Design and Implementation of Autonomous Takeoff and Landing UAV System for USV Platform

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***Abstract*—In order to realize the autonomous takeoff and landing function of the unmanned aerial vehicle (UAV) on the unmanned surface vehicle (USV) platform to improve the operation capability of the UAV in wide waters. In this paper, a phased takeoff and landing method is proposed and a corresponding hardware system is designed. The system is mainly an UAV system and an USV platform system.The UAV system designed in this paper is divided into a communication control part and a sensor part. The communication control part contains flight control board, take-off and landing harpoon device and wireless digital transmission. The sensor part contains infrared thermal imaging module and non-differential global positioning system (GPS), etc.The equipped infrared thermal imaging sensor is used as a precise position data feedback when it is closer to the USV platform. It uses visual processing to accurately identify the location of the positive temperature coefficient PTC heat source in the center of the USV and feeds it back to the UAV.The non-differential GPS is used for position data feedback at longer distances. The landing harpoon device is used to secure the UAV to the landing net to prevent the small sway of the USV platform from causing the UAV to tip over.The USV system is equipped with a landing net, a PTC heat source, and a 4G communication module and a 2.4G communication module. Finally, the experimental verification of the autonomous takeoff and landing system in this paper was conducted.The designed system can realize the autonomous takeoff and landing function of the UAV on the USV platform. The landing can be completed when the USV platform is moving at 20cm/s and its attitude angle wobble is less than 10 degrees.**

Keywords*—*UAV, USV, autonomous takeoff and landing, infrared thermal imaging, tracking

I. INTRODUCTION

The importance of UAV in modern aviation is increasing day by day, and they are increasingly favored by navies as the ideal weapon for future unmanned operations due to their excellent maneuverability, low cost, and low takeoff and landing requirements to perform reconnaissance and strike missions autonomously, and to effectively avoid casualties [1-2]. However, the flight time of UAV is limited by the battery energy, and they cannot perform long-duration missions. UAV performing reconnaissance missions in wide waters need to take off from the shore, fly to the designated area for operations, and reserve the power required for return on the way, which will lead to a significant reduction in the effective operating time of UAV and make it difficult to perform long-duration operational missions. In this paper, we design an autonomous takeoff and landing system for UAV based on an USV platform, using the advantage of the long endurance of the USV to form a complementary advantage with the UAV, transporting the UAV to the designated area by means of the USV carrying the UAV, which then performs autonomous takeoff and landing using the USV as the takeoff and landing platform, so that the working time of the UAV in the air can be increased and the operational capacity can be effectively improved [3]. The key of this technology lies in how the UAV completes autonomous takeoff and landing on the USV platform.

Many scholars at home and abroad have conducted research on the problem of autonomous take-off and landing of UAV. Wang et al [4] designed a set of landing device for the landing of UAV on ground vehicle, which was used to fix the UAV on the ground vehicle to prevent the UAV from capsizing and falling into the water due to the violent rocking of the USV. However, the structure of its designed landing device is more complex and not easy to use on small UAV, so we simplified its landing device under the premise of meeting the demand for small UAV. Liu et al [5], on the other hand, designed a phased takeoff and landing strategy for the autonomous takeoff and landing of unmanned helicopters, and designed an autonomous takeoff and landing system on board unmanned helicopters. Their research focuses on the takeoff and landing strategy of unmanned helicopters and their landing requires a larger landing platform. The IPAC team at Shanghai Jiao Tong University researched and designed an unmanned helicopter to achieve autonomous water precision landing through visible light vision guidance. However, the visible light vision guidance method they used can lead to a reduced recognition rate in the case of strong sunlight, thus making the UAV unable to land.

In recent years, although many scholars have proposed many solutions for the autonomous takeoff and landing of UAV, there is no good solution to this problem due to the complexity of the environment and the cost. To address these problems, this system uses a combined positioning method of non-differential GPS and infrared thermal imaging module and a phased autonomous takeoff and landing strategy [6], where non-differential GPS has low cost and average

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positioning accuracy for rough positioning, while the infrared thermal imaging module uses image processing methods to accurately identify the location of the heat source at close range by installing a PTC heat source on the USV platform, thus providing the UAV with landing by providing precise position information. The phased takeoff and landing strategy provides a decision method for the autonomous takeoff and landing of the UAV and improves the autonomous decision making capability of the UAV.

