Efficient Warehouse Management with Autonomous Drones

Siddhartha Mahesha Pundit[1*], Swathi Bhat[2], Sameer Guruprasad Belthur[2]

[1]Department of Computer Science and Engineering, Jyothy Institute of Technology, India

[2]Department of Electronics and Communications Engineering, Jyothy Institute of Technology, India

* Corresponding author: siddhartha.pundit@gmail.com

doi: https://doi.org/10.21467/proceedings.7.4.8

ABSTRACT

Considering the rapid ascendancy of e-commerce, the logistics industry is facing highly unprecedented demand in its quest to increase efficiency, speed, and accuracy. Most conventional warehouse facilities that still rely on human aids, for example, physical inventory and parcels tracking, tend to be inefficient with locked up operational costs and risks such as lack of safety complying with today's supply chain standards. In this paper, we propose a novel approach: the Warehouse Drone (WD), which is an autonomous quadcopter based automated warehousing logistics system that will be used to locate, recognize and handle the packages more accurately and intelligently. The system operates in a fully automated fashion, fitted within the warehouse environment, using techniques like computer vision, path planning, and scanning. Therefore, it can navigate, plan its route without collisions, and can also scan the positions and the states of the packages in real time. Built on a range of tools such as ROS2, OpenCV, Rivz2, and several others, the WD has the ability to interface with the central warehouse system, facilitating efficient warehouse operations by reducing the need for human interaction in repetitive processes as well as reducing errors after manual handling. In addition, the Warehouse Drone helps tackle significant issues faced in logistics by improving the accuracy of inventory management, operational efficiency, and safety. This paper includes the design of the WD, autonomous navigation approaches, and the use of drones within a warehouse in general.

Keywords: Autonomous drones, Warehouse automation, Inventory management.

1 INTRODUCTION

Due to the increase in consumerism in the modern day, the demand for goods is ever increasing. For the fulfilment of this ever-increasing demand by the human race, warehouses have become crucial to meet these demands. The warehouse management practices of the olden days are insufficient to handle the large volume of stock in extremely large warehouses. To keep up with the sheer number of incoming and outgoing goods, the inventory management system also needs to be upgraded. Several pressing issues can be observed in present warehouse management systems. First, limited stock visibility can cause interruptions in warehouse operations. When stock identification is done incorrectly, it leads to inconsistencies in the recorded inventory, i.e., between the recorded inventory and how much stock is actually available. The primary consequence of this is the delay in dispatching goods, which hinders warehouse operations [1]. Secondly, the hassle in identifying mislocated goods can emerge due to a lack of real-time tracking systems. This causes delays in retrieving necessary products, which further causes delays in shipping them. It also connects back to the first issue discussed, where a mislocated item could potentially be treated as non-existing in its category [2]. Drawing from the second issue, mislocated goods can cause warehouse managers to assume that the goods do not exist and can lead to overstocking. This further causes unnecessary financial losses for the warehouse. Furthermore, any perishable goods that might have undergone such misplacement will cause wastage once expired [3].

Proceedings DOI: 10.21467/proceedings.7.4; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-984081-1-2

Inspection and repair work at greater elevations inside warehouses have caused severe injuries, including those that have been fatal. Around 30,000 non-fatal electrical shock accidents occur each year. Among the fatalities, around 1,000 of them can be attributed to electrocution [4]. Additionally, pests and rodents are the biggest threat to warehouses storing produce. Not only do they cause significant economic losses by eating said produce, but also contaminate the stock with their excretions. Identifying the existence of those pests manually is based on the likeliness that an individual spots it, otherwise going unnoticed [5]. To mitigate these issues, we propose the Warehouse Drone (WD) system. The following section speaks about how warehouse drones can improve warehouse efficiency.

