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Research on the River Channel-adaptive Inspection Technology of Sewage Outlets Based on DJI M300 Flight Platform Equipped with Orthogonal Laser Radar

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Abstract: *Water pollution control for black and odorous water bodies becomes increasingly concerned in China. As the final checkpoint for pollutants entering the water body, the management of sewage outlets is an important task of water pollution control and the black and odorous water bodies' remediation work. This research fully considers the urban river inspection scene to develop a river channel-adaptive inspection system based on the DJI M300 flight platform equipped with a circular orthogonal laser radar as the sensor, which provides automatic obstacle avoidance and route planning functions. The UAV inspection system overcomes shortcomings in traditional artificial inspection work such as incomprehensive, time-consuming, and high labor cost, and helps management departments to build up a long-term control mechanism of water quality management.*

Keywords: *UAV Inspection, Flight Route Planning, Obstacle Avoidance, Sewage Outlets Management, Water Pollution Control*

1. Introduction

With the increasing awareness of environmental protection, water pollution problems in China, especially in developed industrial areas, have become increasingly concerned than ever. Water quality problems, especially those black and odorous water bodies have brought serious ecological and environmental problems, which affect the daily life of urban residents. Since the release of “Ten Water Regulations”, the Chinese government has taken the treatment of black and odorous water bodies as one of the most important political tasks and livelihood projects. The sewage outlet is the final checkpoint for pollutants entering the river, and therefore, the management of the sewage outlet in the river is an important task of water pollution control and the black and odorous water bodies' remediation work.

Due to the wide distribution range of urban rivers and those surrounding environmental factors, Management departments often use manual walk inspections, motorboat inspections, or IOT(Internet of Things) monitoring methods in river flood inspections and management. These traditional methods have many drawbacks and shortcomings. For example, the coverage area is relatively small, the inspection results are not comprehensive enough, and pollution sources are hard to trace and information response processing speed is relatively slow. As a result, the inspection data cannot accurately reflect the actual number of sewage outlets and water quality problems at the time of inspection.

UAV (Unmanned Aerial Vehicle) inspection is a new technology that has gradually developed and become popular in the past ten years. The advantages of UAV inspection methods include fast response speed, high data collection timeliness, high data accuracy, and relatively low time and space constraints. UAV inspection is commonly used in the areas of urban planning[1], land and resources survey[2,3], power equipment inspection[4,5], agriculture, forestry and plant protection[6], environmental protection and water conservancy[7]. At present, there are few actual cases of automatic sewage outlets inspection

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based on UAV[8], especially for areas with complicated surrounding environments. Also, it is hard to automatically identify the current status of sewage outlets. Therefore, the inspection of sewage outlets is highly skill-needed and experience-needed, which makes this work difficult to promote widely.

In response to the problems mentioned above, this research fully considers the urban river inspection scene to develop a river inspection system based on the DJI M300 flight platform equipped with orthogonal laser radar, which provides automatic obstacle avoidance and route planning functions and is able to conduct independent and refined inspection work of the entire river. The system can not only guarantee the flight safety of drones, but also will improve the efficiency and quality of inspection work. Therefore, it provides the basic support for the management departments to make efficient, accurate, and scientific decisions on water pollution control.

2. Research Objects and Method

2.1. Research Objects

There is a complex environment in the urban river, especially for branches of trees on both sides of the river which might block the flight. In this research, the orthogonal laser radar is equipped on the drone to implement obstacle avoidance and control flight in the urban river environment. By fully analyzing the complex environment of urban riverss, this study develops the strategies on obstacle avoidance and adaptive route planning for drones, which make it possible to conduct sewage outlets inspection work automatically and efficiently.

2.2. Research Equipment

Considering the complex environment on both sides of the river, the drone needs to hover over the middle of the river to shoot and collect panoramic images of the river. To speed up the patrol and image acquisition, a 360° omnidirectional circular orthogonal laser radar is used as the sensor of the flight system to control and plan the flight of the UAV for obstacle avoidance. In the shooting process, a Chansi H20 camera combined with RTK position information is used for panoramic fixed-point automatic shooting. The architecture diagram of the flight system is shown in Figure 1.

