A Review of Research Progress on Intelligent Perception Technology for Construction Machinery

Guanye Wu
Jinan Innovation Zone Haichuan Secondary School, Jinan, Shandong, China.

Abstract: With the profound integration of new-generation information technology and the construction machinery industry, intelligent perception technology has emerged as the core impetus driving the automation and intelligent development of construction machinery. This paper conducts a systematic review of the research trends in the field of intelligent perception technology for construction machinery both in domestic and international contexts. Substantial advancements have been witnessed in this domain globally. In China, multi-dimensional research efforts have been exerted in aspects such as the intelligence of excavators, mechatronics, and intelligent hydraulic systems, encompassing related fields including intelligent equipment and digital transformation. Abroad, there exists a distinct advantage in the application of intelligent perception technology, with achievements spanning scenarios such as multi-energy complementary systems, shock load identification, and medical and healthcare. Currently, several challenges remain: Domestic research on the in-depth application and optimization of intelligent perception technology for construction machinery is inadequate, and technical bottlenecks such as video transmission latency and perception accuracy persist; while foreign research has yielded abundant achievements in the application of intelligent perception, there is a dearth of specialized studies addressing the complex working conditions and specific demands of construction machinery. This review contends that it is imperative to deepen the research on intelligent perception technology by integrating with the actual scenarios of construction machinery to rectify the existing shortcomings.

Keywords: Construction Machinery; Intelligent Perception Technology; Research Progress; Automation; Intelligentization

1. Introduction

In recent years, propelled by the rapid technological advancements, intelligent technologies have been extensively applied across diverse fields, and the construction machinery sector is no exception. In the construction machinery industry, intelligentization has become an inevitable development trend, prompting numerous scholars and enterprises to invest substantial efforts in related research endeavors [1]. A continuous stream of research achievements has emerged, enabling construction machinery to make remarkable strides in aspects such as automated operation and remote control. For example, certain large-scale construction machinery can now achieve automated operations in specific processes, significantly enhancing construction efficiency and quality [2]. Simultaneously, the continuous progress of related technologies, such as sensor technology and communication technology, has provided robust support for the intelligent development of construction machinery.

Focusing on the specific realm of intelligent perception technology for construction machinery, its development is rooted in significant practical necessities. During the actual operation of construction machinery, it often encounters complex and changeable working conditions and environments, including harsh weather conditions and intricate topographies. Traditional construction machinery mainly relies on operators' experience and limited monitoring means, making it arduous to accurately and promptly acquire information regarding equipment status and the working environment [3]. This not only undermines construction efficiency and quality but also poses a high risk of safety accidents. Therefore, enhancing the intelligent perception capability of construction machinery, enabling it to autonomously and accurately perceive its own status and surrounding environmental information, has become a pivotal link in the intelligent development of construction machinery.

This research is centered on the intelligent perception technology of construction machinery, with the aim of conducting an in-depth exploration of the research progress of this technology. At present, although the intelligent perception technology of construction machinery has witnessed certain development, numerous issues still exist, such as insufficient sensor accuracy, limited data processing capabilities, and imperfect multi-sensor fusion technology. Through a systematic review and analysis of existing research findings, this study can comprehensively understand the current development status and existing problems of this technology, providing theoretical support and technical guidance for further improving and perfecting the intelligent perception technology of construction machinery. Addressing these issues will contribute to enhancing the intelligence level of construction machinery, improving its adaptability and reliability under complex working conditions, and promoting the construction machinery industry's development towards a more efficient, safe, and intelligent direction.

2. Research Status at Home and Abroad

2.1 Current Domestic Research Status

The intelligentization of construction machinery has been a prominent research focus in the construction machinery field in recent years. It involves the integration of multiple technologies, including artificial intelligence, automatic control, and cyber-physical networks, and holds great significance in improving the operational efficiency, precision, and safety of construction machinery. Gao et al. [4] conducted a comprehensive review of the latest advancements in excavator intelligence in recent years, taking into account the high technical complexity and broad disciplinary scope involved in the intelligent operation of excavators. They summarized the bottleneck problems in existing technologies, such as excessive video transmission delay and insufficient perception accuracy, and analyzed key technologies, including working environment perception, immersive vision, and remote control. Additionally, they proposed the existing challenges and potential research directions. Intelligent excavators represent the product of the deep integration of traditional excavators with multiple technologies, featuring advantages such as high power utilization and operational precision. The authors reviewed the current domestic and international research status from four aspects: trajectory control, environmental perception, remote control, and intelligent fault diagnosis, and pointed out the existing problems and development trends.

