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NB-IoT-based Robust Kalman Filter Trajectory Optimization for Surface Cleaning Unmanned Vessels

Junyi Huang, Bohao Dai, Han Liang*, Jiaqing Sun, Wenxiu Xie, Jingru Zhang, Fubing Huang

International Maritime Academy, Hainan Tropical Ocean University, Sanya, China

*Corresponding author e-mail: 1024484869@qq.com

Abstract

In order to solve the impact of solid floating and suspended materials such as water plants on the environment and ship navigation, a water surface cleaning unmanned ship is designed. The boat uses solar energy as the energy source, OpenCV and NB-IoT technology to achieve route planning and wireless remote communication, combined with robust Kalman filtering technology, to address the problem that the filtering accuracy of Kalman filtering will decrease or even diverge when the non-Gaussian noise or the statistical characteristics are inaccurate, a Kalman filtering trajectory optimization based on NB-IoT IoT technology and OpenCV technology is proposed. Algorithm. Surface garbage collection is realized through devices such as a roller at the front end of the hull. Compared with the existing garbage disposal devices, this type of ship is characterized by good economy and green environmental protection.

Keywords

Surface Cleaning Unmanned Vessel; OpenCV; NB-IoT; Hull Design.

1. Introduction

With the development of Hainan Free Trade Port, shipping activities are becoming more and more frequent, and the number of ships coming and going in the waters around Hainan Island has increased, in order to ensure the efficient development of shipping activities, the efficiency of ship navigation and navigation safety must be guaranteed. However, due to the eutrophication of the water body and the impact of human operations, every year there will be a large number of water plants, solid waste gathered in the port and the river estuary, a large number of floating, suspended solids in the destruction of the ecology of the waters, at the same time, will be to the navigation safety of the ships, navigation efficiency and equipment service life of the threat. How to quickly and effectively remove these hidden dangers has become a major hotspot in current research.

At present, many forms of water surface cleaning devices are used at home and abroad, but there are many shortcomings: Most of the devices need to be operated manually, and the treatment process is time-consuming and ineffective, which is not in line with the requirements for high efficiency[1] ; Secondly, the devices are too large in size, with a low degree of automation, and the various types of parts are very bulky and heavy, and the operation and maintenance costs, which raise the cost of cleaning up the water plants and solid wastes[2] . In path planning, the carrier's attitude, position and velocity are relative to a certain reference system, in order to avoid the roughness problem caused by the wild values of satellite signals, their harmonization through the filter method is the first condition of information fusion. For this reason, scholars have proposed a large number of approximate estimation methods and applied them to various fields. Aiming at the problem that the filtering accuracy of Kalman filtering decreases or even disperses when the non-Gaussian noise or the statistical characteristics are inaccurate, this paper designs an automatic water surface cleaning unmanned boat based on NB-IoT communications technology and OpenCV technology. The boat consists of drive module, control module, power module, pass-through module and other functional units, and is able to realize autonomous route planning, object recognition, and automatic operation while efficiently and safely removing water plants and solid garbage. The use of this unmanned boat can effectively improve the efficiency of removing floating and suspended materials such as water plants and solid garbage in the waters, reduce the treatment cost, and contribute to the environment of the waters and the safety of ship navigation.

2. Overall design concept

The total hull design is divided into 3 modules. (1) Surface garbage collection module, which collects water plants cut by lawn mowers as well as fixed garbage floating on the water surface. (2) The garbage disposal module, which collects garbage through the garbage collection module, and the collection device is placed in the central connection part of the boat. (3) Drive module, the boat is powered by lithium batteries with solar panels and propelled by bright wheels on both sides of the hull[3] . The hull design is shown in Figure1.