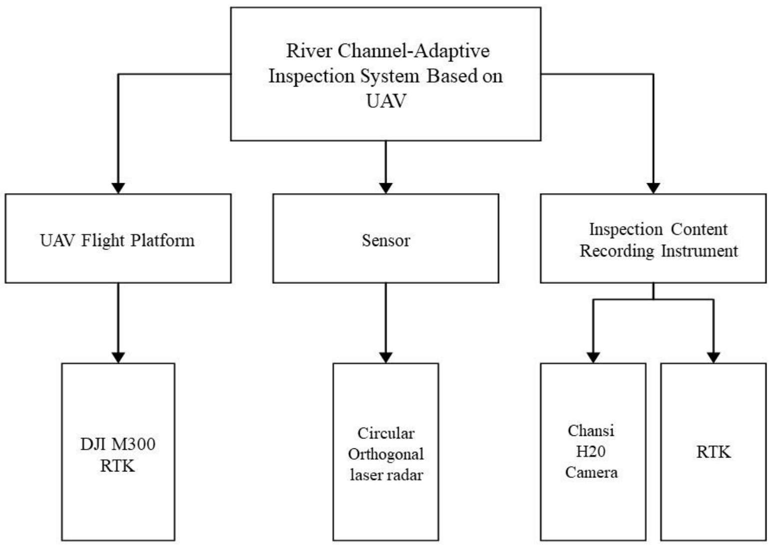

Figure 1: Composition of river channel-adaptive UAV flight module.

The flight platform adopts DJI M300 RTK(DJ-Innovations Company), which can support a vertical and horizontal hovering accuracy within 0.1m when RTK positioning, and within 0.3m when visual positioning. Therefore, the platform is suitable for maintaining a stable hovering posture over urban rivers. With a flight duration of 55min, it is able to support long-duration river patrol and shooting missions.

The circular orthogonal laser radar is mounted on the UAV, as shown in Figure 2. The detection range for the radar is 1.5-30 meters, which can detect an omnidirectional range of area in the horizontal direction and above the machine, and make it possible to avoid obstacles.

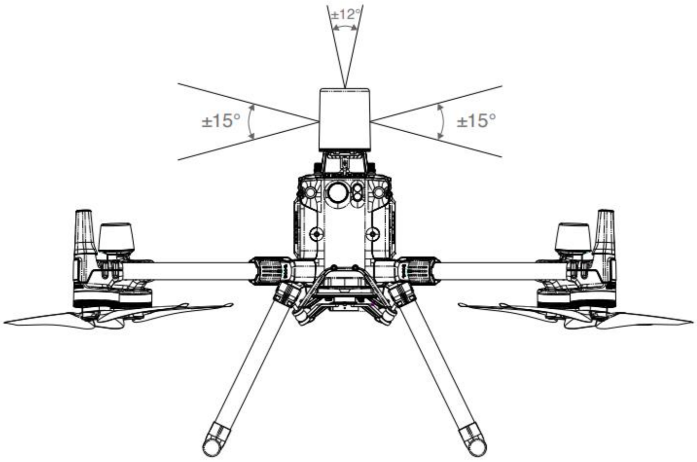

Figure 2: Circular orthogonal laser radar mounted on the UAV.

2.3. Obstacle Avoidance Strategy

2.3.1. Obstacle Avoidance Method

During patrol over the river, the drone's flight path may be blocked by the branches of vegetation on both sides of the river. For the typical single-obstacle flying scene, we adopt a lateral obstacle avoidance strategy. As shown below, the scanning range is taken as the radar scanning area, and the whole point set in this area is defined as $\mathrm{p}(y,z)$, the distance between the drone and the obstacle ahead is defined as D_{f}, the obstacle avoidance distance is defined as D_{a}, the safety distance is defined as D_{s}, the absolute value of difference between the obstacle distance ahead and safety distance ahead is defined as E_{f}, and the absolute value of the difference between the side obstacle distance and side safety distance is defined as E_{b}.