II. THEORY AND MTHODS

A. *Infrared Thermal Imaging Module Positioning System*

The key to the autonomous takeoff and landing of UAV lies in the acquisition of accurate position information, and the methods used on UAV to acquire position information include differential GPS, non-differential GPS, and visual recognition [7].

Differential GPS positioning accuracy can reach centimeter level, which is an ideal positioning means for autonomous takeoff and landing of UAV, but the cost is high and a reference station needs to be established. If only relying on differential GPS for autonomous takeoff and landing, the UAV will not be able to operate in areas without reference station coverage, making its working range restricted.

Non-differential GPS positioning cost is low, and it can be used in outdoor places with satellite signal coverage, but the positioning accuracy is only 2.5 meters, so it is difficult to achieve autonomous takeoff and landing only by non-differential GPS, and it needs to be used in combination with other positioning methods.

Visual recognition is a more used positioning method for UAV [8-10], relying on visible light cameras and image processing algorithms, which can accurately obtain location information, visible light vision positioning accuracy mainly and sunlight visible light vision, because UAV often work in outdoor environments, the sunlight is strong, which can lead to a reduction in visible light vision recognition rate. Therefore, infrared thermal imaging vision is used instead of visible vision, infrared thermal imaging mainly identifies the temperature of the target, which is less affected by sunlight and can effectively identify the heat source in the center of the USV platform, and the recognition rate is high, and then the relative distance information between the USV and the drone can be obtained through image processing and fed back to the drone, and the drone corrects the horizontal offset position with the USV through position control, so that The UAV is always kept above the vertical of the USV platform.

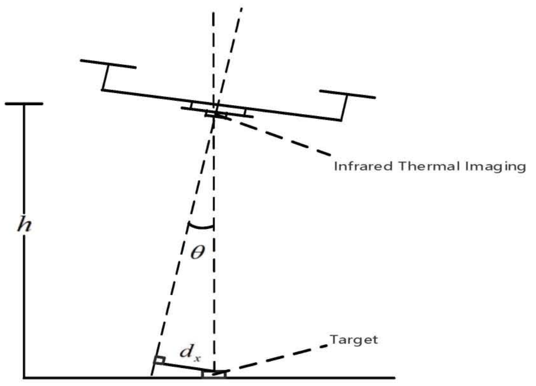

Fig. 1. Effect of UAV pitch changes on measurements

The infrared thermal imaging module mounted on the UAV is susceptible to the influence of the UAV attitude change resulting in the deviation of the obtained position data, which needs to be corrected for the position information obtained. Fig.1 shows the position error of the infrared thermal imaging module due to the UAV pitch change.

From the relationship between height and angle in the figure, the formula for calculating the correction amount can be derived through simple mathematical reasoning.

$$\begin{aligned} d_x &= h\sin\theta \\ d_y &= h\sin\varphi \end{aligned} \tag{1}$$

where d_x, d_y is the correction quantity in x-direction and y-direction respectively, h is the height value of the UAV from the USV platform, θ , φ is the pitch and roll angle of the UAV respectively.

After the correction amount is obtained, the output value of the thermal imaging module is added to the correction amount to obtain the angularly corrected position information. However, since the data output of the thermal imaging module is zero when the infrared heat source target is not found, the correction amount is only corrected when the infrared heat source target is found.

B. *Phased Autonomous Landing Strategy*

The process of landing the UAV on the USV platform adopts a segmented landing strategy. In the first stage, the UAV will raise its vertical height and keep it at 10 meters, while acquiring the GPS position data of the USV in real time and subtracting it from its own GPS position data to get the position deviation input to the position controller, and the UAV will gradually approach the vertical top of the USV platform. When the UAV is less than 1 meter from the horizontal distance of the unmanned ship, enter the second stage.

