

Unidock: A Cloud-Orchestrated Autonomous Charging Dock for Continuous Quadcopter uav Operations

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Abstract

There has been a rise in the use of UAVs, especially quadcopters, in defense, agricultural, delivery and surveillance applications. The current UAV applications are limited by the manual charging requirements. The current solutions include battery hot-swap and manual charging. UNIDOCK(Universal Charging Dock for Quadcopter UAV) aims to solve this problem by providing personalized charging for individual UAVS. Each UAV continuously monitors its SOC and upon reaching a predefined threshold value, it autonomously navigated to the nearest dock using GPS. The whole system is integrated with a cloud platform that stores the battery profiles and GPS coordinates of docks. The cloud backend, implemented using Supabase software enables real-time communication and monitoring of UAVs through a secure channel. The queuing algorithm implemented ensures proper charging discipline and minimize charging delays. The dock is provided with a programmable CC-CV charging system to ensure proper charging of LiPo batteries, and the BMS(Battery Management System) ensures that all cells of the LiPo battery are equally charged. A threshold of 85% SOC was set where the transition from CC-CV operation was verified using MATLAB simulation which confirmed safe and effective LiPo battery charging. A dock assigning algorithm was developed to coordinate multiple UAVs by computing the shortest path based on straight line distance and remaining SOC. UNIDOCK aims to provide a cost effective, reliable, and sustainable solution to existing charging problems. The future improvements include better efficiency modules, and an auxiliary solar-powered source.

Keywords: Autonomous docking, CC-CV battery charging, pogo-pin interface, cloud assisted scheduling

INTRODUCTION

Unmanned Aerial Vehicles (UAVs), mainly quadcopters have become of great importance in various sectors such as surveillance, agriculture, army, infrastructure inspection, disaster management etc. These drones are working 24/7, so they need to be charged at regular intervals They serve as a great help in areas of data collection, monitoring and task execution which are difficult for human operators. Despite their advantages and applications, one of the major constraints of UAVS are their flight time. These drones are working 24/7, so they need to be charged at regular intervals. UAVs of current generation mainly have a

flight time of about 20 to 40 minutes depending on payload, weather conditions etc. This limitation mainly arises due to the application of Lithium Polymer battery usage in UAVs, which serves as the main power source for small to medium sized UAVs. The efficiency of UAVs is greatly affected by frequent swapping of batteries and human intervention to recharge. Since most of the UAV applications such as surveillance, agricultural monitoring etc. requires continuous monitoring, their efficiency gets reduced due to battery replacement and human intervention.

The total cost of autonomous UAV systems increases due to a number of factors such as coordinating multiple UAVs, each requiring specialized charging profile, and careful scheduling to maintain operational continuity. These logistics of battery management in multi drone operations shows additional challenges. Though there is a lot of research going on in this field and many solutions have been put forward, none of them are as good as DJI Dock series. It is nearly a perfect solution for this, but it has two major flaws: only specific DJI drones are compatible with the dock, and they are expensive. This is where the UNIDOCK (Universal Charging dock for Quadcopter UAVs) comes in; it offers a cost effective and reliable charging solution, and it is universally compatible with all drones. UNIDOCK provides a solution for challenges faced by UAVs such as limited flight duration and need for manual battery management. This project is a fully autonomous charging station that enables quadcopter UAVs to navigate to the nearest charging station, land with precision, recharge their batteries with minimal human intervention and finally continue their operations.

The universal compatibility is achieved by a programmable Constant Current-Constant Voltage(CC-CV) charging module and a battery box attached to the drone. The whole system is integrated into cloud, so real time monitoring of available docks and charging status is possible. The next major problem is when multiple UAVs want to charge simultaneously, it will cause complete chaos. To address this problem, we have implemented a dock finding algorithm as well as a queuing algorithm. For simplicity, we merged both into a single optimized dock finding algorithm. The optimized dock finding algorithm helps to find the nearest dock to the drone. If that dock is unavailable, it will search for the next nearest dock and calculate if it is possible to reach with the current battery capacity. If it is reachable that dock is selected and drone navigates there, but in case that dock is unreachable, the drone will be sent to the queuing pad next to the dock. To avoid clashing, the dock's status will be set to occupied as soon as a drone selects that dock. This small but effective change can improve the overall efficiency of the algorithm.

USA and China have made advancements in autonomous UAV charging stations, with companies such as Skydio, DJI etc. offering docking solutions but are often expensive for the common citizens. India's drone ecosystem is still in its primitive stage of development. UNIDOCK provides a cost-effective solution that expands globally and includes technologies such as GPS navigations, sensor fusion and CC-CV charging. By reducing human intervention in the charging cycle, this system can enable true autonomous operation and can extend mission durations through quick battery replenishment and enhanced scalability.

Literature Review

Several approaches were researched throughout the years in the area of autonomous UAV landing and charging systems. These approaches include docking platforms, wireless charging mechanisms, automated battery replacement solutions etc. The followings studies were conducted in this field and the limitations were also identified for each research.