2 RELATED WORK

The application of autonomous aerial vehicles in warehouse management has recently drawn significant attention due to the potential for advancement of inventory and logistics operations. Early research focused on the feasibility of using drones for real-time inventory tracking. Vuong (2024) demonstrated how drones with RFID scanners traversed warehouse aisles and scanned shelves more accurately than manual methods, especially in large warehouses with multiple units [6]. Further developments by Karamitsos et al. (2021) proposed the integration of drones with warehouse management systems (WMS) for the real-time synchronization of inventory updates. They highlighted the need for robust fleet coordination algorithms when deploying multiple drones simultaneously [7]. Cordova and Olivares (2016) addressed these concerns by proposing an algorithm for drone fleet management, which optimized flight paths for drone fleets, to optimize inventory scanning and retrieval [8]. A study by Christ et al. (2021) validated the efficiency and accuracy of inventory auditing through drones. They found that such systems could reduce audit times by over 90% while improving data accuracy [9]. The potential of drones for worker safety has also been a topic of research. Nooralishahi et al. (2021) examined the use of drones for inspections in hazardous conditions, such as high elevations, poorly lit areas, and electrically unsafe sections of warehouses. They demonstrated that drones could replace manual inspections in such areas using high-definition cameras and sensors, thereby reducing the risk of workplace injuries and fatalities [10].

In the context of environmental monitoring, Heydari et al. (2020) presented a vision-based algorithm for detecting rodent activity in agricultural fields using drones for aerial filming and image processing. The study involved using a quadcopter with a high-resolution camera, and support vector machine (SVM) classifiers to identify burrow holes with high precision [11]. The application of such techniques in warehouses can potentially improve pest detection methods. Moreover, the integration of pest control modules into drone platforms, as discussed by Xue et al. (2016), facilitates targeted pesticide application, allowing for immediate mitigation along with surveillance [12]. From an economic perspective, Çıkmak et al. (2023) focused on the economic feasibility of drone adoption in warehouses. They conducted a cost-benefit analysis and found that while initial implementation costs can be high, the long-term benefits in terms of reduced labour costs, improved inventory accuracy, and enhanced operational efficiency significantly outweighed the expenses [13]. These studies support the feasibility of autonomous drones in warehouse settings, and establish a foundation for further innovations, like the modular WD system we propose in this paper.

3 METHODOLOGY

This study proposes a layered architecture for an autonomous drone system for warehouse applications, as illustrated in Figure 1. The architecture was designed to be modular, which facilitates system scalability and adaptability across various warehouse environments. It consists of four interdependent layers: hardware, operating system, control, and services.