$$D_{\mathrm{b}} = \min_{D_{\mathrm{p}(x,z)}} (\mathrm{p}(x,z)) \tag{1}$$

$$E_{\mathrm{b}} = |\mathrm{D_b} - \mathrm{D_s}| \tag{2}$$

$$D_f = \min_{D_{p(y,z)}} (p(y,z)) \tag{3}$$

$$E_{\mathrm{f}} = |\mathrm{D_f} - \mathrm{D_s}| \tag{4}$$

As shown in Figure 3 below, when $D_{\mathrm{f}} \le D_{\mathrm{a}}$, the obstacle avoidance strategy is triggered, and the UAV automatically enters Bypass Mode, during which the drone will fly at a certain speed in the forward direction and keep a safe distance from the side obstacle.

During the process of obstacle avoidance, the drone enters the Avoidance Mode when $E_{\mathrm{f}} \ge \alpha$. When $E_{\mathrm{b}} \ge \beta$, the drone is controlled to maintain a safe distance from the side of obstacles.

When $E_{\mathrm{f}} < \alpha$, $D_{\mathrm{f}} > D_{\mathrm{a}}$,the drone enters the normal Crossing Mode, that is, the aircraft crosses the obstacle at the original forward speed, and the drone is controlled to maintain a distance from the side of obstacles. When the drone meets the obstacle avoidance trigger conditions, the control terminal sends an obstacle avoidance command to control the drone to fly around and fly as shown in Figure 4.

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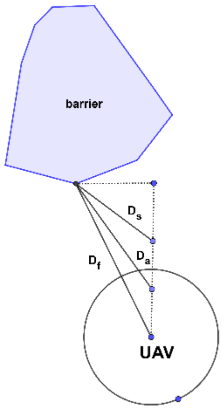

Figure 3: UAV flight encounters obstacle.

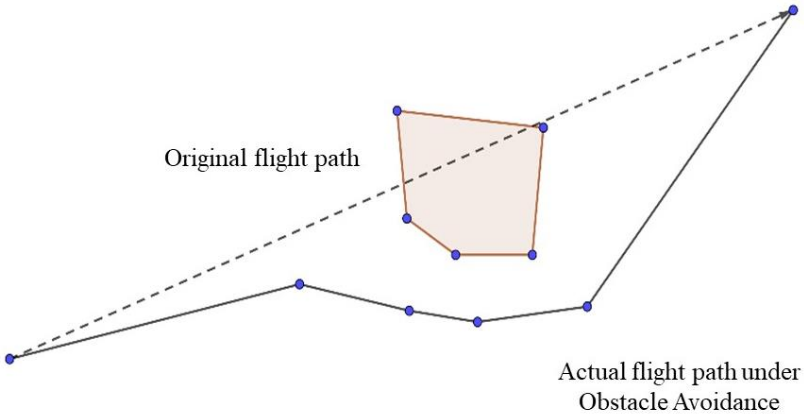

Figure 4: Top view of the flight path of the UAV when it encounters obstacles.

2.3.2. Obstacle Avoidance Control Algorithm

With the UAV at the center, the distance and angle of the section point of the riverbank can be obtained through the circular orthogonal laser radar carried by the drone. Thus, according to, the offset e of the horizontal distance and the setting distance between the drone and the obstacle can be calculated by the trigonometric function formula. The controller uses the PID(proportional-integral-derivative) control algorithm to control the pitch and yaw of the drone, so as to ensure the accurate control of the drone to maintain a fixed vertical distance from the river surface and a safe horizontal distance from obstacles[9,10]. PID control algorithm is used to reach the goal of autonomous obstacle avoidance control of UAV, as shown below:

$$\mathrm{u}(t)=K_p e(t)+K_I\int_0^t e(\tau)d\tau+K_D\frac{de(\mathrm{t})}{dt} \tag{5}$$

Among which, $\mathrm{u}(t)$ is the controlled variable, t is the sampling period, and $\mathrm{e}(t)$ is the error between the actual output value and the expected output value, K_p is the proportionality coefficient, K_I is the integration coefficient, and K_D is the differential coefficient.

