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# A MACHINE LEARNING BASED FRAMEWORK FOR OPTIMIZING DRONE USE IN ADVANCED WAREHOUSE CYCLE COUNTING PROCESS SOLUTIONS

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**Abstract**. *In each warehouse, managing inventory is an ongoing cycle that is a part of the supply chain. Warehouse inventory management is a process that involves receiving, storing and tracking inventory inside a warehouse followed by optimizing storage space and costs. Optimized inventory management provides improvements in fulfillment, shipping and the customer experience. In large warehouses, an inventory check generally means that staff members are lifted to high shelves where they physically reach and examine each standardized pallet, which is a tedious, expensive, risky and energy ineffective process. To increase performance, optimize work and reduce labor costs in contemporary Warehouse 4.0, the use of autonomous Unmanned Aerial Vehicles (UAV) for the cycle counting process and others is considered in this paper. Using UAVs for cycle counting provides a revolutionary solution to scanning pallets in a warehouse, using the latest drone platforms, hardware, software, scanning and communications technology. To use drones with integrated camera systems in the Warehouse 4.0 concept, efficient machine learning algorithms are needed in tasks such as scanning barcodes on each pallet, recording the location of each item, drone route optimization and many others. The framework proposed in the paper provides faster and more reliable operation but opens novel problems and challenges that need to be solved.*

**Key words:** *Unmanned Aerial Vehicle, Drone, Warehouse 4.0, Logistic 4.0, Machine Learning*

## 1. Introduction

A warehouse is a place to store the stock or the inventory and one of the most important tasks inside each warehouse is inventory management. Moreover, most of the tasks that occur in a warehouse are related to inventory management. These tasks include accumulating the receipts of products, issuing products, recording changes and tracking the movement of inventory [1]. Therefore, the final role of a warehouse is to process inventory from entry to exit, e.g., end-to-end operations inside a warehouse. To provide

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effective customer service inside a warehouse, all processes of inventory management need to be respected, divided into five stages (receiving, putting away, storing, order picking, and packing and shipping) [1] as presented in Fig. 1.

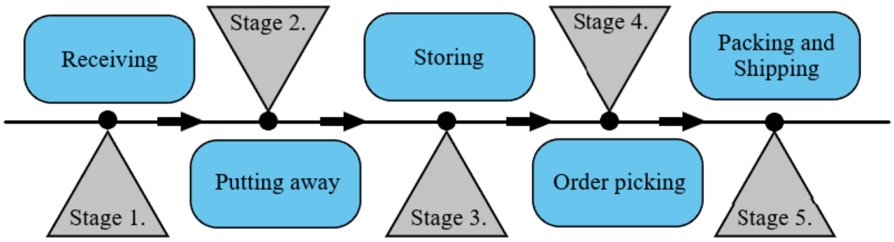


**Fig. 1.** Warehouse management process

If any of these phases are not fulfilled properly, consequences for all subsequent operations occur. Otherwise, if all processes are successfully finalized with the packing and shipping process, the completed orders are shipped. If the packages arrive on schedule, with the required paperwork and in the desired condition, shipping can be considered successful.

Apart from this, to support smooth warehouse operations, accurate inventory management is required. Managing inventory is an ongoing cycle where the regular cycle count is a way of keeping track of products which are currently in stock and in certain quantities. Doing cycle counting is a method of counting physical inventory on a rolling basis rather than in a single annual "wall-to-wall" count. Cycle counting is less disruptive to day-to-day operations and is generally more accurate than a complete physical inventory count [2]. The main purpose of cycle counting is to identify inventory inaccuracies, which, once identified, should be researched and eliminated [3]. By verifying that the locations of items and serviceable quantities on hand match the information recorded in inventory records, cycle counting helps to ensure that inventory records are operationally correct. Accurate inventory records are necessary to properly manage inventory levels and maximize operational efficiency. On the other hand, any counting in large warehouses requires staff members who are generally lifted onto high shelves by a forklift, truck or scissor lift where they physically inspect and scan each standardized pallet. This process is tedious, expensive, risky, and energy ineffective.

Nowadays, Unmanned Aerial Vehicles (UAVs) or drones, are increasingly prevalent in the efforts of large companies to reduce labor costs, optimize operations, automate processes, as well as solve many problems that various sectors of the industry face in numerous practices. Such solutions are good because drones are easily deployable, accurate and, together with high-resolution cameras equipped with high-end sensors, can take photos and videos of excellent quality and accumulate large amounts of data for further analysis. They are extremely safe for the environment, as well as increasingly economical to purchase. Additionally, logistics is a crucial component of supply chain management and plays an important part in the current global economy. How inventory is managed in the warehouse affects how efficiently the supply chain operates. It is estimated that transportation and warehousing make up 10-15% of the price of the finished product for European companies, and that part of these costs can be reduced by improving and optimizing cycle counting.

