Expert System in Additive Manufacturing: A Review

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Abstract

Additive manufacturing, commonly known as 3D printing, has emerged as a transformative technology in modern manufacturing. The convergence of expert systems, driven by artificial intelligence and knowledge-based algorithms, with additive manufacturing has opened up new frontiers of possibilities. This abstract provides a concise overview of a comprehensive review that explores the diverse and multifaceted applications of expert systems in the field of additive manufacturing. It highlights their pivotal role in enhancing efficiency, precision, and innovation across various industries. Expert systems play a crucial role in optimizing the 3D printing process by fine-tuning variables, such as layer thickness, print speed, temperature, and material selection, reducing the need for trial-and-error testing. They also enable real-time quality assurance, monitoring and controlling the printing process to ensure high-quality components, especially in industries like aerospace and healthcare. Expert systems aid in material selection by drawing from extensive databases, optimize designs for additive manufacturing, and predict maintenance needs to prevent costly equipment downtime. Furthermore, they streamline the additive manufacturing workflow, enabling automation of routine tasks, reducing manual labor, and increasing production efficiency. Expert systems drive customization and mass personalization trends, contributing to sustainability through optimized material usage and reducing waste. They also play a vital role in ensuring regulatory compliance, which is essential in industries with strict standards. These systems empower research and development by simulating new printing techniques and materials, supporting innovative designs and pushing the boundaries of what is achievable with 3D printing. Their adaptability, versatility, and intelligence make expert systems indispensable components of the future of manufacturing, ushering in an era of efficient, customized, and sustainable production across diverse industries. The review delves into the various applications, challenges, and future directions in the integration of expert systems in additive manufacturing, emphasizing their pivotal role in transforming the manufacturing landscape.

Keywords: Additive Manufacturing; 3D Printing; AI in AM; Expert Systems in AM

Introduction

Additive manufacturing, often referred to as 3D printing, has been a disruptive force in the manufacturing industry, revolutionizing the way we design and produce a wide array of products. The fusion of expert systems, driven by artificial intelligence and knowledge-based algorithms, with additive manufacturing has ushered in a new era of possibilities. In this comprehensive review, we delve into the multifaceted applications of expert systems in the realm of additive manufacturing, highlighting their pivotal role in enhancing efficiency, precision, and innovation. One of the foundational applications of expert systems in additive manufacturing is process optimization. These systems dive deep into the intricacies of 3D printing, fine-tuning variables like layer thickness, print speed, temperature, and material selection. With the aid of artificial intelligence (AI) and vast databases, expert systems analyze these parameters to recommend the optimal settings for specific print jobs, effectively reducing the need for extensive trial-and-error testing and expediting development cycles (Ahn et al., 2017). The outcome is a significant improvement in the efficiency and cost-effectiveness of the 3D printing process, as well as a substantial reduction in material waste.

Quality assurance stands as a cornerstone of additive manufacturing, especially in industries where structural integrity and performance are non-negotiable, such as aerospace and healthcare. Expert systems play a pivotal role in real-time monitoring and control of the 3D printing process. Equipped with machine learning and image recognition capabilities, these systems can swiftly detect anomalies, irregularities, and deviations from predefined quality standards. They can also make real-time adjustments to ensure that the printed components consistently meet the highest quality requirements (Huang et al., 2020). By guaranteeing real-time quality control, expert systems substantially reduce defects, enhance the reliability of printed parts, and contribute to overall manufacturing quality. Selecting the most suitable material for a specific additive manufacturing application is a complex and multifaceted decision. Mechanical properties, thermal characteristics, cost-effectiveness, and regulatory compliance all come into play. Expert systems facilitate material selection by drawing from extensive databases and knowledge repositories, providing recommendations that align the material choice with the specific requirements of the intended application (Bikas et al., 2015). The result is an optimized material selection, reducing costs and minimizing waste while maintaining performance and compliance standards.

Designing parts for additive manufacturing demands a unique approach. Expert systems provide valuable design assistance by offering insights into optimal part orientation, support structures, and lattice designs. This assistance helps maximize the performance of printed parts while minimizing material consumption (Wang et al., 2018). Design assistance from expert systems empowers designers to explore innovative and efficient designs that fully exploit the capabilities of additive manufacturing technology. Maintaining additive manufacturing equipment is vital for sustained productivity. Expert systems predict maintenance needs by analyzing machine data, historical maintenance records, and equipment usage patterns. This predictive capability helps prevent costly downtime, enhances equipment reliability, and extends operational lifespans (Yun et al., 2016). The implementation of predictive maintenance reduces the risk of unexpected equipment failures and associated production disruptions. Expert systems streamline the additive manufacturing workflow by automating routine tasks such as file preparation, slicing, and post-processing instructions. This automation minimizes the need for manual labor, reducing the risk of human error and improving efficiency (Murr & Li, 2018). Workflow automation is particularly advantageous for high-throughput and batch production in additive manufacturing. Expert systems are contributing to advances in additive manufacturing research and development. Researchers employ these systems to simulate and model new printing techniques and materials. By analyzing numerous scenarios quickly, expert systems help researchers explore innovative solutions and push the boundaries of what is possible with 3D printing (Hirt et al., 2021). The incorporation of expert systems in additive manufacturing supports sustainability goals. By optimizing material usage, reducing defects, and enhancing production efficiency, these systems contribute to environmental sustainability (Reuter et al., 2019). Expert systems enable the cost-effective customization of products at scale. This optimization of design and production processes allows for the efficient creation of custom, one-of-a-kind products, driving the mass personalization trend in industries such as healthcare, footwear, and consumer goods (Dizon et al., 2018). In industries subject to rigorous regulatory standards, such as aerospace and healthcare, expert systems are crucial for ensuring that each printed component complies with the necessary regulations. They provide a level of control and traceability that is indispensable for product certification (Regazzoni et al., 2018).

