The Applications of the Combinations of Deep Learning and Blockchain Technology in Manufacturing Production Process: A Comprehensive Investigation

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Abstract: In recent times, both deep learning and blockchain technology have garnered significant interest, attributed to their respective strengths in predictive accuracy and data security enhancement. As the push towards intelligent manufacturing gains momentum, the integration of these two technologies holds the potential to fundamentally transform the manufacturing production process. This paper explores the applications and significance of the combination of deep learning and blockchain technology in manufacturing production process, discussing the benefits and areas for further improvement. Specifically, this work first briefly introduces the related concepts of deep learning and blockchain technology. Furthermore, the possible applications and benefits of the combination of deep learning and blockchain technology in manufacturing are discussed. The three potential proposed applications include predictive maintenance, quality control, and supply chain management. Finally, after discussion, this work points out that challenges such as large computational resource requirements, large training data labeling effort and training data privacy and security issues still need to be improved.

1 INTRODUCTION

In recent years, the convergence of deep learning and blockchain technology has recently emerged as a promising approach to revolutionize the manufacturing production process. As a branch of machine learning, deep learning has demonstrated remarkable success in extracting meaningful information from complex datasets, enabling accurate predictions and decision-making. Meanwhile, blockchain technology, originally designed for secure and transparent transactions in cryptocurrencies, has found diverse applications due to its decentralized and immutable nature. By combining the strengths of deep learning and blockchain, manufacturers can potentially overcome significant challenges, boost productivity, and established more robust and efficient supply chains.

Deep learning algorithms, specifically deep neural networks, have shown exceptional capabilities in processing and analysing large volumes of data generated in the manufacturing sector. By leveraging techniques such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), manufacturers can learn high-level patterns, make accurate predictions, and optimize production processes (LeCun et al. 2015). These algorithms can analyse sensor data from machinery, predict equipment failures, detect anomalies in real-time, and optimize maintenance schedules (Zhao et al. 2016). Additionally, deep learning algorithms can be employed to improve product quality control by analysing image data, ensuring consistent and reliable manufacturing standards (Soori et al. 2023).

On the other hand, blockchain technology provides a decentralized and secure platform for recording, sharing, and verifying data throughout the manufacturing supply chain. The irreversibility and transparency of blockchain records ensure information’s integrity, making it an ideal solution for traceability and provenance verification (Nakamoto 2008). By immutably recording data related to production processes, quality control, and logistics on the blockchain, manufacturers can enhance the visibility of supply chain, reduce the risks of counterfeit, and strengthen trust among stakeholders (Jackson et al. 2023).

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The combination of deep learning and blockchain technology offers a few potential applications in manufacturing production process. For example, predictive maintenance, a critical aspect of manufacturing operations, stands to benefit greatly from this combination. Deep learning algorithms can predict equipment failures by analysing historical sensor data, while the blockchain can secure and distribute these predictions to relevant stakeholders, enabling proactive maintenance and minimizing downtime (Lee et al. 2020). Furthermore, supply chain management can be improved through the integration of deep learning and blockchain. Deep learning models can analyse historical data to identify patterns, optimize inventory management, forecast demand, and identify potential bottlenecks in the supply chain (Tadayonrad & Ndiaye 2023).

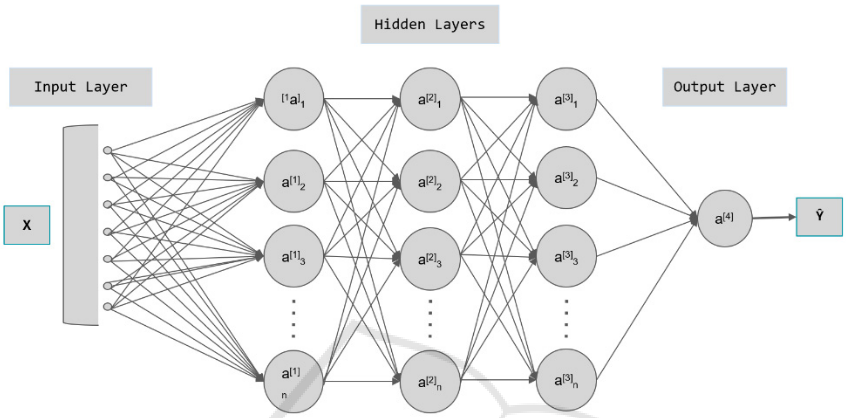

Figure 1: The architecture of the neural network (Photo/Picture credit : Original).