Grlj et al.[1] provided a review of UAV docking station that have been developed over the last few years. Their research explored both fixed and moving docking platforms, categorizing them according to their

mobility, charging methods and landing guidance techniques. The study showed the significance of accurate landing mechanism for UAV operations. It also discussed about how advancements in computer vision and autonomous navigation algorithms facilitated developments in landing systems. But many of the docking platforms needed costly hardware and specialized infrastructure.

Galimov et al.[2] performed a thorough classification of UAV positioning mechanisms utilized in landing stations. Their research evaluated both passive and active positioning techniques, including guiding funnels, alignment pins and servo-actuated platforms. The study showed that while passive systems are straightforward, they require highly precise UAV landings, whereas active systems enhance docking reliability by rectifying minor alignment issues. The limitation was that it mainly concentrated on mechanical positioning mechanisms, neglecting charging and communication systems.

Zhao and Pei[3] introduced an enhanced vision-based landing algorithm for UAVs that employs a blend of image processing and feature detection techniques. Their approach utilized camshaft tracking and SURF feature extraction to identify landing targets and direct the UAV towards the landing platform. Experimental findings indicated improved detection accuracy compared to conventional image processing methods. However, vision-based systems are vulnerable to environmental factors such as variations in lighting, shadows and background noise.

Junaid et al.[4] created a self-sufficient wireless charging system for multirotor UAVs utilizing inductive power transfer. The study proposed employed image processing methods to direct the UAV to the charging pad, facilitating wireless charging without any need for physical contact. It illustrated that the wireless charging platform could attain around 75% efficiency in power transfer. But it was found that wireless power transfer has lower efficiency than direct conductive charging and can take longer charging duration for the UAV batteries.

Lim et al.[5] proposed an autonomous UAV landing strategy that combines semantic segmentation with LiDAR-based depth sensing to identify safe landing zones. The approach evaluates terrain characteristics such as slope, flatness, and surface conditions while incorporating environmental context for improved decision-making. By integrating multiple sensor modalities, the system enhances landing reliability under varying conditions. Experimental results demonstrated effective real-time performance in complex outdoor environments. However, the system relies on computationally intensive processing and additional sensor hardware, which may increase system complexity and cost.

Saviolo et al. [6] introduced AutoCharge, an autonomous UAV charging system utilizing a portable ground station with a flexible tether and circular magnetic connectors for orientation-independent docking. The electromagnet-assisted mechanism improves tolerance to landing inaccuracies and ensures reliable docking and undocking. Experimental results demonstrated consistent performance in long-duration operations. However, the tethered design restricts UAV mobility during charging, and the use of electromagnetic components increases system complexity and power consumption.

Dhanasekar et al. [7] proposed a building-integrated photovoltaic system with wireless charging capability for UAVs, enabling efficient space utilization and autonomous energy replenishment. The system employs inductive power transfer, reducing the need for precise alignment during docking. Experimental results demonstrated effective charging performance under optimized panel configurations. However, wireless charging suffers from lower efficiency compared to contact-based methods, and reliance on solar energy limits performance under adverse weather and nighttime conditions.

Fujii et al. [8] developed an automated battery swapping system that enables continuous UAV operation by replacing depleted batteries with charged ones. The system incorporates motion capture-based

positioning and mechanical guidance to ensure accurate alignment during battery exchange. Experimental validation demonstrated reliable operation for extended missions. However, the system requires complex mechanical infrastructure and additional battery storage, making it bulky and less suitable for scalable or cost-effective deployment

Despite these advancements, numerous current solutions are limited by reduced charging efficiency, complex mechanical systems for UAV environments. UNIDOCK overcomes these limitations by integrating efficient conductive charging alongside cloud-based management and sensor fusion-based landing control.

System Architecture

UNIDOCK is composed of three primary subsystems: the quadcopter UAV, docking station and the cloud-based architecture as shown in figure 1. These elements combine to form the autonomous UAV docking and charging. During its operation, the UAV monitors its battery level or State of charge(SOC). When the battery level falls below a certain threshold value, the drone initiated a return to dock command. With the help of the cloud database and GPS navigation, the UAV makes its way to the nearest available docking station. As the UAV reaches the nearest docking station, the sensors integrated in the UAV such as GPS, IMU etc. helps in position estimation. This guarantees precise alignment with the docking station during the final stage of landing. Upon landing on the station, electrical contact is made through pogo pin contact that connect with charging pads which is fixed to the drone's landing gear.

