The Design of Intelligent Spray Painting System for Ship Panel Based on UAV

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Abstract. This paper proposes a new form of using UAVs to carry spray painting process equipment to spray outer plates of ships, which solves the painting points of poor practicality, poor versatility and low intelligence of existing robotic spray painting and has received wide attention from experts in the industry. It includes two types of hardware equipment and three software systems, among which the hardware equipment includes intelligent spray painting platform and material supply platform, and the software system includes intelligent planning system of spray painting path, intelligent spray painting stability control system and "double platform" dynamic joint control system. Through experimental verification, the intelligent spray painting system of ship outer plate based on UAV proposed in this paper realizes intelligent spray painting of ship outer plate, improves safety, economy and efficiency of ship outer plate spray painting, and further promotes intelligent transformation of ship construction and high-quality development of ship industry.

1. Introduction

Ship painting is the process of coating protection in ship construction and is one of the three pillars of modern shipbuilding process, including four major steps of grinding, sandblasting, rust removal and surface painting, and consists of five process stages: segment painting, platform painting, dock painting, in-dock painting and outfitting painting[1-3]. Among them, in-dock painting is to spray the surface paint of the ship's outer plate before the ship is launched, and it needs to be done in a small dock space[4]. Through researching the leading ship enterprises, we found that the existing wall-climbing spray painting robots, orbital frame spray painting robots and overhead car spray painting robots have problems such as poor adaptability to complex surfaces, complex building and large space occupation in the spray painting process[5-7]. Intelligent manufacturing has become an important direction for the development of ship construction. Due to the characteristics of large structure, large surface and large space of hull parts, the existing spray painting equipment is difficult to meet the development needs of wide adaptability and intelligence of ship outer plate spray painting[8-9]. To this end, this paper proposes an intelligent spray painting system based on UAV, which consists of a six-axis and six-rotor UAV, an adaptive spray painting device, an intelligent follow-me cart and a pipeline automatic collection and discharge device. The new form of using UAV as a platform to carry spray painting process equipment has the advantages of high spray painting efficiency, uniform spray painting film thickness, adaptability to complex curved ship exterior panels and high intelligence compared with the traditional spray painting operation method.
2. Hardware components
The hardware equipment composition of the UAV-based intelligent spray painting system for ship outer panels is shown in Figure 1.

![Figure 1. The composition diagram of the intelligent spray painting system for the outer panel of the ship based on UAV](image)

2.1. Intelligent spray painting platform design
The intelligent spray painting platform includeing the UAV body and the adaptive spray painting device, and the detailed design process is described as follows.

The UAV body, as the carrier of the intelligent spray painting platform, supports the multi-degree-of-freedom stable motion of the adaptive spray painting device, and mainly consists of the flight control system, power system, map transmission system, obstacle avoidance system, positioning module, ground station control system, and frame body. Meanwhile, to ensure that the UAV has intelligent flight and environment sensing capability, laser range measurement module, ultrasonic sensor, carrier phase differential positioning module (RTK), high-precision structured light camera are added, as shown in Figure 2. The functions of forward-looking obstacle avoidance flight, environmental object distance sensing, 3D real-world modeling, and autonomous spray painting for route planning are realized. Through the testing and certification of the third-party testing institution, the rated load of this spray painting implementation platform is 80kg. The rated operation duration can reach 2h. The horizontal and vertical positioning accuracy is within ±0.025m.

And the maximum spray painting height is 30m, which is fully equipped with the basic conditions as an intelligent spray painting platform for ship outer panels.

![Figure 2. Sensors added to drones](image)
The designed adaptive adjustment spray painting device consists of a rotating telescopic table, nozzle angle adjustment mechanism, pipe line retracting mechanism, spray gun, etc. The rotating telescopic table is controlled by pulse signals to ensure the left-right and forward-backward adjustment of the spray painting rod to compensate for the error generated by the UAV's own flight. The nozzle angle adjustment mechanism uses the rudder as the active device and the nozzle as the follower. The angle control is realized by the PWM signal generated by the flight control to ensure that the nozzle is always vertical to the outer plate of the ship during the spray painting operation to achieve the best spray painting effect. Torque sensor and photoelectric encoder are installed on the pipe reel mechanism to obtain real-time torque sensor pull information and reel speed information. The speed of the reel is calculated by comparing with the threshold value, and then the PLC controller drives the motor to drag the reel to achieve the function of automatic line take-up during the vertical movement of the spray painting platform. The designed pipe line rewinding device avoids the pulling of the pipe line on the spray painting platform and improves the stability and safety of the spray painting platform during the spray painting process.

