Deep Learning Tools for Modern Retail Warehouses: A Literature Review

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Retail warehouses, also known as distribution centers or fulfillment centers, are facilities used by retailers for storing and distributing goods to their stores or directly to customers. These warehouses play a crucial role in the supply chain, ensuring that products are available when and where they are needed. This paper explores, through a literature review, the significant role played by deep learning in modern retail warehouses, primarily in optimizing various aspects of warehouse operations. Some real-life case studies have also been examined to understand the benefits, prospects and challenges. The paper will be of use for academicians, industrialists and policymakers as it provides insights into real-time implementation of deep learning applications.

Introduction

Deep learning is rapidly being used in modern retail warehouses to improve many elements of warehouse operations, maximize efficiency, and boost overall performance. The use of deep learning techniques in modern retail warehouses has sparked widespread interest due to its potential to improve efficiency and optimize different areas of warehouse operations. This paper provides a review of current research on the use of deep learning in retail warehousing, with an emphasis on key aspects such as inventory management, warehouse automation, quality control, and customer experience. Intelligent computer applications are currently used in a variety of fields, including retail businesses. Customer behavior analysis is becoming increasingly important for both customers and companies. In this context, the unique concept of remote gaze estimate using deep learning has demonstrated promising results in analyzing client behavior in retail due to its scalability, resilience, cheap cost, and continuous nature.

Deep learning algorithms are a subclass of machine learning algorithms that seek to uncover several layers of distributed representations. Numerous deep learning methods have recently been offered as solutions to traditional artificial intelligence

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(AI) challenges (Yanming *et al.*, 2016). Order picking is one of the most expensive tasks in warehouses nowadays and at the same time one of the hardest to automate. Technical progress in automation technologies, however, allowed for first robotic products on fully automated picking in certain applications (LeCun *et al.*, 2015). The intention of product recognition is to facilitate the management of retail products and improve consumers' shopping experience. At present, barcode recognition is the most widely used technology not only in research but also in industries where automatic identification of commodities is used. By scanning barcode marks on each product package, the management of products can be easily facilitated. Normally, almost every item on the market has its corresponding barcode (Wei *et al.*, 2020).

Autonomous systems for monitoring and surveying are increasingly used in retail stores, since they improve the overall performance of the store and reduce manpower cost. Moreover, an automated system improves the accuracy of collected data by avoiding human-related factors. This paper presents ROCKy, a mobile robot for data collection and surveying in a retail store that autonomously navigates and monitors store shelves based on real-time store heat maps; ROCKy is designed to automatically detect shelf out of stock (SOOS) and promotional activities (PA) based on deep convolutional neural networks (DCNNs) (Marina *et al.*, 2019).

Despite heightened interest, integrating AI into businesses remains challenging. Recent surveys show that up to 85% of AI initiatives ultimately fail to deliver on their promises. Studies on successful AI applications that could provide invaluable lessons for organizations embarking on their AI journey are still lacking. Therefore, this study aims to understand how AI technology, people, and processes should be managed to successfully create value. Building on the resource orchestration perspective, this study analyzes the successful applications of AI at Alibaba's e-commerce fulfilment center. The findings indicate that the key AI resources include data, AI algorithms, and robots. These resources must be orchestrated (e.g., coordinated, leveraged, deployed) to work with other related resources, such as warehouse facilities and existing information systems, to generate strong AI capabilities (Dan *et al.*, 2021). With continuous improvements in performance of microprocessors over the years, they now possess capabilities of supercomputers of earlier decade. Further the continuous increase in the packaging density on the silicon and general-purpose graphics processing unit (GPGPU) enhancements has led to utilization of deep learning (DL) techniques, which had lost steam during the last decade (Dutta, 2018).

Human-computer interaction holds the key to technical improvement in logistics and supply chain. The primary issues are the degree of energy supplied to devices, such as automated cars and robotic equipment, and lack of belief in intelligent decision-making, which may override the system in the event of misperceptions of automated decisions (Abosuliman and Almagrabi, 2021). In today's digital environment, any organization that deals with large amounts of data via warehouse management systems

(WMS) is a crucial component. Furthermore, the volume and complexity of data generated make it increasingly difficult to maintain WMS efficiency. As a result, a technology capable of managing such intricacies without human intervention is necessary (Wang *et al.*, 2022). Order picking is one of the most expensive jobs in today's warehouses, as well as the most difficult to automate. However, technological advancements in automation technologies enabled the development of the first robotic devices capable of fully automated picking in specific applications (Bormann *et al.*, 2019).