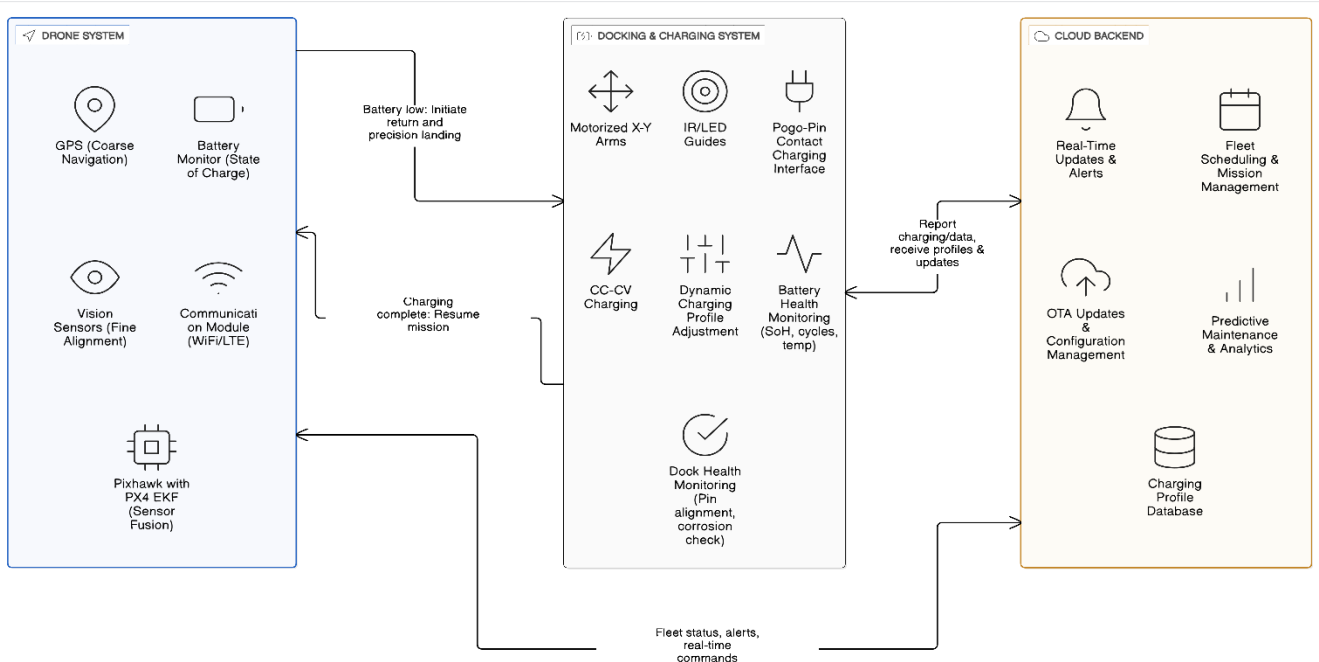


Figure 1: System Block Diagram of the UNIDOCK Autonomous Charging Architecture

The charging circuit then initiates the charging of the battery using the CC-CV charging method. The cloud database stores information about UAV status, availability of docking stations and different charging profiles of UAVs. This allows for coordination of multiple UAVs functioning within the same area or network. The operational workflow is shown in figure 2. The architecture makes sure smooth interaction between the UAV, docking station and the cloud platform with the help of continuous data exchange. Based on different status parameters from the UAV such as battery level and position to the

cloud database. Based on this information, the cloud system assigns corresponding docking stations to the UAVs while considering factors such as availability and battery constraints.

The docking station not only serves as a charging platform but also communicates with the UAV and cloud server for the respective operations. This helps in allowing multiple UAVs and docking stations to function effectively and efficiently. The integration of navigation, communication and charging systems ensures a fully autonomous system with minimal human intervention.

