Research on Internet of Things based Hand-Pushed Wheel Rangefinder Technology

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Abstract: In order to address the accuracy issues of the hand-pushed wheel rangefinder, this paper proposes a solution that integrates IoT technology and angle sensors into the device to enhance accuracy and informationization level. A wheel rangefinder based on Internet of Things (IoT) technology is designed. The central control device of this system adopts a STM32 microcontroller. The system includes a voltage boosting and dropping circuit, a reset circuit, a gyroscope module, an indicator light module, and a Wireless Fidelity (WiFi) transmission module. The gyroscope module is designed to calculate the actual running distance of the handcart through angle measurement, enabling real-time recording and remote transmission of measurement data. Compared with total stations, rangefinders, and measuring ropes, this system is of good effectiveness and its average error is within 1%. At the same time, it has the capability to save measurement information to the database.

Keywords: Accuracy; Informationization; STM32 Microcontroller; Manually Propelled Wheel; Rangefinder; Detection; IoT

1. Introduction

The rapid advancement of smart industrial products has ushered in widespread applications of angle detection technology in recent years [1-3]. Among these innovations, the hand-pushed wheel-based rangefinder system stands out as a notable distance measuring device that leverages this cutting-edge technology. Through the coordination of multi-dimensional sensor modules, the system has the capability to simulate electrical signals, providing an accurate reflection of the real environment and transmitting crucial data to the main control device for real-time feedback [4].

In manufacturing processes, the need often arises to measure irregular and long-distance special areas, where conventional straight-line measurement methods may yield substantial errors. In contrast, the hand-pushed wheel rangefinder system offers superior measurement accuracy in such scenarios, making it an invaluable asset in industrial settings [5,6]. Furthermore, by integrating WiFi devices for remote data transmission, the system effectively reduces the bulk of the measuring equipment, thus enhancing its adaptability to diverse distance detection requirements in various environments [7].

The utilization of angle detection technology in the hand-pushed wheel rangefinder system signifies a significant leap forward in precision measurement capabilities, particularly for challenging industrial environments. Its ability to provide accurate measurements of irregular and long-distance areas, coupled with the convenience of remote data transmission via WiFi, positions the system as a highly beneficial tool for modern industrial applications. As industries continue to embrace smart technologies, the hand-pushed wheel rangefinder system exemplifies the potential for innovative solutions to address complex measurement challenges and enhance operational efficiency in industrial settings.

2. Solution Design

2.1 Development Background and Methodology

The development of a handheld rangefinder with information storage capabilities based on the Internet of Things aims to provide a high-efficiency and intelligent measurement tool to meet the modern industrial and commercial needs for precise measurement and data management.

Sensor Technology: Advanced sensor technologies, such as laser rangefinder modules or ultrasonic sensors, are utilized to achieve high-precision distance measurements.

IoT Connectivity: The rangefinder is connected to the Internet of Things (IoT) using wireless communication technologies like WiFi or Bluetooth, enabling data transmission and remote monitoring.

Data Storage and Management: The rangefinder integrates storage devices that can store a large volume of measurement data, which can be managed and analyzed through cloud platforms or mobile applications.

2.2 System Functional Analysis

(1) Detect the angle changes of the hand-pushed wheel during rotation using a gyroscope, and calculate the distance traveled by the hand-pushed wheel by combining the changes in angle values with the circumference of the wheel.

(2) Set up a WiFi data transmission module, provide real-time feedback of the distance values detected by the hand-pushed wheel rangefinder, and display on the mobile app interface.

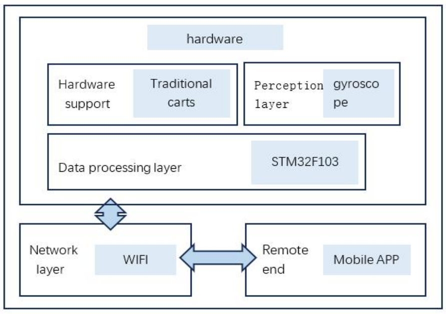

Figure 1. The Overall Framework of the System

2.3 Overall Solution Design

According to the working principle of the STM32F103 microcontroller, we have implemented the corresponding reset and enable circuits [8]. are designed. This system includes hardware circuits and software parts. It utilizes angle sensors to detect changes in the rotation angle of the cart [9] and digitizes the information for the microcontroller. The microcontroller analyzes the digital signals detected by the sensors, converts them into distance information, and transmits it to the remote end, achieving long-distance wireless measurement and data storage. The system framework design is illustrated in Figure 1.

2.4 Distance Detection Scheme Design

During the rolling of the hand-pushed wheel, the angle changes of the wheel are detected in real-time through the detection sensor. In this design, the MPU6050 which is a six-axis gyroscope, is chosen to detect real-time angle of the wheel.

