A Wind Direction Tracking Control Method Based on the Sail’s Angle of Attack and Attitude

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Abstract. A new navigation-assisting sail is designed based on the sail’s angle of attack and attitude to realize wind direction tracking. Based on the boat’s state and environmental parameters, combined with a given database, the motor is used to drive the ball screw to realize self-adaptive control of the sail’s angle of attack. Intelligent control of the sail effectively increases the utilization rate of wind energy during sailing and provides a new solution for ship energy saving and emission reduction.

1. Research background

With the establishment of ship emission control zones in China and in the context of sustainable development, the emission control standards for ship air pollutants become stricter, leading to emergence of new energy cruise ships at the historic juncture. Sail-assisted navigation can reduce the power consumption of boats by providing extra power and utilizing the new energy of wind, thus providing a reference for future development of boats. However, the current form of sail-assisted navigation is monotonous and the sail is fixed, unable to make full use of the wind energy.

Thus, this paper designs a self-adaptive sail based on real-time adjustment of the sail’s angle of attack and attitude to realize wind direction tracking during the sailing process, which will improve wind energy utilization efficiency, reduce power consumption and cut emissions.

2. Overall design

Real-time parameters including the wind speed, wind direction, solar incident angle, and irradiance, as well as the navigation direction retrieved from the database were selected as parameters for computation. The response is performed by a stepper motor.

The specific working process is as follows: first, the GPRS module is used to collect the future weather information of the current water area, and the GPS module, anemometer, wind direction meter and irradiation sensor are used to capture real-time information about the water area and the period detection tests are carried out. When analyzing the period of computation, the micro-control device is called to control the main function and the corresponding threshold algorithm to achieve the optimal control mode. Through the output IO connected to the motor driver, the control signal is output to realize the adjustment of the sail’s attitude and angle of attack.
3. Components of the automatic control system

Figure 1 shows the intelligent sail control system. It consists of the following components: a solar sail, a ball screw, a stepper motor, a motor driver, a travel switch, an anemometer, a wind direction indicator, a radiation sensor, a GPRS module, a GPS module and a controller.

![Figure 1. Intelligent sail control system.](image)

This system is used to control the sail’s angle of attack and attitude. The components are connected in the following manner: the gear and the solar sail are reinforced by threads and meshes with the rack; the rack is fixed on the slide rail (screw motor type), one end of the slide rail is connected to the stepper motor 1, and the rack is controlled by the motor 1. The movement of the wing further controls the wind direction tracking of the sail wing; the inside of the rolling cylinder is connected to the slide rail by a welding part, and the outside in contact with the groove on the top of the ship is connected to the motor 2, which increases the stability of the moving parts during operation, and the cylinder is fixed by a fixation device. The limit switch is electrically connected to the input IO port of the micro-control device which is connected to the motor driver; the input and output ports of the GPRS module, GPS module, anemometer, wind direction meter and radiation sensor are electrically connected to the bidirectional IO ports of the micro-control device. The stepper motor 1 drives the ball screw connected to the solar sail, and the stepper motor 2 drives the sail lifting device.

The motor driver installed on one side of the motor is the actuator that controls the stepper motor, that is, the micro control device sends the PWM signal to the motor driver through the output IO port so that the stepper motor can respond accordingly.

The GPS module and the GPRS module are installed on the circuit board where the microcontroller is located. Under the control of the micro-control device, the GPRS module is connected to the weather forecast interface. Each computation cycle acquires data on the wind speed and sailing direction to guide the micro-control device’s prediction of wind energy. The GPS module, based on satellite timing and geological information, accurately computes the light energy by using the collected data on radiation.

4. Design of the automatic control system

4.1 Hardware design.

Information that needs to be collected by the system including the following: current geographic location, forecast wind speed and wind direction, current wind speed and wind direction, and solar radiation intensity. Thus, the GPS module, GPRS module, anemometer and wind direction meter are used (Figure 1). The main control chip is STM32F103RCT6. This MCU has the advantages of abundant peripheral resources, low power consumption, and adaptability to wide range of operating environments, which can ensure its stable operation in harsh conditions. The chip has 512K Flash bytes and can be expanded with FLASH through the SPI interface to store the data needed during navigation.
The SPI interface FLASH uses W25Q128, which can expand the storage space of 16M bytes for the system and is used to store data obtained during the sailing process.