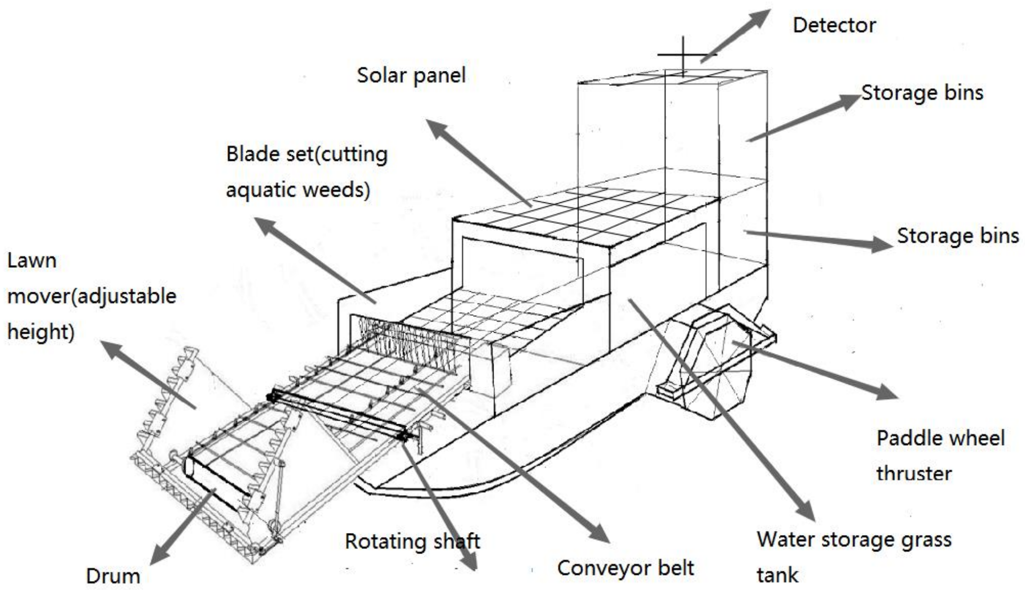

Figure1 Hull design

3. General hull structure

3.1. Hull structure design

The hull material is made of fiberglass reinforced plastic, aluminum alloy, steel, etc., with sufficient strength and rigidity. The hull shape is streamlined to ensure the ship's driving performance, stability and resistance to wind and waves.

3.2. Collection design

The main part of the collection module consists of a mower and a roller unit, the mower running at high speed ensures the reliability of its unmanned boat work, and the roller unit ensures that the cut water plants do not stay in the front-end unit, and can be transported to the transfer and processing unit. The roller unit is shown in Figure2.

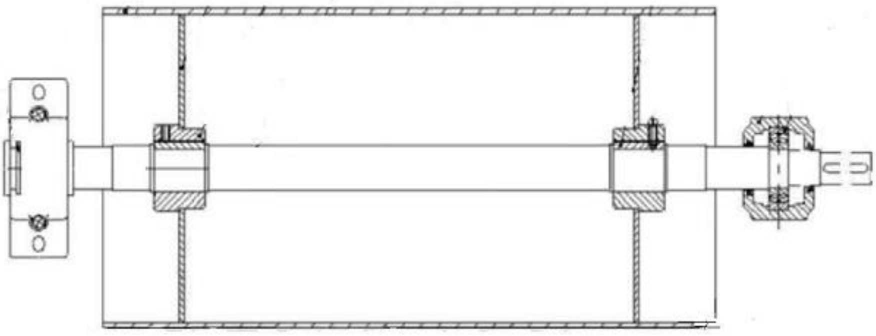

Figure2 Roller unit of collection module

3.3. Transmission and processing design

The transfer and processing device mainly consists of conveyor belt and blade set, as shown in Figure3 and Figure4. The conveyor belt can move up and down for a certain distance based on the horizontal plane, which is adaptable to a variety of complex working conditions. The blade set consists of several blades connected in parallel, with high efficiency of cutting grass. The special solid garbage such as water grass is collected by the front-end collection device and finally reaches the cabin by the transmission and processing device, completing the whole collection process. The processed garbage will be transmitted to compress the garbage and then transferred to the garbage transfer station, which will be classified, processed and recycled.