Cycle counting combined with UAV technology leads to accurate inventory counting and operation, with reduced human labor. It has been shown that if UAVs are paired with data processing methods, such as artificial intelligence and machine learning algorithms, the automation of previously manual activities can be effectively accomplished. Therefore, this is one of the most effective strategies to enhance the supply chain, optimize storage and use technology to automate processes to lower human error.

A lot of research inside Warehousing and Logistic 4.0 has been done with the aim of combining digital technologies, drones and machine learning to optimize and automate the inventory process. In a comprehensive overview of the implementation and critical factors of UAVs in warehouse management [4], several benefits of UAVs have been identified in warehouse management such as increased efficiency, improved accuracy, and reduced cost, with identified critical factors that need to be considered to acquire better working conditions, including safety, security, regulations and technical limitations. An autonomous drone-based technology with marker localization system has been introduced for efficient navigation in storage areas [5]. Autonomous drones can navigate in storage areas very efficiently, scanning and locating the maximum number of items in motion while sending inventory status feedback. Generally, a GPS-based navigation system is used for autonomous drones, but due to indoor warehouse environments GPS technology provides less navigation precision. Therefore, a marker on a drone and an overhead camera to track the marker thus tracking the drone is superior.

On the other hand, an environment based on Robot Operating System (ROS) and Gazebo simulator is suggested for simulation and analysis. The application of reinforcement learning in optimizing logistics distribution routes of UAVs [6] has been also proposed, where reinforcement learning helps to significantly improve the efficiency and effectiveness of UAV-based logistics distribution systems. In [7] a drone-based solution for inventory management in warehouses using Wi-Fi and camera modules [8] for image processing and barcode scanning is presented. A step forward is taken by describing drone-based inventory management as an attractive solution for industries using cost-friendly drones which are designed to keep accurate inventory records [9] in warehouses. An approach to automate manual inventory using camera-drones and AI in object detection models, trained on a custom dataset to extract and count relevant objects based on images of the warehouse, is presented in [10]. In [11] the focus is on developing algorithms for the automatic extraction of 1D barcodes from video scans for inventory management, where three key techniques for barcode recognition are introduced: 1) using Harris corner detector and Hough transform to orient bars, 2) using connectivity and geometry property to recognize multiple barcode regions in a single frame, and 3) using histogram difference to extract barcode information efficiently. The barcode scanning task is divided into two low-level tasks: video data collection and barcode extraction. The algorithm for barcode region detection is implemented in OpenCV. In contrast to that, in [12] computer vision techniques are used to detect and decode 2D barcodes in real-time from images taken by drones, also for inventory management purposes in warehousing applications. A solution for autonomous stocktaking in warehouses using UAVs equipped with a CNN-based barcode detection system is presented in [13]. A combination of computer vision techniques and UAV trajectory optimization algorithms is proposed to accurately detect and track barcodes on products in a warehouse environment with the results of the study that the proposed solution is effective in reducing the time and resources required for stocktaking compared to traditional manual methods. A CNN-based barcode detection system provides a high degree of accuracy and efficiency in detecting barcodes.

The central contribution of this paper is to explore and establish a machine learning framework that can optimize the deployment of autonomous drones within the warehousing environment, thereby transforming and streamlining end-to-end inventory management processes. By leveraging the capabilities of machine learning, this study aims to address the intricate challenges of inventory management - from receiving to shipping - and to demonstrate how intelligent drone technology cannot only automate but also enhance accuracy and efficiency in warehousing operations. An in-depth analysis of the integration of UAVs into the core stages of warehouse management is offered, enabled by machine learning-based approaches that allow drones to perform complex tasks such as cycle counting and barcode scanning with minimal human intervention. Ultimately, a forward-looking perspective on the synergy between drones and artificial intelligence in the era of Logistics 4.0 is presented, outlining a future where warehouses operate with unprecedented precision and agility.

The rest of the paper is organized as follows. In Section 2 current warehouse technology is addressed with the formulation of the cycle count problem and drone technology in warehouse operations is outlined. In Section 3 a framework for drone warehouse solutions based on machine learning is presented. Finally, in Section 4 some conclusions are formulated.