How to establish a coordinate system: based on the module's PCB board; the z-axis is from the bottom to the top; the y-axis is from left to right; the x-axis is from back to front. The raw data includes acceleration values and angular velocity values in the x, y, and z directions. By algorithmically processing the values, the angle change of the module can be accurately calculated. By combining the change in angle values with the circumference of the wheel, the distance can be calculated. As shown in Formula (1).

The calculation process is as follows:

$$y = L \times \frac{\Delta x}{360} = \frac{L \times (x_2 - x_1)}{360} \tag{1}$$

Where L represents the circumference, x_1 represents the previous angle, x_2 represents the current angle, and $\Delta x = x_2 - x_1$.

Table 1. Comparison of Wireless Communication Methods

	NB-IOT	LoRa	LoRa	WIFI	Bluetooth
network topology	cellular networking	lora gateway	lora gateway	wireless router	Bluetooth mesh gateway
transmission distance	＞10km	＞20km	<100m	<50m	<10m
network access capacity	about 200,000	about 60,000	200-500	about 50	60,000
battery life	10 years	10 years	2 years	several hours	several days
cost	5-10$	5$	1-2$	7-8$	
frequency bands	licensed bands,	unlicensed bands	unlicensed bands	unlicensed bands	unlicensed bands
transfer speed	＜100kbps	0.3-50kbps	<100kbps	>1M	1M
network latency	7S -11S	TBD	＜1S	＜1S	＜1S
suitable place	outdoor	outdoor	indoor	indoor & outdoor	

2.5 Wireless Signal Transmission Scheme Design

After diverse data captured, it can be conveyed to the end-user application via high-precision long-range wireless devices. There are several transmission schemes that can be chosen and are shown in Table 1.

After comparing various technical factors [10], we ultimately opt for WiFi, which is known for its high-efficiency.

2.6 System Circuit Design

All chips used work at a voltage of 3V, therefore this system utilizes a 3V power supply. In addition, the MP1584EN has good voltage regulation linearity, so this module is chosen.

The WiFi module selected is the ESP8266 module, renowned for its high stability. It interfaces with the microcontroller via UART protocol to facilitate wireless data transmission.

The gyroscope (MPU6050) module communicates with the microcontroller via the I2C protocol, and they are connected by two bus lines, SCL and SDA.

The schematic diagram of the system circuit design is depicted in Figure 2.

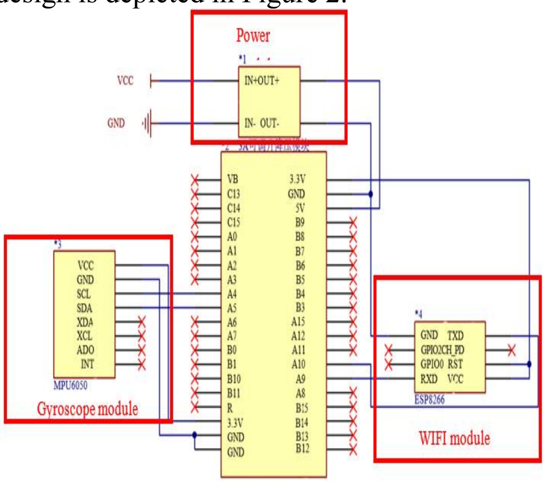

Figure 2. System Circuit Diagram

3. System Software Design

The primary objective of incorporating the STM32F103 microcontroller within the system is to facilitate the conversion of angle values detected by the MPU6050 gyroscope module into distance values of the wheel. This process involves leveraging the processing power of the microcontroller to accurately compute and convert the angle measurements into corresponding distance values, providing crucial data for the operation of the wheel rangefinder.

Upon the successful conversion of angle values to distance values, the system is designed to transmit this information remotely to a dedicated mobile application via the integrated WiFi module. The use of the WiFi module enables seamless, wireless communication and data transmission, allowing for real-time display of the distance values on the mobile app. This remote accessibility and real-time display feature enhance the usability and practicality of the wheel rangefinder, providing users with immediate access to accurate distance measurements.

The overall system flowchart, delineating the sequential process from angle detection to distance value transmission, is visually depicted in Figure 3. This flowchart serves as a comprehensive illustration of the entire operational pathway, showcasing the interconnectedness of the components and the systematic flow of data from detection to remote display. By effectively capturing the essence of the system's functionality, the flowchart offers a clear and concise representation of the system's operational logic and data flow.

In sum, the integration of the STM32F103 microcontroller, MPU6050 gyroscope module, and WiFi module serves to enable the seamless conversion, transmission, and real-time display of distance values, thereby enhancing the effectiveness and practicality of the wheel rangefinder system.

