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Application of non-base station positioning system in rice transplanting

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Abstract. Rice transplanting machines have significantly increased the efficiency of rice planting and reduced labor costs. However, the transportation and loading of rice seedlings in the paddy fields still require a substantial amount of labor. In response to this need, implementing a fully automated rice transportation and loading system has become a demand for some enterprises, with the positioning of the rice transplanting machine being a critical subsystem to help locate the transportation destination. This paper, based on the theories of micro-controllers and multi-target positioning algorithms without base stations, utilizes literature review and theoretical analysis to design a base-station-free positioning system on a micro-controller. The system uses the Inertial Measurement Unit (IMU) module of the lower machine to collect the relative positions of the path nodes of the rice transplant machine. The upper machine's Multi-target Dead Reckoning (MDR) algorithm then determines the actual path, thereby pinpointing the specific location of the transplanter. This design will help complete the positioning of the rice transplanting machine in the paddy fields, reduce the impact of environmental factors on positioning accuracy, and lower the modification costs.

Keywords: Base-station-free positioning, rice transplanting machine, paddy field transportation, micro-controller.

1. Introduction

In China, rice is one of the main food crops [1]. In recent years, mechanized planting techniques have gradually replaced manual transplanting to improve production efficiency. However, the transportation of rice seedlings still relies on manual labor [2].

In terms of paddy field transportation, the College of Engineering at Heilongjiang Bayi Agricultural University has developed a rail-based transportation cart [3]. This design uses a PLC control method based on a remote wireless communication module, with batteries and a DC servo motor providing power to the cart. By laying transportation tracks on the paddy field ridges, it prevents the destruction of the field structure and achieves mechanized transportation of seedlings to the working position of the rice transplanter. Fujin Pengwei Agricultural Equipment Co., Ltd. has also developed an electric rail-based paddy field transporter. Compared to the transportation cart developed by the College of Engineering at Heilongjiang Bayi Agricultural University, this design includes distance sensors [4]. The cart can detect obstacles via the distance sensors and automatically stop, further enhancing the cart's level of intelligence. However, both designs still require manual operation to determine the transportation target and select the path, and have not achieved full automation and unmanned operation.

Regarding the positioning algorithm, this paper adopts the Multi-target Dead Reckoning (MDR) algorithm proposed by Hongyang [5]. This algorithm introduces a new method to address the problem of base-station-free multi-target 2D positioning. It uses multidimensional scaling analysis to convert the topological structure of multi-target positions based on ranging into a form of relative coordinates. Through this conversion, the optimization problem is transformed into a Procrustes problem concerning the positioning results of the odometer and the relative topological structure of multi-target positions. A topological fitting algorithm is then employed to obtain a closed-form solution to this optimization problem. This approach not only simplifies the original optimization problem but also enhances the utilization of ranging information.

This paper utilizes the MDR algorithm to design a base-station-free positioning system based on a microcontroller, achieving the positioning of rice transplanters in complex environments. This design combines the Internet of Things with agriculture, providing an accurate positioning method for the automated transportation system of rice seedlings in the field, and helping the transport vehicle quickly locate the rice transplanter. To some extent, this design also offers some valuable suggestions for the development of agricultural mechanization and intelligence.

2. Lower Computer Design

2.1. Main Control Chip

This design utilizes the STM32F103C8T6 chip, a 32-bit microcontroller based on the Cortex-M3 core, developed by STMicroelectronics. It features 37 GPIO ports and 4 timers/counters [6].

This microcontroller offers low cost, ease of development, and high reliability. It supports various development tools and programming languages, such as Keil, IAR, and C, making development relatively easy. With a relatively low price, it achieves high reliability and stability, making it suitable for large-scale applications in industrial control, automotive electronics, and other fields.

2.2. Inertial Measurement Unit

An Inertial Measurement Unit (IMU) is a device that integrates multiple inertial sensors to measure and estimate an object's motion state in space. There are two types of IMUs on the market: "6-axis IMU" and "9-axis IMU." A "6-axis IMU" has gyroscopes and accelerometers mounted on three orthogonal axes, providing six degrees of freedom, which can measure an object's angular velocity and acceleration in three-dimensional space. A "9-axis IMU" adds a magnetometer to the 6-axis IMU's accelerometer and gyroscope. This design uses STMicroelectronics' 9-axis IMU sensor LSM9DS1 for the experiment.

