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Research on Optimizing Campus Takeout Delivery System under the Background of Low-altitude Economy: Based on the Transformation of Takeout Cabinets and Optimization of Low-altitude Delivery Processes Using Drone Tracks

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ABSTRACT

The rapid development of e-commerce and the food delivery industry is driving the transformation of delivery services towards efficiency and convenience. Traditional manual delivery has high costs and limited efficiency, especially during peak hours and adverse weather conditions. Drone delivery has become a research hotspot due to its efficient and flexible advantages, but its precise docking with takeaway cabinets is a key challenge. This study focuses on the optimization of campus food delivery systems under the low altitude economy. Through the transformation of food delivery cabinets and innovation in drone rail delivery processes, an efficient, stable, and secure system is constructed to meet consumers' demand for fast delivery.

KEYWORDS

Low-altitude economy; Campus food delivery; Drone delivery; Aerial track; Intelligent food delivery cabinet

1 Introduction

With the rapid development of e-commerce and the food delivery industry, consumers' demand for delivery efficiency and convenience is increasing. Traditional food delivery methods mainly rely on manual labor, which has problems such as high labor costs, significant impact of traffic conditions on delivery efficiency, and difficulty in ensuring timely delivery, especially during peak hours or adverse weather conditions. In this context, drone delivery, as an emerging technology, has gradually become a research hotspot in the field of logistics and distribution due to its advantages of high efficiency, flexibility, and not limited by ground transportation. Drone delivery can not only significantly improve delivery efficiency and shorten user waiting time, but also effectively reduce labor costs, especially in remote areas or areas with inconvenient transportation, where its advantages are more obvious. However, the widespread application of drone delivery still faces many challenges, among which how to achieve precise docking between drones and receiving terminals (such as takeaway cabinets) is a key link to ensure the safe and efficient transfer of goods.

2 Research Status at Home and Abroad

2.1 Current Research Status of UnmAnned Aerial Vehicle Technology

In recent years, drone technology has made significant progress in navigation, positioning, obstacle avoidance, and other areas. Meituan's fourth generation unmanned aerial vehicle has obtained the country's first low altitude logistics operation qualification certificate and started normal commercial operation. GPS RTK technology has achieved centimeter level outdoor flight navigation, providing a foundation for precise drone flight. At the same time, the fusion application of multiple sensors such as visual recognition systems, LiDAR, IMU (Inertial Measurement Unit), etc. This further enhances the flight stability and autonomy of drones in complex environments. For example, visual recognition technology based on YOLOv8 algorithm can accurately recognize ground markings and achieve precise landing of drones.

2.2 Research Status of Takeout Cabinet Technology

As the "last mile" solution for food delivery, takeaway cabinets have been widely used. Traditional takeaway cabinets mainly achieve the functions of storing and retrieving food, but with the development of the Internet of Things and automation technology, intelligent and mechanized upgrades have become a trend. By integrating communication modules, automated transmission systems, etc., takeaway cabinets can collaborate with cloud based dispatch centers, drones, and other equipment to improve delivery efficiency.

2.3 Research Status of Docking Technology Between Drones and Ttakeout Cabinets

Although both drone and takeaway cabinet technologies have made progress, combining the two to achieve precise docking between drones and takeaway cabinets is still a relatively emerging research field. At present, there have been some studies and practices both domestically and internationally exploring the technical route and system architecture of unmanned aerial vehicle landing for food delivery cabinets. For example, by designing dedicated connecting channels, mechanical interfaces, etc. the physical connection between drones and takeaway cabinets can be achieved; By optimizing communication protocols, data exchange formats, etc., ensure the stability, real-time, and security of information flow within the system. However, in practical applications, there are still problems such as insufficient docking accuracy and the need to improve system stability.

3 Research Content and Methodology

3.1 Research Content

This article focuses on the key technologies of drone docking with takeaway cabinets, aiming to build an efficient, stable, and secure delivery system. The specific research covers preliminary preparation and system design, determining the overall architecture, communication protocols, etc; Implementation of unmanned aerial vehicle technology; Technical transformation of food delivery cabinets; And system collaboration and operation support, simulating and optimizing docking processes to ensure smooth operation.

3.2 Research Methodology

Literature review method: By reviewing relevant literature, this study aims to understand the current research status and development trends of unmanned aerial vehicles, food delivery cabinets, and their docking technologies, providing theoretical support for this research. System design method: Design the overall system architecture of "drone delivery cabinet cloud dispatch center", clarify the communication protocol and data exchange format between each node, and ensure the stability, real-time, and security of information flow within the system. Case analysis method: Analyze actual cases of unmanned aerial vehicles and food delivery cabinets docking at home and abroad, summarize experiences and lessons learned, and provide practical references for this study.

