questions. This type of capability exists today on a purely theoretical level, but is an important part of the future AI discourse [3]. Below are listed the technological solutions known to date for this capability:

Machine Learning is an artificial intelligence-based technology that allows computer systems to learn and evolve automatically by processing experience and data, without the need to explicitly program each step. Algorithms recognise patterns in data sets and can use them to make predictions, decisions or classifications. The three main types of machine learning are supervised learning, where the model learns with known input-output pairs. Unsupervised learning, which can discover hidden structures and clustering, and reinforcement learning, where the system develops its decision strategies based on rewards and punishments. Today, machine learning is widely used in applications such as recommender systems (Netflix, Spotify), financial forecasting, health diagnostics, fraud detection and self-driving vehicles.

Deep Learning is a special branch of machine learning that uses deep neural networks. These networks learn from large amounts of data and can perform complex tasks. Examples include image recognition and natural language processing. A special feature of deep learning is that it uses multilayer neural networks that can generate hierarchical representations of data. This allows the system to interpret information at progressively more abstract levels. Deep learning techniques have led to significant advances in machine vision, speech recognition and natural language processing. For example, Convolutional Neural Networks (CNNs) are excellent for image recognition tasks, while Long Short-Term Memory (LSTM) networks are efficient for processing sequential data such as text [4].

Deep learning and computer vision play a key role in the development of self-driving cars. Such systems use convolutional neural networks (CNNs) to process data collected by cameras and sensors. These networks can recognise and interpret the environment, such as road signs, pedestrians, other vehicles and road conditions. Self-driving cars continuously learn and adapt to different traffic situations, increasing safety and efficiency. The use of deep learning and computer vision allows cars to navigate autonomously, avoid obstacles and drive safely without human intervention. Uber and Tesla, for example, have made significant advances in this area and are continuously developing their self-driving technologies [5].

Natural Language Processing (NLP) is a branch of AI that focuses on understanding and generating human language. Applications of NLP include autocorrect and spell-check functions that help correct spelling mistakes and clarify text. In addition, NLP is used for sentiment analysis, which allows the detection and analysis of the emotional content of texts, for example in social media posts or customer reviews. NLP can also be used in question-answering systems that automatically answer users' questions, such as customer service chatbots. In addition, NLP technology is used for text translation, allowing automatic translation between different languages, for example in Google Translate. Other applications of NLP include speech recognition, which enables the conversion of spoken language into text, for example in Siri and Alexa virtual assistants. Some popular NLP software solutions [6]:

- spaCy is a Python-based library that supports more than 72 languages and enables efficient text processing;
- MonkeyLearn is a Machine Learning platform that enables text analysis and data visualization;
- Stanford CoreNLP is a Java-based NLP tool that produces linguistic annotations from text and supports multiple languages;
- IBM Watson is a comprehensive enterprise text analysis solution that can perform a variety of NLP tasks.

Computer Vision allows computers to interpret images and videos. Applications of computer vision include face recognition, object recognition and self-driving cars.

Facial recognition systems can identify and authenticate people by their faces. For example, FaceID technology on Apple devices allows users to unlock their devices using their face. Face recognition is also used in security systems, for example to identify passengers at airports [2, 7].

Object recognition systems can identify and categorise different objects in images. For example, the YOLO (You Only Look Once) algorithm provides high-performance object recognition in real-time applications such as security cameras and industrial automation. In Amazon Go stores, object recognition helps to power automated check-out systems, where customers can simply pick items from the shelves and the system automatically invoices them [8]. Some popular software solutions for computer vision [9]:

- OpenCV is an open source machine learning and computer vision library that contains over 2500 algorithms for various tasks such as face recognition, object identification and tracking moving objects;
- TensorFlow is an open-source machine learning framework widely used in computer vision projects such as image classification and object recognition;
- YOLO is a high-performance object recognition algorithm designed for real-time applications and is widely used in security systems and industrial automation.

Action Planning is the process by which intelligent systems can sense their environment, make decisions and act. Robots are used in various industries and in healthcare. Industrial robots use action planning to optimise manufacturing processes, for example in automotive manufacturing, where robots can sense the position of parts, make decisions about assembly sequences

and perform assembly operations with precision [10]. Healthcare robots use action planning in surgical procedures, such as the Da Vinci surgical system, which can sense the patient's anatomical structures, make decisions about the most optimal cutting paths, and perform surgical interventions with precision [11]. In logistics networks, action planning helps optimize the delivery of shipments, for example, drones can sense their environment, make decisions about the most optimal routes, and deliver packages safely [12]. Agricultural robots use action planning to care for plants, for example, robots can sense the condition of plants, make decisions about the amount of nutrients and water needed, and perform care operations with precision [13].