A three-axis accelerometer is an inertial sensor that measures acceleration by calculating the tension of a spring. The corresponding formula is shown as (1), where a_m represents the measured acceleration, f represents the spring tension, and m represents the mass of the mass block.

$$a_m = \frac{f}{m} \tag{1}$$

The obtained accelerations along the X, Y, and Z axes are denoted as a_X, a_Y, and a_Z, respectively. To obtain the corresponding displacement, the acceleration in each direction needs to be integrated twice with respect to time, as shown in formula (2):

$$\Delta X = \iint a \ d^2t \tag{2}$$

The number of a is determined by a_X, a_Y, and a_Z altogether:

$$a_{horizontal} = \sqrt[2]{a_X^2 + a_Y^2} \tag{3}$$

The direction is:

$$\tan\beta = \frac{a_X}{a_Y} \tag{4}$$

Since the working surface of the rice transplanter is not horizontal, errors can arise due to bumps. To minimize these errors, the $a_{horizontal}$ value is corrected based on the Z-axis acceleration measurement.

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The Z-axis acceleration is primarily influenced by Earth's gravitational acceleration. During moments of bumpiness, the Z-axis acceleration is given by:

$$a_Z = g\cos\alpha \quad (5)$$

Through calculations, the vertical tilt angle α can be determined, and the actual horizontal acceleration can be obtained as:

$$a_{real} = (a_{horizontal} + a_Z\tan\alpha)\cos\alpha \quad (6)$$

A three-axis gyroscope measures angular velocity using the Coriolis force. The Coriolis force is a fictitious force that arises when a straight-line motion is observed in a rotating system, causing the straight trajectory to deviate. In reality, the straight-line motion is not affected by any force, as shown in formula (7):

$$F_{coriolis} = -2m^b\omega \times v \quad (7)$$

The angular velocity can be obtained as:

$$\omega = \frac{F_{coriolis}}{(-2)vm^b} \quad (8)$$

A magnetometer is a device that uses the Earth's magnetic field to determine direction. It provides data on the magnetic field experienced along the X, Y, and Z axes, which is then transmitted to the microcontroller's computation unit to calculate the heading angle relative to the magnetic north, enabling geographic orientation detection. Magnetometers typically use three orthogonally positioned magnetoresistive sensors, with each sensor on a different axis used to detect the magnetic field strength in that direction.

3. Host Computer Design

The host computer receives two types of data through LoRa: the magnitude of acceleration a_{real} from the accelerometer and the angular velocity ω from the gyroscope. To reduce errors, the data received within 0.1 seconds is processed:

$$X_k = X_{k-1} + v_{k-1}\Delta t + \frac{1}{2}a_{real}\Delta t^2 \quad (9)$$

$$v_k = v_{k-1} + a\Delta t \quad (10)$$

$$\theta_k = \theta_{k-1} + \omega\Delta t \quad (11)$$

Where X_k, v_k, and θ_k represent the displacement, velocity, and rotation angle calculated after receiving the k-th set of data, respectively.

After obtaining the corresponding data, the host computer uses the Multi-target Dead Reckoning (MDR) algorithm to plot the path of the transplanting machine. First, it needs to draw the real-time topological structure of the machine's operating path, as shown in Figure 1, where S_k represents the position of the transplanting machine at the k-th moment, X_k is the displacement value estimated from time k-1 to k, θ_k is the angle value estimated from time k-1 to k, and the initial position is S_0.

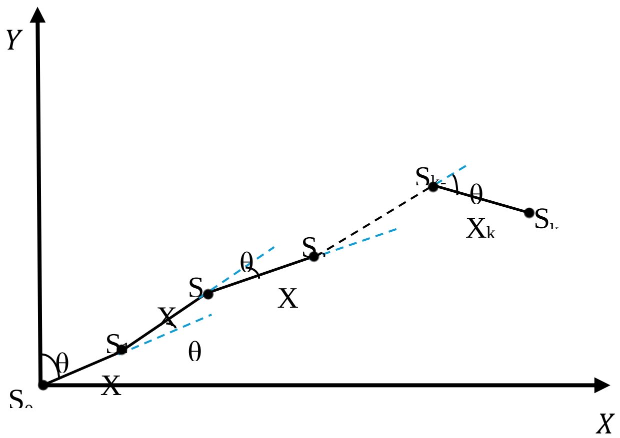

Figure 1. Example of Transplanting Machine Path Topology Diagram

If $S_k = [x_k, y_k]$, then the position of the target at time k can be obtained using the following formula:

$$x_k = x_0 + \sum_{i=1}^{k} X_i \sin\left(\sum_{j=1}^{k} \theta_j\right) \quad (12)$$

$$y_k = y_0 + \sum_{i=1}^{k} X_i \cos\left(\sum_{j=1}^{k} \theta_j\right) \quad (13)$$

The algorithm directly uses the odometry results, combining the results at time k with the position estimates at time k-1 to obtain the prior estimates for all targets at the current moment. Additionally, using the relative distance information from all nodes, the Multi-Dimensional Scaling (MDS) algorithm calculates the relative position coordinates that represent the node position topology. This way, the relative position coordinates can represent the true topology and, when combined with prior information, establish an optimization problem. The Time-Varying Kalman Filter (TFA) algorithm is used to solve this optimization problem, providing the analytical expressions for the positions of all targets at the current moment.