## 2. CURRENT WAREHOUSE WITH CYCLE COUNT PROBLEM FORMULATION AND DRONE TECHNOLOGY USAGE

The modern warehouse incorporates advanced technologies such as the Internet of Things (IoT), contemporary warehouse management system (WMS) and robotics, while distribution of goods to markets is driven by the cross dock process. Warehouse 4.0 is a response to the growing demand for faster, more efficient, and more flexible supply chain operations. Considering each cross dock good is delivered as a full or 80% loaded pallet, operations need to be sufficient to meet market demands timely, fulfilling market request without errors. Since cross-docking is a simple but fast-moving process of shifting intact pallets from one form of transportation to another with no storage time or low storage time in-between, ideally the number of counted items versus the items on record has to be the same. In this case inbound less-than-truckload shipments are unloaded, sorted, scanned, and reconsolidated with packages that have the same next destination.

On the other hand, looking at cross-docking more strategically, the goal is almost the same as in a traditional warehouse - receiving, storing goods, order picking, and shipping. In any case, to maintain costs, inventory accuracy must be at a very high level. Based on this, to secure costs, cycle count is used as a check point to ensure that the physical inventory count matches the inventory records reporting back this as inventory accuracy:

$$Inventory\_accuracy = \frac{Counted\_items}{Items\_on\_record} \times 100 \ [\%]. \quad (1)$$

Cycle count is a typical inventory counting technique that allows businesses to count a certain number of products distributed throughout the warehouse without having to count the entire stock. This approach allows the tracking of goods, because when the physical inventory differs from the actual stock count, a problem arises. This study considers a typical scenario where cycle count has to be conducted regularly in order to avoid mismatching with a physical stock, maintaining costs at a required level. Goods are stored in bays, as shown in Fig. 2. The warehouse system is responsible for storing pallets randomly. Each bay has levels marked with letters A, B, C, D, etc., and a number of marked places per level.

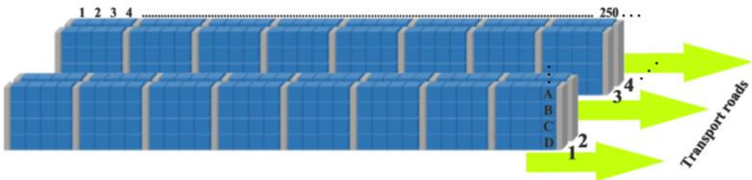


**Fig. 2.** Pallet Storage in a Warehouse

On the other hand, cycle count organization requires a lot of energy, manpower organization and supervision invested in the process, and increases the risk of possible mistakes. One end-to-end counting cycle to cover all racks in the warehouse usually takes several days, where goods are partially counted and checked. The process is typically organized with manual scanners connected to Warehouse Management System (WMS) via wireless connection to the main server. Once the location of a QR code has been scanned, inputs about goods and their quantity are given manually. Based on system check within System Applications and Products (SAP), a widely used enterprise resource planning software driven by an administrator, an audit count can be created with another team. This can happen due to possible human mistakes or missing goods.

One of the possible solutions based on upgrading warehouse operations to an autonomous level is considered here, where overall cycle count is conducted by machine support – the Unmanned Area Vehicle (drone, Fig. 3) and high intelligence systems, which avoid manual work.

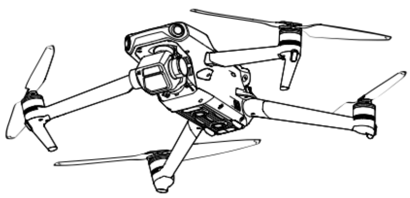

**Fig. 3.** Drone equipped with cameras

To be in line with technology requirements and enable one of the key features of Warehouse 4.0, it is necessary to use real-time data to optimize warehouse operations. This data is collected through a variety of sensors and devices that are integrated into the warehouse, including RFID tags, barcodes, cameras, and drones. The data is then supposed to be analyzed using artificial intelligence and machine learning algorithms to identify patterns, optimize workflows, and improve efficiency.

The considered solution includes a comprehensive integration of key components through a WMS. It emphasizes real-time detection and precise estimation of marker positions within the video stream. The plan suggests equipping drones with motion sensors and 3D cameras to facilitate the screening and analysis of the warehouse's interior. Moreover, it anticipates the use of GPS for indoor navigation, supplemented by intelligent automation software that would grant the drones capabilities for autonomous flight, precise hovering, and accurate landings. For specific navigation needs, the proposal recommends the utilization of markers [7], a proven solution to be placed at each storage level, allowing for streamlined tracking within the inventory space.