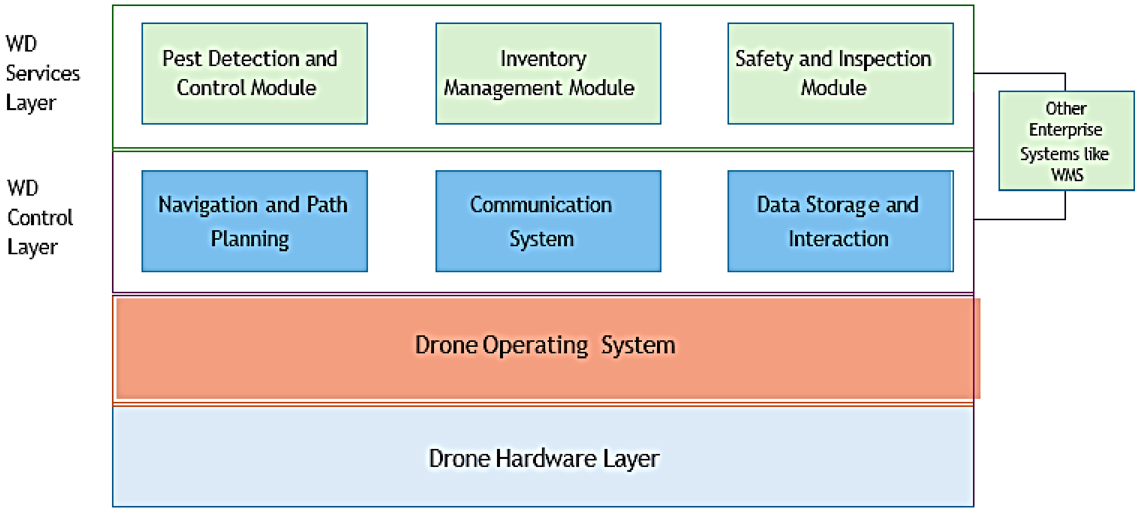

Figure 1. Layered Architecture of WD System

At the foundation is the drone hardware layer, which is constructed with lightweight, modular components. The drone body is fabricated with a lightweight yet durable frame to achieve a balance between maneuverability and payload efficiency. This frame supports modular attachments and can safely accommodate various sensors [14]. High-efficiency propellers and propulsion systems drive navigation, and flight safety is enhanced by integrating LiDAR and ultrasonic sensors for obstacle avoidance [15]. In order to support the various operational modules on board, viz., RFID/barcode scanners, cameras, and other specialized equipment required for inventory and safety operations, an adaptable payload bay is integrated on-board [16]. To monitor the environmental conditions of the warehouse, thermal imaging cameras are integrated for pest detection, and air quality sensors monitor the storage environment [17].

The next layer, the drone operating system, provides the software foundation for the drone's autonomy. It incorporates embedded software for autonomous navigation, handling sensor input, and real-time data-driven decision-making [18]. The drones are programmed for autonomous functionalities such as takeoff, landing, and docking at charging stations. This reduces human intervention and makes operations seamless [19]. To maintain flight stability, a set of adaptive Proportional–Integral–Derivative (PID) controllers are implemented, with individual controls for pitch, roll, and yaw angles. Through these controllers, the system responds dynamically to environmental disturbances, which is essential for warehouse settings with tight spaces and frequent human activity [20].

The control layer is the operational core of the system. The drones use simultaneous localization and mapping (SLAM) algorithms for indoor navigation of complex layouts. High-precision localization is achieved by combining global positioning system (GPS) modules for outdoor reference and real-time kinematic (RTK) systems for indoor positioning [21]. Dynamic path planning algorithms are implemented to reduce energy consumption, avoid obstacles, and minimize flight time [22].

Communication between drones and the warehouse management system (WMS) is facilitated through wireless communication systems like Wi-Fi, enabled with 5G protocol, which facilitates real-time transmission of inventory data [23].

At the top of the architecture, the services layer includes high-level modules for specific tasks such as inventory tracking, safety inspections, and pest detection. Inventory tracking is carried out by RFID scanning and barcode analysis in real-time, with the data relayed to the WMS for automated stock updates [24]. For safety inspections, thermal imaging sensors are integrated on-board, to identify pest and rodent activity [25], and a pest mitigation mechanism is introduced through ultrasonic repellents and pesticide dispersion [26]. Real-time video feeds are included in the system, along with the ability to control the drones remotely, which enables inspections in hazardous areas without risking the safety of workers [27]. The architecture is designed to be compliant with warehouse safety regulations, such as adhering to certain weight limits, or avoiding no-fly-zones [28]. This layered approach also facilitated modular testing, supporting independent validation of each component before system-wide integration and performance evaluation.

4 RESULTS AND DISCUSSIONS

The Warehouse Drone (WD) system proposed in this system was evaluated through multiple simulations. Each simulation sheds light on key operational objectives such as inventory tracking, path optimization, safety inspections, and pest detection. The results demonstrated the layered architecture's effectiveness in addressing the core challenges of warehouse management. They also revealed certain operational trade-offs. In simulations of a multi-UAV system focused on inventory tracking, a swarm of six independently operating autonomous drones with RFID readers successfully scanned over 90% of inventory items in 12 minutes. When the simulation was extended to 60 minutes, the system achieved 100% coverage, with all RFID tags detected in 27 minutes. These results validated the system's ability to conduct accurate and timely inventory audits. However, some instances of redundancy in tag detection and occasional overlapping in scanning paths were observed, particularly in simulations lacking inter-drone coordination. This highlighted the importance of optimizing fleet management protocols for large scale deployments [24]. Path planning simulations using a point-line visual SLAM algorithm showed high responsiveness, with real-time processing rates of up to 73 Hz on desktop systems and 40 Hz on embedded processors. The algorithm consistently achieved reliable localization under varying lighting conditions and complex environments, outperforming traditional SLAM methods both in terms of accuracy and drift reduction. However, in environments with densely packed obstacles, navigation updates experienced minor latency, which indicated the need for hardware acceleration or algorithmic refinement in high-density scenarios [21].