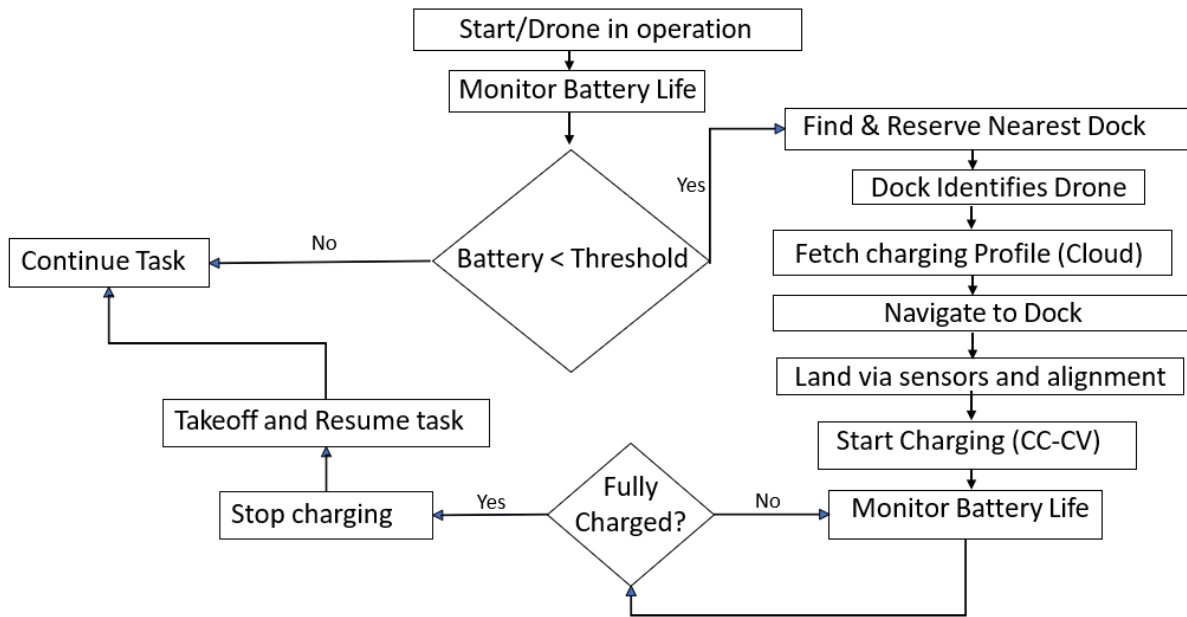


Figure 2: Operational flow of UNIDOCK

Design and Implementation

The docking station acts as a medium between the UAV and the charging interface. It serves as a landing surface, alignment mechanism and electrical charging interface. The platform is developed as a flat and stable landing surface which is capable of supporting the UAV during the landing and charging process. The station is constructed to ensure mechanical stability and provide sufficient clearance for the landing gear of the UAV.

Unlike systems that depend on mechanical actuation mechanisms, the docking station uses a passive alignment approach along with the natural landing accuracy of the UAV. This approach simplifies the system design while improving reliability and reducing power consumption. Once the UAV lands on the docking station, the charging interface is enabled with the help of conductive pads on the station and corresponding pogo pin connectors on the drone. The pogo pins ensure that proper alignment takes place between the drone and the docking station during landing.

The electrical contact between the UAV and the dock is implemented using the pogo pin connectors. They help in reliable electrical contact even when minor alignment errors occur. The charging circuit architecture is shown in figure 3. It consists of an AC to DC rectifier which is followed by a buck converter which provides the appropriate voltage and current to the battery. The charging process follows the CC-CV method which ensures a safe and reliable charging system for LiPo batteries. At the beginning, a constant current is given to the battery to quickly charge it and after reaching a threshold value it transitions

to constant voltage phase where the current gradually decreases as the battery gets fully charged. This prevents overcharging and any damage to the battery as well as improve its lifespan. \

Any additional protective mechanisms can be provided to improve system reliability such as overcurrent protection, voltage regulation etc. These additions can make sure the stable operation of the charging system under varying load conditions.

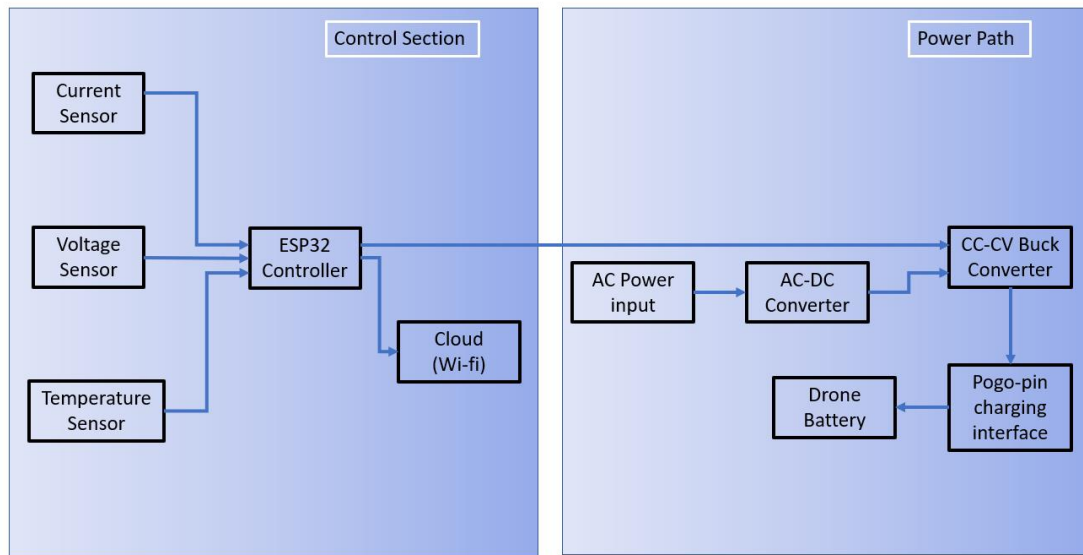


Figure 3: CC-CV charging circuit architecture of UNIDOCK

Simulation Result

The performance of the proposed UNIDOCK system was evaluated through comprehensive simulations focusing on battery charging behavior, autonomous landing accuracy, and intelligent docking coordination. The simulations were carried out using MATLAB/Simulink as shown in figure 4 for electrical validation and Gazebo for dynamic UAV modelling, enabling a realistic representation of both power and operational aspects of the system .