Given the novelty of the combination of deep learning and blockchain in manufacturing, it is critical to understand their potential applications in manufacturing and the implications for production and supply chain management. In order to gain a deeper understanding of this field, this review paper aims to explore the applications and significance of the combination of deep learning and blockchain technology in manufacturing production process. This paper will examine the current prevalent methods and techniques, discuss their benefits and limitations, and identify areas for further improvement.

2 METHOD

2.1 Introduction of Deep Learning

As a subset of machine learning, deep learning models and understands complex patterns in datasets with artificial neural networks which have multiple layers, which has been widely applied in many tasks (Chen et al. 2023, Kayalibay et al. 2017, Qiu et al. 2022). The structure of a neural network shown in Fig. 1 consists of an input layer, one or more hidden layers, and an output layer. And all layers contain nodes that connect to nodes in the subsequent layer, forming a "web" of interconnected nodes or "neurons" (LeCun et al. 2015). The functionality of deep learning is based on the concept of 'learning representations from data', which means, given a set of features, the model learns to recognize patterns and make predictions or decisions without being explicitly programmed to perform the task. The learning process involves adjusting the weights and biases of the network through a process called backpropagation and optimization algorithms like stochastic gradient descent (LeCun et al. 2015).

2.2 Introduction of Blockchain Technology

Blockchain technology, as a decentralized distributed database, enables point-to-point transactions with no intermediaries. It utilizes encryption, consensus algorithms, and smart contracts to enhance security, traceability, authenticity, and collaboration (Ye et al. 2017). The key technologies of blockchain basically include distributed ledgers, asymmetric encryption, consensus mechanisms, and smart contracts. 1) Distributed ledger, as decentralized data storage technology (Ølnes et al. 2017), enables decentralized data storage and synchronization, reducing maintenance costs and improving efficiency (Ostern

2017). It uses a network composed of multiple nodes to realize data sharing and synchronization. 2) Asymmetric encryption utilizes public and private keys for secure encryption and decryption (Mofer et al. 2017). The public key is public and used for encryption, and the private key corresponding to the public key is private and used for decryption. At present, common asymmetric encryption algorithms include hash function, Rivest-Shamir-Adleman (RSA), Elgamal, Diffie–Hellman key exchange (D-H) and elliptic curve encryption algorithm (Shi et al. 2021). 3) Consensus mechanisms enable the verification and confirmation of data in the network of each node, thus ensuring data consistency and trust among participants (Lashkari & Musilek 2021). Common consensus mechanisms include Proof of Work (PoW) and Proof of Stake (PoS) (Khamar & Patel 2020). 4) Smart contracts, as a computer protocol, executed automatically based on predefined conditions, can facilitate trusted transactions without intermediaries, reducing costs and improving efficiency (Mourouzis 2019).

2.3 Predictive Maintenance

Predictive maintenance is a crucial aspect of modern manufacturing. Deep learning algorithms can achieve efficient predictive maintenance by analysing sensor data from machinery, predicting equipment failures, and optimizing maintenance schedules. For instance, a study by Butte et al. (2018) demonstrated the use of machine learning including deep learning like CNN and Deep Belief Networks (DBN) for predictive maintenance in a semiconductor manufacturing industry. In their study, generalized distributed linear model, distributed random forest, Gradient Boosting Machine, DBN and CNN were applied to analyse sensor data and predict device failures. It combines predictions from multiple different models based on cross-validation. It not only reduces downtime and increases productivity, but also reduces the risk of high variability and low accuracy because of relying on a single method and makes Product Data Management (PdM) systems robust. Blockchain technology complements this by providing a secure and transparent platform for sharing these predictions with relevant stakeholders, ensuring proactive maintenance (Rachad et al. 2023).

