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QUALITY CONTROL OF 3D BRAILLE MODELS IN ADDITIVE MANUFACTURING USING ARTIFICIAL INTELLIGENCE TECHNOLOGY

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Additive manufacturing is one of the most advanced manufacturing technologies, capable of transforming manufacturing processes, and helps in accelerating the production of complex 3D models, including the use of Braille for blind people. The unique characteristics and creation of 3D models with embossed dot Braille for blind people open up not only opportunities, but also problems in ensuring their quality control. This scientific research aims to optimize the quality control processes of tactile 3D models through the integration of artificial intelligence (AI). Considering the current challenges faced in testing the quality, accuracy, and ability of blind people to accurately read information from such models, it is necessary to explore how the use of information technology and AI algorithms can improve quality control measures. In this article, the role of artificial intelligence technologies is also analysed in additive manufacturing to determine the most effective approaches to ensure the accuracy and reliability of 3D Braille models. Through analytical research and benchmarking demonstrating the successful integration of artificial intelligence into quality control, the significant impact of these advances on the additive manufacturing industry is identified. This article will provide diagrams of how AI is developing and what future awaits it. Expected future advances in artificial intelligence for quality control of 3D Braille models will also be discussed, highlighting the potential for further innovation in this important area of research and practice. This research will help in the development of AI as well as its integration into additive manufacturing, which will result in an effective increase in the quality of development of inclusion and accessibility for blind people. It is also discussed why AI is a necessary information technology to integrate into all additive manufacturing processes.

Keywords: *artificial intelligence (AI), additive manufacturing (AM), blind people, inclusive, 3D-models, 3D-printing, Braille.*

Formulation of the problem. The development of additive manufacturing, or in other words, 3D printing began to develop back in the 20th century, and active development and integration began in the 21st century, integrating into many areas of production, thereby transforming production processes and improving the quality of creating models, parts, etc. Thus, in parallel with additive manufacturing, the foundation for the development of artificial intelligence began to be laid at the beginning of the 21st century, and active use began in 2020, integrating into all spheres of life, the

Internet, education, programming, etc. Artificial intelligence can now do incredible things, analyze information at a fast speed, generate ideas, analyze information and evaluate it, etc. The relevance of this research scientific topic is to study and analyze the use of artificial intelligence in additive manufacturing to control the quality of evaluation of finished printed products 3D models with embossed dot Braille. Since the process of assessing the quality of finished 3D models with Braille is quite complex, therefore, to solve this problem, it is proposed to use artificial intelligence to control the quality of tactile models. This will help solve problems with assessing the quality of finished 3D models with Braille, save financial expenses and speed up the process development of inclusive education and open wide access to information.

Analysis of recent research and publications. Articles on the topic of this research are mainly devoted to the analysis of the use of artificial intelligence in additive manufacturing, with the possibility of checking the quality control of printed 3D models in Braille. Most often, scientists describe the basic principles of using AI in printing production, and there was no mention of integrating AI into additive manufacturing for quality control of 3D Braille models. However, most articles describe standards and quality control of created Braille models, but do not address the problem of how to use new information systems, such as AI in additive manufacturing and assessing the quality of printed models.

Aim. To analyze the benefits of using AI for quality control of 3D Braille models in additive manufacturing and consider how AI can evaluate 3D models as well as the use of AI solutions in additive manufacturing to control the quality of tactile models.

Presentation of the main research material

The innovative process of using software to create 3D Braille models highlights dramatic changes in the production of tactile graphics and educational materials for the visually impaired. Software is required to convert user input into Braille and forms the basis of the technology that enables the design and creation of complex tactile graphics, maps and training modules that meet the needs of the visually impaired community [1]. Once these designs are completed, they can be sent directly to a 3D printer that can convert digital models into tangible Braille labels and detailed tactile graphics [1]. This advancement not only makes Braille labels more accessible and affordable, but also allows users to design and print these labels in the comfort of their own homes, significantly increasing the independence of the visually impaired [1]. Furthermore, by incorporating Braille into 3D models, these innovative tools open up new aspects of tactile communication, broadening the horizons of visually impaired people and allowing them to better navigate and interact with their environment [1], [2].