Lu et al. [5] incorporated the concept of intelligent construction machinery into the category of intelligent construction. Taking excavators as a typical example, they elaborated on the classification and definition of their intelligence, expounded on the research progress and practical application achievements, and analyzed the hydraulic technology and positioning technology on the path of intelligent development. Xu et al. [6] provided an overview of the concept and development history of mechatronics technology for construction machinery, elaborated on its applications in the design, manufacturing, control, and maintenance of construction machinery, and put forward solutions and suggestions for the problems existing in its application. Previous studies have also analyzed the connotation and evolution process of intelligent hydraulic systems, expounded on their architectures, summarized three major characteristics, reviewed the domestic and international research progress, revealed the existing problems and challenges, and explored the research paths and development trends to overcome these challenges.

Some research utilized data from core journals in authoritative databases and, through the visual citation analysis software CiteSpace, systematically sorted out the literature context of the development overview of artificial intelligence in the construction machinery field from multiple perspectives, exploring research hotspots and cutting-edge trends. From the perspective of user perception, the perception elements of users towards the shape of construction machinery products were discussed. Based on the theory of sensory engineering, an evaluation index system for the shape of construction machinery was constructed. By combining the Analytic Hierarchy Process (AHP) and the VIKOR mathematical decision-making method, the evaluation schemes were ranked, verifying the feasibility of the method. Through a review of relevant domestic and foreign literatures, the related concepts and development background of industrial design and research of construction machinery were expounded. The current design and research status in aspects such as brand identity and appearance modeling were analyzed, the design processes and methods were summarized, the laws of goal-oriented design were discussed, the theory of brand building was explored, and hotspots and development trends were proposed.

Research on intelligent equipment and infrastructure construction mainly focuses on the development and application of various intelligent equipment as well as the intelligent construction of infrastructure, aiming to enhance the intelligence level and operational efficiency of various industries. Ge et al. [7] conducted an in-depth analysis of the technical issues of coal mine robots, proposed a comprehensive technical system framework for coal mine robots, precisely defined their technical basis and product boundaries, clarified the common key technical support for coal mine robot research and development, analyzed the research progress of related common key technologies, and reviewed the current domestic research and application status of various types of coal mine robots. They also proposed new directions for future research and development. Ouyang et al. [8] analyzed the challenges currently faced by the development of intelligent agricultural machinery in China from aspects such as key core technologies, common basic standards, digital infrastructure, enterprise competitiveness, and talent and regulatory factors. They proposed that efforts should be made to accelerate the breakthrough of key core technologies and other aspects to enhance the comprehensive strength and competitiveness of intelligent agricultural machinery equipment and promote the high-quality development of China's agricultural machinery equipment industry.

Dong et al. [9], based on an overview of the current research status of intelligent emergency rescue equipment and key technologies, analyzed and found that there were problems such as the lack of efficient mechanism design methods in the current research, and pointed out that intelligent emergency rescue equipment would develop towards advanced structural design and other directions. Wu et al. [10] focused on smart highways and systematically elaborated on the key technologies in the "design, construction, management, supervision, and operation" links of transportation from five aspects, including multifunctional pavement materials, related research achievements, key common technologies, and future development trends at home and abroad. Previous studies have also systematically explored the requirements and complexity of smart city perception, sorted out the development process and network architecture of the smart city perception technology system, proposed a brand-new smart city perception base station solution in response to the important challenges of future smart city perception, discussed its important role, introduced the system operation principle [11], and analyzed and prospected its application prospects.

