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Design and testing of a control system associated with the automatic feeding boat for farming Chinese river crabs

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ABSTRACT

In order to address the issues of nonuniform feeding and high labor cost plaguing the process of farming Chinese river crabs, the present study proposes a multifunctional automatic river crabs feeding boat based on Advanced RISC Machine (ARM) and Global Positioning System / Inertial Navigation System (GPS/INS) integrated navigation. This paper proposes a new calculation method based on real time point insertion. This method calculates the current target position of the boat in the real time according to the position of the boat and the turning points of the current route. A new turning and route-switching strategy is also presented in this paper to improve the ship's operational efficiency and prevent the ship from veering off the target route due to its high speed. Considering the boat's unique movement characteristics including non-linearity, large delay and underdamped nature, a route-speed dual-loop control algorithm is designed based on fuzzy Proportion Integration Differentiation (PID) method. Through analyzing the bait distribution associated with the feeding machine, the present study proposes an inner-spiral-based full coverage traversal method and a travel distance optimization model so as to improve the uniformity of the automatic feeding. Results show that the speed overshoot is no more than 5% and the steady-state error can be kept within 3%. Compared with the finite point method, the real time point insertion method decreases the peak route deviation errors by 82.82% and 84.14% while turning and going straight.

1. Introduction

As a major crabs farming country, China faces the daunting challenge for delivering uniform feeding during crabs farming (Sun et al., 2016). Bait is critical for breeding large and high-quality crabs, and therefore the evenness of feeding is of great importance to the quality of crabs (Kwan et al., 2016). Due to their physical limitation, crabs crawl at a very low speed, and their foraging range is also limited. Nonuniform feeding not only increases the operational cost, but also leads to fighting among regional crabs for the scarce bait in some local areas. Moreover, at different life stages, crabs have different demands for bait, and the bait distribution should be adjusted according to seasons, water temperature, weather, etc. This makes it necessary to precisely control the bait quantity (Zhao et al., 2016). Therefore, designing an automatic feeding boat to enable an accurate bait flow control carries special significance.

Currently, the study on automatic feeding boat is at its initial stage in both China and other countries. The bait feeding is mainly categorized into three types, namely, manual feeding, fixed-point machine feeding, and sides of machine feeding boat (Sun et al., 2015). Among them, manual feeding suffers from the lowest efficiency, high labor intensity and certain risk. Fixed-point machine feeding can dispense bait with a high accuracy in timing and quantity, and reduced labor intensity (Siikavuopio et al., 2017). However, the feeding machines are placed at fixed locations, and therefore cannot cover the central region of a crab pool. Sides of machine feeding boat need manual navigation across the crabs pools, and the feeding machines placed onboard are used to deliver bait (Jiang et al., 2014). This feeding method is relatively flexible and overcomes the drawback of limited coverage associated with the fixed-point feeding method. However, navigating the boat through the desired circular routes is a nontrivial task whose quality strongly depends on the operator's experience (Liu et al., 2013). This technical difficulty leads to the randomness of the actual route the boat effectively takes, which in turn causes the resulting feeding sites to change from time to time. Consequently, the evenness of bait distribution is compromised (Zhao et al., 2016).

As far as the driving mode is concerned, the feeding boat can mainly be categorized into three different modes, i.e., propeller mode, fan

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thruster mode and paddle wheel mode. Among them, paddle wheel mode can deliver large propulsion power, supreme anti-winding capability, small turning radius, etc., and it has been successfully applied to powering ship in rivers and lakes (Lynch et al., 2015). However, a typical paddlewheel ship exhibits a multitude of challenging control characteristics, including considerable nonlinearity, time delay and underdamped dynamics (Liu et al., 2014). Failing to fully account for those characteristics, the traditional PID control strategy cannot deliver an ideal performance in controlling feeding ships (Twu et al., 1997; Theorin and Hägglund, 2015).

To deal with the aforementioned issues, the present study proposes a novel design concerning the automatic feeding boat based on paddle wheel mode. In our control strategy, ARM serves as the main controller, and the locations of the target points on the navigation route are calculated in real time by the developed route calculation algorithm based on on-the-fly point insertion. A fuzzy-PID-based double closed loop motion control methodology is adopted here for speed and heading control. By analyzing the bait distribution generated by the automatic feeding machine, the present study designs an inner-spiral-based full coverage traversal method for navigating through crabs pools. Moreover, the travel distance and spacing are mathematically modeled and optimized, in an effort to reduce labor cost and enhance the efficiency of farming river crabs.