Based on 3D Braille model creation software, 3D printing technology through the use of multi-layer molding, the production and customization capabilities of 3D tactile Braille models can be greatly expanded, allowing them to be adapted for different purposes. This technological advancement will enable the creation of a wide range of Braille models, creating a more accessible and personalized environment for people who are blind or visually impaired [1]. A direct benefit of using 3D printing in this context is that it eliminates the waiting time typically associated with the delivery of traditional

models and Braille components [1]. In addition, utilizing 3D printing capabilities significantly reduces the need for expensive Braille embossing machines, which used to be a major cost item in Braille production [1]. This not only makes the process more economical, but also opens up the possibility of producing objects with improved Braille and the innovative use of relief dot printing for Braille identification [3]. This method is particularly useful because it improves the quality, accessibility and safety of inclusion for people with visual impairments and allows for a variety of forms [3].

An example of this approach was the use of selective laser sintering (SLS) 3D printing technique to print Braille patterns onto cylindrical prints specifically designed to assist blind or visually impaired patients [3]. The effectiveness of this method was further demonstrated by the successful printing of all 26 Braille and Lunar alphabets onto 3D printed models that were not only visible, but also recognizable by touch, as confirmed by a blind member of the Royal National Institute of Blind (RNIB) laboratory [3].

The challenges of 3D model quality control, especially when it comes to quality control testing of 3D tactile Braille models, are multifaceted and require attention to detail in various aspects of the 3D printing process. Manufacturers of tactile models, and others, must carefully monitor numerous processes and elements throughout model production, from digital 3D model creation to printing and post-print processing, to ensure that both manufacturers and users are fully informed about how to effectively make changes to variables [4]. This tracking is critical because using 3D modeling software requires a steep learning curve. However, basic familiarity with computer-aided design (CAD) can greatly mitigate these problems [4]. Additionally, the legibility of Braille, which is necessary to enhance the accessibility of the medium, varies significantly between uppercase and lowercase letters, indicating the need for precise control over print parameters to ensure readability [4]. This accuracy is complicated by the lack of standardized norms for adhesion testing procedures for various materials, which is critical to ensure proper fit and durability of printed models [5]. Moreover, quality control is further complicated by the need to determine the best adhesion material and understand how the width and height of printed lines affect sample delamination, which is a key factor in the functionality and efficiency of 3D printed models [5]. These challenges highlight the difficulty of maintaining high quality control in 3D printing processes, especially when the goal is to create an accessible and customizable environment through Braille label printing.

Integrating information systems and artificial intelligence (AI) algorithms into additive manufacturing processes and model development, as well as improving the quality and speed of creation of 3D Braille models, will mark significant progress, especially in the manufacturing, inclusion and healthcare sectors, where accuracy and quality control are paramount meaning. In manufacturing, the use of computer vision or artificial intelligence-based neural networks to inspect products and detect defects simplifies the quality assurance process, ensuring that products meet strict standards before they reach the consumer [6]. This technological leap not only improves the efficiency and accuracy of quality control systems, but also minimizes downtime and increases productivity,

thereby ensuring the delivery of high-quality products [7]. For example, in the inclusion industry, AI will play an important role in the creation of Braille models. By identifying artifacts and making recommendations to improve font and model legibility, AI makes a significant contribution to improving inclusion and developing accessibility for people with disabilities, thereby integrating the use of AI in the field of inclusion for blind people.

In the realm of additive manufacturing, the integration of Artificial Intelligence (AI) technologies has revolutionized the approach toward quality control, addressing limitations inherent in human-based inspection methods such as fatigue and inconsistency, as well as the inability to process and analyze vast amounts of data in real-time [6]. Specifically, AI-based sensors and monitoring systems have been identified as pivotal, providing continuous, automated inspection throughout the manufacturing process, thus ensuring a consistently high quality of output [9]. Moreover, the advent of AI in this field brings predictive analytics into play, allowing for the anticipation of potential flaws or failures before they occur, thereby not only preserving resources but also significantly reducing waste and improving overall efficiency [9]. Together with AI-enabled data collection and analysis systems, these technologies enable a previously unattainable depth and breadth of quality control, facilitating the real-time adjustments and optimization necessary to maintain the integrity of the manufacturing process [9]. Furthermore, the application of machine vision further enhances these capabilities, enabling the detection of even the smallest inconsistencies and defects that human inspectors might miss with unparalleled accuracy [6]. Collectively, these AI technologies represent the state-of-the-art in quality control of additive manufacturing and set new standards for accuracy, reliability and efficiency.