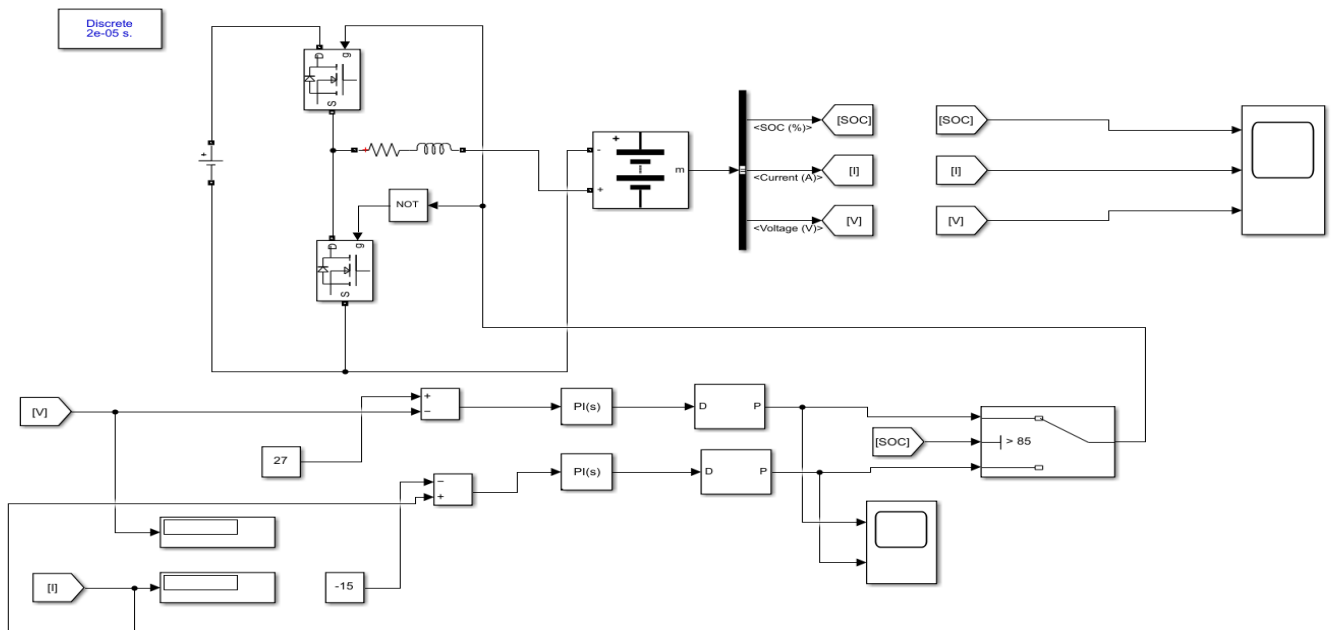


Figure 4: Simulink model of the CC-CV charging system

The Li-Po battery charging process was analysed using a closed-loop Constant Current–Constant Voltage (CC–CV) control scheme. The simulation results demonstrate that during the constant current phase, the charging current remains stable at approximately 5 A, allowing rapid replenishment of battery capacity. As the terminal voltage approaches the maximum threshold of 16.8 V, the system transitions smoothly into the constant voltage phase. In this stage, the current gradually decreases while maintaining a constant voltage, ensuring safe and efficient charging. The results obtained across different state-of-charge intervals as seen in figure 5 confirm that the transition between CC and CV modes is well-regulated, with no observable overshoot or instability. Furthermore, the charging current tapers to a safe cutoff level, thereby preventing overcharging and enhancing battery lifespan. These observations validate the effectiveness of the implemented charging strategy for Li-Po batteries .

