Visualization Analysis of Artificial Intelligence Application in Bridge Engineering

Huijun Wu, Aidi Liu

***Abstract*— With the continuous advancement of artificial intelligence and big data technologies in recent years, the application of artificial intelligence in bridge engineering has garnered increasing attention. This article examines the development history of artificial intelligence and neural networks, along with their applications in bridge engineering in China. The CiteSpace visualization tool is employed to analyze literature from 1995 to 2024, focusing on publication volume, keyword co-occurrence, and institutional partnerships. This analysis further elucidates the research hotspots within the field.The findings indicate that artificial intelligence has achieved significant developments and breakthroughs in bridge engineering. However, the uneven progress may pose limitations in practical applications. The article concludes by summarizing current shortcomings and outlining potential directions for future development.**

***Index Terms*— Artificial Intelligence; convolutional neural networks; visualized analysis; bridge engineering**

I. Introduction

There is a close relationship between Artificial Intelligence (AI) and Neural Networks, which are an important branch and tool in the field of AI. Neural Networks are a model inspired by biological nerves, just like the human brain, which consists of a large number of simple neurons, which are gradually connected to each other for information transmission and processing. As a computational model and tool, neural network is closely related to artificial intelligence, and it plays an important role in the field of artificial intelligence, providing effective solutions for realizing various intelligent tasks and systems.

In recent years, China has vigorously invested in the construction of infrastructure, and the number of bridges has exceeded the sum of thousands of years, and at this stage the number of bridges has occupied the first place in the world, and consequently the pressure of bridge maintenance is increasing. According to literature data, more than 90% of concrete bridge damage is caused by cracks [1]. In order to achieve high-quality development of bridge design and maintenance, artificial intelligence technology is applied to bridge inspection and maintenance, which profoundly changes the development of bridge maintenance and greatly improves the digitalization and intelligence of the bridge engineering industry. The CiteSpace literature analysis tool was used to visualize and analyze the papers related to neural networks and bridges in the China Knowledge Network (CNKI) database. By summarizing the current research status in China, exploring the current research hotspots, discovering the future research trends, and proposing suggestions for the existing problems.

Manuscript received October 15, 2024

Huijun Wu, School of Civil Engineering, Dalian Jiaotong University, Dalian, China

Aidi Liu, School of Civil Engineering, Dalian Jiaotong University, Dalian, China

II. The Development of Artificial Intelligence

The development of AI can be divided into several important stages, each marking a significant breakthrough in AI theory, technology, and application.

(1) Symbolic AI Era. The foundational period of Artificial Intelligence spans from the 1950s to the early 1980s. During the 1950s, with the advancement of computer technology, scientists began exploring ways to endow computers with capabilities that resemble human intelligence. The Dartmouth Conference of 1956 is widely recognized as the seminal event that marked the official inception of Artificial Intelligence as a distinct academic field. This conference laid the groundwork for AI research and development. However, as media coverage and public expectations escalated, AI experienced significant hype, leading to two notable periods of stagnation known as the "AI winters"

(2) Connectionist Era. Spanning from the mid-1980s to the early 1990s saw the emergence of connectionist approaches, prominently featuring neural networks and machine learning techniques. This period witnessed the introduction and widespread use of backpropagation algorithms and the nascent stage of deep learning. The emergence of backpropagation algorithms greatly facilitated the development of neural networks, enabled the effective training of multi-layer neural networks, and thereby revolutionizing their learning capabilities and laying the groundwork for the subsequent evolution of deep learning.

3) Knowledge Explosion Era. During the 1990s and early 2000s, the advent of the Internet and the explosion of information posed new challenges for artificial intelligence, particularly with respect to managing large-scale data and knowledge. Technologies such as information retrieval and data mining gained prominence as a result. This period also highlighted significant limitations in scalability, largely due to insufficient computational power. The complexity of networks exceeded the capabilities of existing technology, leading to the second AI winter. However, with advancements in computing power, AI experienced a resurgence in the mid-1990s, marking the beginning of the third wave of AI research and interest.