2. Materials and methods

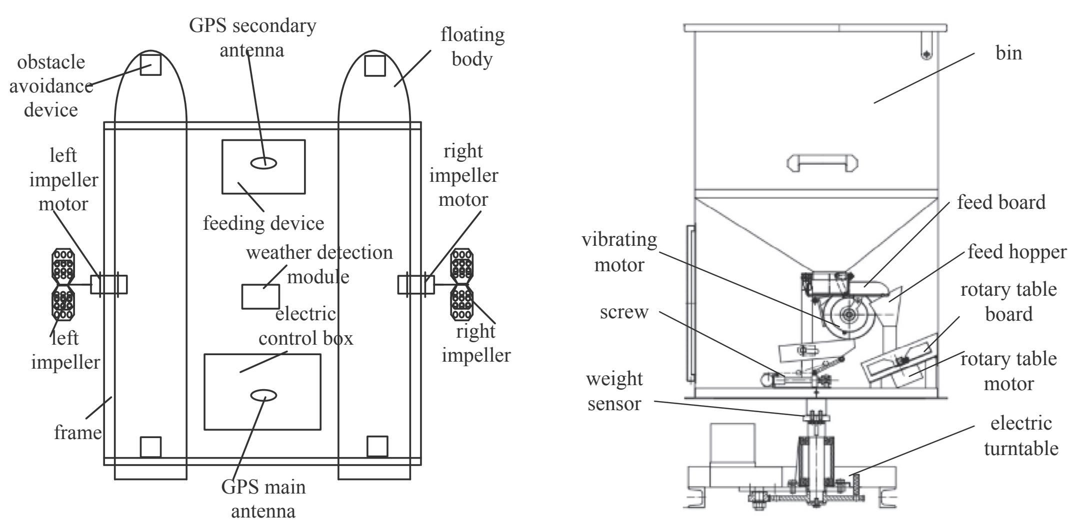
2.1. The structure of the feeding boat

2.1.1. Overall feeding boat design

The overall structure of the feeding boat is shown in Fig. 1a. The main part of the boat consists of two sizable floating bodies fixed in place by a central body frame. The left and right paddle wheels are fixed onto the body frame, and are used to power the boat. The feeding machine can deliver a controllable quantity of bait, the casting device can deliver an adjustable casting range, and the quantity of the remaining bait in the storage box is measureable. A collection of these devices is mounted on an electric turntable placed at the front of the boat, as shown in Fig. 1b. The electric controlling cabinet equipped with an ARM controller, a GPS radio station, a GPRS wireless communication device, a paddlewheel motor control module, a feeding device control module and a storage battery is installed at the stern of the boat (Bhattacharyya et al., 2015; Tenkanen et al., 2015). The primary antenna and the secondary antenna of GPS are mounted to the top of the electric control cabinet and the top of the feeding device, respectively, which provides the information concerning the boat's position, heading and speed. GPS navigation module is used the BD982 model, the navigation device is developed by the United States Trimble navigation company. It is configured to RTK mode, and its positioning accuracy can reach less than 10 mm. INS device module is used the IG-500E-G4A3P1-S, which is developed by the French SBG Systems company. Its positioning accuracy of heading angle is less than 0.5° (Ruan et al., 2017). Obstacle avoidance devices are installed at the front and the end of the two floating bodies, which detect and help the paddlewheel boat avoid obstacles during the navigation process. The boat is also equipped with a weather station module providing meteorological date such as wind speed and direction. These devices can collectively guarantee the safe operation of the boat and dynamically adjust the feeding strategy according to the working condition in real time.

2.1.2. System hardware structure

To flexibly respond to the operation requirements posed by various environments, the automatic feeding boat for river crabs farming can be operated in manual control, remote control and automatic navigation modes, with the corresponding structure of the hardware system shown in Fig. 2. Among them, the main controller is made with a cost-effective S3C2440A 32-bit processor designed by SAMSUNG based on ARM920T core. In automatic navigation mode, the main controller collects the position data from the GPS module, the attitude data from the Inertial Navigation Module (INM), and the draft date from the ultrasonic module. Subsequently, the assembled data set is processed by the built-in navigation algorithm, with the results fed into the Pulse Width Modulation (PWM) generation module and the General Purpose Input Output (GPIO) module to enable a flexible control of the boat navigation and the feeding operation. The corresponding information is displayed on an Liquid Crystal Display (LCD). Serial port communication is used for the interaction between GPRS module and S3C2440A so as to receive the instructions from the upper computer in real time, as well as uploading the information concerning the working mode, speed, heading, draft depth, remaining bait quantity and the remaining power in the battery back to the upper computer.



a. Overall structure of feeding boat b. Structure of automatic feeding machine

Fig. 1. Structure of feeding boat.