Artificial intelligence is currently being applied in many areas. The aim is to harness the benefits of AI to improve quality of life, increase problem solving efficiency and support innovation. Here are some areas where AI has been used (Figure 1).

This research aims to explore and investigate the potential of artificial intelligence to support CNC technology. The adaptation of AI to some area of CNC technology involves several steps and aspects. The idea of adaptation raises a number of questions. Does AI have solutions that can positively impact CNC technology? Another big question is whether there is an area of CNC technology that can be supported by AI? The first step in this long process is to examine the subjects of adaptation and to identify the key areas and tasks for the application of AI.

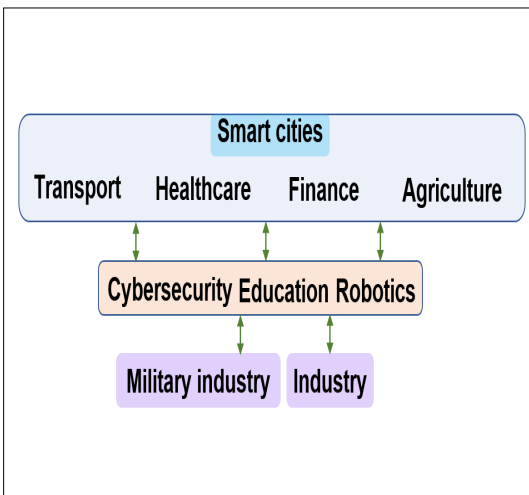


Fig. 1. Areas of use of AI.

2. CNC technology

The letters CNC stands for Computer Numerical Control. Manufacturing equipment in which the necessary movements are performed by motor(s) (stepper, servo) without human intervention. The operation of the motor or motors is controlled by a computer, which is called control of the machine tool.

CNC technology is used in the field of machining, in manufacturing processes such as turning, milling, drilling, grinding, where the material removal process is controlled by a computer using programming codes. The computer numerical control machine is the mainstay of modern manufacturing, dating back to the 1940s when the first NC machines appeared.

After the Second World War, the Cold War period focused on the importance of arms production, which called for an increase in the efficiency and productivity of production. In the late 1940s, in 1949, John T. Parsons, an early pioneer in computer science, developed the first concept of numerical control while working on an Air Force research project at the Massachusetts Institute of Technology (MIT).

At MIT's Laboratory of Servomechanisms, an experimental milling machine was built that could be used to produce helicopter blades and stiffer shells for aircraft using motorised shafts. In the 1940s and 1950s, early Numerical Control machines still used a punched tape to input instructions, a common tool for telecommunications and

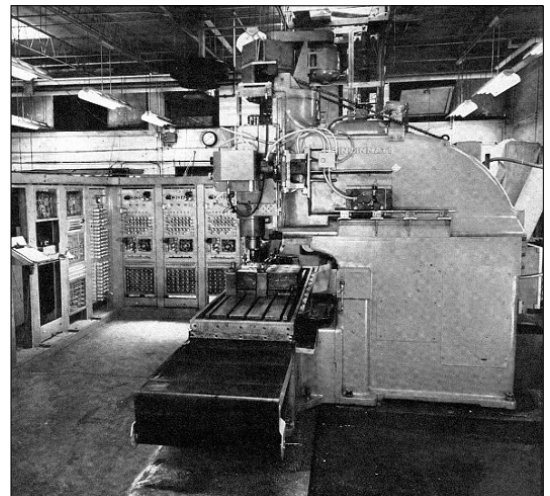


Fig. 2. The first NC milling machine (Cincinnati Milacron Hydrotel).

data storage at the time. This technology was later replaced by analogue computing.

In 1952, Richard Kegg, in collaboration with MIT, created the first NC milling machine (**Figure 2**), which became known as the Cincinnati Milacron Hydrotel. At this time, NC technology was limited primarily to machining centers.

The 1960s and 1970s saw the emergence of digital technologies, which significantly automated and made manufacturing processes more efficient.

In the 1970s, the use of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) brought great advances in CNC machining.

Since the 1990s, CAD and CAM systems have become an integral part of CNC technology, enabling even more precise and flexible manufacturing solutions [14].