4 Retrofitting Takeout Cabinets and Optimizing Low-altitude Drone Delivery Processes Along Designated Tracks

4.1 Process Diagram of Drone Docking with Takeaway Cabinets

The technical roadmap for unmanned aerial vehicle docking with food delivery cabinets can be divided into four core stages: preliminary preparation and infrastructure construction, implementation of unmanned aerial vehicle technology, transformation of food delivery cabinet technology, and system collaboration and operation and maintenance support.

4.1.1 Preliminary Preparation and Infrastructure Construction

Focus on environmental assessment, scheme design, and standard formulation, design the architecture of "drone delivery cabinet cloud dispatch center", determine the communication protocol (such as 4G/5G and Wi Fi 6) and data exchange format between nodes, and ensure stable, real-time, and secure information flow.

4.1.2 Implementation of Unmanned Aerial Vehicle Technology

Using GPS RTK to achieve centimeter level outdoor navigation, switching the visual recognition system when approaching the takeaway cabinet, Use cameras to recognize guidance signs and achieve millimeter level alignment. Combining multi-sensor data such as LiDAR and IMUTo deal with GPS signal obstruction areas and improve flight stability. Design mechanical interfaces to achieve physical connection and cargo hold transfer between drones and takeaway cabinets.

4.1.3 Technical Transformation of Takeaway Cabinet End

Establish a dedicated connecting channelEquipped with electric waterproof cabin doors and integrated automation systems inside the cabinets to facilitate cargo transportation. Add unmanned aerial vehicle communication and docking control modules to make the food delivery cabinet an intelligent node for active collaboration.

4.1.4 System Collaboration and Operation and Maintenance Support

Simulate and optimize the docking process to ensure seamless connection between each link. Deploy charging equipment next to the food delivery cabinet to provide endurance support for drones, ensuring the continuous, stable, and safe operation of the system.

4.2 Pre established Route Map for Drone Flight on Campus

4.2.1 Track Master: Professional Route Planning Software

Waypoint Master is an industrial level planning tool, Capable of overcoming complex terrain and route design challenges, supporting multi drone operation path presetting and obstacle avoidance optimization. It offers 13 types of flight routes, suitable for various scenarios; Built in national high-definition satellite base map and terrain data, capable of loading campus maps, annotating building coordinates, generating KML files, and importing them into drone remote control for use. Support mainstream DJI models and multi lens loads, synchronously plan flight parameters. Outstanding advantages, comprehensive functions, easy planning, capable of handling complex surveying and mapping, ensuring safety, and can also preprocess POS information for some camera photos.

4.2.2 Machine Collaboration and Collision Avoidance Technology

The distributed model predictive control (DMPC) collaborative framework focuses on multi drone off peak collision avoidance and provides a dynamic environmental conflict resolution method. It adopts a "local decision-making+global collaboration" mechanism, combined with improved ant colony algorithm to optimize the path, reduce multi machine collisions, and also comes with MATLAB simulation code framework. The Dream Optimization Algorithm (DOA) is used for multi-objective path planning, innovating the "memory+forget" mechanism, detailing the three-stage process, and providing a method for setting obstacle parameters. In addition, the principle of drone avoidance has been clarified, Determine the priority order based on different situations and orientations such as straight ahead, rotor, etc.

4.2.3 Practical Guide and Scenario Plan

Route planning is a prerequisite for the execution of unmanned aerial vehicle missions, which affects operational efficiency and safety. It must follow the principles of systematicity, safety, and economy. The actual planning process is divided into four stages: data collection and integration of various information; Preliminary design utilizes software to draw basic flight routes; Fine optimization is adjusted through algorithms; Develop contingency plans and prepare backup plans. In terms of key technical points in route design, hybrid path planning schemes are often used, vertical space should be reserved for altitude control, obstacle avoidance technology based on LiDAR affects flight safety, and data processing has four stages.

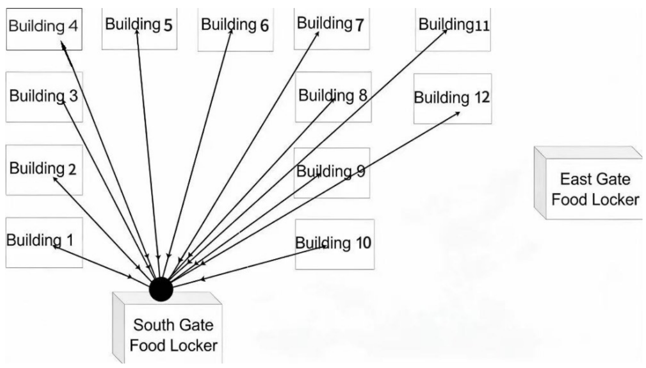


Figure 1 Drone Transfer Flow Chart

4.3 Process Diagram for Drone Docking with Dormitory Rooftop Connection Platform

The docking process between drones and the rooftop floor connection platform is divided into five stages, with the core revolving around multi device collaboration to achieve precise and safe food transportation.

