

AI-Controlled Hybrid Wind-Solar Charging Dock of Delivery Drones

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Abstract— The growing need for sustainable and efficient delivery drone operations calls for advanced energy management solutions. This system leverages solar and wind renewable energy to power docking stations, creating a reliable and eco-friendly charging infrastructure. To ensure uninterrupted power, dual high-capacity batteries store surplus energy, providing a buffer during periods of low renewable generation. At the heart of the system is an AI-driven discharge optimization mechanism that intelligently manages battery usage based on real-time demand forecasts and environmental conditions. By balancing charging and discharging cycles across the two batteries, the AI extends battery life, boosts system reliability, and maintains consistent energy availability for drone operations. This intelligent control reduces maintenance costs while improving overall efficiency. In essence, this hybrid renewable energy solution with AI-based battery management delivers a resilient, sustainable, and future-ready charging network for drone delivery systems. It demonstrates how combining renewable resources with advanced AI can transform autonomous logistics, enabling greener and more reliable urban delivery.

Keywords—Artificial Intelligence, Hybrid Energy System, Wind-Solar Power, Smart Charging Dock, Autonomous Delivery Drones, Renewable Energy Integration, Energy Optimization, Sustainable Logistics, Adaptive Control System.

I. INTRODUCTION

In the fast-growing sector of drone delivery services, maintaining a dependable and sustainable power supply for docking stations has become a key challenge [1]. Incorporating renewable energy sources like solar and wind provides an environmentally friendly alternative that lessens reliance on conventional power grids while boosting operational autonomy [2]. By leveraging the complementary advantages of solar panels and wind turbines, these systems can deliver clean energy continuously, adjusting to changing weather conditions to ensure docking stations remain efficiently powered[3].To optimize renewable energy use, implementing advanced energy management strategies is crucial. A dual-battery configuration, paired with AI-driven

discharge shifting, offers an efficient solution for energy storage and distribution [4]. This setup intelligently tracks energy demand and weather conditions. Combining wind-solar hybrid charging with AI-powered discharge management marks a major advancement in creating autonomous and sustainable drone infrastructure [5]. These systems ensure uninterrupted drone operations while promoting a cleaner and more resilient logistics network [6]. As drone delivery continues to expand, the adoption of smart, renewable-energy docking stations will be crucial for building efficient and eco-friendly urban mobility solutions [7].



Figure 1. Main System Goals

II. LITERATURE SURVEY

The rapid evolution of drone technology has transformed last-mile delivery systems, driving significant research into effective and sustainable docking solutions for autonomous delivery drones [7]. A key focus has been the design and optimization of docking stations that enable fast and reliable recharging, maintenance, and deployment of UAVs (Unmanned Aerial Vehicles) [8]. Various charging methods—such as wired, wireless, and solar-powered systems—have been investigated to enhance energy efficiency and operational autonomy (Smith et al., 2020; Lee & Kim, 2021) [9].Incorporating renewable energy sources like solar and wind into drone docking stations has emerged as a promising strategy for ensuring sustainable operations, particularly in remote or off-grid regions (Zhao et al., 2019) [10]. Furthermore, recent advances highlight the role of intelligent power management systems that leverage AI-driven algorithms to maximize energy utilization and extend battery

life (Chen & Patel, 2022). With the rising demand for scalable, eco-friendly drone delivery networks, ongoing studies continue to address challenges in energy harvesting, storage, and automated docking technologies to strengthen the efficiency and reliability of drone logistics infrastructure [11]. With the ongoing growth of e-commerce, logistics providers face increasing pressure to address the challenges of last-mile delivery. Drones and trucks working together to build more adaptable and effective delivery systems is one suggested remedy. This study examines and evaluates and discussed various delivery methods that combine hybrid trucks and drone. The operation of HTDDs in last mile delivery systems is investigated in this paper. First, an overview of potential drone delivery usages and how they can co-exist with other vehicles is presented to convey a sense of the operational nature and its implications. The literature review is subsequently classified based on vehicle roles, system structures, problem formulations, as well as solution methodologies. The problem under consideration is the last-mile delivery and hybrid truck-drone delivery systems (HTDDS). First, a summary of potential applications for drone delivery is provided, along with information on how they can be used with other vehicles. Most existing studies assume that customer requests are known prior to delivery operations. However, the increasing demand for instant delivery underscores the necessity of real-time optimization to support e-commerce operations more effectively. In order to mitigate performance problems a threshold was trained and fine-tuned in a simulated environment. Experimental results indicate that drone delivery Designing drones for a wide range of applications has witnessed significant progress ever since the emergence of AAVs (Autonomous Aerial Vehicles), popularly referred to as drones, and the exponential growth of the AAV industry. Advancements have occurred very rapidly, especially over the past decade and new drone use cases are being discovered all of the time. Among these, drone-based delivery services have shown considerable promise for future deployment. But there's one major hitch: This solution takes the drones' lack of range into account. To address this drawback, we present a machine learning-based approach for range extension of drones leveraging public transportation as carriers. In fact, it solves the fine-grained routing problem by Deep Reinforcement Learning (DRL) with Hybrid Pointer Networks (HPNs). The main goal is to reduce the overall drone flying distance while taking scheduled itineraries and bus capacity limitations into consideration. Crucially, once the bus roof capacity is fully utilized, the model ensures that no more drones are assigned.