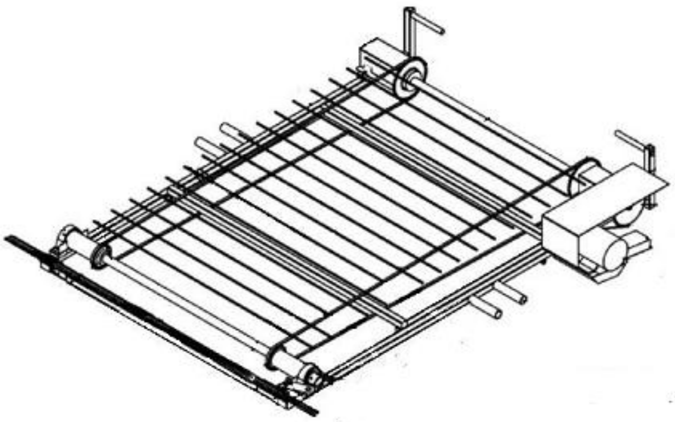

Figure 3 Conveyor Belt

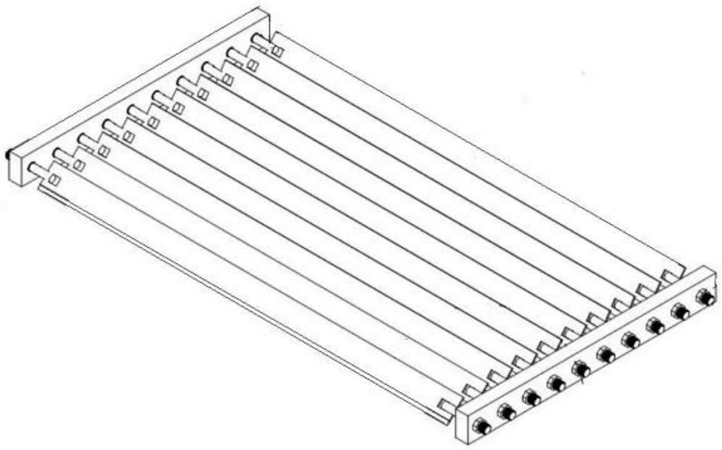

Figure 4 Blade set

3.4. Driver design

The hull of this type of ship is large and the power required for work is high, so the power part selects lithium battery with solar panel to provide power, which ensures fast charging and reduces the consumption of fossil fuels to reduce the pollution to the environment. The motor-driven open wheel is used as the power source[4] , the open wheel drive system has a simple mechanical structure, easy to install and maintain, and at the same time has a high propulsion efficiency, which can be applied to a variety of water environments, including rivers, lakes, oceans and so on. Moreover, the noise generated by the open wheel during operation is relatively low, which has less impact on the surrounding environment and organisms. The underwater propeller is shown in Figure5.

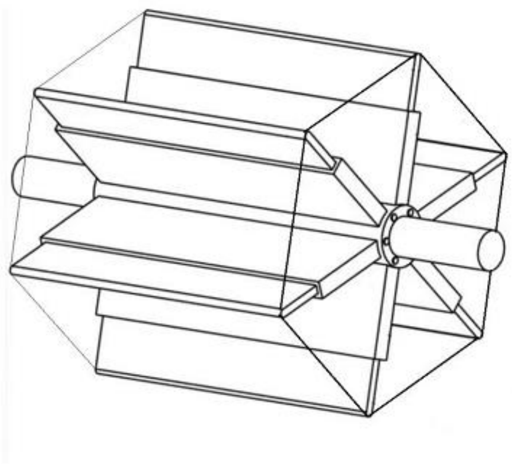

Figure5 Bright wheel propeller

4. Control system design

4.1. General scheme of control system

The surface cleaning unmanned ship is based on NB-IoT IoT technology. Take STM32 as the main control core, external environmental information acquisition unit, power propulsion unit, operation operation and control unit, communication and remote control unit and power supply unit[5]. It realizes the data transmission between ship and shore by the shore-based monitoring and control platform, and carries out dynamic monitoring of the work of this type of ship in real time. The basic framework of the control system is shown in Figure6.