(4) Statistical Learning Era. From the 2000s to the early 2010s, machine learning technology matured significantly. During this period, statistical learning methods such as support vector machines, random forests, and Bayesian

networks gained widespread adoption. These advancements provided a robust foundation for large-scale data analysis and predictive modeling, greatly enhancing the ability to analyze and interpret complex datasets.

(5) The Deep Learning Era. In the 2010s, a dramatic performance leap in artificial intelligence sparked a revolution in the field, reigniting interest in deep learning. This period has witnessed explosive advancements in deep learning technology, driven by the training and optimization of multi-layer neural networks. Deep learning has achieved remarkable success in areas such as image recognition, natural language processing, and speech recognition, establishing itself as the core technology of contemporary artificial intelligence.

(6) The Multimodal Fusion Era. At present, artificial intelligence is increasingly engaging in multimodal fusion, which involves integrating and processing various forms of information, such as images, text, and speech. This includes cross-modal joint modeling and reasoning, which fosters the advancement of multimodal intelligence.

(7) The Intelligence + Era. In the future, artificial intelligence is expected to permeate various domains more extensively, facilitating integration and innovation across multiple fields such as intelligence and healthcare, intelligence and manufacturing, and intelligence and finance. This will drive the deep integration of AI technology with industry, contributing to social progress and economic development.

III. VISUALIZATION KNOWLEDGE GRAPH

With the rapid development and application of intelligent technology, more and more industries have begun to explore how to apply artificial intelligence to solve practical problems, including bridge engineering. In terms of structural design optimization, AI can help engineers optimize structural design through big data analysis and machine learning algorithms to improve structural performance and efficiency; in terms of inspection and maintenance, AI can help monitor the health of the building structure in real time, discover potential problems in advance and carry out preventive maintenance; in terms of construction management, AI can help optimize the construction progress and resource deployment to In construction management, AI can help optimize construction progress and resource allocation to improve construction efficiency and safety.

CiteSpace is a tool for visualizing and analyzing academic literature[2], which is mainly used for exploring the correlations and trends among the literature.

A. A Data collection and research methods

Firstly, the data source was identified as the China Knowledge Network (CNKI) database. The research scope was defined to include neural networks and bridges, with a focus on road and waterway transportation. The search process involved filtering out irrelevant data, such as conference reports, news articles, books, and patents. Consequently, a total of 2,216 relevant documents were identified.

Based on the search results, a list of documents was exported in RefWorks format, including information such as title, author, abstract, keywords, and citation count.

In this study, both qualitative and quantitative analyses were performed using CiteSpace 6.3.R1 (64-bit) bibliometric visualization and analysis software. The analysis covered the period from 1995 to 2024, with a time slice set to one year. The screening criterion employed was a g-index scale factor (k) of 11, while other parameters were set to their default values.

B. Analysis of knowledge base of sample data

(1) Analysis of the number of annual publications

From 1995 to 2024, the number of publications related to neural networks in bridge engineering in the CNKI database has shown an increasing trend. The annual publication counts and the corresponding trend are illustrated in Fig. I.

From 1995 to 2000, the field of neural networks in bridge engineering was in its early development stage. During this period, which coincided with the connectivist era of AI in the early 90s, AI was not initially applied to bridge engineering. Although the 2000s marked an explosion of AI knowledge, its application in bridge engineering lagged behind. The period from 2000 to 2010 saw steady development, with machine learning and statistical methods maturing. Notably, the number of relevant publications exceeded 100 by 2008. From 2010 to 2016, the field experienced a smooth transition, with approximately 70 articles published annually. The rapid development phase from 2016 to 2023 was characterized by significant breakthroughs in algorithms for speech and visual recognition, leading to increased attention to neural networks in bridge engineering. Annual publication numbers remained high, reaching 250 articles in 2022.