The drones also performed well in simulated safety inspection scenarios. High-resolution video streams allowed for remote inspection of elevated storage racks and dimly lit areas of the warehouse. Structural defects, such as cracks and corrosion, were successfully identified, thereby reducing the need for manual inspections in hazardous areas [10]. However, battery limitations occasionally disrupted extended inspection tasks, highlighting energy management as a critical area for improvement. Dust and low visibility conditions occasionally compromised sensor reliability, indicating a need for adaptive filtering techniques or environmental adjustments [25]. Pest detection tests using thermal imaging achieved an accuracy of 96.1% in identifying rodent-made burrow hole locations, based on simulated temperature anomalies. The high precision was attributed to the use of support vector machine (SVM) classifiers, which were trained on colour and texture features from high-resolution images [11]. Simulations of

Proceedings DOI: 10.21467/proceedings.7.4
ISBN: 978-81-984081-1-2

Series: AIJR Proceedings
ISSN: 2582-3922

pesticide dispersion further demonstrated sub-meter targeting accuracy, with a 7-meter swath width and wind speeds of 0-2 m/s, ensuring consistent coverage and minimizing waste, especially under low wind conditions. This suggests that drones could function effectively as both detection and mitigation tools for pest management in food storage facilities [24].

The coordination of multiple drones was evaluated using a planning strategy based on Signal Temporal Logic (STL), allowing the simultaneous operation of up to sixteen drones without risk of collisions. The system demonstrated continuous and balanced task distribution, and maintained consistent task execution across the fleet, while also avoiding the oversimplified abstractions commonly seen in other approaches. However, increasing the number of drones led to slight delays in coordination updates, especially while navigating shared corridors. This implies that hybrid coordination models or decentralized control systems could improve scalability [28]. In emergency scenarios, the drones successfully detect thermal anomalies resembling fire outbreaks and transmitted alerts to the control centre. The system also demonstrated potential in guiding evacuation paths and delivering emergency supplies, including first-aid kits. Though effective, these simulations highlighted the need for faster battery recharge cycles and improved performance in high-temperature environments.

Overall, the simulations validated the core functions of the WD system, and highlighted its potential to replace or enhance existing manual processes. The system showed significant potential in improving inventory accuracy, inspection coverage, pest control techniques, and emergency response capability. The identified limitations, such as battery endurance, inter-drone coordination, and sensor durability, provide clear paths for further research and improvement.

5 CONCLUSION

This study presented an autonomous drone-based system designed to optimize warehouse operations by automating inventory management, safety inspections, and pest control. The system was built on a layered architectural framework, integrating modular hardware, embedded autonomy, real-time navigation, and high-level service modules. Simulation results showed that the drone swarm was capable of performing efficient inventory audits, navigating complex environments dynamically, and accurately detecting pests and hazards. The drones were also able to perform coordinated operations and emergency response tasks, highlighting the system’s versatility. Although the simulations validated the operational viability of the system, challenges such as limited battery life, occasional sensor interference, and coordination delays in multi-drone scenarios were observed. These limitations emphasize the need for improvements in energy efficiency, sensor calibration, and real-time communication systems. Despite these challenges, the WD system present a scalable and modular solution for issues in modern warehouses, with the potential to reduce dependency on manual labour, improve safety standards, and optimize logistics workflows. Future developments may focus on integrating predictive analytics for inventory forecasting, improving environmental monitoring with advanced sensing technologies, and exploring hybrid systems that integrate both aerial and ground-based automation. The findings highlight the increasing importance of autonomous aerial platforms in industrial environments and provide a practical framework for their integration into warehouse management.