The first stage is device pre collaboration and readiness. After receiving the order, the cloud system synchronously issues instructions to the rooftop connection platform control and drone dispatch terminal. Wake up the target floor track unit from the main control of the docking platform, deploy the protective cabin door, activate the positioning beacon, and preheat the transmission motor; The drone dispatch terminal pushes the coordinates and task priorities of the rooftop connection platform to the drone.

The second stage is precise positioning and identity verification. The drone first uses GPS coarse positioning, and then switches to the Mi Fly positioning system, combining multiple data to achieve centimeter level precision hovering. At the same time, the visual recognition camera of the docking platform captures the drone identification, verifies the matching, and the track unit sends a "allow docking" signal to ensure safe and accurate docking.

The third stage is dynamic docking and physical locking. After obtaining authorization, the docking platform extends to the docking hatch, and its attitude sensor sends data to the drone. The drone adjusts its attitude to complete the physical assembly. The hatch rotating claw component triggers locking to resist external interference and ensure stable docking.

The fourth stage is meal transportation and system linkage. After stable docking, the drone pushes the food to the transfer tray. After receiving feedback from the tray sensor, the control panel starts the transfer system to transport the food to the pickup area.

The fifth stage is task closure and state reset. After detecting the "food leaving the cabin", the docking hatch is retracted and closed, and the "docking completion" is reported; Release the lock of the drone and return, transmitting mission data back; Summarize device status in the cloud and notify users of meal delivery.

This process achieves a fully automated closed-loop from cloud commands to user meal retrieval. The system is centered around the cloud and utilizes an efficient device pre collaboration mechanism to synchronously wake up the track and drone system. In the core positioning and verification stage, precise positioning and visual recognition are integrated to provide a dual guarantee for secure docking. The subsequent dynamic docking and locking process demonstrated the precise attitude coordination and rigid connection capability between the drone and the track mechanism. Meals are transported through cross system linkage and accurately delivered to the target floor via a three-dimensional rail network. Ultimately, all devices automatically reset, status data is transmitted back to the cloud, and users are notified, forming a self-contained, efficient, and reliable unmanned delivery service loop.

4.4 The Preset Route Map for Delivering the Dormitory Rooftop Track to the Dormitory Entrance

4.4.1 Conveyor Belt Sorting and Transportation

After the drone lands on the delivery platform, the automatic unloading device on the upper level of the delivery cabinet begins to operate. This device can quickly and stably unload the takeout carried by the drone and place it on the conveyor belt. As the core link of intelligent sorting and conveying, the conveyor belt adopts advanced sensors and intelligent control systems. After the takeout is placed on the conveyor belt, the sensor will immediately recognize the relevant information on the takeout, such as the order number, dormitory number, etc., and transmit this information to the central control system. The central control system intelligently sorts the takeout on the conveyor belt based on the received information. By adjusting the running speed and direction of the conveyor belt, the takeaway food from different dormitories is guided to the corresponding conveyor channels. During the sorting process, the conveyor belt is also equipped with multiple detection points for real-time monitoring of the status of takeaway food, ensuring that there will be no dropping, damage, or other situations during the transportation process. After intelligent sorting, the takeaway is transported to the end of the conveyor belt, waiting for the robotic arm to grab it.

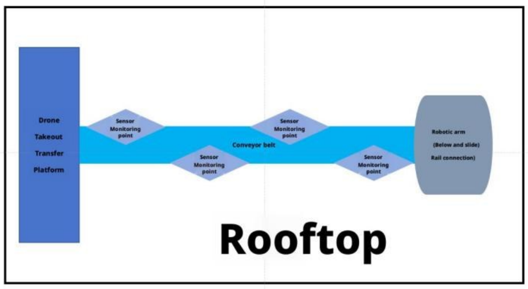


Figure 2 Transmit the Preset Route Map

4.4.2 Gravity Sliding Rail Sliding and U-shaped Track Transmission in the Corridor

The mechanical arm at the end of the conveyor belt is a key equipment connecting the rooftop and corridor delivery. It can accurately grasp the takeout at the designated position at the end of the conveyor belt according to the instructions of the central control system, and then place it on the gravity slide rail. The gravity slide rail utilizes the principle of gravity, with the track tilted, allowing food delivery to slide down by its own gravity. Its special material and surface treatment process reduce friction, and it is also equipped with a buffering device to ensure smooth and safe sliding. After the takeout descends to the hallway, it enters the U-shaped track transmission stage inside the hallway. The sliding rails in the corridor are distributed in a U-shape to form a circular track, making full use of space and ensuring continuous and efficient delivery. The system is equipped with an electrically driven robotic arm that moves cyclically along the track. Its design is compact and flexible, allowing it to move freely in narrow spaces. It is also equipped with advanced positioning and navigation systems that can accurately identify the position. During movement, the robotic arm communicates in real-time with the central control system to obtain information on food delivery and target dormitories. Based on this, it automatically adjusts its speed and direction to quickly and accurately reach the designated location, preparing for delivery at the dormitory entrance.