4. LoRaWAN

LoRa Wide Area Network (LoRaWAN) is a wide-area IoT communication protocol based on LoRa technology. It provides a low-power, long-range, and large-scale connectivity solution suitable for a wide range of IoT applications. The design goal of LoRaWAN is to achieve low-cost, low-power wireless connections while providing wide-area coverage and high reliability [7]. This paper employs this technology to achieve real-time communication between the upper-level and lower-level systems.

The LoRaWAN protocol defines three types of end devices: Class A, Class B, and Class C.

Class A (all) devices use the ALOHA protocol for on-demand data reporting. After each uplink transmission, two short downlink receive windows follow, allowing for bidirectional communication. The upper-level terminal must wait for the lower-level device to report data before sending data to it.

Class B (beacon) devices, in addition to the random receive windows of Class A, open receive windows at specified times. To enable the upper-level terminal to open receive windows at specified times, it needs to receive time-synchronized beacons from the gateway.

Class C (continuous) devices keep their receive windows almost always open, closing briefly only when sending data to the lower-level devices. Since Class C devices are in continuous receive mode, data can be sent to them at any time.

Due to the need to transmit a large amount of data in real-time, the Class C terminal was chosen for this positioning device design.

The data communication protocol between the upper-level and lower-level devices is shown in Table 1:

Table 1. LoRaWAN Communication Protocol

Byte Order	Function
Byte 1	Upstream Frame Header,Fixed Value, 0xAA
Byte 2	First Two Digits of Device ID(Device ID is the last 4 digits of DevEui, for example, the first two digits of the ID 0095690100000102 are 0x01.)
Byte 3	Last Two Digits of Device ID(Device ID is the last 4 digits of DevEui, for example, the first two digits of the ID 0095690100000102 are 0x02.)
Byte 4	The data reporting count starts from 0 and increases by 1 with each report. After 0.1 seconds, it resets back to 0.
Byte 5	High Byte of Acceleration Data(High 8bit)
Byte 6	Low Byte of Acceleration Data(Low 8bit)
Byte 7	High Byte of Angular Velocity Data(High 8bit)
Byte 8	Low Byte of Angular Velocity Data(Low 8bit)
Byte 9	Frame Tail,Fixed Value, 0x0F

5. Discussion

Through thorough research on the current intelligent needs in rice planting, this design implements a base-station-free positioning system. By using LoRa to transmit relative direction and distance, the system fits and constructs the absolute position, aiding in the localization of the transplanter.

Compared to existing positioning methods, such as the Global Navigation Satellite System (GNSS) and 5G positioning, which are significantly affected by environmental factors, and RFID positioning, which is constrained by the range of positioning [8-11], commonly used distance-based positioning technologies—such as those based on visual sensors, ultrasonic positioning, Bluetooth signal strength, and Ultra-Wide Band (UWB)—can only provide the relative topology of targets and cannot determine the exact absolute position.

This positioning system, utilizing a base station-free approach, not only reduces costs but also meets the positioning needs in complex environments such as rice paddies. It provides an economical solution for fully automated rice planting methods and offers a new perspective for the intelligent development and upgrading of existing manually controlled transport equipment. Additionally, it presents a novel solution for positioning in complex environments, such as for rescue equipment in disaster sites like fires or earthquakes.

6. Conclusion

This paper, through studying and researching LoRa IoT signal transmission methods and based on a microcontroller control chip, designs a positioning system for rice transplanters. The system's lower-level component uses an IMU (Inertial Measurement Unit), which includes a three-axis accelerometer, three-axis gyroscope, and magnetometer to accurately measure the movement distance and rotation angle of the transplanter over short time intervals. The data obtained is then transmitted to the upper-level machine via LoRa. Upon receiving the data, the upper-level machine uses the MDR algorithm to create a path map to locate the transplanter, assisting the unmanned transport vehicle in finding its target.

In the current research and design, transportation vehicles are generally controlled manually from a backend system. The stationless positioning system offers a new approach and method for intelligent updates to the design of current rice paddy transport vehicles, further advancing the development of agricultural mechanization and automation. This system also provides a viable product option for positioning needs in complex environments.

In the design process of this solution, due to geographical and time constraints, the results were not optimized using Kalman filtering, and the system could not be validated and tested in an actual rice paddy field. Future research will focus on optimizing the accuracy for real-world applications, and there is potential for developing three-dimensional positioning capabilities, rather than being limited to a two-dimensional plane.

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