6 Publisher's Note

AIJR remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

How to Cite

Pundit *et al.*, “Efficient Warehouse Management with Autonomous Drones”, *AIJR Proc.*, vol. 7, no. 4, pp. 73-79, Jun. 2025. doi: https://doi.org/10.21467/proceedings.7.4.8

References

[1] F. Yiğit, "Challenges in Inventory Management and a Proposed Framework," in *Theory and Research in Engineering*, Gece Publishing, 2020, pp. 311-334.

[2] E. Frazelle, *World-Class Warehousing and Material Handling*. New York, NY, USA: McGraw Hill Professional, 2002.

[3] G. Richards, *Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*. London, U.K.: Kogan Page Publishers, 2017.

[4] Bureau of Labor Statistics (BLS), "Fatal occupational injuries and nonfatal occupational injuries and illnesses," 2023. [Online]. Available: https://www.bls.gov/. [Accessed: Dec 03, 2025].

[5] K. Affrin and N. Kumar G., "Real Time Warehouse Pest Control and Management Using WSNs," *JETIR*, vol. 6, no. 6, pp. 251-260, June 2019.

[6] P. Vuong, "Enhancing Inventory Counting Process with Drone Technology," M.S. thesis, Metropolia University of Applied Sciences, Helsinki, Finland, 2024.

[7] G. Karamitsos, D. Bechtsis, N. Tsolakis, and D. Vlachos, "Unmanned aerial vehicles for inventory listing," *International Journal of Business and Systems Research*, vol. 15, no. 6, pp. 748-756, Jan. 2021, doi: 10.1504/IJBSR.2021.118776.

[8] F. Cordova and V. Olivares, "Design of drone fleet management model in a production system of customized products," *2016 6th International Conference on Computers Communications and Control (ICCCC)*, Oradea, Romania, 2016, pp. 165-172, doi: 10.1109/ICCCC.2016.7496756.

[9] M. H. Christ, S. A. Emett, S. L. Summers, and D. A. Wood, "Prepare for takeoff: Improving asset measurement and audit quality with drone-enabled inventory audit procedures," *Review of Accounting Studies*, vol. 26, no. 4, pp. 1323-1343, 2021.

[10] P. Nooralishahi, C. Ibarra-Castanedo, S. Deane, F. López, S. Pant, M. Genest, N. P. Avdelidis, and X. P. V. Maldague, "Drone-Based Non-Destructive Inspection of Industrial Sites: A Review and Case Studies," *Drones*, vol. 5, no. 4, p. 106, 2021. doi: 10.3390/drones5040106.

[11] M. Heydari, D. Mohamadzamani, M. G. Parashkouhi, E. Ebrahimi, and A. Soheili, "An algorithm for detecting the location of rodent-made holes through aerial filming by drones," *Archives of Pharmacy Practice*, vol. 11, no. 1, pp. 55-60, 2020.

[12] X. Xue, Y. Lan, Z. Sun, C. Chang, and W. C. Hoffmann, "Develop an unmanned aerial vehicle based automatic aerial spraying system," *Computers and Electronics in Agriculture*, vol. 128, pp. 58–66, 2016. doi: 10.1016/j.compag.2016.07.022.

[13] S. Çıkmak, G. Kırbaç, and B. Kesici, "Analyzing the challenges to adoption of drones in the logistics sector using the best-worst method," *Business and Economics Research Journal*, vol. 14, no. 2, pp. 227–242, 2023. doi: 10.20409/berj.2023.413.

[14] B. Bay and M. Eryıldız, "Design and Analysis of a Topology-Optimized Quadcopter Drone Frame," *Gazi University Journal of Science Part C: Design and Technology*, vol. 12, no. 2, pp. 427–437, 2024.

[15] J. Saunders, S. Saeedi, and W. Li, "Autonomous aerial robotics for package delivery: A technical review," *Journal of Field Robotics*, vol. 41, no. 1, pp. 3-49, 2024. doi: 10.1002/rob.22231.