3. The CNC technology and the AI

The development of machine tools and the associated CNC technology is unique. The result of this evolution is faster, more accurate and reliable part production. Machines with 5-8-10 axes (e.g. turning centre, machining centre) available today enable increasingly complex part production. The current state of CNC technology shows significant advances in intelligent manufacturing systems, especially in the context of Industry 4.0.

Digital twin technology in the CNC industry is based on the creation of exact digital replicas of physical entities such as machine tools, tools, workpieces and manufacturing processes that are synchronised with their physical counterparts through real-time data link. The combination of IoT devices, advanced sensors, data analysis algorithms and simulation tools enables continuous data collection, analysis and real-time monitoring of system health.

The sensors record real-time data on the state of physical systems, such as temperature, pressure or vibration, which is transmitted to central data processing systems via computer networks such as WiFi or industrial Ethernet. Here, cloud computing ensures secure data storage and processing, providing real-time insight into the operation of systems.

Digital twins not only monitor the current state, but can also simulate the behaviour of systems. They can use physics-based simulations to visualise possible changes in processes, such as a machine malfunction or component wear. Artificial intelligence (AI) and data analysis algorithms can detect anomalies, predict failures and suggest

maintenance or optimisation actions. The most striking feature of the digital twin is its two-way communication: this technology not only receives data, but also provides feedback, for example with automatic system adjustments or decision-support suggestions. This reduces downtime due to failures while increasing the operational efficiency of the assets.

Using Augmented Reality (AR), digital twins offer visual interfaces that make it easier to quickly identify and deal with errors. For example, a maintenance engineer can monitor the current status of machines with AR glasses. Cyber security, such as data encryption and access control, ensures data protection and authenticity.

The technological innovations of the digital twins will bring new levels of efficiency, sustainability and resilience to industrial operations, contributing to the objectives of Industry 4.0 and reducing environmental impacts [15].

Artificial intelligence is used in many areas of CNC technology, typically to optimise and increase the efficiency of manufacturing processes. Some solutions for the application of AI:

- Tool wear prediction;
- Machining parameter optimisation;
- Predictive maintenance;
- Surface quality prediction;
- Toolpath optimisation.

Tool wear prediction: AI helps predict tool wear in CNC machines, which can increase tool life and improve machining efficiency.

Machining parameter optimisation: AI systems optimise machining parameters such as cutting speed and depth of cut to improve surface quality and reduce energy consumption.

Predictive maintenance: MI enables predictive maintenance of CNC machines, which helps to anticipate machine service needs and minimise downtime.

Surface quality prediction: AI techniques, in particular machine learning and deep learning models, can predict the surface quality of machined parts, which can improve the accuracy and reliability of manufacturing processes.

Toolpath optimisation: AI algorithms can optimise toolpaths, reducing programming time and minimising tool positioning errors. For example, Autodesk Fusion 360 CAM software uses AI to increase the efficiency of CNC programming [4].

4. Conclusions

CNC technology is one of the fastest growing players in the industry. Its most active expansion has been in the field of component manufacturing (turning, milling, drilling, grinding) and continues today. The use of manually operated machining centres is now limited to special cases and has been replaced by CNC-controlled production machines. One reason for this is the incredibly rapid change in computer technology. With the advent of artificial intelligence (AI), we can delegate tasks to AI that can make the manufacturing process more efficient, more accurate, safer and improve maintenance planning.

An examination of the current relationship between AI and CNC confirmed the importance of research supporting the collaboration between AI and CNC technology. The involvement of artificial intelligence to support CNC programming is a key element in AI-related research. In addition to existing roles, new potential applications can be formulated to further enhance manufacturing efficiency at any stage of the production process. AI, as a technological assistant, can suggest several alternatives for the manufacturing process of a product and can also enable the creation of flexible part machining codes at the manual CNC programming level.

This research aims to apply artificial intelligence in the field of CNC technology in secondary and university education. The aim of using AI solutions is to increase the quality and efficiency of education, in a way that the application of new technology does not involve extra work and is as safe as possible. The integration of AI in education is a long and complex process, the first task of which will be to identify the characteristics of the related fields (AI, education, CNC) and their adaptation and interaction effects. To do this, I will carry out a SWOT analysis for the three domains. Then, I will treat the three areas as a single entity according to my research objective and investigate their viability through another SWOT analysis. Depending on the results obtained, I will identify the strategically important tasks.