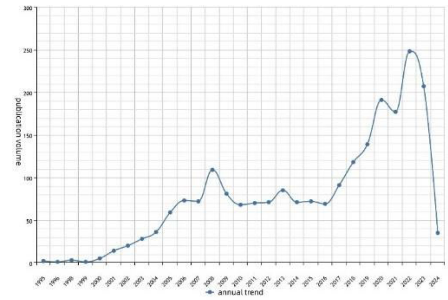

Figure I. Annual publications of neural networks in the field of bridge engineering

(2) Keyword frequency and centrality analysis

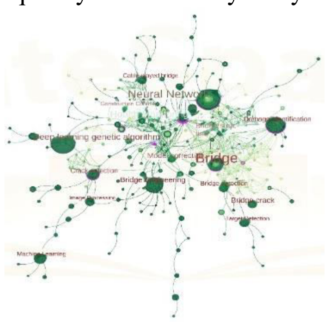

Figure II. Keyword co-occurrence network

In this study, we construct a keyword co-occurrence network by generating a knowledge graph using CiteSpace. The analysis identifies 282 nodes and 720 edges. To enhance the clarity and readability of the network, we set the keyword threshold parameter to 20, thereby excluding keywords with lower frequencies of occurrence. This adjustment helps in presenting a more streamlined and comprehensible network.

The nodes are displayed in a temporal layout, where the size of each node corresponds to the frequency of occurrence: larger nodes indicate more frequent keywords[3] and a stronger relevance to the topic. The connecting lines between nodes represent the co-occurrence relationships among keywords[4]. Node color reflects the year of occurrence, with the innermost part of each node representing the first year of appearance and the outermost part indicating the last year of appearance [5]. Additionally, a purple halo around the node signifies that the node's intermediary centrality is at least 0.1, identifying it as a hub node within the network [6]. As shown in Table I, the top five keywords by frequency are "deep learning," "damage recognition," "neural network," "bridge engineering," and "health detection." These keywords collectively illustrate the diverse applications of neural networks within the field of bridge engineering.

Centrality is defined for each node in the network, quantifying the likelihood that a node lies on the shortest path between other nodes. The table generated by the software analysis identifies the keywords with the highest centrality as "health detection," "information fusion," "bridge," "optimization algorithm," and "damage recognition." Among these, "health detection" has the highest centrality score of 0.51, indicating its prominent role throughout the development of bridge engineering. This is followed by "information fusion" and "optimization algorithm," with centrality scores of 0.32 and 0.31, respectively. These findings suggest that current research hotspots are primarily focused on bridge health detection and damage recognition.

Table I. Frequency statistics (part)

No.	Frequency	Keyword	No.	Frequency	Keyword
1	195	Deep Learning	6	57	Bridges
2	184	Damage Recognitio n	7	45	Cable-Stayed Bridges
3	155	Neural Networks	8	40	Bridge Structures
4	69	Bridge Engineering	9	27	Image Processing
5	58	Health Monitoring	10	26	Crack Detection

Based on the keyword co-occurrence analysis and centrality assessment, it is evident that the application of artificial neural networks in bridge engineering primarily focuses on health detection. As artificial intelligence technology continues to advance, neural network models are consistently being proposed and optimized. This progress has led to the emergence of machine learning and deep learning techniques. Consequently, neural networks are experiencing ongoing development and innovation in fields such as computer vision and image processing, which has resulted in increased research interest and activity.

In recent years, disease detection, including crack detection and overall bridge health monitoring, has become a significant area of focus. The knowledge graph highlights bridge detection as a prominent research topic. Additionally, the rapid advancements in drone technology have led to their widespread use in bridge inspection. Drones equipped with cameras can quickly capture images of bridge surfaces, which are then analyzed using neural network models.

Deep learning techniques are extensively applied in bridge detection, with various models including convolutional neural networks (CNN), recurrent neural networks (RNN), deep convolutional generative adversarial networks (DCGAN), attention mechanisms, and deep reinforcement learning models. Each of these deep learning models has distinct advantages and is suited to specific scenarios in bridge detection.