E_f and E_b are taken as the control quantity of PID control algorithm, and its control flow chart is shown in Figure 5 below.

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2.4. Inspection Route Planning Strategy

Inspection route planning refers to the planning of a reasonable flight path for the target route before the takeoff operation of the drone, to ensure that the drone passes through all the target points in a relatively efficient way during the inspection process. The path optimization algorithm must consider not only the UAV's own performance constraints but also the target task constraints in inspection work, which is a multi-constraint parameter optimization process. Before the path optimization, the corresponding spatial coordinate system was established, the corresponding expression was established to represent the search space, and the optimal value of the optimization evaluation function was obtained by using the algorithm.

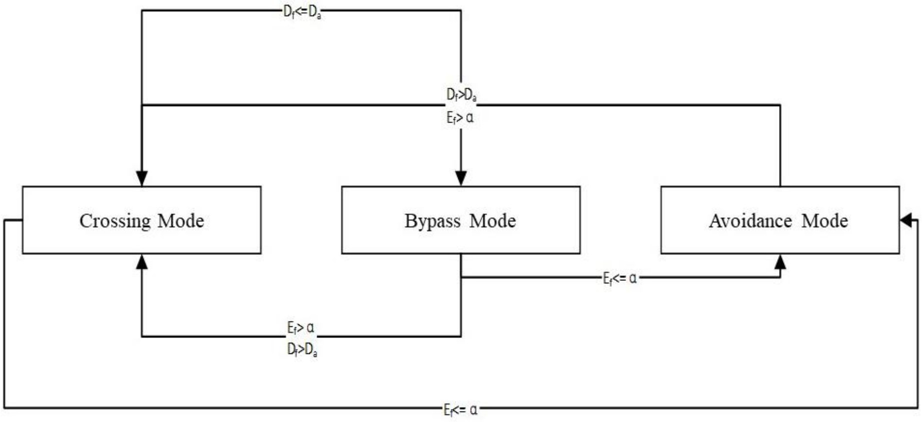

Figure 5: Control flow chart of obstacle avoidance.

Starting from the initial point, passing through various hovering shooting points and finally arriving at the target point, the entire flight path of the drone can be represented as the connection of the path position points in the two-dimensional space. Assumed $\{A, P_1, P_2, \cdots P_n, B\}$ as a set of spatial sequence points, where A is the starting point of the inspection operation and B is the target point of the inspection path, $P_1, P_2, \cdots P_n$ represent the nodes corresponding to the flight path of the drone in spatial grid. Each node has its corresponding coordinates. Then, the coordinate points of its flight path can be shown as Figure 6.

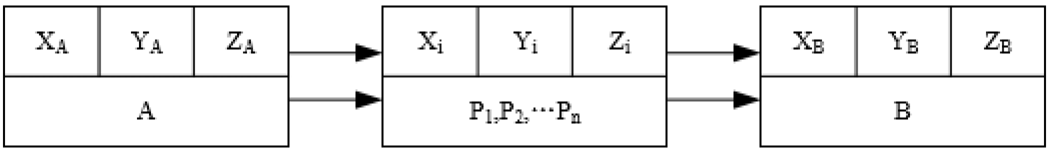

Figure 6: The coordinate points of flight path.

In the process of river patrol inspection, as coordinates of all sewage outlets have been collected in previous artificial work, the main task of inspection path optimization is to plan the GPS coordinates that the drone needs to shoot at the fixed point during river inspection. Considering that the length of the river surge as L, the flight speed as V, the current battery lifetime as T, the time required for each fixed-point shooting as t, and the safe flight height of the UAV inspection as H, the control end needs to determine the GPS points for fixed-point shooting on the river inspection route according to these constraint conditions and optimization algorithm.