Following the transformative impact of 3D printing technology, the integration of artificial intelligence (AI) into quality control processes will further transform the way industry addresses the numerous challenges of maintaining high quality standards. AI's ability to improve the accuracy and efficiency of quality management is critical as it directly addresses the pressing need to maintain stringent quality standards while managing the complexity of modern manufacturing processes [10]. For example, using predictive analytics, AI can proactively identify potential defects and inefficiencies in production lines, enabling proactive adjustments that significantly reduce waste and improve product quality [10]. Furthermore, the integration of AI and machine vision technologies exemplifies how synergy between human expertise and advanced AI capabilities can lead to superior product quality and improved customer satisfaction [6][8]. This fusion is not only driving operational efficiencies, but also setting new benchmarks of excellence in the quality management system (QMS) industry and demonstrating the fundamental role of AI in meeting the future challenges of quality management [10][9].

In the area of quality control of tactile 3D Braille models, the integration of artificial intelligence (AI) may result in an increase in the number of successfully created tactile models, thereby speeding up the production process, improving quality and reducing the cost of testing such models. In particular, in this study the importance of integrating

AI into additive manufacturing is highlighted as well as the quality control of not only tactile 3D models, but also other more complex models for various applications. They also identify the efficiencies and problems associated with the integration of AI into model quality control processes. Moreover, these case studies collectively highlight the importance of practical application as they offer significant insight into real-life scenarios, thereby allowing a deeper understanding of theoretical concepts in action [13]. Such research will be able to push for new research and studies to integrate AI into additive manufacturing and will also develop the creation of new information systems and technologies. This is an innovation to improve quality control processes in the emerging field of 3D modeling and additive manufacturing using Braille.

After exploring the key role of software in enabling 3D Braille printing, one needs to delve deeper into how practical applications and case studies further improve our understanding of the impact of additive manufacturing in various industries. These case studies, embodying real-life scenarios, shed light on the adaptability and efficiency of additive manufacturing processes in solving complex design and manufacturing problems [13]. This synergy between academic discourse and practical application embodies the transformative potential of additive manufacturing, driving innovation and operational efficiency across all sectors.

The growing field of 3D printing technology, especially in the creation of tactile models using Braille, not only expands the possibilities of tactile learning, but also requires a strict quality control process to ensure the accuracy and readability of Braille. Expected advances in AI for quality control in this area aim to automate and improve the 3D model inspection process. Integrating artificial intelligence can significantly reduce human error and simplify the quality assurance phase, ensuring that Braille labels on 3D printed models are accurate and easily interpretable by visually impaired users. This is especially important since tactile feedback from Braille models is the primary means of information for these individuals. Moreover, through the application of case studies, as emphasized by Yin in a comprehensive study of the subject [11], the potential of AI in improving quality control mechanisms can be thoroughly explored. In particular, by studying individual case studies [12][15], researchers can identify specific challenges and solutions faced in integrating AI into the quality control process of 3D Braille printing, paving the way for practical applications and improvements [13]. This not only highlights the need to incorporate AI into the quality control process, but also the importance of professional research and case studies to push the boundaries of what is possible in the application of 3D printing technology for the visually impaired.

Quality control of 3D models, namely for tactile models with raised-dot Braille, where high accuracy of dots is required, where a small flaw will make it impossible for a visually impaired person to read information from the tactile model. To improve the quality of creating tactile models, it is proposed to use artificial intelligence, but AI has certain cutting-edge technologies that it uses. Below is an example of what AI technologies can be used to control the quality of tactile models with raised-dot Braille:

1. Quality control of models based on computer vision.

Using computer vision based on artificial intelligence to assess the quality of extruded parts. Integrating such technologies and different methods such as color analysis in the CIELAB color space, shape analysis using the Canny edge detector and defect detection using surface flaw detection. As in some studies and articles, it is mentioned that the system shows an overall accuracy of 86.5% in the classification of parts and the detection of defects on surfaces, but it all depends on the 3D models and the AI model, so there is a large error in this data.

2. Artificial intelligence based on data management:

Using artificial intelligence models to create optimal tool paths and determine the best parameters for surfacing. In addition, this will make it possible to increase productivity and quality while reducing production costs.

3. Integrated machine learning design

Fully integrate machine learning as part of Design Additive Manufacturing (DfAM) processes to improve and automate production.

4. Optimization with AI

Use artificial intelligence to optimize the additive manufacturing process, including less common methods such as WAAM and DMD.

The use of such AI technologies will be able to improve control over the quality of created 3D models with Braille, resulting in improved quality of these models.