In the context of AI, it is necessary to examine what technologies and applications are currently available, where and in what form AI is used in CNC technology and education. In its current form, is it suitable for the task at hand and to what extent can it solve it? The potential for developing the AI system should be explored. The running environment, software solution, operating princi-

ple and learning methodology of the AI should be defined. It is important to explore how available AI systems (e.g. ChatGPT, Gemini, Copilot, etc.) can be integrated into an existing, well-functioning user environment, such as Moodle.

Overall, the involvement of AI in supporting CNC programming is a key element in AI-related research. In addition to existing roles, new potential uses can be formulated to further enhance manufacturing efficiency at any stage of the production process. As a process assistant, AI can suggest several alternatives for the manufacturing process of a product and can also enable the generation and control of flexible part machining program code. This calls for the formulation and research of the role of AI in education and the educational methods related to the development of AI.

References

- [1] Russell S., Norvig P.: *Artificial Intelligence – a Modern Approach*. Series in Artificial Intelligence, Prentice Hall, Englewood Cliffs, NJ, 2009.
- [2] Goodfellow I., Bengio Y., Courville A.: *Deep Learning*. Genet Program Evolvable Mach, 19. (2018) 305–307.
<https://doi.org/10.1007/s10710-017-9314-z>
- [3] Bostrom N.: *Superintelligence: Paths, Dangers, Strategies*. Oxford University Press, 2014.
- [4] LeCun Y., Bengio Y., Hinton G.: *Deep Learning*. Nature, 521. (2015) 436–444.
- [5] Khurana D., Koli A., Khatter K.: *Natural Language Processing: State of the Art, Current Trends and Challenges*. Multimedia Tools and Applications, 82. (2023) 3713–3744.
<https://doi.org/10.1007/s11042-022-13428-4>
- [6] Kuei-Hu Chang: *Natural Language Processing: Recent Development and Applications*. Department of Management Sciences R.O.C. Military Academy, 2002.
<https://doi.org/10.3390/app132011395>
- [7] Lynn T.: *Computer Vision Applications*. (2025).
<https://blog.roboflow.com/computer-vision-applications/> (accessed on: 2025. 04. 09.)
- [8] Lynn T.: *Computer Vision Examples*. (2025).
<https://blog.roboflow.com/computer-vision-examples/> (accessed on: 2025. 04. 09.)
- [9] Gao M., Zou G., Li Y., Guo X.: *Recent Advances in Computer Vision: Technologies and Applications*. Electronics, 13 (2024) 2734.
<https://doi.org/10.3390/electronics13142734>
- [10] Singh G. & Pidadi P., Malwad D.: *A Review on Applications of Computer Vision*. (2023).
https://doi.org/10.1007/978-3-031-27409-1_42.
- [11] Gao J, Yang Y, Lin P, Park DS.: *Computer Vision in Healthcare Applications*. Journal of Healthcare Engineering, 2018 Mar 4; 2018:5157020.
<https://doi.org/10.1155/2018/5157020>.

- [12] Jalal A. M., Toso E. A. V., Morabito R.: *Integrated Approaches for Logistics Network Planning: a Systematic Literature Review*. International Journal of Production Research, 60/18. (2021) 5697–5725. <https://doi.org/10.1080/00207543.2021.1963875>
- [13] Jiachen Yang, Jingfei Ni, Yang Li, Jiabao Wen Desheng Chen: *The Intelligent Path Planning System of Agricultural Robot Via Reinforcement Learning*. Sensors, 22/12. (2022) 4316. <https://doi.org/10.3390/s22124316>
- [14] Noah Harrison: *CNC History: The Origination and Evolution of CNC Machining*, 2021. <https://www.rapiddirect.com/blog/cnc-history/> (accessed on: 2025. 02. 28.).
- [15] Daraba D., Pop F., Daraba C.: *Digital Twin Used in Real-Time Monitoring of Operations Performed on CNC Technological Equipment*. Applied Sciences, 14/22. (2024) 10088. <https://doi.org/10.3390/app142210088>
- [16] Kusiak A.: *Smart Manufacturing*. International Journal of Production Research, 56/1–2. (2017). 508–517. <https://doi.org/10.1080/00207543.2017.1351644>
- [17] Teti R., Jemielniak K., O'Donnell G., Dornfeld D.: *Advanced Monitoring of Machining Operations*. CIRP Annals, 59/2. (2010) 717–739. <https://doi.org/10.1016/j.cirp.2010.05.010>