VISUAL WAREHOUSE MANAGEMENT BASED ON YOLO DEEP LEARNING FOR FORKLIFT OPERATIONS

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Abstract

In the rapidly evolving landscape of logistics and warehousing, efficient inventory management is one of the most important issues. Forklifts, as indispensable tools in these environments, play an essential role, especially in the movement of goods. This paper introduces an innovative application of the You Only Look Once (YOLO) deep learning algorithm in the realm of visual warehouse management, specifically tailored for forklift operations. YOLO, as a state-of-the-art object detection algorithm applied to warehouse environment monitoring, can detect, classify, and track various items and obstacles in real-time. Our work presents the results of field trials and demonstrates the substantial improvements in warehouse management achieved through the implementation of YOLO-based visual perception of forklifts. The application not only streamlines inventory control, but also enhances safety, reduces operational costs, and ensures compliance with industry regulations. The innovative approach offers a holistic solution for real-time inventory monitoring, safety enhancement, and operational efficiency. It represents a significant stride towards the realization of smart, autonomous warehouses that promise to revolutionize the industry.

Keywords: Deep learning, warehouse operations, YOLO, object detection, forklift detection

1. INTRODUCTION

The integration of Artificial Intelligence (AI) and Machine Learning (ML) technologies has become a milestone in efficiency and innovation in the rapidly changing logistics and supply chain management. An innovative approach to warehouse management was presented at the 11th Carpathian Logistics Congress in November 2023 in Prague, Czech Republic, highlighting the potential of AI/ML to revolutionize conventional logistics operations. Logistics is just one of the areas that AI and ML have transformed. Delivery efficiency and inventory management have improved significantly due to the use of AI in logistics [1]. ML algorithms have made the optimization of supply chain routes possible [2], which has also helped lower operating costs and increase customer satisfaction. The concept of a Warehouse Management System (WMS) involves the use of visual data, such as images and video feeds, to supervise and manage warehouse activities. This approach improves the visibility and accuracy of inventory tracking in real time [3, 4]. Popular AI/ML features in TMS/WMS/YMS platforms include:

- application of computer vision technology in warehouse and storage facility management;
- development of AI/ML-based predictive models to forecast key transportation indicators and help plan transportation tasks;
- transformation of various types of data, including transportation information, IoT sensor readings, and external condition data, into meaningful semantic information;

- linking of scheduling and routing algorithms to large-scale cloud platforms such as Azure, AWS, and Google Cloud;
- development of business analytics modules and key performance indicators (KPIs) specifically tailored to storage, warehousing, and transportation processes.

YOLO's (You Only Look Once) algorithm's ability to process images in real time has made it a game-changer in various fields, including security and autonomous driving [5]. In the context of warehouse management, YOLO's application, authors [6], has shown promising results in detecting and tracking equipment and inventory, thereby streamlining warehouse operations. The specific application of AI in forklift operations has been a subject of interest in recent years. Highlighted the role of AI in reducing forklift-related accidents, a significant concern in warehouse management [7]. Moreover, authors [8] noted that integrating AI in forklift operations leads to better resource allocation and operational efficiency. Integrating AI and ML technologies with existing Warehouse Management Systems (WMS) is a critical step towards modernization. Importance of seamless integration, ensuring that the benefits of AI can be harnessed without disrupting existing workflows. An example of such an application is the industrial vision systems already in operation, as shown in **Figure 1**.

Figure 1 Optidata object detection applications (from left: load occupancy estimation, unit load defect detection, real-time object detection)

2. PROBLEM DEFINITION

WMS offers numerous benefits but comes with challenges and the necessary use of best practices. Computer vision and deep learning for industrial/logistics operations in the context of object detection in Warehouse Management Systems (WMS) are concerned with, among other things, traceability and tracking of objects, vision-based identification of goods, dimensioning of goods and pallets, visual documentation and monitoring, equipment condition monitoring, warehouse occupancy, and traffic areas.

Visual Warehouse Management represents a cutting-edge method for enhancing warehouse operations using visual data and technologies. This approach employs strategically positioned cameras and visual sensors throughout the warehouse to facilitate advanced technologies such as deep learning, computer vision, and object detection. It offers real-time insights into warehouse activities, enabling monitoring of goods, equipment, and personnel movements. Additionally, it seamlessly integrates with existing Warehouse Management Systems (WMS) and automation technologies, augmenting their capabilities for improved operational efficiency. The proposed system (**Figure 2**) uses various inputs and processes to monitor and manage warehouse operations.