Through the use of HPNs, the model efficiently captures the intricate interactions among drones, buses, and delivery points, thereby simplifying optimization and achieving state-of-the-art results. To improve performance, the system was trained and adjusted in a simulated setting. Results from experiments show that including drone delivery with bus services not only reduces overall energy consumption but also significantly improves the system's ability to meet delivery demands.

III. PROPOSED SYSTEM

The proposed solution integrates the use of renewable energy sources like solar panels and wind generators to supply a drone docking station, equipped with two batteries, for sustainable electricity. Energy collected from these sources is controlled by the intelligent battery System Management (BMS) process and AI calibrated charging/discharging that its module adapted for. The AI-driven discharge management mechanism continuously monitors battery health, load demands, and environmental conditions to determine the most efficient sequence of battery use, thereby extending battery lifespan and ensuring an uninterrupted power supply. During periods of surplus energy generation, excess power is stored across both batteries, while during drone operations, the system dynamically alternates between batteries based on real-time data, load conditions, and predictive analytics. This intelligent energy management approach not only improves system reliability but also maximizes the utilization of renewable resources, significantly reducing reliance on conventional power grids. Arduino: Making Electronics Easy for Beginners and Experts Alike You don't have to be a programmer, with easy-to-implement hardware and software. If you give an Arduino a read-in (like light from a sensor, a button press or even a tweet) it can channel that into some sort of output (like flicking on an LED, spinning a motor or sharing data online). The Arduino software (IDE), which is based on Processing, and the Arduino programming language, which is based on Wiring, are used to program the board by transmitting commands to its microcontroller. Arduino has developed into the central component of innumerable projects over the years, spanning from commonplace gadgets to cutting-edge scientific tools.

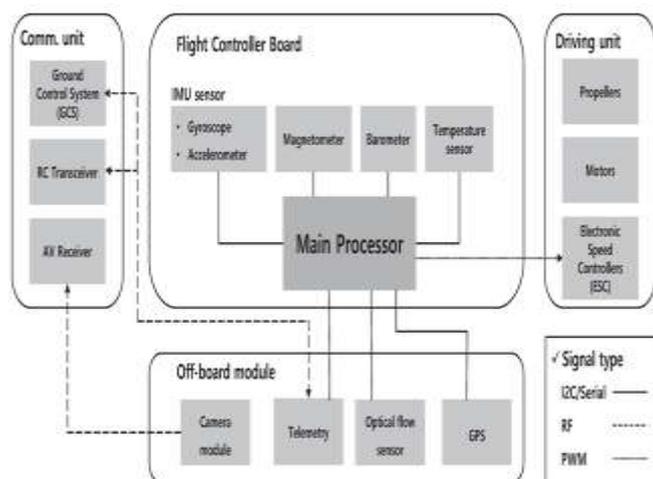


Figure 2. Exiting Model Diagram

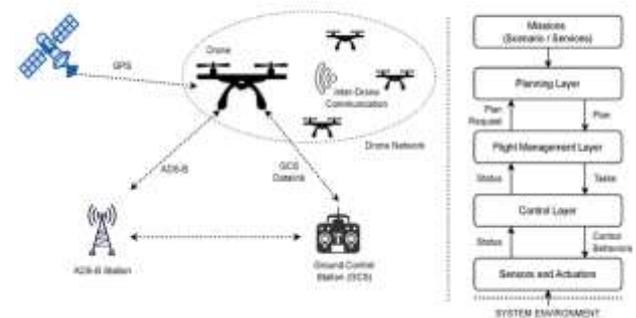


Figure 3. System Architecture

The Arduino was initially created is a simple prototype tool for students with no prior electronics or programming experience at the Interaction Design Institute. As the platform expanded to a broader community, Arduino boards evolved to meet diverse needs and challenges—growing transitioning from simple 8-bit boards such as wearables, embedded systems, 3D

printers and Internet of Things devices. Since every Arduino board is completely open-source, clients are free to make their own boards as well as modify and adapt them for their specific needs. Additionally, the program is open source and continues to be enhanced by its global developer community. Embedded C is nothing but a set of language extensions for the C programming language, introduced by the C Standards Committee to address commonality issues that exists between C implementations in embedded systems. Nonstandard extensions are commonly employed in embedded C programming to facilitate advanced microprocessor features such as multiple memory banks, fixed-point arithmetic and low-rent input/output.