Furthermore, in view of the existing problems in the informatization construction of open-pit mines in China, the definition of intelligent open-pit mines was proposed [12]. The relationship between relevant levels, construction principles, and the phased construction of the "1+4" intelligent system were analyzed. The key construction contents of each system were planned, the composition of the intelligent open-pit mine construction system was pointed out, and the corresponding construction approaches and goals were proposed. Zhang et al. [13] discussed rescue equipment with characteristics such as high mobility, multiple functions, modularization, and lightweight. They conducted a comparative analysis of domestic and foreign rescue equipment, pointed out the challenges faced by existing rescue equipment, and on this basis, proposed the development direction and trend of rescue equipment. Meanwhile, the development of rescue robots was prospected. Huang [14] focused on the intelligent inspection requirements of transmission lines, sorted out different inspection methods for transmission lines, introduced the required system framework equipment and intelligent algorithms, and mainly summarized the intelligent inspection methods based on traditional image processing and deep learning. He summarized the relevant detection methods for different faults and conducted a comparative analysis. Finally, he sorted out the research difficulties and prospected the development trend of transmission line detection based on deep learning methods.

Academic research on highway and bridge engineering focuses on multiple fields, such as technological innovation, structural design, and operation and maintenance support, continuously promoting the development and progress of the industry. Research on digital transformation focuses on how to use digital technologies to drive changes in enterprises in areas such as green transformation. The editorial department of *China Journal of Highway and Transport* systematically analyzed the current research status and future development directions of seven major fields at home and abroad, including intelligent and environmentally friendly pavement technology and advanced pavement materials, based on typical problems in actual pavement engineering and the technological innovation content of national science and technology awards, providing references for professionals in the pavement engineering field. Ma et al. [15] systematically reviewed and summarized the technological development changes and achievements of China's highway transportation industry over the past 40 years of reform and opening up, analyzed the future development trends, distilled valuable experiences and inspirations, pointed out problems such as insufficient scientific and technological innovation, and believed that the development of the highway transportation industry requires the implementation of multiple measures.

The editorial department of China Highway Journal systematically sorted out the current domestic and international academic research status, hot frontiers, and other aspects in the field of bridge engineering in recent years, summarized the latest progress in all aspects, looked forward to key issues, challenges, and development trends, and provided new perspectives and basic data for the bridge engineering discipline. The editorial department of China Highway Journal systematically summarized the latest scientific and technological innovation achievements in the field of bridge engineering in China in recent years, sorted out the key future development directions, covering 21 hot research directions, and analyzed and discussed the current academic research status and other situations, providing guidance for the discipline's development. Yu et al. [16] systematically summarized the relevant domestic and international technologies, analyzed in detail the research progress of key technologies for engineering vehicle unmanned driving from aspects such as environmental perception, pointed out that some technologies still need to be broken through, and proposed to adopt multiple methods to promote its development. Yin et al. [17] expounded on the concept of mechanical intelligence based on the mechanism and technical characteristics of mechanical seals. They reviewed the existing technical means and difficulties of mechanical seal intelligence from the three capability dimensions of perception, analysis, and action, and believed that in the long run, an overall design method at the system level should be adopted. Wang [18] proposed the concept of entering the 2.0 stage based on the current development status of coal mine robots, discussed the phased development process, clarified the prerequisites for the development path, expounded on the thinking and task characteristics of the development path in the 2.0 stage, put forward specific research plans, and explored the future development direction. Based on the resource allocation theory, a longitudinal single-case study method was adopted to deeply investigate the stage characteristics and internal mechanisms of the digital-driven green transformation of manufacturing enterprises. The researchers discovered the three leaps in the digitalization process of manufacturing enterprises and their green transformation and development, revealed the internal driving logic, and expanded the research context and connotation of the resource allocation theory.

2.2 Current Research Status Abroad

In the field related to intelligent perception technology, foreign scholars have carried out extensive research from multiple aspects. Regarding the existing problems in the current multi-energy complementary integrated energy system, such as complex equipment operation, incomplete monitoring of operation data, and multi-time-scale characteristics of monitoring data, research on distributed intelligent sensing technology has been conducted. By utilizing the multi-time-scale data model and the ultra-lightweight flow encryption scheme, the existing measurement and control methods have been optimized, and a multi-index comprehensive evaluation system for system operation has been constructed from the aspects of economy, technology, and environmental protection. The distributed intelligent perception technology was employed to collect and monitor the operation data of the load side and various energy systems (including electricity, gas, cold energy, and heat energy), and a multi-energy complementary integrated energy distributed measurement and control system was designed and constructed. Through the analysis of application examples, the rationality and reliability of the flow encryption scheme and the multi-index comprehensive evaluation method were verified. The data acquisition and transmission mode was optimized, achieving high-reliability data acquisition and real-time communication of multi-energy streams and improving the performance of the energy system [19].