Table II. Keyword centrality statistics (part)

No.	Centrality	Keyword	No.	Centrality	Keyword
1	0.51	Health Detection	6	0.18	Pattern Recognition
2	0.32	Information Fusion	7	0.17	Drones
3	0.31	Optimization Algorithms	8	0.17	Displacemen t Modal
4	0.24	Bridges	9	0.16	Genetic Algorithms
5	0.20	Damage Identificatio n	10	0.15	Crack Detection

Based on keyword co-occurrence and keyword centrality, the focus and hotspots of bridge engineering research from 1995 to 2024 are summarized. Additionally, considering the temporal dimension is crucial for understanding evolving research trends. Analysis of temporal trends reveals notable changes in research focus. In the first decade, damage identification experienced rapid development, driven by advancements in neural network models, which were predominantly applied to crack detection in bridges. Subsequent research has shifted towards areas such as mechanical analysis and damage early warning systems. Despite the lower centrality and frequency of these keywords, a review of the relevant literature suggests that these areas may represent promising directions for future research.Zhao[7] introduced a Bayesian dynamics model designed to forecast the future performance of bridges. Sun [8]employed a fuzzy neural network to predict the performance of prestressed concrete bridges. Their findings validated the feasibility of this methodology. Yu [9]integrated the deep learning algorithms YOLOv5 and U-Net3+ for intelligent identification and measurement of bridge cracks. The results demonstrated that combining machine learning techniques with bridge monitoring and condition prediction significantly enhances the accuracy of bridge maintenance and optimizes the utilization of maintenance data.

C. Hotspot map

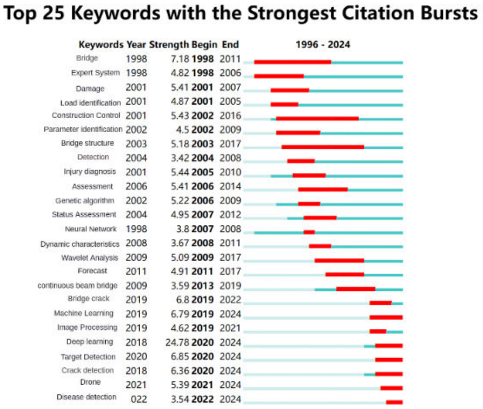

Figure III. Hotspot map

Research on neural networks in bridge engineering from 1996 to 2015 is considered to be in its early stages. During this period, the primary advancements were in areas such as expert systems, damage diagnosis, and load recognition, with overall intelligence levels being relatively low. For instance, the highest intensity value achieved in damage diagnosis was 5.44. In contrast, the period from 2016 to the present represents a significant advancement in neural network applications within bridge engineering. This period has seen substantial progress due to the continuous development of artificial intelligence technologies. Researchers have expanded their focus to include machine learning, image processing, neural network modeling, deep learning, crack detection, and unmanned aerial vehicle (UAV) inspection. Notably, deep learning research has achieved an intensity value of 24.78, reflecting a high level of development. This stage, spanning approximately four years, indicates a rapid evolution in the use of neural networks in bridge engineering.

IV. OUTLOOK

In this paper, we utilize CiteSpace software to visualize and analyze the Chinese literature on the application of neural networks in bridge engineering in China since 1995. We aim to provide a comprehensive overview of the current state of research in this field and to offer insights into future trends and developments.

A. Equalization

Currently, the application of neural networks has significantly advanced the digitalization and intelligence of bridge engineering, garnering substantial attention and research. However, most studies have predominantly focused on intelligent maintenance, resulting in a limited exploration of other potential research directions. This narrow focus has led to a singular development trajectory. To address this, it is essential to broaden the research scope and actively promote the application of neural networks across diverse areas within bridge engineering. Furthermore, with the proliferation of new neural network models, there is an unprecedented variety in neural network architectures. Future research should aim to enhance and optimize the application of these diverse models across all aspects of bridge engineering to achieve comprehensive intelligence throughout the entire lifecycle of bridge projects.

B. In-depth research

Based on the collation and integration of database literature and the aforementioned visualization analysis, it is evident that current research predominantly focuses on neural network development, big data processing, and deep learning. These efforts are primarily directed towards the visible detection of bridges. However, there remains a significant gap in the intelligent analysis of more intricate aspects of bridge deterioration. Compared to advancements in other fields, the level of intelligence applied to bridge engineering is relatively underdeveloped.