## 3. Framework for Drone Warehouse Solutions Based on Machine Learning

An example of a highly suitable choice for the cycle counting procedures in a technologically advanced Warehouse 4.0 setting is DJI Mavic Series Drones. Their dual-camera systems, with a wide-angle camera and a telephoto lens, capture high-resolution images and high-quality videos, essential for precise inventory management. The video capabilities and wide fields of view allow for detailed aerial inspection necessary for accurate cycle counts. Equipped with intelligent flight paths, automatic subject tracking and an omnidirectional obstacle sensing system, the drones ensure safe and efficient navigation through the warehouse space. The Mavic drones' long flight times and considerable ranges are conducive to thorough inventory checks without the need for frequent recharging. Features like Return-To-Home and ability to hold a steady position make them an invaluable tool for seamless and accurate inventory cycle counts, aligning with the operational excellence required in a Warehouse 4.0 environment.

The processing and relaying of captured data to the WMS cloud are also essential. This integration is poised to enhance the efficiency and accuracy of the cycle counting process within Warehouse 4.0. In case of missing GPS signals, cameras can be used for drone localization and control via markers.

### 3.1 Machine Learning Techniques to Support Drone Operation

There are several machine learning techniques that can be used in drone control inside warehouses to improve the cycle count process, where some of them are considered for further framework and optimization solutions, such as:

- Metaheuristic optimization,
- Deep learning, particularly as a part of Computer Vision,
- Natural language processing.

The challenge of path optimization for autonomous drones within the confines of warehouse environments necessitates sophisticated computational strategies, among which metaheuristic optimization emerges as an influential tool. These techniques, which include, but are not limited to, Genetic Algorithms, Ant Colony Optimization, or Particle Swarm Optimization, provide a non-deterministic yet efficient means of determining optimal flight paths amidst the labyrinthine aisles and varying altitudes characteristic of modern storage facilities. The inherent complexity of warehouse topography, combined with the stochastic nature of inventory movement and storage density, requires adaptive and intelligent path planning to ensure time-sensitive and energy-efficient navigation of drones. Metaheuristic algorithms thrive in such scenarios due to their probabilistic approach to exploring and exploiting the search space, enabling drones to dynamically adjust their flight paths in response to real-time environmental feedback and operational contingencies.

Applying Deep Learning (DL) techniques particularly as part of the Computer Vision, drones can be trained to recognize specific inventory items or warehouse features. For example, drones can be trained to recognize specific products or to identify when a storage bin is empty.

Finally, Natural language processing (NLP) can be used to enable voice-based control of drones. Warehouse workers can use voice commands to direct drones to specific locations in the warehouse or to perform specific tasks. Having such an option is helpful in case of repeated count during mismatch.

Overall, all machine learning techniques can enable drones and help them to operate more efficiently and effectively in warehouse environments, improving inventory management and reducing labor costs as a result.

### 3.2 Computer Vision in Warehouse Management

Using computer vision, drones can use algorithms to analyze images and videos of the warehouse environment. By analyzing this data, drones can navigate through the warehouse, avoid obstacles, and identify inventory items for picking and shipping.

As elaborated previously, drone-based warehouse inventory management is becoming more and more popular and the majority of these involve either using cameras to read barcodes or capture images, then identifying items using computer vision techniques, or using other automated identification technologies to make object identification easier. After that, machine learning can be utilized to make the right choices regarding, among other things, the next object to pick up or store in the warehouse, the location of recently delivered goods, and the order in which tasks should be completed. With better analysis, tracking and inventory control, overall process control is more effective. Supporting physical technology is a cloud-based platform that delivers key insights into inventory and oversees drone fleet operations. A key component of this strategy is a user-centric dashboard that provides real-time data access and the capacity to take prompt corrective action in the event that inventory irregularities are found. Warehouse management is made more effective by having accurate and up-to-date inventory records thanks to such a comprehensive system.

Furthermore, warehouses can also use vision-based technologies for object inspection and detection. Also, object tracking is a technique for finding moving objects using video camera streams. Both object detection and tracking create a potential use case for warehouse management, for example to find bottlenecks caused by forklift traffic, detect damaged pallets, or detect defective products on the racks. Computer vision is also employed for enhanced industrial robotic operations, unmanned forklift driving, facial recognition, and security detection. By assessing the space availability in the storage racks, these techniques can also be used to find available storage space in the warehouse. Vision-based item detection is the perfect answer for boosting productivity and efficiency due to rising competition and the strong demand for agility in supply chains.