The system uses closed-loop stepper motors and stepper motors as power output devices, and uses limit switches to achieve closed-loop control.

The matrix keyboard is used to select the corresponding routes, and the OLED screen displays the necessary data for human-computer interaction.

4.2 Software design
In terms of software design, the route and other settings are implemented by triggering external interrupts by pressing of buttons, and data acquisition and control responses are completed in timer interrupts. When the user turns on the system, the system will prompt the user to select the route and other parameters through the OLED screen which displays the options to guide the user to complete the configuration. After the configuration is complete, the user needs to wait for the timer interrupt to be triggered. If the user wants to switch routes, he/she can trigger external interrupt by pressing the button, enter the configuration interface to re-set the parameters, and then return to the main function after completion.

The decision-making process of the control system is as follows: first, it obtains the data on the forecast wind speed and wind direction through the GPRS module, compares them with the detected current values to determine whether the current wind condition is stable, and then selects the required data source (the forecast wind speed and wind direction or the measured current wind speed and direction). It then adopts the wind direction self-adaptive strategy and adjusts the sail’s attitude through the stepper motor to maximize the utilization efficiency of wind energy.

In the control algorithm, two cycles are defined: the sampling cycle and the computation cycle. The sampling cycle is the sampling period of the anemometer, wind direction meter, and radiation sensor; the computation cycle which consists of n sampling periods is the execution period of the main control function.

There are three states realized by a state machine: the sailing state, the furling state, and the standby state. The initial state is the sailing state. The system computes the wind energy based on the wind direction, and the solar energy based on the sun's irradiation angle, the current geographic location and the current time, and then compares these two energy solutions. If the wind energy utilization rate is high, the state is shifted to the sailing state. At this time, the motor rotates along the wind direction. When the wind energy is small, the state is shifted to the furling state to maximize the solar energy acquisition rate.

In the main control function, the energy parameters and commands are set as follows:
- E without wind 1: Effective value of wind energy obtained in the future using forecast data;
- E without wind 2: Effective value of wind energy calculated by the anemometer and wind vane over a period of time in the future
- E current wind: Effective value of wind energy for a period of time calculated from the motor position
- E forecast light: Effective value of light energy in the future period calculated based on the data collected by the irradiation sensor
- Et: Accuracy threshold of weather forecast data in the current environment determined by the current radiation
  - a.: analysis time arrives and start the function
  - b.: inquire forecast wind speed and direction data using the GPRS module
  - c.: filter data on the wind speed, wind direction, and irradiated power measured during the entire analysis period. The filtering method adopted is the median-average filtering method, which removes a maximum value and a minimum value of n data sampled in a period, and then calculates the arithmetic average value of n-2 data to eliminate the errors caused by noise;
  - d.: calculate future wind energy 1 by forecast data, calculate future wind energy 2 by measured current data, current angular wind energy and future light energy;
e.: by comparing the difference between wind energy 1 and wind energy 2, the current stability of wind energy is judged. If the wind energy is relatively stable, wind energy 1 is taken for computation; if the wind energy is unstable, wind energy 2 is taken for computation.

f.: Threshold algorithm 1 is currently executed for the sailing state, and threshold algorithm 2 is executed for the furling state. Through the abovementioned computation, the system can adjust the state of the sail and maximize the utilization efficiency of wind energy.

5. Conclusions
The wind direction tracking system designed in this paper adaptively controls the sail’s angle of attack according to the state and environmental parameters of the boat, and changes the sail attitude to enable the sail to track the wind direction so as to achieve intelligent sail control and maximize the utilization efficiency of wind power. The research results, if widely used in practice, can greatly reduce the power consumption of boats, and in the long run, bring in greater economic and environmental benefits, which is in line with the concept of sustainable development.

References
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