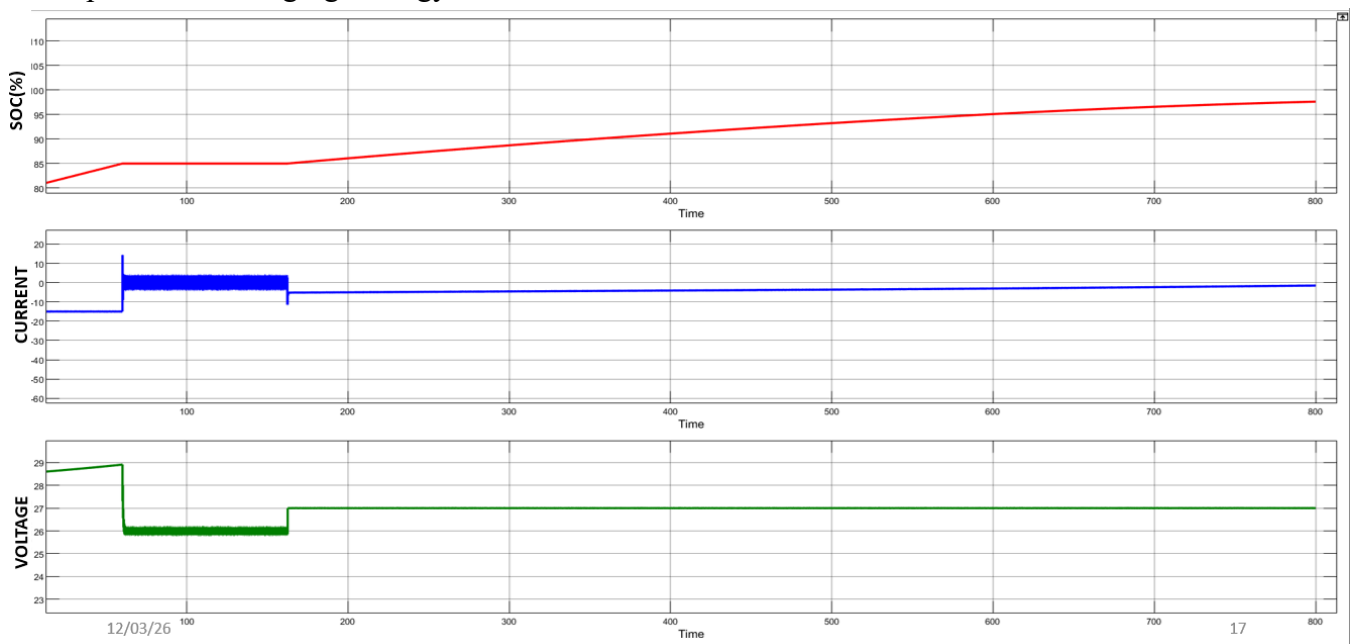


Figure 5: CC-CV charging from 80% to 100% SOC

In addition to charging performance, the accuracy of the autonomous landing system was evaluated using an Extended Kalman Filter (EKF)-based sensor fusion approach. The simulation integrates data from GPS and IMU sensors to estimate the UAV’s position and orientation in real time. The results indicate that the fusion algorithm significantly reduces measurement noise and positional error, particularly during the critical landing phase. While GPS alone exhibits fluctuations at lower altitudes, the fused output provides a stable and accurate estimate, enabling controlled descent and precise alignment with the docking station. The error convergence observed over time further demonstrates the robustness of the EKF implementation under varying conditions, including disturbances and sensor uncertainties. This confirms that the proposed sensor fusion framework is capable of ensuring reliable and repeatable autonomous landing performance. The docking station selection algorithm was also validated through simulation to assess its effectiveness in multi-UAV scenarios. The algorithm determines the optimal docking station based on parameters such as remaining battery capacity, distance to available docks, and current dock occupancy. The results show that UAVs consistently select the nearest feasible docking station while minimizing energy consumption. In scenarios involving multiple UAVs, the system dynamically allocates docking resources and avoids conflicts by prioritizing drones with lower battery levels. This dynamic allocation mechanism ensures efficient utilization of docking infrastructure and reduces waiting time, thereby enhancing overall system

productivity. The simulation confirms that the algorithm is capable of supporting scalable and coordinated fleet operations without requiring manual intervention .

A complete system-level validation was performed within a simulated environment that integrates UAV dynamics, cloud communication, and database interaction. The Gazebo-based model successfully demonstrates the full operational cycle, including battery monitoring, dock identification, navigation, landing, and charging initiation. Additionally, the cloud platform enables real-time data exchange and storage, ensuring seamless coordination between the UAV and the docking station. The successful execution of this end-to-end workflow confirms that the UNIDOCK system operates as an integrated autonomous ecosystem.

The cloud database of UNIDOCK is implemented using Supabase which provides real time monitoring and communication abilities. The database stores important information such as UAV identification, battery status and docking station availability.

id	uuid	name	text	latitude	numeric	longitude	numeric	altitude	numeric	capacity	int4	status	bool	last_updated	timestamp
27f7b17d-0917-4c51-85e7-a008c8b6bdf7		Station 9		12.971600		77.954600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
5b929893-3170-4165-971d-ad49ec804c5e		Station 7		12.971600		77.864600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
5e5b36e5-79a3-4104-8954-1cc17cc8e612		Station 5		12.971600		77.774600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
66f58595-b7f9-47e2-a45b-382bf4f22f21		Station 8		12.971600		77.909600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
675312e0-6651-4a22-aa9d-74565bcd4192		Station 1		12.971600		77.594600		NULL		2		FALSE		2025-10-03 15:45:51.182249	
69557266-d84f-4224-ad3c-1212cef6a6dd		Station 2		12.971600		77.639600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
916dfa99-f4af-4626-acf4-d33e8a5be03c		Station 4		12.971600		77.729600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
b084bc7b-6399-4912-8a3a-93fd4b4732e		Station 6		12.971600		77.819600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
b4147eff-a489-495a-9d37-cd2f81c18055		Station 3		12.971600		77.684600		NULL		2		TRUE		2025-10-03 15:34:56.217783	
fefcb5b9-5770-4a9c-9a89-167e3a1c5aa3		Station 10		12.971600		77.999600		NULL		2		TRUE		2025-10-03 15:34:56.217783	

Figure 6: Database stored in Supabase software

As shown in figure 6, the cloud system enables two-way communication between the UAV and the docking station through wireless connection. UAVs update their status in real time to the database, while docking stations retrieve scheduling information and charging profiles.