2.2. Material supply platform
The material supply platform provides continuous power supply for the intelligent spray painting platform and consists of an electric vehicle body, equipment cabin and apron, which contains a battery pack, inverter, control cabinet, paint and paint bucket. To ensure the real-time following function of the material supply platform, RTK positioning technology is used to ensure that the positioning accuracy error is controlled within ±0.025m, and the relative position coordinates of the material supply platform and the spray painting platform are obtained in real time to ensure that the following position error is within ±0.2m; to realize the intelligent collection and discharge function of the pipeline, torque sensors and PLC controllers are added to control the pulling force of the pipeline on the spray painting platform according to the In order to realize the function of intelligent pipe collection and discharge, torque sensor and PLC controller are added to control the pipe collection and discharge and cable discharge in real time to reduce the load of the spray painting platform; meanwhile, the battery pack and paint pump installed on the material supply platform can provide long-time operation conditions for the system spray painting, and the endurance can reach 120 minutes.

2.3. Performance Indicators
This work is suitable for ship exterior spray painting below 30m in height, especially for curved exterior spray painting, and it can also reach any curved exterior spray painting by adjusting the nozzle type and spray painting paint type. In addition to ship curved spray painting, it can also be used for spray painting the curved walls of high-rise building facades, elevated bridge spray painting, high-altitude steel structure spray painting and other high-altitude dangerous places, and its main performance parameters are shown in Table 1

| Category            | Indicator items               | Indicator value |
|---------------------|-------------------------------|-----------------|
| Operation index     | Spray painting height         | ≤30m            |
|                     | Spray painting rate           | 600m²/h         |
| Performance         |Rated load                    | ≤80kg           |
| Indicators          |Rated operating hours         | 2h              |
|                     |Spray painting point           | Level:≤±10mm    |
|                     |positioning accuracy          | Vertical:≤±10mm |
| Spray painting      |Dry film thickness testing    | ≥95%            |
| quality index       |compliance rate                |                 |
|                     |Appearance defects             | None            |
3. experimental procedure
In this paper, multiple spray painting experiments were conducted with the outer panel segments of the ship, and the operation flow of the system is as follows:

Step 1: Based on the tilt photography technology, the image acquisition of the ship's outer plate environment is carried out by the on-board camera, and the images are acquired every 3° around the ship's hull. After the images are transmitted to the ground station, the 3D inverse modeling of the ship's outboard environment is carried out with the support of Context Capture Master software to generate a 3D model of the ship's outboard environment.

Step 2: Based on the 3D model of the outer plate of the ship obtained by inverse modeling and the painting area division rule established by combining the hull area division, the hull is divided into different painting areas. Then, based on the knowledge base of paint film thickness growth model and surface meshing results, the spray painting trajectories of each spray painting sub-region are generated. Finally, coupling the UAV flight parameters, coating process parameters and the optimization results of the spray painting trajectory, the final global UAV spray painting path of the ship outer panel is generated, and the latitude and longitude information and height information of the UAV flight point are obtained. The boundary point of the waterline region is defined as the initial origin of the spray painting path.

Step 3: First, install the nozzle adjustment structure to the nozzle, fix the gun to the rotating telescoping table, attach one end of the figure paint tube to the end of the gun and wrap the remaining part to the tubing take-up device, connecting the other end of the paint tube to the high pressure airless sprayer and insert the sprayer inlet into the paint bin. Then, the gun portion of the adaptive spray painting mechanism is fixed under the center panel of the UAV. Finally, the software system regulation is carried out to establish the communication connection between the intelligent follow-me cart, the UAV and the ground station, The planned path of the outer plate of the ship is transmitted to the UAV control system. And then the system parameters are set.

Step 4: The drone takes off from the apron to the starting point of the spray painting path, the system software turns on the solenoid valve and sprays according to the basic rules from top to bottom and left to right, during which the ground station software monitors in real time the attitude and position of the drone and the accompanying trolley, the spray painting speed, the spray painting pressure, the nozzle angle and other status information. The spray painting process is controlled and decided by the system software in order to achieve the purpose of intelligent spray painting.

The system spray painting process and the final spray painting effect are shown in Figure 3. After inspection, the dry film thickness conforms to the 85/15 rule of the ship coating film thickness testing requirements, and the coating appearance has no obvious defects such as flow hanging, pores and bubbles.

Figure 3. Spray painting experiment process diagram.
4. Conclusions
The use of the UAV with the spray painting mechanism achieves full coverage of the spray painting area and no crushing of the primer. Compared with other spray painting equipment such as manual and orbital frame spray painting robots, this system has good quality assurance while ensuring efficiency. After actual testing, the appearance quality and film thickness of the coating conform to the standard of "Technical Requirements for Acceptance of Marine Painting Quality", and it can be applied to the coating needs of many types of ships’ exterior panels.

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