In the second phase, the UAV will maintain the position control adopted in the previous phase while descending at a uniform speed of 30cm/s. At this time, the main controller of the USV platform controls the relay to turn on, so that the PTC module is energized and starts heating. When the UAV height is reduced to 6m, it will temporarily keep 6 m, while the USV platform detects the temperature of the PTC heat source through the thermocouple temperature sensor, when the temperature reaches 200 degrees Celsius, the USV platform sends a notification to the UAV, The drone receives a notification and turns on the thermal imaging, at which point the input for position feedback switches from GPS to thermal imaging module data. The position control will control the UAV to the position directly above the center of the landing net, and the UAV will descend at a speed of 20cm/s. When the vertical height of the UAV is 0.3 meters from the landing net, it will temporarily maintain the height, while the USV platform will judge its own attitude angle change in real time, when the attitude angle change is less than 10 degrees and lasts for more than five seconds, the USV platform sends a safe landing command to the UAV, at which time the UAV will adjust its descent speed to 60cm/s and immediately turn off the motor output when the UAV touches the landing net. Fig. 2 illustrates the autonomous landing process with a flow chart.

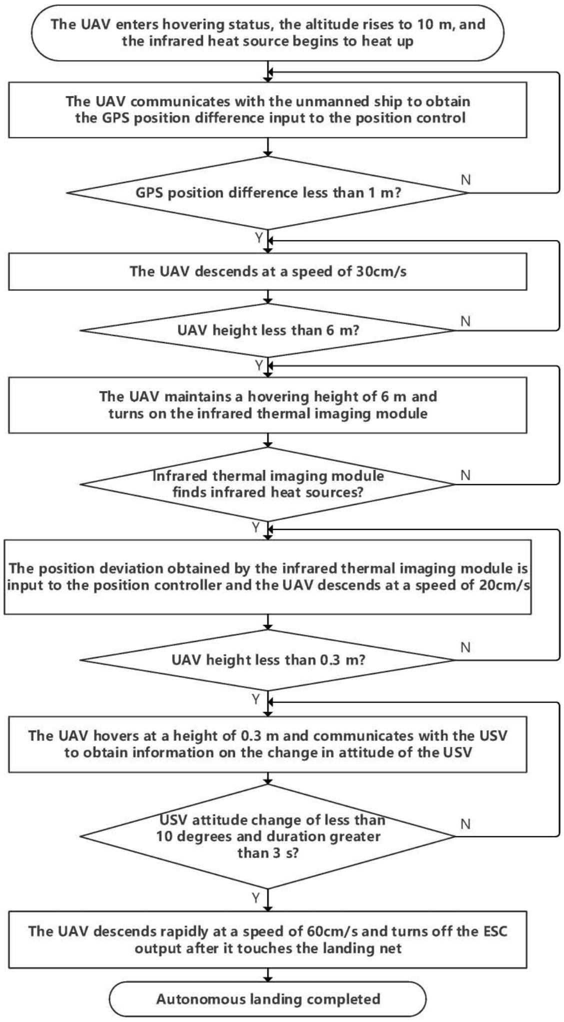

Fig. 2. Autonomous landing flow chart

III. Design and Implemention

The autonomous takeoff and landing UAV system for USV platform is composed of two parts: UAV system and USV platform system. The USV constitutes a movable landing platform, the UAV as a reconnaissance device takes off and lands on the USV, and sends the detected data information to the USV through the wireless data transmission module during the flight, and the USV integrates the data and sends the data to the upper computer by the 4G module.

A. UAV System

The UAV system consists of a flight control subsystem, an infrared thermal imaging subsystem, a wireless communication system and an energy power system. The flight control subsystem controls the attitude, speed and position of the UAV, and executes the corresponding takeoff and landing strategy by judging the infrared thermal imaging data, the status information of the UAV and the USV and making autonomous decisions during the takeoff and landing of the UAV. The infrared thermal imaging subsystem provides the imaging data of the heat source in the center of the UAV and calculates the horizontal offset distance between the current UAV and the center of the UAV in real time through feature point identification and data processing. The wireless communication system is responsible for the information interaction between the UAV and the USV. The energy power system provides the power required for the UAV to fly.