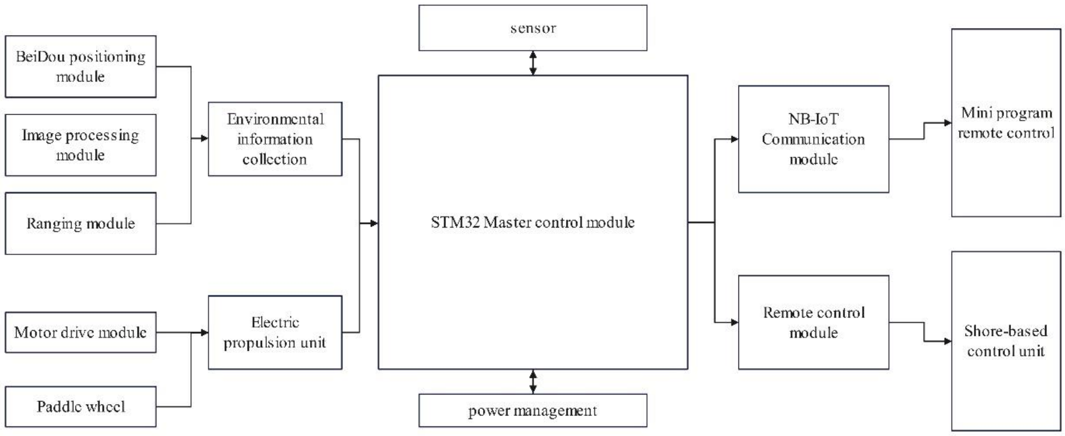

Figure6 Basic framework of the control system

4.2. Hardware system design

In this project, STM32-F407ZGT6 processor is used as the main control core. LM1117-3.3 (adjustable voltage regulator) is used as the output control circuit chip of the 3.3 V linear regulated power supply, and LM2596 (step-down DCDC chip) is used as the output control circuit chip of the 5 V DC output switching regulated power supply. All of the output is fed back to the input. The difference (i.e., the deviation signal) between the input and the feedback signal is added to the controller, which then adjusts the output of the controlled object to form a closed-loop control loop. Control system structure and software design block diagram structure shown in Figure7.