Overall, the simulation results demonstrate that the proposed system achieves stable charging characteristics, accurate landing performance, and efficient multi-UAV coordination. The integration of electrical, mechanical, and software components results in a reliable and scalable solution for autonomous UAV operation. These findings validate the feasibility of the UNIDOCK architecture and provide a strong foundation for experimental implementation and real-world deployment.

Hardware Results and Discussion

The hardware implementation of the UNIDOCK system was carried out to validate the practical feasibility of autonomous UAV docking and charging under real-world conditions. The developed prototype integrates the power supply module, DC–DC charging controller, docking interface, and control circuitry into a unified system shown in figure 7. Experimental testing was conducted to evaluate charging performance, docking reliability, and overall system stability.

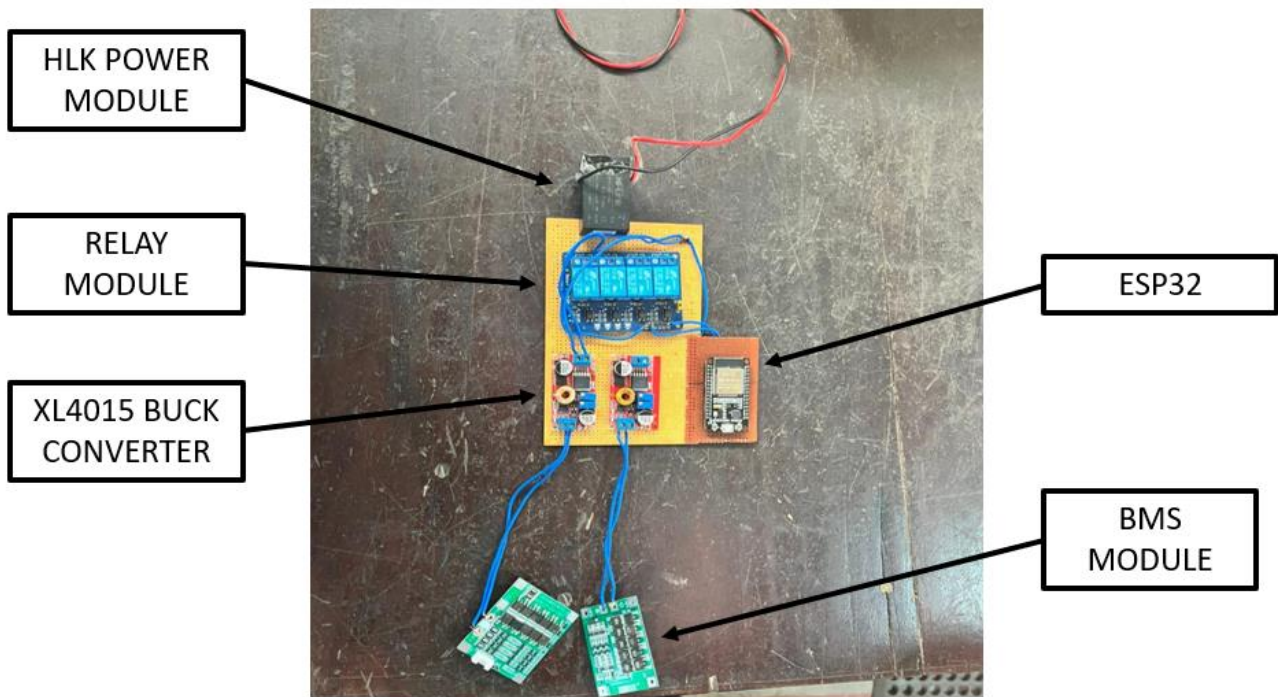


Figure 7: Hardware of the charging circuit

The charging subsystem was tested using a 4S Li-Po battery with a nominal voltage of 14.8 V and a full charge voltage of 16.8 V. The hardware results confirm that the system successfully operates in the Constant Current–Constant Voltage (CC–CV) mode as intended. During the initial charging phase, the current was maintained close to the designed value of 5 A, demonstrating stable current regulation without oscillations. As the battery voltage approached 16.8 V, the system transitioned smoothly into the constant voltage phase, during which the charging current gradually decreased. The termination of charging occurred when the current dropped to approximately 0.25 A, indicating proper implementation of safe cutoff conditions. These results closely match the simulation outcomes, validating the accuracy of the charging control design .

The performance of the power electronics module was also evaluated under continuous operation. The HLK-10M24 AC–DC converter provided a stable 24 V DC supply from the mains input, while the buck converter efficiently regulated the output to the required charging voltage. The measured output remained consistent under load conditions, with minimal voltage ripple and acceptable thermal performance. Heat generation in the converter and associated components was observed to be within safe limits, confirming that the thermal design is adequate for sustained operation.