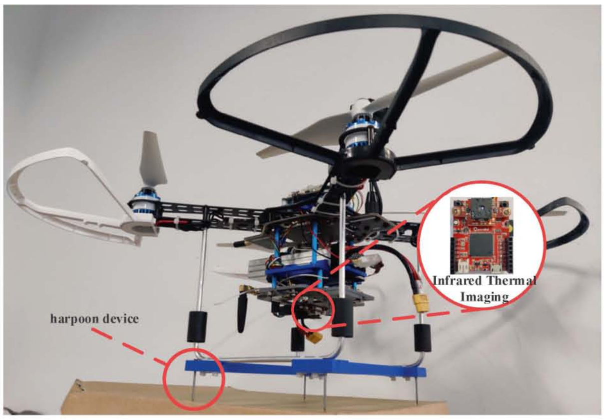

Fig. 3. UAV hardware

In order to prevent the UAV from slipping when the USV platform is shaking, a harpoon device for fixing the UAV with the landing net is designed, which can keep the UAV from slipping off the USV platform when the tilt angle of the UAV changes no more than 10 degrees, and the device can also ensure that it can land safely when the UAV is shaking at a small angle, reducing the requirements for the stability of the landing platform.

B. USV Platform System

The USV platform system consists of landing net, USV, power system, energy management system, USV control system, infrared heat emitter and its temperature measurement system and 4G communication module. As shown in Fig. 4. The landing net is made of wire mesh and wooden frame, the net surface area is 80cm square and the height is 18cm. the hull length of the unmanned boat is 101×47cm and the height is 7cm. The power system consists of two sets of turbojet thrusters and their ESCs to provide sufficient power for the USV landing and takeoff platform. The infrared heat source is installed in the center of the landing net to provide the infrared heat source target for the use of infrared thermal imaging module during the landing of the UAV. The maximum temperature of the heat source can reach 200 degrees Celsius, which can make the infrared thermal imaging module effectively identified within 8 meters, and it is equipped with the corresponding temperature sensor for detecting the temperature of the infrared heat source and providing real-time feedback on its work.

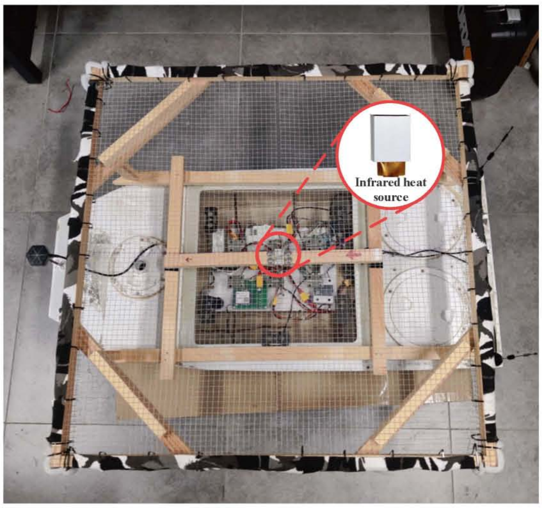

Fig. 4. USV hardware

The 2.4G digital transmission module is used for communication between the USV and the UAV, and the 4G module is used for communication between the and the upper computer. The USV aggregates and processes its own data information with that of the UAV and then sends it to the upper computer through the 4G module in a unified manner. The commands from the upper computer to the UAV can also be sent to the USV first by sending them to the UAV, and then forwarded to the UAV by the USV.

IV. VERIFICATION

A. Infrared Thermal Imaging Data Correction

In order to verify the infrared thermal imaging module position correction results, we its performed experimental verification. The UAV is fixed on a single-axis rotatable commissioning of a certain height, with the infrared target fixed directly below the UAV. Change the pitch angle of the UAV and read the IR thermal imaging module data, the UAV attitude data and the corrected data. The results are shown in Fig 5.

From the experiment, it is known that the infrared thermal imaging module data error increases with the increase of attitude angle. The error of the infrared thermal imaging data after attitude correction is significantly reduced, and the error does not exceed 5 cm when the pitch angle changes within 25 degrees.