Artificial intelligence is now integrated into quality checking of 3D models. AI helps identify defective elements of the model. If the model contains any error in the design, then it becomes difficult to figure out the correct manufacturing technology. But AI can suggest corrections needed by the model. Integration begins with identifying problem regions that need to be corrected. To correct incorrect or missing features in the model, AI suggests the exact details that need to be added or changed. Once the model is error-free, the AI searches for the best manufacturing technology and material needed for the model. AI is also used to compare the model with the real object and identify their similarities and differences. If the model is a new design that does not have a prototype, then AI can compare it with similar objects and simulate the result of the model's functioning. It is also useful for finding the best design among few design alternatives.

Conclusion. The integration of artificial intelligence (AI) to optimize the quality control of 3D Braille models for laminate molding represents a major advance in improving accessibility and independence for the visually impaired. By incorporating Braille into 3D models, this innovative technology facilitates the creation of tactile graphics and educational materials. The use of 3D printing technology further simplifies the production and customization of Braille labels, eliminating the waiting time associated with traditional methods and allowing the creation of multiple labels to suit individual needs. It allows multiple labels to be created to suit individual needs. Future developments in AI for quality control offer promising opportunities to automate and improve the inspection process of 3D models and ensure the accuracy and interpretability of Braille labels on printed models. Using synergies and case studies between AI and machine

vision technologies, researchers can identify specific problems and find solutions in improving quality control mechanisms, paving the way for practical applications and improvements in this field. The introduction of AI not only increases the efficiency and cost-effectiveness of production processes, but also extends the ability to apply Braille patterns directly to objects such as medicines, improving accessibility and safety for the visually impaired. Discussions on the use of AI in quality control processes highlight the importance of dedicated research and case studies to push the boundaries of feasible applications of 3D printing technology for the visually impaired. Overall, the integration of AI into the quality control process of 3D Braille models has great potential to revolutionize haptic manufacturing and move the field of additive manufacturing in a more inclusive and innovative direction.

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КОНТРОЛЬ ЯКОСТІ 3D-БРАЙЛІВСЬКИХ МОДЕЛЕЙ В АДИТИВНОМУ ВИРОБНИЦТВІ ВИКОРИСТОВУЮЧИ ТЕХНОЛОГІЇ ШТУЧНОГО ІНТЕЛЕКТУ

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Адитивне виробництво є однією з найпередовіших виробничих технологій, здатних трансформувати виробничі процеси, а також допомагає прискорити виробництво складних 3D-моделей, у тому числі з використанням шрифту Брайля для незрячих людей. Унікальні характеристики та створення 3D-моделей з рельєфним точковим шрифтом Брайля для незрячих людей відкривають не тільки можливості, але й проблеми в забезпеченні контролю їх якості. Це наукове дослідження спрямоване на оптимізацію процесів контролю якості тактильних 3D-моделей за допомогою інтеграції штучного інтелекту (ШІ). Враховуючи поточні проблеми, з якими стикаються під час тестування якості, точності та здатності

сліпих людей точно зчитувати інформацію з таких моделей, необхідно дослідити, як використання інформаційних технологій і алгоритмів ШІ може покращити заходи контролю якості. У цій статті ми також проаналізуємо роль технологій штучного інтелекту в адитивному виробництві, щоб визначити найбільш ефективні підходи для забезпечення точності та надійності 3D-моделей Брайля. За допомогою аналітичного дослідження та порівняльного аналізу, що демонструє успішну інтеграцію штучного інтелекту в контроль якості, ми визначимо значний вплив цих досягнень на індустрію адитивного виробництва. У цій статті будуть представлені діаграми того, як розвивається штучний інтелект і яке майбутнє його чекає. Також обговорюватимуться очікувані майбутні досягнення в області штучного інтелекту для контролю якості 3D-моделей Брайля, підкреслюючи потенціал подальших інновацій у цій важливій галузі досліджень і практики. Це дослідження допоможе в розробці ШІ, а також його інтеграції в адитивне виробництво, що призведе до ефективного підвищення якості розробки інклюзії та доступності для незрячих людей. Ми також обговоримо, чому штучний інтелект є необхідною інформаційною технологією для інтеграції в усі процеси адитивного виробництва.

Ключові слова: *штучний інтелект (ШІ), адитивне виробництво (АМ), люди з вадами зору, інклюзія, 3D-моделі, 3D-друк, шрифт Брайля.*

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