[16] B. Vergouw, H. Nagel, G. Bondt, and B. Custers, "Drone technology: Types, payloads, applications, frequency spectrum issues and future developments," in *The Future of Drone Use: Opportunities and Threats from Ethical and Legal Perspectives*, The Hague: T.M.C. Asser Press, 2016, pp. 21-45. doi: 10.1007/978-94-6265-132-6_2.

[17] K. K. Jena, S. Mishra, S. Mishra, and S. K. Bhoi, "Stored Grain Pest Identification Using an Unmanned Aerial Vehicle (UAV)-Assisted Pest Detection Model," in *Machine Vision Inspection Systems: Image Processing, Concepts, Methodologies and Applications*, vol. 1, Beverly, MA, USA: Scrivener Publishing, 2020, pp. 67–83.

[18] L. D. Ortega, E. S. Loyaga, P. J. Cruz, H. P. Lema, J. Abad, and E. A. Valencia, "Low-Cost Computer-Vision-Based Embedded Systems for UAVs," *Robotics*, vol. 12, no. 6, p. 145, 2023. doi: 10.3390/robotics12060145.

[19] N. Nadig, P. Minde, A. Gautam, A. B. Asokan, and G. S. Malhi, "Conceptual Design of Aerostat-Based Autonomous Docking and Battery Swapping System for Extended Airborne Operation," *Drones and Autonomous Vehicles*, vol. 1, no. 4, p. 10013, 2024. doi: 10.70322/dav.2024.10013.

[20] W. Arfa, C. B. Jabeur, and H. Seddik, "Hybrid multi control for better drone stability," *International Journal of Modelling, Identification and Control*, vol. 45, no. 2-3, pp. 164-177, 2024. doi: 10.1504/IJMIC.2024.10064246.

[21] K. Xu, Y. Hao, S. Yuan, C. Wang, and L. Xie, "AirSLAM: An efficient and illumination-robust point-line visual SLAM system," *arXiv preprint*, arXiv:2408.03520, 2024.

[22] M. Gubán and J. Udvaros, "A path planning model with a genetic algorithm for stock inventory using a swarm of drones," *Drones*, vol. 6, no. 11, p. 364, 2022. doi: 10.3390/drones6110364.

[23] S. Chen, W. Meng, W. Xu, Z. Liu, J. Liu, and F. Wu, "A Warehouse Management System with UAV Based on Digital Twin and 5G

Technologies," in *Proc. 2020 7th International Conference on Information, Cybernetics, and Computational Social Systems (ICCSS)*, Guangzhou, China, 2020, pp. 864-869, doi: 10.1109/ICCSS52145.2020.9336832.

[24] J. H. Ong, A. Sanchez, and J. Williams, "Multi-UAV System for Inventory Automation," in *Proc. 2007 1st Annual RFID Eurasia*, Istanbul, Turkey, 2007, pp. 1-6, doi: 10.1109/RFIDEURASIA.2007.4368142.

[25] K. S. Subramanian, S. Pazhanivelan, G. Srinivasan, R. Santhi, and N. Sathiah, "Drones in insect pest management," *Frontiers in Agronomy*, vol. 3, p. 640885, 2021. doi: 10.3389/fagro.2021.640885.

[26] J. Irizarry, M. Gheisari, and B. N. Walker, "Usability assessment of drone technology as safety inspection tools," *Journal of Information Technology in Construction (ITcon)*, vol. 17, no. 12, pp. 194-212, 2012.

[27] F. T. Gaba and M. Winkenbach, "Regulatory Implications for Unmanned Aerial Vehicles in Last-Mile Delivery," Massachusetts Institute of Technology, Center for Transportation & Logistics, Cambridge, MA, USA, Tech. Rep., Oct. 2022.

[28] Y. V. Pant, H. Abbas, R. A. Quaye, and R. Mangharam, "Fly-by-logic: Control of multi-drone fleets with temporal logic objectives," in *Proc. 2018 ACM/IEEE 9th International Conference on Cyber-Physical Systems (ICCPS)*, Apr. 2018, pp. 186–197. doi: 10.1109/ICCPS.2018.00023.