In the additive manufacturing ecosystem, expert systems are increasingly supporting human-machine collaboration. They can act as decision-support tools, providing valuable insights to human operators, who can then make informed decisions about design, materials, and process parameters (Erden et al., 2019). This collaborative approach ensures that the strengths of both humans and machines are leveraged to achieve optimal results. Expert systems contribute significantly to reducing waste in additive manufacturing. They optimize print settings, reducing overruns and minimizing post-processing requirements. This resource efficiency aligns with sustainability goals by conserving material and energy resources (Singh et al., 2018). The integration of expert systems in additive manufacturing bolsters supply chain resilience. By enabling on-demand, localized production, these systems reduce dependencies on global supply chains, mitigating risks associated with disruptions and delays (Ding et al., 2020). Expert systems are instrumental in creating complex geometries that would be challenging or impossible to achieve using traditional manufacturing methods. By harnessing computational algorithms, these systems enable designers to explore intricate and lightweight structures (Zhang et al., 2020). The real-time monitoring and optimization capabilities of expert systems shorten lead times in additive manufacturing. Rapid decision-making, based on AI-driven insights, accelerates production cycles and reduces time-to-market (Thakur et al., 2020).

Expert systems are pivotal in medical and dental applications of additive manufacturing. From custom implants to prosthetics, these systems ensure precise and tailored solutions in the healthcare industry (Hans et al., 2019). The aerospace industry has seen notable advancements in lightweight, high-strength components due to expert systems' optimization of materials and design. These systems help meet the rigorous demands of aircraft and spacecraft (Campbell et al., 2019). The automotive industry benefits from expert systems by optimizing parts and reducing weight, enhancing fuel efficiency, and sustainability. These systems drive innovations in electric vehicles, autonomous driving, and custom components (Lipson & Kurman, 2013). Additive manufacturing powered by expert systems contributes to improved energy efficiency. By designing components with reduced weight and optimized performance, less energy is required in the operation of machinery and vehicles (Gebisa & Wei, 2017). Expert systems are used in educational and training programs related to additive manufacturing. They aid in simulating printing scenarios, allowing students and professionals to gain practical experience in a controlled environment (Krishna & Misra, 2020). The adaptability of expert systems has led to their adoption in diverse industries, including construction, electronics, and consumer goods. They play a pivotal role in the development of customized products and materials (Ligon et al., 2017).

Expert systems enhance a company's ability to respond to market demands quickly. By allowing for flexible production, businesses can rapidly adjust their product offerings and respond to changing customer preferences (Abdel-Rahman et al., 2016). The materials landscape in additive manufacturing benefits from expert systems' contributions. They aid in the development of new materials and combinations that improve the properties and applications of 3D-printed components (Shishavan et al., 2016). In the era of digital manufacturing, expert systems are instrumental in safeguarding intellectual property. These systems can provide digital rights management solutions to protect 3D models and manufacturing processes (Lu et al., 2015). Expert systems contribute to the establishment of quality and certification standards in additive manufacturing. They assist in ensuring that 3D-printed components meet industry-specific and regulatory requirements (Lindemann et al., 2018).

In industries such as automotive and aerospace, expert systems facilitate reverse engineering by converting physical objects into digital models. This process is valuable for redesign, replication, or improvement of existing components (Sam et al., 2017). The synergy of expert systems with the Internet of Things (IoT) enhances real-time monitoring and control in additive manufacturing. Data from IoT-connected machines can be analyzed by expert systems, optimizing the production process and quality control (Jayalath et al., 2017). The advancement of machine learning and AI is closely tied to the evolution of expert systems in additive manufacturing. These technologies continuously enrich the capabilities of expert systems by enabling more sophisticated pattern recognition and prediction (Ley et al., 2018). Additive manufacturing software often incorporates expert systems for seamless operation. The integration of these systems enhances the user experience and ensures a high degree of automation (Cheng et al., 2016). The integration of expert systems in additive manufacturing is not solely a technological advance. It carries economic and business implications, impacting supply chains, business models, and workforce skillsets (Shukla et al., 2020).

While the integration of expert systems in additive manufacturing offers significant advantages, there are challenges that need to be addressed. These include the need for more extensive databases, ongoing refinement of AI algorithms, and the development of standardized interfaces for interoperability. Additionally, cybersecurity and intellectual property protection in the digital manufacturing landscape will continue to be critical concerns (Bir et al., 2019).

Conclusion

Expert systems are at the forefront of advancing additive manufacturing, addressing complexities, enhancing efficiency, and fostering innovation. As the field of additive manufacturing continues to evolve, expert systems will remain vital for realizing its full potential across a myriad of industries. Their adaptability, versatility, and intelligence make them indispensable components of the future of manufacturing. By leveraging the power of AI and knowledge-based algorithms, expert systems enable the efficient production of high-quality, customized, and sustainable products, contributing to the ongoing transformation of the manufacturing landscape.

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