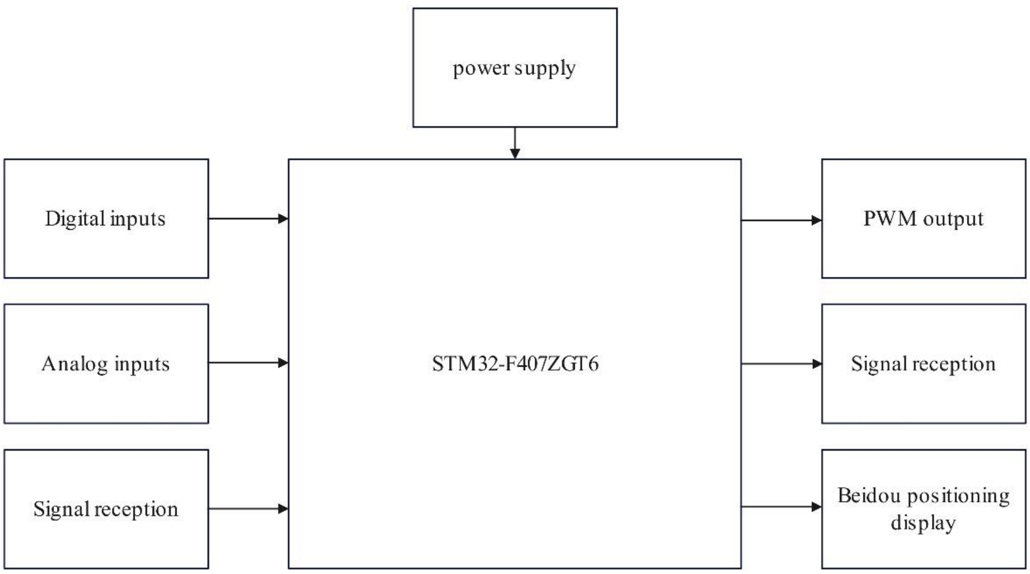

Figure7 Control system structure

4.3. Communication system design

Remote wireless communication uses NB-IoT (Narrowband Internet of Things) technology, a technical service managed by the three major domestic communications carriers, which operates in authorized frequency bands, and network communication can be quickly deployed using a module capable of supporting NB-IoT communication. In this project, the communication module M5311 is used as the hardware basis for NB-IoT communication. The main pin assignments are shown in Table1.

Table1 M5311 Pin Assignments

M5311 Wireless Communication Module	STM32F407ZGT6 Processor	Functional Description
WAKEUP	PB4	Wake-up control pin
RESET	PG8	reset module
PWR	PG6	Control module power-up and power-down

The operation of the M5311 module can be controlled by sending an AT command from the STM32 to the M511. If you want to start the MQTT service of the module, you need to send the character code (ASII code) control signal through the serial port of the STM32 microcontroller, and the complete flow is as follows:

(1) Obtained IMEI number: The IMEI number is the International Mobile Equipment Identity Code, which is used to uniquely identify cell phones such as GSM, WCDMA, and iDEN, and certain satellite phones.

(2) Write the MQTT connection code for the device: use the IMEI number of the M5311 module as the client ID for the MQTT connection and specify the topic to subscribe to.

(3) Connecting to the MQTT server: The address, port and connection credentials of the selected MQTT server will connect the device to the MQTT server. Ensure that you use the device's IMEI number as the client ID when connecting and subscribe to the selected topic.

4.4. Environmental information acquisition unit design

This project uses OpenCV (Cross Platform Computer Vision Library) technology which consists of related C/C++ language functions that can implement many general algorithms in image processing and computer vision[6] . Using this technology, the environmental information is collected by means of machine vision, and the targets in the field of view and the distance to the target point are observed in real time. When the unmanned boat encounters obstacles such as reefs, it will carry out autonomous avoidance; when the unmanned boat encounters water plants and solid garbage, it will return the coordinate value of this target to the main control core, and the main control chip, after receiving the feedback signal, will drive the processing and transmission device to carry out recovery. When the solid collection box is full, it sends a signal to the cloud platform through NB-IoT communication, and then carries out automatic return.

4.5. Algorithmic system design

The Kalman filter algorithm is applied in two places in this project: (1) A more robust Kalman filter is used for multi-sensor data fusion. (2) The tracking record of the navigation trajectory is recorded using an MPC trajectory tracking algorithm with constraints based on the robust Kalman filter.

The fundamentals of Kalman filtering are reflected in the fact that it is characterized by a recursive algorithm and data fusion. The recursive algorithm is an algorithm that infers the current estimate from the previous estimate, which is derived from the data measured by the sensor. Data fusion is where the difference between the measured value and the previous estimate affects the current estimate, allowing the measured and estimated values to be fused together.

(1) Robust Kalman filter: The traditional Kalman filter can fuse the data measured by multiple sensors and correct the distance data measured by the sensors. This distance is the distance between the ship's body and the target point, which is used to assist machine vision distance recognition to improve the accuracy of route planning. Kalman filtering needs to operate under the assumption of zero-mean noise, i.e. white noise, which is sufficient in most applications, but the water is characterized by nonlinear coupling and uncertainty in the model parameters leading to a large amount of colored noise interference in the system, which makes it difficult to be practically applied on unmanned ships. Therefore, this project calculates the error of the maximization estimate based on the Kalman filter, above which the system will not have a significant response output, a threshold value, and this approach attenuates as much as possible the response of the system's largest one in the target frequency range.