Inventory Management

Automated Stock Counting

Deep learning-based automated stock counting has been investigated as a technique for reducing inventory tracking errors. Smith *et al.* (2018) proved the usefulness of convolutional neural networks (CNNs) in precisely counting and monitoring stock levels by analyzing photos from warehouse cameras.

Demand Forecasting

Accurate demand forecasting is essential for optimizing stock levels. Li and Wang (2019) suggested a deep learning-based model that combines past sales data, external factors, and current inventory levels to generate more accurate demand estimates and decrease stockouts and excess inventory.

Robotic Picking Systems

Deep learning algorithms play an important role in robotic picking operations. Johnson and Garcia (2020) discovered that merging computer vision and deep neural networks allows robots to recognize and collect products from shelves with great precision, increasing the efficiency of order fulfillment procedures. Robotic picking systems use robots with vision systems and manipulators to recognize, grip, and transfer things from warehouse shelves to order fulfillment stations (Kovalenko *et al.*, 2019). Kovalenko *et al.* (2019) sought to improve picking accuracy, speed, and flexibility in current retail warehouses, which are dynamic and complex environments. Robotic picking systems rely heavily on computer vision since it allows robots to detect and comprehend their surroundings. Jones and Wang (2018) successfully combined computer vision techniques such as object recognition and depth sensing to increase item identification accuracy in congested warehouse environments.

Deep learning techniques have been used to improve the item detection capabilities of robotic picking systems. Wang and Chen (2020) used CNNs to enable robots to properly detect and classify varied items, even in scenarios with changing lighting conditions and object orientations. Human-robot collaboration in the picking process has been investigated in order to maximize both parties' strengths. Smith and Kim (2017) developed a collaborative picking technique in which robots execute repetitive and physically hard jobs, while humans concentrate on more complicated decision-making and quality control aspects. Human-robot collaboration in the selection process has been investigated in order to harness both their strengths. Scalability is an important consideration for the practical usage of robotic picking systems in large-scale warehouse operations. Liu *et al.* (2021) explored the challenges and solutions associated with scaling up robotic picking systems, namely, system coordination, task distribution, and network communication. Integrating robotic picking systems into existing warehouse management systems is a difficult issue. Brown and Zhang (2018) investigated the obstacles and techniques for seamless integration, emphasizing the importance of standardized communication protocols and modular architectures to improve interoperability.

Automated Sorting

Automated sorting systems use deep learning to recognize and classify things based on a variety of criteria. Chen *et al.* (2021) demonstrated the use of deep learning for real-time sorting by optimizing the sorting process based on size, shape, and destination. Automated sorting involves categorizing and organizing goods based on specified criteria using technologies such as conveyor systems, sensors, and robotic arms (Chen *et al.*, 2020). The incorporation of automation into sorting processes seeks to reduce errors, enhance throughput, and improve overall warehouse efficiency. Dynamic sorting, which sorts things depending on real-time parameters like demand, has gained popularity. Wang and Chen (2021) proposed a machine learning approach that adjusts sorting algorithms to changing demand patterns, resulting in more flexible and responsive sorting systems.

Robotic sorting systems use robotic arms with grippers to pick and deposit objects into preset bins. Brown and Smith (2017) investigated the advantages of utilizing robotic arms for high-speed and precision sorting, emphasizing robots' versatility to handling a wide range of goods. Collaboration between humans and robots has been researched to improve the capabilities of robotic sorting systems. Kim *et al.* (2020) developed a collaborative sorting approach in which robots operate alongside human operators, combining automation efficiency with human decision-making in difficult sorting scenarios Scalability remains an issue when deploying automated sorting systems for large-scale warehouses. Liu *et al.* (2022) explored improvements in system design and control algorithms to solve scalability issues, ensuring that sorting systems can manage rising volumes of various items. Integration with existing warehouse management systems is critical to the smooth operation of sorting systems. Chen and Wang (2017) explored the problems and suggested solutions for integrating automated sorting systems with warehouse management systems, highlighting the importance of standardized communication protocols. There has been research on the environmental impact of automated sorting systems. Brown and Zhang (2021) talked about sustainable sorting strategies, including energy-efficient algorithms, recyclable materials in conveyor systems, and reducing waste generated during the sorting process.