This system receives visual inputs from a CCTV camera network and movie and image files. These inputs will likely include footage and images of the warehouse's interior, capturing real-time activities. Processing steps such as processing the input to estimate how much space is occupied within the storage facility, which is crucial for inventory management and optimizing space utilization, identifies and tracks the movement of people within the warehouse, detecting the presence and movement of forklifts and simply detecting forklifts, the system determines whether they are carrying cargo or are empty. The processed visual data is compiled into a movie file, which likely includes an annotated video showing the results of the occupancy, people, and forklift detection processes. This file could be used for review, training, or continuous improvement. This specific output provides data on whether forklifts are empty or loaded. This information can be fed into warehouse management systems to inform decision-making regarding forklift dispatching, route planning, and load scheduling.

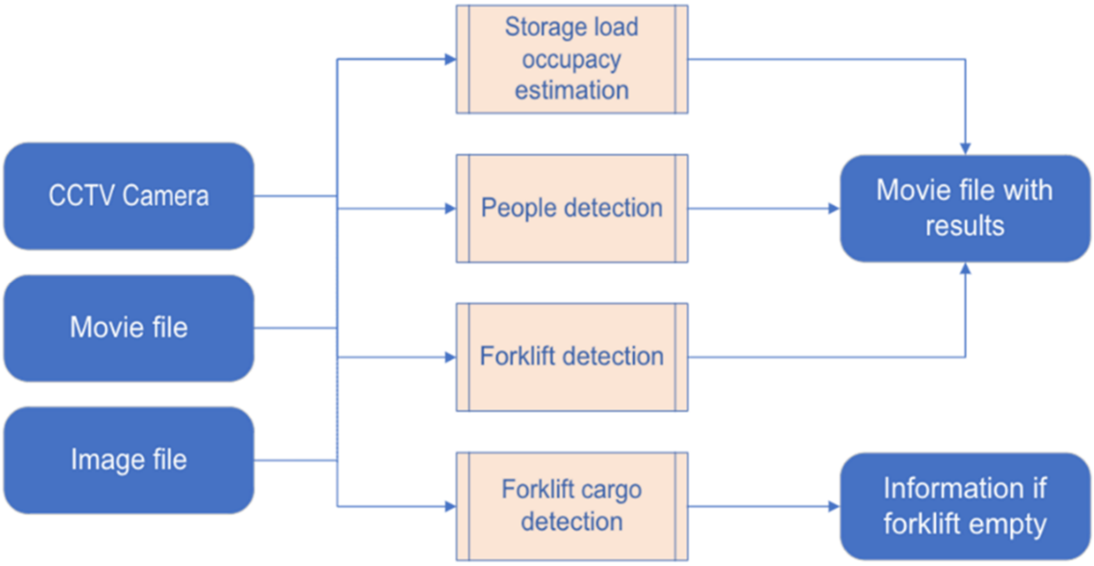

Figure 2 Application of Visual Warehouse Framework System

In order to construct a visual warehouse management system (VWMS), it is necessary to prepare and calibrate the machine learning (ML) and deep learning algorithm YOLO (You Only Look Once) capabilities correctly for real-time object detection. Finally, the problem considered in the paper is:

- Exploring the application of YOLO deep learning for real-time detection of forklifts (**Figure 3**) and their comparison with classical SVM and NN models.
- Discussing the potential of YOLO-based visual warehouse management in improving inventory accuracy and order fulfillment

Figure 3 Visual Warehouse Management concept shown with forklift detection

3. YOLO DEEP LEARNING: AN OVERVIEW

YOLO (You Only Look Once) is a deep learning framework for real-time object detection, utilizing a single neural network to predict bounding boxes and class probabilities from images in a single evaluation. It offers considerable accuracy in real-time detection while requiring less processing power compared to traditional two-step detectors. A range of studies have explored the application of YOLOv5 in forklift operations. Li [9] and Wan [10] improved the YOLOv5 model for forklift efficiency and obstacle detection. Li's model was found to be lighter and faster, while Wan's model achieved higher detection accuracy and distance detection. Ren [11] used YOLOv5 for intelligent forklift cargo transfer, significantly improving pallet recognition and docking accuracy. Yuen [12] proposed a VR simulation system for forklift operations, which could potentially benefit from the improved YOLOv5 models. Collectively, these studies demonstrate the potential of YOLOv5 in enhancing visual warehouse management for forklift operations. YOLO, despite its efficiency and accuracy in various applications, has limitations in specialized tasks such as forklift detection in warehouse environments, where the standard pre-trained models may not fully capture unique features and operational contexts. Transfer learning (**Figure 4**) emerges as a crucial strategy to address this gap.