B. UAV Autonomous Takeoff and Landing Experiment

The experiment is carried out in Haiyun Lake of Jiangsu University of Science and Technology. Fig.6 shows the experimental site. Firstly, the USV platform will carry the UAV from the lake shore to the central position of the lake, and after reaching the designated position, the upper computer will send the take-off command, and the UAV will execute the autonomous take-off command. After takeoff the drone will reach a certain altitude and automatically enter autonomous cruise mode. Secondly, the drone cruises to the USV platform for a certain distance, the upper computer sends the return command, the UAV autonomous return and autonomous landing, after the autonomous landing is completed and stably stays in the USV platform, the USV platform carries the UAV back to the shore.

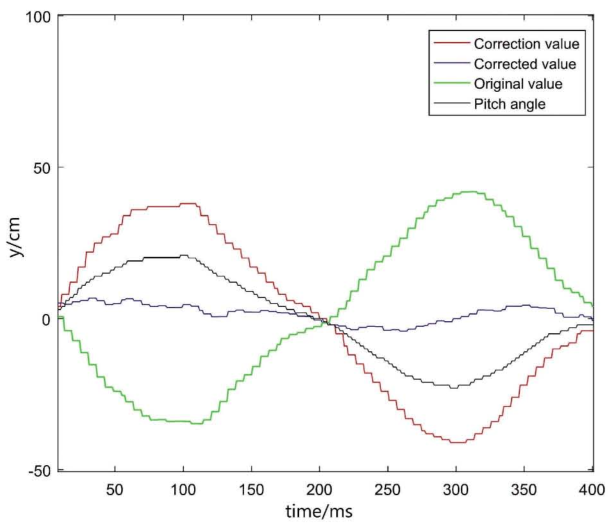

Fig.5. Infrared thermal imaging position data correction

Fig.6. Conducting experiments in the lake

In the process of autonomous take-off and landing, the autonomous take-off function is relatively simple and only requires the UAV to quickly raise its altitude to leave the USV platform. The autonomous landing is more complicated and difficult, so we focus on the autonomous landing process. Fig. 7 shows the 3D position data of the UAV we collected during the autonomous landing.

The UAV autonomous landing was tested several times under the different speed of the USV platform movement, and the experiment concluded that the UAV can safely land on the USV platform when the movement speed of the USV platform is less than 25cm/s. When the movement speed of the USV is greater than 25cm/s, the low data tracking frequency of the infrared thermal imaging module will lead to the loss of the infrared target and thus cannot land.

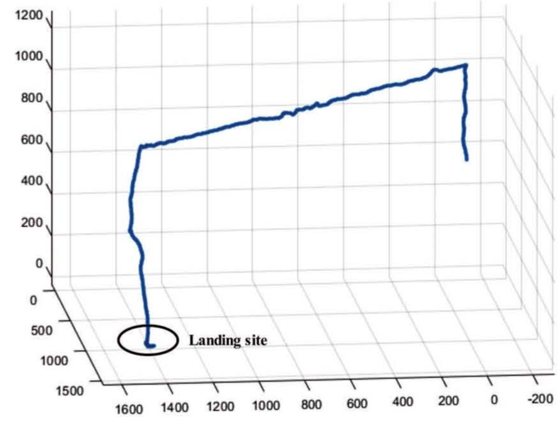

Fig.7. Drone landing trajectory

V. CONCLUSION

The autonomous takeoff and landing UAV system for USV platform designed in this paper uses infrared thermal imaging sensor and landing harpoon with landing net device to overcome the problems of excessive position error in the case of using non-differential GPS module to meet the landing requirements and the USV platform swaying on the water surface causing the UAV to slip down. The upper computer software supporting the system can control the system through 4G network to perform the corresponding tasks and provide real-time feedback on the status information of the system, which can realize remote control function. Compared with the traditional single UAV and single UAV system, the system has the advantages of long action distance and long aerial detection time, and is more suitable for performing tasks in wide waters.

At present, the system can perform fewer functions, in the future we will continue to improve the system to achieve more functions, so that the system can be capable of handling more tasks.

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