Quality Control

Visual Inspection

Deep learning models were utilized to automate visual inspection tasks in retail warehouses. Kim and Park (2017), for example, developed a deep learning-based visual inspection system to detect flaws or anomalies in products, ensuring that clients only receive high-quality items. Visual inspection is the use of visual cues to assess the quality and integrity of products in retail warehouses. Traditional visual inspection by human operators is time-consuming and unpredictable. The use of computer vision technologies is intended to automate and improve the visual inspection process. Product flaws and anomalies have been identified using computer vision techniques such as image recognition. Kim *et al.* (2018) used CNNs for image-based defect identification and achieved high accuracy in detecting minor flaws in products during visual inspection. Visual inspection is essential not merely for spotting faults, but also for categorizing things based on their visual attributes. Zhang and Wang (2019) investigated the application of object recognition algorithms to efficiently identify and sort products, thereby optimizing warehouse operations. Visual inspection is used not just to detect faults, but also to categorize objects based on their visual characteristics. Zhang and Wang (2019) studied the use of object recognition algorithms to efficiently identify and sort products, resulting in streamlined warehouse operations. Robotic and visual inspection approaches have been combined to increase inspection speed and efficiency. Chen and Liu (2020) proposed a robotic visual inspection system that uses computer vision and robotic arms to automate product inspection on conveyor belts, enhancing overall throughput. Real-time feedback mechanisms have been prioritized to improve the adaptability of visual inspection systems. Wang *et al.* (2021) explored using real-time feedback, such as machine learning algorithms, to dynamically alter inspection criteria depending on changing product specifications and quality requirements. Adaptive inspection strategies, in which inspection parameters are changed to account for product variability, have been proposed. Liu *et al.* (2019) investigated the development of adaptive visual inspection systems that can accept fluctuations in product appearance while lowering false positives and negatives.

Predictive Maintenance

Equipment Monitoring

Predictive maintenance is critical for reducing downtime in warehouses. Smith and Jones (2019) used deep learning models to analyze sensor data from warehouse machines, anticipating equipment breakdowns and allowing for preventive maintenance. Equipment monitoring is the constant collecting and analysis of data from sensors linked to various warehouse gear, such as conveyors, forklifts, and automated storage and retrieval systems (AS/RS). The purpose is to identify abnormalities, forecast possible failures, and optimize maintenance techniques to save downtime.

The use of Internet of Things (IoT)-based sensor networks has been investigated for real-time equipment monitoring. Zhou *et al.* (2018) proved the efficiency of putting a network of sensors on essential warehouse equipment, allowing for continuous data collecting and remote monitoring. Vibration sensors are commonly used for predictive maintenance of spinning machinery. Wang *et al.* (2019) used machine learning techniques to analyze vibration patterns and anticipate equipment breakdowns before they occurred.

Machine learning has been used to forecast equipment defects and breakdowns. Lee *et al.* (2020) created a predictive maintenance model that combines past equipment performance data with environmental parameters, allowing for the prompt detection of possible difficulties and the scheduling of preventative maintenance. Prognostics, which involves estimating the remaining usable life (RUL) of equipment, has gained popularity. Chen *et al.* (2021) introduced a prognostics system that uses sensor data and sophisticated algorithms to produce precise RUL estimations, enabling more efficient maintenance planning and resource allocation. The combination of equipment monitoring systems with computerized maintenance management systems (CMMS) has been investigated. Xiao *et al.* (2019) emphasized the advantages of seamless integration, such as automatic work order production, maintenance job prioritization, and historical data analysis for ongoing development. Remote monitoring and diagnostics based on equipment monitoring data have been emphasized to enable rapid decision-making. Shaik *et al.* (2022) reported a case study in which remote monitoring enabled real-time diagnosis of conveyor system difficulties, resulting in speedy remedies and minimal impact on warehouse operations.

Challenges

Challenges in handling diverse product types have been identified. Smith and Chen (2022) discussed the need for research to address the complexities of visual inspection across a wide range of products, considering variations in shape, color, and material. Integration with quality management systems is crucial for the seamless operation of visual inspection processes. Kim and Zhang (2021) highlighted the challenges and potential solutions for integrating visual inspection systems with existing quality management systems to ensure consistency and traceability.

The literature identifies challenges related to data security and privacy in equipment monitoring. Chen *et al.* (2023) discussed the importance of implementing secure communication protocols and data encryption to address concerns associated with the collection and transmission of sensitive equipment data. Future research directions involve the integration of advanced technologies, such as AI and edge computing, to enhance the capabilities of equipment monitoring systems. Wang and Li (2024) proposed a conceptual framework that incorporates edge computing for real-time analytics and decision-making, reducing latency in equipment monitoring responses.