2.4 Quality Control

Quality control is another critical application area. Deep learning algorithms can analyse image data to ensure consistent and reliable manufacturing standards. The study of Villalba-Diez et al. (2019) shows an application of deep learning on increasing the accuracy and decrease the computational resources requirement of industrial visual inspection process in the process of printing. And a study by Jianqiang et al. (2023), proposed a blockchain-based quality control methodology. In their research, blockchain technology and machine learning are used to secure the safety and privacy of information operations and managing data sets, providing a secure platform for delivering relevant predictions and preserving relevant data sets. Its quality control was established based on comprehensive techniques that accurately reflected the intricate world and determined the actual positivity rate of the platform's standard control methodology.

2.5 Supply Chain Management

Supply chain management also benefits greatly from the integration of deep learning and blockchain technology. Deep learning models can analyse historical data to optimize inventory management, forecast demand, and identify potential bottlenecks in the supply chain. A study by Henkelmann (2018) proposed an approach based on deep learning for supply chain management in the automobile spare part industry. The approach used deep learning algorithms to analyse historical sales data and forecast demand, thereby optimizing inventory management. Blockchain technology can improve this process by providing a secure and transparent platform for sharing these forecasts with relevant stakeholders, thereby enhancing supply chain visibility (Saberi et al. 2018).

3 DISCUSSION

The combination of deep learning and blockchain technology holds immense potential for revolutionizing the manufacturing production process. One of the significant advantages of deep learning algorithms in manufacturing is their ability for processing and analysing large volumes of data. Deep neural networks, such as CNN and RNN, can extract high-level patterns from sensor data and make accurate predictions. This capability is particularly useful in predictive maintenance, where the algorithms can analyse historical sensor data to detect anomalies and predict equipment failures (Butte et al. 2018). By proactively identifying potential issues, manufacturers can optimize maintenance schedules, reduce downtime, and increase productivity.

Additionally, deep learning algorithms can improve quality control in manufacturing by analysing image data. This application is evident in the printing industry, where deep learning models have been employed to increase the accuracy and reduce the computational resources requirement in industrial visual inspection processes (Villalba-Diez et al. 2019). By automatically detecting defects and inconsistencies, manufacturers can ensure consistent and reliable manufacturing standards, leading to higher product quality.

Blockchain technology complements deep learning in several ways. Its decentralized and immutable nature makes it an ideal solution for traceability and provenance verification. By recording data related to production processes, quality control, and logistics on the blockchain, manufacturers can enhance supply chain visibility, reduce counterfeit risks, and strengthen trust among stakeholders (Jackson et al. 2023). For instance, a blockchain-based quality control methodology can secure information operations and manage datasets, providing a secure platform for delivering relevant predictions and preserving data integrity (Gu et al. 2023).

Another significant application of the combination of deep learning and blockchain is in supply chain management. Deep learning models can analyse historical data to optimize inventory management, forecast demand, and identify potential bottlenecks in the supply chain (Henkelmann 2018). By leveraging the power of deep learning, manufacturers can make decisions driven by data which can save cost and improve efficiency. Blockchain technology can further enhance this process by providing a secure and transparent platform for sharing forecasting data with relevant stakeholders, ensuring trust and collaboration (Saberi et al. 2018).

Despite the numerous benefits, there are some limitations and challenges to consider. Deep learning algorithms require substantial computational resources and large amounts of labeled training data. Acquiring and labeling such datasets can be time-consuming and costly, especially in complicated manufacturing environments recognizing changes in scenarios and situations is a must when collecting and using datasets required for training (Gu et al. 2023). Additionally, ensuring the privacy and security of sensitive data used in deep learning models is a significant concern. Manufacturers need to apply robust data protection techniques to prevent unauthorized access and data breaches. At present, advancements in federated learning might address privacy concerns associated with deep learning. Federated learning allows training models on distributed data without sharing the raw data, thereby preserving data privacy (Kamp et al. 2021). Implementing federated learning in the manufacturing sector will help enable collaborative model training while helping ensure data security and privacy.

4 CONCLUSION

In this work, the applications and significance of the combination of deep learning and blockchain technology in manufacturing production process have been explored. The author has discussed the current prevalent methods and techniques, their benefits, limitations, and identified areas for further improvement in the field of deep learning, blockchain and their integration in the manufacturing process.

This research shows that the integration of deep learning and blockchain has several applications in manufacturing, including predictive maintenance, quality control, and supply chain management.

After discussing the current related applications, there are still some challenges to overcome in the future, including the need for substantial computational resources, large training data labeling effort and training data privacy and security issues.

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