C. Strengthening cooperative research

According to the study, current research on artificial intelligence (AI) in bridge engineering is predominantly confined to academic institutions (see Fig. IV). Moving forward, it is crucial to enhance collaboration across the entire field of intelligence to address issues related to limited integration and information silos in bridge engineering.

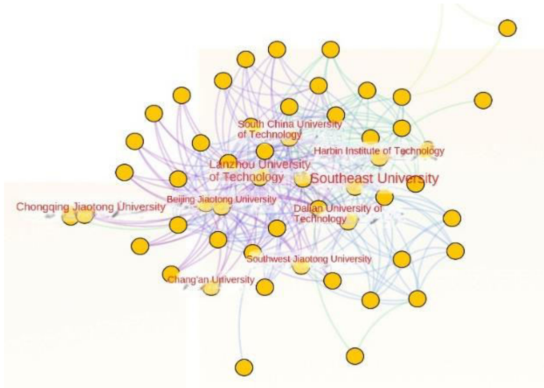

Figure IV. Map of major research organizations

In the future, alongside enhancements in computational capacity and data acquisition methods, there is a need for multi-party collaboration and multifaceted development. These efforts are anticipated to lead to significant breakthroughs in the application of neural networks within bridge engineering. Neural networks are expected to facilitate more intelligent and efficient management and maintenance of bridge engineering systems.

V. CONCLUSIONS

The widespread application of artificial intelligence has increasingly drawn attention to the use of neural networks in bridge engineering. The advanced computational and learning capabilities of neural networks, particularly those of deep learning techniques, have facilitated their adoption across various fields. Given that bridge engineering is a crucial component of infrastructure development, there is a growing interest in leveraging these sophisticated technologies to enhance the efficiency and accuracy of design, monitoring, and maintenance processes.

The technical advantages of neural networks in bridge engineering are significant. Firstly, they excel at managing complex nonlinear relationships, resulting in highly accurate predictive outcomes, which is crucial for structural health monitoring of bridges. Secondly, neural networks possess robust real-time processing capabilities, enabling the rapid analysis of large datasets and providing immediate feedback for bridge health monitoring and maintenance. This capability is essential for prompt responses to potential issues. Lastly, neural networks exhibit remarkable adaptability, continuously learning from new data to enhance model accuracy and adaptability. This continuous learning process contributes to the ongoing improvement of bridge monitoring and maintenance strategies.

REFERENCES

[1] Zou, J. (2021). Research on appearance damage identification methods for RC bridges based on convolutional neural networks [Master's thesis, Chongqing Jiaotong University].
[2] Chen, C. (2004). Searching for intellectual turning points: Progressive knowledge domain visualization. Proceedings of the National Academy of Sciences, 101(Suppl 1), 5303–5310.
[3] Chen, C., & Li, J. (Eds.). (2014). Scientific knowledge frontier maps: Theory and practice (CiteSpace's analysis principles). Higher Education Press.
[4] Liu, H., Zhang, F., Chen, Z. (2024). Research status and prospects of artificial intelligence applications in civil engineering. Journal of Civil and Environmental Engineering (in Chinese and English), 46(01), 14-32.
[5] An, J., Pan, S., Wang, Z. (2023). Visualization analysis of road, bridge, and tunnel operation and maintenance management based on CiteSpace and VOSviewer. Journal of Civil Engineering and Management, 40(03), 88-95.
[6] Li, J., & Chen, C. (2022). CiteSpace: Scientific text mining and visualization (3rd ed.). Capital University of Economics and Business Press.
[7] Zhao, X., & Zhang, Y. (2020). Bridge technology condition degradation prediction based on Bayes dynamic model. Earth and Environmental Science, 446, 052017.
[8] Sun, F., Wu, X., & Huo, J. (2022). Prediction of PC bridge performance based on fuzzy neural networks. Highway, 2(2), 95-98.
[9] Yu, J., Liu, B., & Yin, D. (2022). Intelligent identification and measurement of bridge cracks based on AYOLOv5 and U-Net3+. Journal of Hunan University.