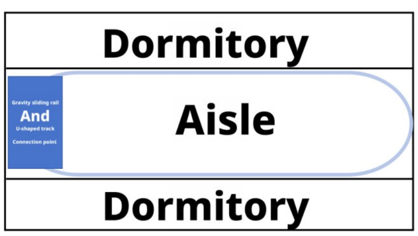
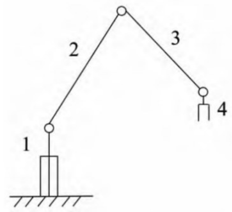


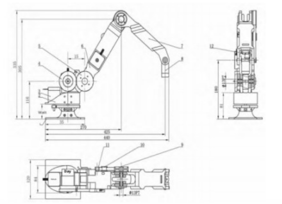
Figure 3 Track Transmission in the Corridor

4.4.3 Delivery of items Placed on the External Shelf Outside the Bedroom

When the robotic armmoves along the U-shaped track to the designated area at the entrance of the designated dormitory (the shelf on the wall between every two doors), it enters the final delivery stage. This designated area has been carefully planned to ensure the accuracy and convenience of delivery. The design of the storage rack is also very user-friendly, with sufficient load-bearing capacity and stability to safely place takeout. After reaching the designated position, the robotic arm will accurately identify the corresponding storage rack outside the dormitory based on the information on the takeaway. Then, the robotic arm smoothly drops the takeout onto the shelf through its precise operating device. During the delivery process, the robotic arm will control the force and angle of the delivery to ensure that the takeout will not fall or be damaged due to improper delivery. After completing the delivery, the robotic arm will provide feedback to the central control system on the successful delivery, so that the system can arrange and record subsequent tasks.



1. Base; 2. Big arm; 3. Lower arm; 4. End effector.



1. Lower base; 2. Upper base; 3.42 stepper motor; 4. Main arm drive gear; 5. Arm driven teeth Wheel; 6. Big arm; 7. Lower arm; 8. End effector; 9. Arm driven wheel; 10. Tensioning wheel; 11. Arm active pulley; 12. SG90 servo motor.

Figure4 Schematic Diagram of Parcel Delivery to the External Shelf of the Dormitory

5 Conclusions and Prospects

5.1 Summary of Research Results

This article successfully constructed an efficient, stable, and safe delivery system for unmanned aerial vehicle docking with takeaway cabinets, achieving a full process research from system architecture design to practical application. By designing the overall architecture of "drone delivery cabinet cloud dispatch center", using GPS RTK navigation, visual recognition, and multi-sensor fusion technology, the drone has centimeter level docking accuracy; Intelligent transformation of external vending cabinets, integrating automated transmission systems and communication modules to form active collaborative intelligent nodes; By combining professional route planning software with multi aircraft collaborative algorithms, the obstacle avoidance optimization problem in complex terrain has been solved, providing a complete technical solution for practical application scenarios.

5.2 Shortcomings

Despite breakthroughs in technological implementation, there are still challenges in terms of environmental adaptability and large-scale application. The stability of the current system in extreme weather (such as strong wind, rainstorm) or complex electromagnetic environment has not been fully verified, and the efficiency of multi machine collaboration still needs to be optimized in large-scale deployment; In addition, the cost-benefit analysis is not thorough enough, including the economic evaluation of equipment procurement, operation and maintenance, and renovation costs, as well as the feasibility study of market promotion, which still needs to be improved, limiting the conversion efficiency of technology from laboratory to commercial implementation.

5.3 Future Prospects

In response to existing shortcomings, future research will focus on three aspects: firstly, improving environmental adaptability, developing anti-interference algorithms and adaptive control technologies, and enhancing the reliability of the system under extreme conditions; The second is to optimize the multi machine collaboration strategy, combined with artificial intelligence to achieve dynamic path planning and resource scheduling, reduce collision risks, and improve delivery efficiency; The third is to deepen the analysis of costs and benefits, evaluate the economy in different scenarios, and expand the technology to express delivery, medical distribution, emergency rescue and other fields, promoting the diversification and large-scale application of drone docking technology.

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