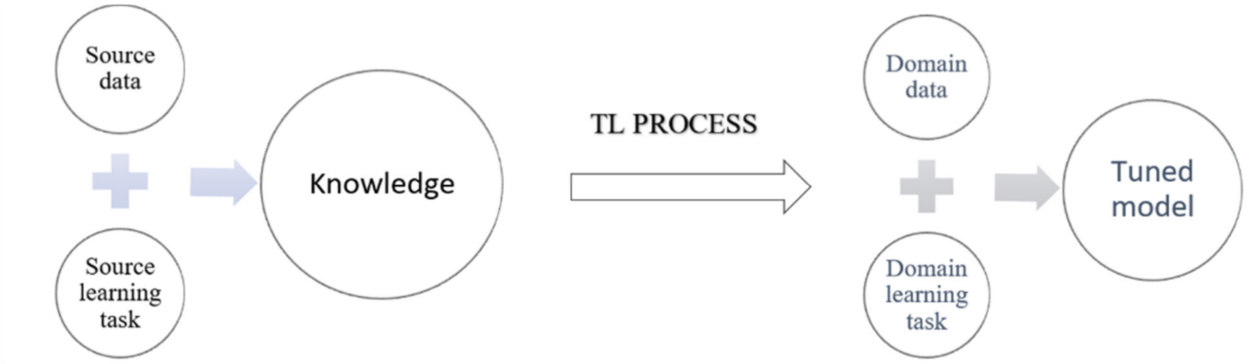

Figure 4 YOLO model tuning – Transfer Learning

Transfer learning allows us to take a pre-trained model, like YOLOv5, which has been initially trained on a broad dataset, and fine-tune it to recognize specific objects such as forklifts. This method leverages the generic features learned by the model on a vast array of objects and adapts it to the more focused task of detecting forklifts without requiring extensive labeled datasets that are costly and time-consuming to create. By retraining the final layers of the YOLO network with a smaller, more specific dataset of forklift images, the model can learn the distinctive attributes of forklifts in various operational states—whether carrying a load or not. This adaptation is efficient and cost-effective as it bypasses the need to develop a detection model from scratch. The existing neural network architecture, already proficient in detecting a wide range of objects, can be repurposed to focus on forklifts with relatively little additional input. This means that within simulation environments or with a limited set of real-world images, the YOLO model can be calibrated to accurately detect and track forklifts, enhancing warehouse operations' overall efficiency and safety. In essence, transfer learning is an indispensable technique to enable the YOLO framework to effectively detect forklifts – a task it does not inherently perform. It empowers the model with the capability to recognize and respond to the unique demands of visual warehouse management, thereby optimizing forklift operations and contributing to the intelligent automation of supply chain logistics.

4. CASE STUDY: FORKLIFT OPERATIONS OPTIMIZATION – YOLO AND MACHINE LEARNING

Due to the growing demand for quicker and more accurate warehouse operations, traditional forklift management techniques are being complemented by AI and machine learning technologies. This case study focuses on a warehouse that streamlined its forklift operations by implementing YOLO deep learning for real-time object detection. The study looks at how YOLO deep learning algorithms are used in warehouses to track and identify forklifts and freight. Important parameters are tracked, including event rates, time efficiency, and detection accuracy (**Figure 5**). The efficacy of the YOLO model is juxtaposed with conventional techniques and alternative artificial intelligence models, such as Support Vector Machines and Neural Networks. The first case study concludes that integrating YOLO deep learning into warehouse forklift operations significantly enhances efficiency, accuracy, and safety. This technology stands as a game-changer in warehouse management, paving the way for more advanced, AI-driven operational methods in logistics.

The YOLO model achieved an average accuracy of 97.4% in detecting forklifts, significantly higher than previous methods. When comparing cargo detection, neural networks showed an accuracy of 91.5%, while Support Vector Machines had an 80.0% success rate. There was a notable increase in the speed and efficiency of forklift operations, with reduced downtime and faster response to loading and unloading tasks. Implementing YOLO deep learning led to a decrease in forklift-related accidents and near-misses, contributing to a safer working environment.

The application of machine learning (ML) in the context of forklift detection in warehouse management is also a growing area of research and application in object detection. By automating the monitoring and administration of forklift operations, machine learning (ML) is being used in this field to improve safety, reduce costs, and increase operational efficiency. Our second case study delves into the application of Machine Learning (ML) for detecting forklifts in warehouses. This advanced ML approach has been instrumental in optimizing warehouse operations, offering significant improvements over traditional methods. In this case study, we analyzed how ML models, trained in visual data from warehouse environments, can discern whether forklifts are loaded with cargo.