Accurate identification of impact loads is of vital importance for structural assessment and design. However, traditional methods rely on complex, costly, and error-prone equipment. A non-contact intelligent recognition method combined with visual sensing technology was introduced, and the differences in identifying impact forces through acceleration and displacement responses were explored via numerical simulation, considering variables such as measurement noise and the number of measurement points. A carefully designed experiment verified the feasibility of this method in measuring the displacement and velocity of fast-moving targets and evaluated its accuracy. A series of impact loading experiments were carried out on the simply supported beam bridge model to verify the effectiveness of the proposed impact force identification method. The results showed that the displacement response measurement was highly consistent with that of the dial indicator. This non-contact method can accurately identify single or continuous impact loads, with a minimum peak relative error of 0.2%. This represents a pioneering application of intelligent visual sensing technology in the field of impact load identification [20].

In response to the difficulties in extracting fetal movement signals and the low recognition rate of traditional machine learning classifiers in fetal movement signal detection, Liang et al. [21] developed a passive fetal movement signal detection system based on intelligent sensing technology. Fetal movement signals were obtained from the abdomen of pregnant women using an accelerometer, and the signals were extracted and identified based on the hidden clinical features in the amplitude and waveform of the fetal movement signals. This system consists of four main stages: fetal movement signal preprocessing, maternal artifact signal pre-recognition, fetal movement signal recognition, and fetal movement classification. The fetal movement signal was reconstructed using Kalman filtering in the context of continuous low-amplitude noise. The maternal shadow signal was identified by the amplitude threshold algorithm. The fetal movement feature dictionary was constructed by adopting an innovative dictionary learning algorithm. The fetal movement signal was identified by the orthogonal matching pursuit and adaptive filtering algorithms, respectively. Finally, mask fusion classification was performed based on the multi-axis recognition results. Experiments showed that the orthogonal matching pursuit algorithm was more effective than the adaptive filtering algorithm in identifying fetal movement signals, with a positive predictive value of 89.74%. This system has great potential in wearable fetal movement health monitoring.

Foreign research has widely applied intelligent perception technology in various fields and achieved remarkable results. In the field of multi-energy complementary integrated energy, system performance has been enhanced; in the identification of impact loads, a new non-contact method has been pioneered; and in the field of medical and healthcare, it has provided an effective solution for fetal movement monitoring. However, for the intelligent perception technology of construction machinery, although these studies have certain technical reference value, there is a lack of in-depth research directly targeting construction machinery. For example, research on intelligent perception under the complex working conditions of construction machinery and the specific perception requirements of different types of construction machinery is relatively scarce. Therefore, conducting research on intelligent perception technology for construction machinery, with a focus on the actual application scenarios and characteristics of construction machinery, holds significant practical significance.

3. Conclusion

Notable progress has been made both in domestic and international research on intelligent perception technology for construction machinery and related fields, offering valuable experience and inspiration for the development of this field. In China, remarkable achievements have been obtained in the research of intelligent construction machinery. Many scholars have conducted research on the intelligentization of construction machinery from various perspectives, such as the intelligent technology of excavators, mechatronics technology of construction machinery, and intelligent hydraulic systems. The research also encompasses multiple related fields, including intelligent equipment and infrastructure construction, academic research on highway and bridge engineering, and digital transformation research. Abroad, there is an advantage in the application of intelligent perception technology. Intelligent perception technology has been widely applied in various fields, such as multi-energy complementary integrated energy, shock load identification, and medical and healthcare, with remarkable achievements.

Nevertheless, several challenges and problems still exist at present. Although domestic research has conducted extensive discussions on the intelligentization of construction machinery, the in-depth application and optimization of intelligent perception technology in construction machinery remain imperfect. Some technical issues, such as video transmission latency and perception accuracy, still need to be resolved. Although foreign research has achieved numerous results in the application of intelligent perception technology, there is a lack of in-depth studies specifically aimed at construction machinery. Research on intelligent perception under the complex working conditions of construction machinery and the specific perception requirements of different types of construction machinery is relatively insufficient. Therefore, in-depth research and exploration in the field of intelligent perception technology for construction machinery are still of great significance. In the future, research on intelligent perception technology for construction machinery should focus on the actual application scenarios and characteristics of construction machinery to address the existing deficiencies in current research.