3. Results

The flight control functions, including the obstacle avoidance function and the inspection route planning function, are tested in simulation experiments in order to prove the effectiveness and feasibility of the control flight algorithm.

3.1. Test on Obstacle Avoidance

The obstacle avoidance control algorithm is simulated in the flight test, during which the drone performs as follows: the normal forward flight speed is 1m/s, and the maximum horizontal speed is 1m/s in bypass mode, the safety distance is set as 5m, and the obstacle avoidance distance is set as 10m. Assume that the initial forward speed of the drone is 1m/s during the inspection, its initial position is (-15,5), and the forward direction is set as the positive direction of the X-axis, where $\alpha = 0.2, \ \beta = 0.1$ are set as parameter thresholds . Its flight path when encountering obstacles is shown in Figure 7, and its horizontal speed control process is shown in Figure 8. When the drone meets obstacles, its speed can be corrected and stabilized within a relatively short time, indicating the effectiveness of its control algorithm.

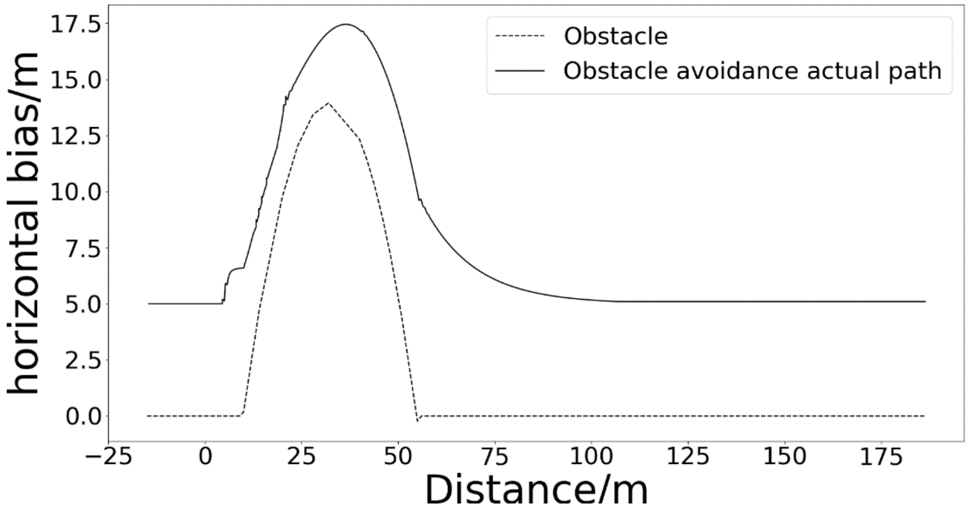

Figure 7: Flight path during obstacle avoidance.

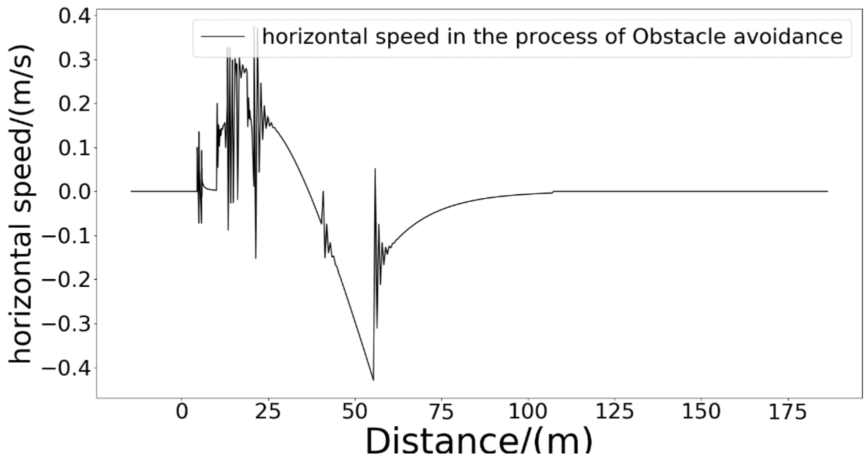

Figure 8: Control of horizontal speed during obstacle avoidance.