IV. RESULTS AND DISCUSSION

The experimental setup of the wind-solar charging system with dual-battery AI-enabled discharge shifting was designed to evaluate both efficiency and reliability in renewable energy harvesting for drone docking stations. The system aimed to demonstrate how intelligent power management could ensure uninterrupted energy supply while reducing dependence on conventional grids. To harness solar energy effectively, photovoltaic panels were mounted on adjustable frames, allowing them to be tilted for optimal sunlight exposure throughout the day. In parallel, small-scale wind turbines were installed in an open area to capture wind energy. The combined power output from these renewable sources was directed through individual charge controllers before being stored in two high-capacity lithium-ion batteries, establishing a dual-storage configuration. At the core of the system was an AI-enabled microcontroller programmed to monitor battery status, predict energy demand based on drone traffic patterns, and execute intelligent discharge shifting between the two batteries. This process balanced the load, prevented overuse of a single unit, and ultimately prolonged battery lifespan. By learning from real-time operational data, the AI system continuously refined its decision-making accuracy.

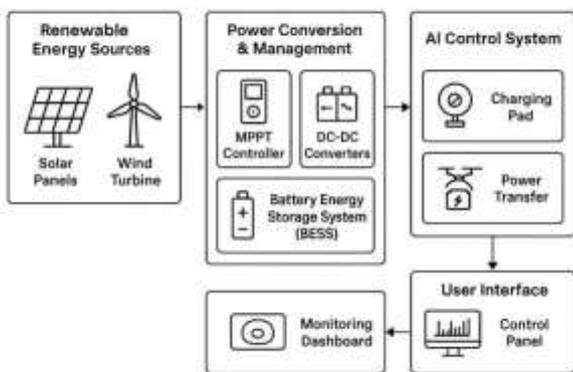


Figure 4. Energy Sources

To support efficient monitoring and evaluation, the setup was equipped with a network of sensors measuring voltage, current, wind speed, and solar irradiance. These sensors enabled real-time data acquisition and provided valuable insights into both environmental conditions and system performance. The integration of sensors ensured that every

aspect of the charging process, from energy input to battery discharge, was closely tracked. The entire system was housed in a controlled environment to simulate realistic operational scenarios, with its output connected to a prototype drone charging dock. Data collected during testing were analyzed to assess the efficiency of renewable energy harvesting, the reliability of the AI-driven power management system, and the overall stability of the energy supply under fluctuating environmental conditions. The findings highlight the system’s potential to enhance drone docking infrastructure through sustainable and intelligent energy solutions.

V. CONCLUSION

The integration of wind and solar energy to power drone docking stations offers a sustainable and innovative approach to supporting the growing demands of autonomous delivery systems. By harnessing these renewable sources, drone operations can rely less on conventional electricity, creating a cleaner and greener logistical framework. Incorporating dual-battery setups enhances the overall reliability of these docking stations. With two batteries working in tandem, energy storage and availability are optimized, ensuring drones remain operational even during periods of low renewable energy generation. A smart AI-based discharge management system further improves energy efficiency. By intelligently shifting power between batteries based on demand and availability, the system prolongs battery lifespan and reduces unnecessary wear, maintaining consistent performance over time. Hybrid renewable energy model offers more than just reliability; it also reduces dependence on traditional power grids. By generating energy on-site from solar panels and wind turbines, docking stations can operate independently, cutting energy costs and minimizing their carbon footprint. Intelligent control mechanisms allow for the precise allocation of energy, ensuring optimal utilization across all components of the docking station. This adaptability is particularly valuable in fluctuating environmental conditions, such as changes in sunlight or wind intensity, keeping operations smooth and uninterrupted.

Overall, combining renewable energy sources, dual-battery systems, and AI-driven control creates a robust and sustainable solution for drone logistics. This approach not only enhances operational efficiency but also fosters environmentally responsible practices, making drone delivery infrastructure more reliable, cost-effective, and future-ready.

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