Reference

[1] Jia M, Komeily A, Wang Y, et al. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. Automation in construction, 2019, 101: 111-126.

[2] Khan A U, Huang L, Onstein E, et al. Overview of emerging technologies for improving the performance of heavy-duty construction machines. Ieee Access, 2022, 10: 103315-103336.

[3] Musarat M A, Khan A M, Alaloul W S, et al. Automated monitoring innovations for efficient and safe construction practices. Results in Engineering, 2024, 22: 102057.

[4] Gao W S, Liang M K, Qu H L, et al. Research Progress on Intelligent Technology of Excavators. Construction Machinery, 2025, 6(04):1-11+210.

[5] Lu L, Wu J K, Sun N, et al. Intelligent Construction - Intelligentization of Construction Machinery. Chinese Hydraulics & Pneumatics, 2022, 46(06):1-9.

[6] Xu T Y, You J R. Application Research on Mechatronics Technology of Construction Machinery. Paper Equipment & Materials, 2023, 52(03):126-128+156.

[7] Ge S R, Hu Y Y Li Y W. Coal mining robot technology progress and the new direction. Journal of coal, 2023, 13 (01): 54-73.

[8] Ouyang A, Cui T, Lin L. Current Situation and Development Suggestions of Intelligent Agricultural Machinery Equipment Industry. Science and Technology Review, 2022, 40(11):55-66.

[9] Dong B Y, Zhang Z Q, Xu L J, et al. Research Status and Development Trend of Intelligent Emergency Rescue Equipment. Journal of Mechanical Engineering, 2020, 56(11):1-25.

[10] Wu J Q, Song X G. Review on the Development of Key Technologies for Smart Highways. Journal of Shandong University (Engineering Science), 2020, 50(04):52-69.

[11] Fadhel M A, Duhaim A M, Saihood A, et al. Comprehensive systematic review of information fusion methods in smart cities and urban environments. Information Fusion, 2024: 102317.

[12] Liu S Q, Liu L, Kozan E, et al. Machine learning for open-pit mining: a systematic review. International Journal of Mining, Reclamation and Environment, 2025, 39(1): 1-39.

[13] Zhang X, Xu J H, Chen T, et al. Research Status and Development Trend of Rescue Equipment for Major Natural Disasters. Science Technology and Engineering, 2021, 21(25):10552-10565.

[14] Huang X B. Review of Intelligent Inspection of Transmission Lines Based on

Image Perception. High Voltage Technology, 2024, 50(05): 1826-1841.

[15] Ma J, Feng Z, Qiu J L, et al. Technological Changes and Implications of China's Highway Transportation Industry in 40 Years of Reform and Opening Up. Journal of Chang 'an University (Social Science Edition), 2018, 20(06):38-67.

[16] Yu X J, Huai Y H, Yao Z W, et al. Engineering vehicles unmanned key technology. Journal of jilin university (engineering science), 2021, (4):1153-1168.

[17] Yin Y, Huang W F, Liu X F, et al. The Technical basis and Development Trend of Intelligent Mechanical Seals. Journal of Mechanical Engineering, 2021, 57(03):116-128.

[18] Wang L. Exploration of the Integrated Development Path of Coal Mine Robots in the 2.0 Stage. China Coal, 2024, 50(10):57-68.

[19] Wei D J, Yu P, Zang Y P, et al. Research on Distributed Intelligent Sensing Technology for Multi-energy Complementary Integrated Energy. 2020 IEEE/IAS Industrial and Commercial Power System Asia (I&CPS Asia), 2020: 51-57.

[20] Zhang S, Ni P, Wen J, et al. Non-contact impact load identification based on intelligent visual sensing technology. Structural Health Monitoring, 2024, 23(6): 3525-3544.

[21] Liang S, Peng J, Xu Y. Passive fetal movement signal detection system based on intelligent sensing technology. Journal of healthcare engineering, 2021, 2021(1): 1745292.