In addition to the above, image processing can also be used in the prevention of disasters, such as fires, saving a huge amount of material resources, and what is even more important, saving human lives. Traditional fire detection methods are mostly present in warehouses, which have a number of disadvantages such as limited coverage, no information about what the cause of the fire is, the requirement for a significant amount of heat and smoke to activate the alarm which often happens when a fire is already out of control [8]. By offering higher detection accuracy, a vision-based system can overcome the drawbacks. The ML model can be trained to detect fires by using convolutional neural network modeling approaches. It also enables identification and analysis of fire origin and precise location for future prevention.

### 3.3 Framework for operation of the system supported by UAVs and ML

After the goods inbounding process, goods are stored in the warehouse according to their categories. The WMS system is designed so as to trigger cycle count according to the procedure rules. The information about cycle count and product locations passes through the system and is delivered to drones' microcontrollers.

The drones move across the warehouse to the selected locations capturing firstly images of the location labels and then pallet labels, where pallet label QR codes contain data about pallet quantities. This information is passed through the WMS cloud to SAP and checked by an administrator. Drones' scannings are repeated until cycle count closure.

A framework of the process with an information transfer scheme and support of the machine learning technologies is presented in Fig. 4.

It is obvious from the devised framework that advanced Warehouse technologies and concepts are joined with advanced computing technologies and drones' technology, but everything is efficiently joined and enabled as a complex but highly efficient and capable operational concept by machine learning, which can be considered as being crucial in the context.

## 4. CONCLUSIONS

Drone integration into current warehouse procedures has initially been met with resistance, as is the case with any new technology. Considering this, three essential elements are shown to be crucial to the success of autonomous drones in warehousing, specifically:

- The reliability, stability, scalability and affordability of drone hardware.
- The ability of software support to enable fully autonomous indoor navigation and automatic scanning of barcodes and QR codes.

- The operational, commercial and strategic fit between inventory drone solutions and the ground realities of warehouse inventory management.

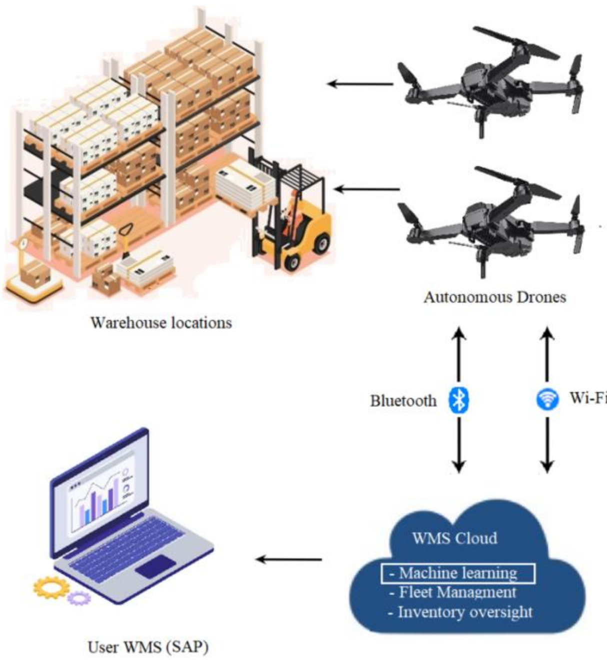


**Fig. 4.** Framework for drones and ML integration in Warehouse 4

These three factors must be put into perspective to ensure a successful integration of drone technology for inventory counting in a warehouse. On the other hand, this has been followed by advantages of utilizing drone technology in the warehouse:

- Lesser manpower is required to perform the inventory count hence, resources can be channeled to other activities.
- There is improved accuracy of count results, easy comparison of count results with the existing inventory data on the WMS. Drones can take picture evidence of the count thus providing greater count evidence.
- Due to the autonomous nature, counts can be operated during off peak hours.
- Drones can move fast while capturing labels at heights, providing time saving.

The ability of the drone to scan barcodes on all of the warehouse's storage supplies, locate empty storage spaces, and identify pallets without their barcodes for identification is fundamental to its operating mandate. The system collects and examines data in a real-time scenario using machine learning techniques in order to maintain an accurate and trustworthy inventory database. The real-time data is compared with the WMS records to help identify any discrepancies or inconsistencies.

Certainly, the flight and operation control of a single and multiple UAVs makes the integration of drone systems into the WMS challenging to manage and can result in erroneous data comparisons and other operational issues. This paper presents the importance and discusses the ways forward for further improvements in the application of machine learning UAV control for contemporary warehouse application, such as:

- Deep learning image processing for QR codes reliable scanning and inventory,
- Drone route optimization by metaheuristic optimization,
- Machine Learning flight control and multiple drones' synchronization, etc.

The strong potential of this strategy undoubtedly outweighs the issues and challenges that still need to be researched and resolved.

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