(2) Robust Kalman filter based MPC trajectory tracking algorithm with constraints

MPC is to optimize the scheme. It is widely used to solve the autopilot trajectory tracking control problem at because it shows better robustness in the face of uncertain parameter disturbances and has great advantages in solving optimization problems with constraints[7].

The underwater navigational drag is characterized by nonlinear coupling and model parameter uncertainty, which leads to oscillations and deviations of the control system, and even can no longer be used. For this reason, this system innovatively proposes a robust Kalman filter-based MPC tracking algorithm with constraints to further improve the robustness of the system. The approach is to use the state estimates provided by the robust Kalman filter as the motion state feedback input to the controller. The block diagram of the MPC control model for the unmanned boat system is shown in Figure8.

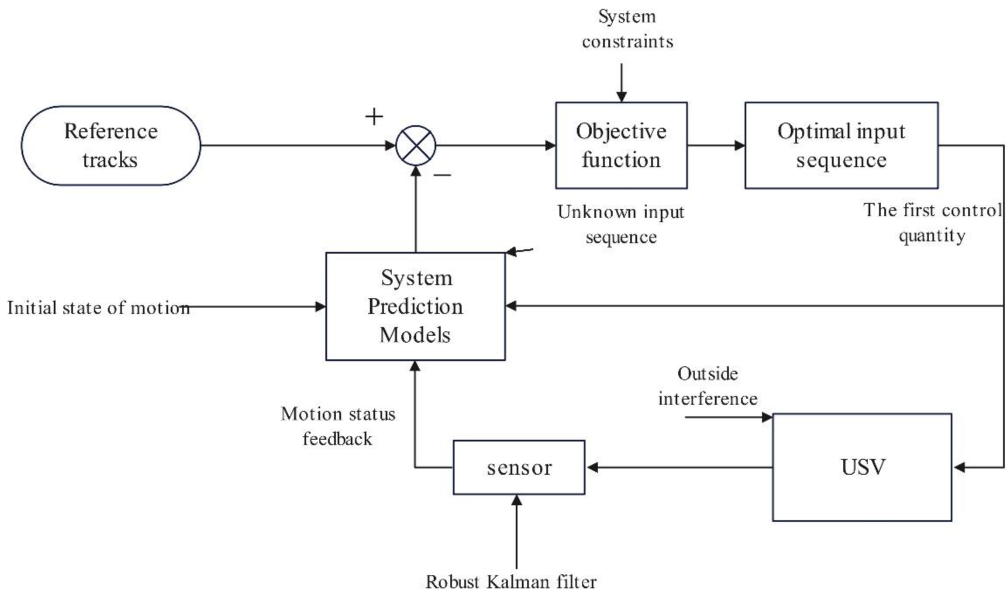

Figure 8 MPC control model framework

In the trajectory tracking process of USV, the current USV motion state is firstly acquired by the sensor, and then the future predicted output trajectory sequence is calculated by combining the system prediction model, the control inputs of the previous moment, and the unknown input sequences; then the predicted output trajectory sequence, the reference trajectory, and the unknown input sequences are substituting into the objective function, and then the optimal input sequences are solved to optimize the value of the objective function by taking into account the constraints of the system. Finally, the first input of the optimal input sequence is applied to the ship and held for one control cycle. Due to the existence of external interference, the real

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state of the ship is different from the predicted state, so it is necessary to obtain the measured motion state of the ship through the sensors, and together with the Robust Kalman Filter, the measured motion state is constantly corrected so that it is approximately equal to the real motion state, and then the state is utilized to carry out the next step of optimal input calculation. Calculation.

3. model variables commonly used for USV trajectory tracking:

(1) Initial state:

Position: The position of the ship in the horizontal plane, expressed in Cartesian coordinates using the Beidou satellite sensor coordinates under the Cartesian coordinate system.

Speed: The speed of a ship in a horizontal plane, including eastward and northward speeds.

Heading angle: the angle between the ship's heading and the reference direction.