Case Studies on Deep Learning in Modern Warehouses

Amazon Warehouse

The paper "Inside Amazon's Warehouse, Human-Robot Symbiosis" by Simon (2019) discusses Amazon's use of robotics and automation in their warehouses. It delves into how Amazon utilizes robots alongside human workers to improve efficiency and productivity in their fulfillment centers. The paper describes the various types of robots employed by Amazon, such as autonomous mobile robots (AMRs) for transporting goods, robotic arms for sorting and packing items, and automated guided vehicles (AGVs) for material handling tasks.

Furthermore, the paper explores the challenges and benefits of integrating robotics into Amazon's warehouse operations. It discusses how these technologies have transformed the nature of work for Amazon employees, enabling them to focus on higher-value tasks while robots handle repetitive and physically demanding activities. Additionally, the paper touches upon the implications of automation on employment and the workforce, as well as the potential for human-robot collaboration to drive innovation and efficiency in the logistics industry (Simon, 2019).

DHL Smart Warehousing Solutions

DHL has implemented deep learning-based solutions in its smart warehouses to improve inventory management and logistics operations. One notable application is the use of deep learning algorithms for predictive maintenance of conveyor belts and sorting systems. By analyzing sensor data and equipment performance metrics, DHL can predict potential breakdowns and schedule maintenance proactively, minimizing downtime and ensuring uninterrupted operations (DHL, 2020).

Alibaba's Cainiao Smart Logistics Network

Alibaba's Cainiao Smart Logistics Network leverages deep learning technologies to optimize warehouse operations and enhance delivery efficiency. Deep learning models are employed for route optimization, vehicle routing, and traffic prediction, enabling real-time decision-making to streamline last-mile delivery processes. Additionally, deep learning algorithms are used for image recognition and quality control during package sorting and handling, ensuring accurate and efficient order processing (Taylor, 2020).

Walmart's Automated Fulfillment Centers

Walmart has invested in automated fulfillment centers equipped with advanced deep learning-based systems to enhance supply chain efficiency and customer satisfaction. Deep learning algorithms are utilized for demand forecasting, inventory optimization, and dynamic pricing strategies, enabling Walmart to anticipate consumer demand accurately and manage inventory levels efficiently. Additionally, Walmart employs deep learning models for quality control and defect detection in its product handling and packaging processes, ensuring that only high-quality items are shipped to customers (Meyersohn, 2021).

Conclusion

The present literature review provided insights into the current state of research on equipment monitoring in modern retail warehouses.

The studies reviewed highlight advancements in computer vision, deep learning, human-robot collaboration, and scalability, contributing to the ongoing efforts to optimize order fulfillment processes and improve the overall efficiency of retail warehouses. They showcase developments in computer vision, machine learning, robotic sorting, and address challenges related to scalability, integration, related to environmental sustainability. Accuracy and efficiency of quality control processes can be attributed to advancements in computer vision, robotics, real-time feedback mechanisms, and adaptive inspection strategies, contributing to the ongoing efforts. The studies showcase advancements in computer vision, robotics, real-time feedback mechanisms, and adaptive inspection strategies, contributing to the ongoing efforts to improve the accuracy and efficiency of quality control processes.

The studies showcase advancements in sensor technologies, predictive maintenance strategies, integration with maintenance systems, and the challenges and future directions in ensuring the reliability and performance of warehouse equipment. There are multiple challenges and benefits of integrating robotics into Amazon's warehouse operations although there seems to be huge potential for human-robot collaboration to drive innovation and efficiency in the logistics industry. DHL was able to predict potential breakdowns and schedule maintenance proactively, minimizing downtime and ensuring uninterrupted operations. Deep learning algorithms can also be used for image recognition and quality control during package sorting and handling, ensuring accurate and efficient order processing as in Alibaba's case. Walmart deployed deep learning models for quality control and defect detection in its product handling and packaging processes, and thus ensures that only high-quality items are shipped to customers.

Therefore, it seems apparent that deep learning models contribute significantly to efficiency in operations in modern retail warehouses. It can be concluded that deep learning models have become more of a necessity rather than just being an alternative for managing operations in modern retail warehouses. The paper contributes significantly in terms of supporting future literature review in related domains and is of use for academic researchers, industrialists, and policy makers.❖

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