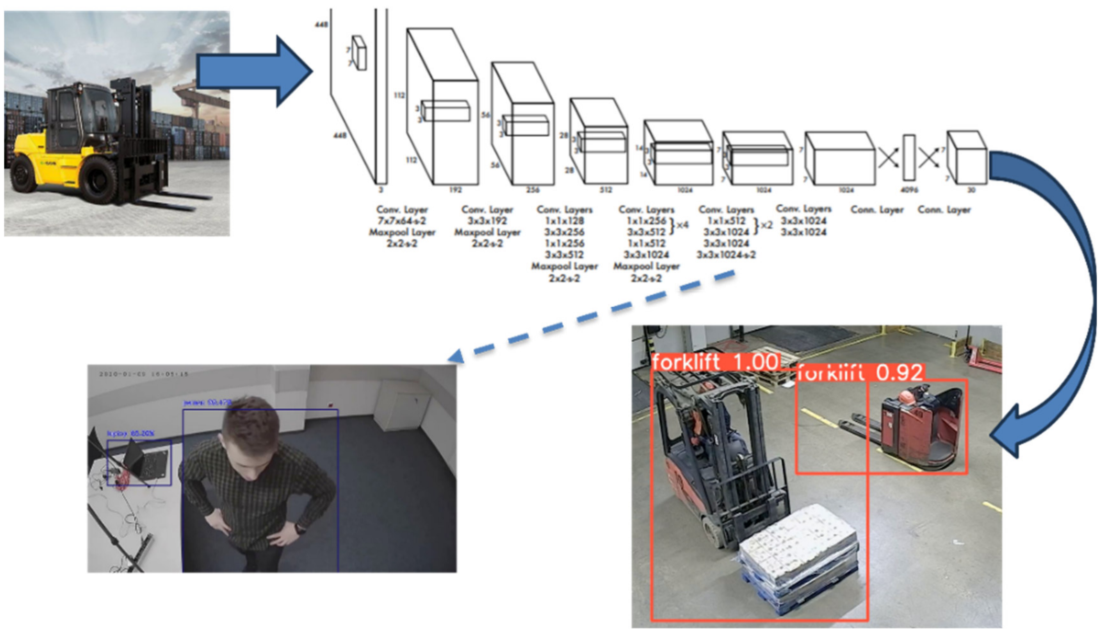

Figure 5 YOLO (You Only Look Once) technology and its application in real-time object detection

Figure 6 shows two confusion matrices for forklift cargo detection using two machine learning models: Support Vector Machines (SVM) on the left and Neural Networks (NN) on the right. Confusion matrices are a specific table layout that allows visualization of the performance of an algorithm, typically a supervised learning one. Each column of the matrix represents the instances in a predicted class, while each row represents the instances in an actual class. The SVM model demonstrates higher accuracy in detecting empty forklifts (86.5% vs. 83.8%) and carrying cargo (91.5% vs. 80.0%) than the NN model. The lower percentage of False Negatives and False Positives indicates that the SVM model performs better on this specific task. On the other hand, the NN model has a higher rate of both False Positives and False Negatives, which could indicate that the model may not be as fine-tuned as the SVM or that it may require a more complex architecture or additional training data to improve its predictive capabilities. In terms of quality, the SVM model appears to be better suited for this particular forklift detection task. However, the assessment of "good" or "bad" quality is relative and depends on the specific requirements and tolerances of the warehouse management system. For example, if the cost of missing a loaded forklift (False Negative) is very high due to the nature of the warehouse operations, even a 13.5% FN rate might be considered too high, and further improvements to the model might be required.

Actual \ Predicted	Empty	Cargo	Σ
Empty	86.5 %	8.5 %	83
Cargo	13.5 %	91.5 %	77
Σ	89	71	160

Actual \ Predicted	Empty	Cargo	Σ
Empty	83.8 %	20.0 %	83
Cargo	16.2 %	80.0 %	77
Σ	80	80	160

Figure 6 Forklift load detection results (left: support vector machines, right: neural networks for loaded and empty forklift)

Both case studies conclude that integrating YOLO deep learning and machine learning into warehouse forklift operations significantly improves efficiency, accuracy, and safety. This technology stands as a game-changer in warehouse management, paving the way for more advanced, AI-driven operational methods in logistics. Based on these findings, the study suggests a wider adoption of such technologies in warehouse management and explores potential future enhancements, including better integration with other warehouse management systems and further improvements in AI algorithms for even greater accuracy and efficiency.

5. CONCLUSIONS AND FUTURE IMPLICATIONS

YOLO deep learning promises to revolutionize warehouse forklift operations, potentially reshaping warehouse management's future. With an average forklift detection accuracy of 97.4% and cargo detection rates of 91.5% using neural networks and 80.0% with Support Vector Machines, it is a pivotal technology in transforming traditional warehouse operations. This approach symbolizes the next step in achieving efficient and safe warehouse management.

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