(2) Control inputs:

Rudder Angle: Controls the angle of rotation of the rudder, used to adjust the ship's heading.

Thrust: the thrust of the propulsion system, used to adjust the speed of the ship.

Paddle Combination: In a two-bladed pod propulsion system, a combination of forward and reverse rotation of the paddles is used to adjust the ship's heading.

(3) System constraints:

Physical limits: thrust limits. Dynamic limits: avoidance of over-acceleration or over-steering of the ship.

(4) Outside interference:

Interference on three degrees of freedom in inertial space

4.USV trajectory tracking reference equation.

The USV surface motion depends on the inertial coordinate system, denoted as $\{n\}=(x_n, y_n)$; there is also the attached coordinate system of the ship itself, denoted as $\{b\}=(x_b, y_b)$; and the description of the trajectory state of the reference motion depends on the SF coordinate system, denoted as {f}=(xf, yf). The inertial coordinate system is defined as follows: the origin O_n is located at the starting point of the desired trajectory, O_nx_n points to the due north, O_ny_n points to the due east; the attachment coordinate system is defined as follows: the origin O_b is located at the center of gravity of the ship, O_bx_b points to the bow along the symmetric profile of the ship, O_by_b points to the starboard side; the SF coordinate system is defined as follows: the origin O_f is located in the current moment of the desired path of the target reference point, O_fx_f points to the direction of tangent to the desired trajectory, O_fy_f points to the direction of the plumbline. The water surface coordinate system relationship is shown in Figure9.

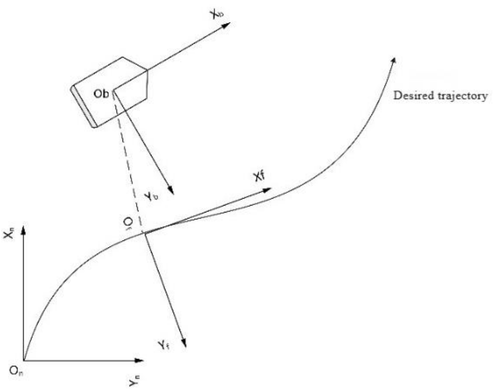

Figure 9 Water surface coordinate relationship

The USV state-space equation is expressed as $\dot{x}(t)=f[x(t), u(t), e(t)]$,where $x(t)=[x, y, \varphi, u, v, r]^T$ is the ship state variable, $u(t)=[\tau_u, 0, \tau_r]^T$ is the control input, $e(t)=[e_u, e_v, e_r]^T$ is set as the disturbance, x, y, φ is the ship position and heading angle, τ_u, τ_r is the stern moment and steering moment, e_u, e_v, e_r is the disturbance in three degrees of freedom, and f denotes the mapping relationship. The control method is to control the ship's center of gravity O_b to be close to the desired point, and then control the ship's combined velocity direction to be close to the tangent direction of the desired trajectory at the desired point, and the tangent direction is obtained by taking the first-order derivatives of the desired trajectory, in order to have a better description of the curves, the upper limit of the integral corresponds to the arc length s to the coordinates x from the starting point of the desired trajectory to the current desired point is set up: $s = I(x) = \int_0^x \sqrt{1 + g'(x)^2}\, dx$, and the independent variable x is converted to s at the end.

5. Conclusion

In this paper, we design a NB-IoT based robust Kalman filter trajectory optimized water surface cleaning unmanned vessel for removing solid floating objects such as water plants. The unmanned boat consists of water surface garbage collection module, garbage disposal module, drive module, driver module, control module, power module, and pass-through conductor module, which realizes the route planning and remote communication functions through OpenCV and NB-IoT communication technology, and the garbage collection by the roller device and transmission device at the front of the hull. The unmanned boat can always sense the changes in the surrounding environment, can sail according to the movement trajectory, the collection devices work together, while real-time monitoring can be carried out through the cloud platform, which completes the efficient \intelligent cleaning of garbage and water plants, and contributes to the environmental management of the waters and the safety of ship navigation.

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