The docking mechanism was tested to assess alignment accuracy and electrical contact reliability. The prototype of the docking station can be seen in figure 8. The spring-loaded pogo pin interface demonstrated consistent electrical connectivity even with minor misalignments during landing. The mechanical compliance of the pins allowed tolerance to positional errors, ensuring uninterrupted power transfer. Repeated docking trials showed that the system maintains stable contact without significant voltage drop or intermittent disconnection. This validates the effectiveness of the pogo pin-based design in achieving reliable charging under practical conditions .

The control system, implemented using an ESP32 microcontroller, successfully monitored charging parameters such as voltage, current, and temperature in real time. The system dynamically adjusted the charging current and ensured safe operation by enforcing limits on voltage and temperature. In cases where

abnormal conditions were simulated, such as sudden voltage fluctuations or potential overheating, the system responded appropriately by reducing or terminating the charging process. This demonstrates the robustness of the protection mechanisms integrated into the hardware.

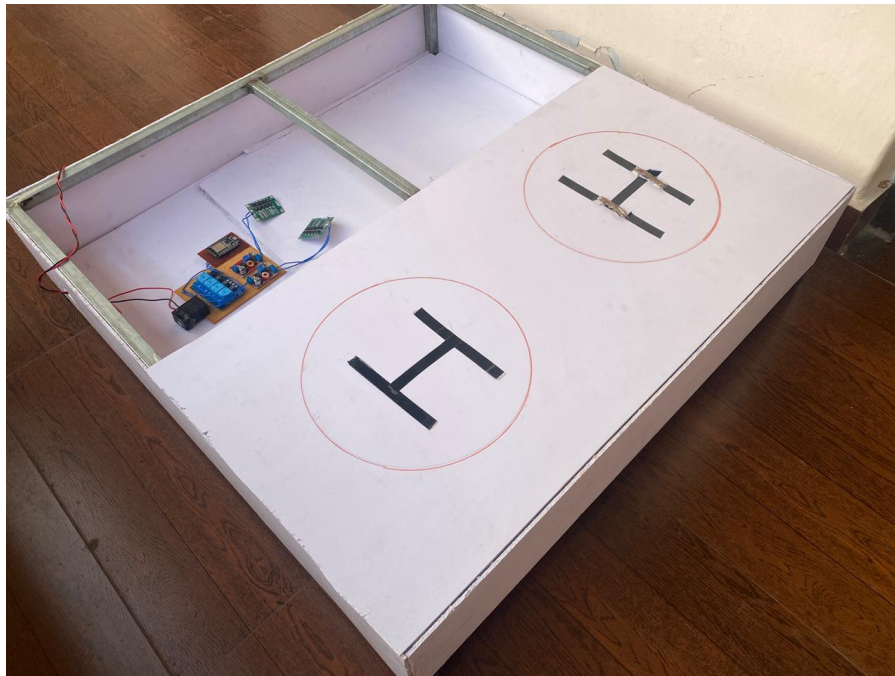


Figure 8: Prototype of the docking station

Additionally, the integration of auxiliary components such as the Battery Management System (BMS) and relay control circuit further enhanced system safety and reliability. The BMS ensured proper cell balancing and protection against overvoltage and overcurrent conditions, while the relay module provided controlled switching of the charging circuit. The combined operation of these components contributed to stable and fault-tolerant performance.

Overall, the hardware results confirm that the UNIDOCK prototype successfully achieves autonomous charging with high reliability and efficiency. The close agreement between simulation and experimental observations highlights the effectiveness of the design approach. The system demonstrates stable electrical performance, reliable docking, and robust control, making it suitable for real-world deployment in autonomous UAV applications.

Conclusion

This work presented the design, simulation, and hardware implementation of UNIDOCK, a universal autonomous charging dock for quadcopter UAVs aimed at enabling continuous and self-sustained drone operations. The system integrates autonomous navigation, precision landing, intelligent charging, and cloud-based coordination into a unified framework, addressing the critical limitation of limited UAV flight endurance due to battery constraints. The simulation studies demonstrated that the proposed system achieves stable CC–CV charging characteristics, accurate state estimation through sensor fusion, and efficient docking station selection in multi-UAV environments. These results confirmed the effectiveness of the control algorithms and system architecture in achieving reliable and optimized operation. The hardware implementation further validated these findings, showing consistent charging performance, reliable docking through pogo-pin contacts, and robust system response under real operating conditions. The close

agreement between simulated and experimental results highlights the practicality of the proposed design. The UNIDOCK system significantly reduces the need for human intervention by automating the entire charging cycle, thereby minimizing downtime and enabling persistent UAV deployment. Its modular and scalable architecture allows compatibility with different quadcopter platforms and supports expansion to multi-dock and multi-drone systems. Additionally, the integration of safety mechanisms such as battery management, thermal monitoring, and controlled charging ensures reliable long-term operation. Overall, the proposed system provides a cost-effective and efficient solution for autonomous UAV charging, particularly suited for applications such as surveillance, precision agriculture, infrastructure inspection, and disaster management. The work establishes a strong foundation for future advancements in autonomous aerial systems and contributes toward the development of fully self-sustaining drone ecosystems.

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