3.2. Test on Inspection Route Plainning

During the inspection work, the sewage outlets are defined as fixed points, as shown in Figure 9 below. Since the coordinates of these points have been collected in previous artificial inspection work, the main task for the test is to calculate and plan the flight route based on the set of fixed points and the actual situation. By considering the minimum number of S_{min} in the visible range of each river channel is set for sewage outlets inspection, and the shooting coordinates are determined under this constraint condition, and the planning result is shown in Figure 10.

Figure 9: Fixed points of the river.

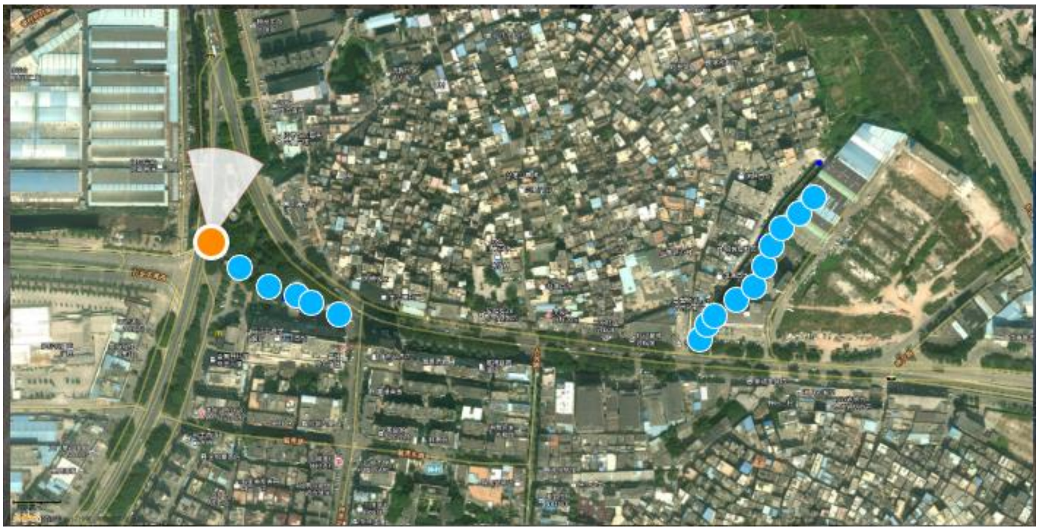

Figure 10: Route planning result of the river.

4. Conclusion

The system uses a multi-rotor flying M300 RTK platform as the carrier UAV, and a circular orthogonal laser radar as the sensor, which can provide complex and real-time calculation on environmental distance by measuring the distance from the objects in the environment around the drone and collecting data in a safe, fast, and accurate way. Orthogonal laser radar is highly portable since its small size, and light weight, which make it convenient enough for inspectors to carry, assemble or disassemble during fieldwork. Furthermore, it provides measurement data with high accuracy, efficiency and quality in the calculation of obstacle avoidance control algorithm.

According to the distance between the surrounding environment and the flight platform, the PID control algorithm is used to autonomously adjust the flight attitude and plan the flight path during the flying process, and the obstacle avoidance strategy is designed in combination with the special complex environment over the river, which can effectively improve the safety of the drone in the flight.

On the basis of UAV equipped with orthogonal laser radar, this study develops river channel-adaptive inspection technology with route planning and obstacle avoidance functions, so that the flight path of sewage outlets inspection work can be independently adapted and planned based on the river environment. The study can not only improve the efficiency of sewage outlet inspection, but also help to reduce the labor intensity of traditional artificial inspection. This UAV-orthogonal laser radar-based river channel-adaptive inspection system highly suits the management requirement and trend in the field of river inspection work and water pollution control, which provides a strong guarantee for improving the information level of management departments and realizing the modern

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management of river inspection. Also, it provides the basic support for the management departments to make efficient, accurate, and scientific decisions on water pollution control, and helps to build up a long-term control mechanism of water quality management.

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