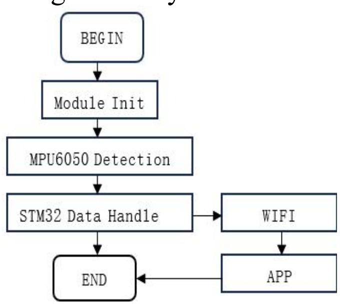

Figure 3. Main Program Flow Chart

Once the communication protocols and drivers for each module are encapsulated and initialized, the WiFi module and MPU6050 module establish communication using the widely adopted I2C protocol. The MPU6050 sensor captures raw data, comprising acceleration and angular velocity measurements along each axis [11]. However, to derive the rotational angle, further algorithmic processing is required.

In this particular design, the MPU6050 module incorporates a digital motion processor (DMP) that plays a crucial role in the calculation of angle values. The DMP, embedded within the MPU6050 module, is utilized to process the raw data and provide quaternion values. From these quaternion values, the rotational angle can be derived using a calculation formula, as presented in Formula 2.

The calculation formula, specified in Formula 2, defines the relationship between the quaternion values and the resulting angle measurements. By implementing this formula, the microcontroller can accurately compute the rotational angle based on the quaternion data obtained from the MPU6050 module. This algorithmic processing significantly enhances the precision and reliability of the angle detection mechanism and ensures accurate distance calculations for the wheel rangefinder system.

In summary, the integration of the WiFi module and MPU6050 module, utilizing the I2C communication protocol and algorithmic processing via the DMP, enables the acquisition of quaternion values from the MPU6050 sensor. These quaternion values serve as the foundation for calculating the rotational angle, ultimately contributing to the accurate determination of distance values by the wheel rangefinder system.

$$pitch = \text{asin}\,(-2 * q_1 * q_3 + 2 * q_0 * q_2)$$
$$roll = atan2(2 * q_2 * q_3 + 2 * q_0 * q_1, -2 * q_1 * q_1 - 2 * q_2 * q_2 + 1)$$
$$yaw = atan2(2 * (q_1 * q_2 + q_0 * q_3), q_0 * q_0 + q_1 * q_1 - q_2 * q_2 - q_3 * q_3) \quad (2)$$

Once the angle values are computed, the system can detect variations in the angle value as the wheel rotates. By combining these angle values with the known circumference of the wheel, distance values can be calculated using Formula 1. This formula establishes a direct relationship between the angle values and the corresponding distances traveled by the wheel.

Upon calculating the distance values, they are encapsulated using the UART (Universal Asynchronous Receiver-Transmitter) protocol. The UART protocol facilitates the serial communication between the microcontroller and the WiFi module. The encapsulated distance values are then transmitted from the microcontroller to the WiFi module.

The WiFi module plays a crucial role in wirelessly transmitting the distance values to a dedicated mobile application. The WiFi module employs wireless communication protocols, such as TCP/IP or UDP, to establish a connection with the mobile app. The encapsulated distance values are sent over this wireless connection to the mobile app in real-time.

Once received by the mobile app, the distance values are displayed on the user interface, providing real-time feedback on the distance traveled by the wheel. Additionally, the mobile app can log and store the received distance values for future reference or analysis purposes.

The entire process, from calculating distance values based on angle variations to transmitting them via the UART protocol to the WiFi module, is illustrated in Figure 4. This figure visually represents the flow of data, starting from the computation of angle values, followed by distance calculation and encapsulation, and concluding with the transmission and display of distance values on the mobile app.

In summary, the system utilizes angle variations during wheel rotation, combined with the known wheel circumference, to calculate distance values using Formula 1. These distance values are then encapsulated using the UART protocol and transmitted to the WiFi module. From there, they are wirelessly sent to a mobile app for real-time display and data logging, enhancing the functionality and usability of the wheel rangefinder system.

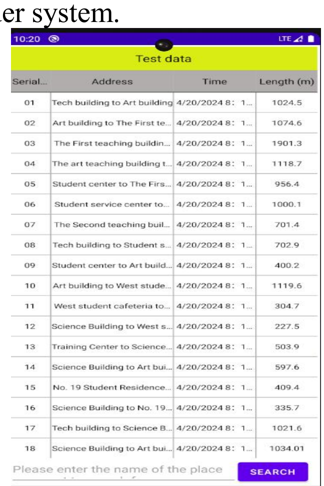

Figure 4. App Displays the Results in Real Time and Saves it

4.System Running Results

Figure 5 provides a comparison of 350 measurements taken by the system, along with measurements obtained from other devices such as the total station, rangefinder, and measuring rope. This comparison aims to evaluate the accuracy and reliability of the system's distance measurements in relation to established measurement methods.

Table 2 presents a detailed comparison of the minimum error, maximum deviation, and mean deviation between the distance measurements obtained from the system and those obtained from other tools such as the total station, rangefinder, and measuring rope. This analysis allows for a comprehensive evaluation of the accuracy and consistency of the system's measurements in comparison to established measurement methods

Table 2. Comparison of Statistic Information between the System and Other Tools

Tool	Minimum Error	Maximum Error	Mean Deviation
Total Station	0	0.4	0.17
Rangefinder	0	1	0.21
Measuring Rope	0	1	0.34

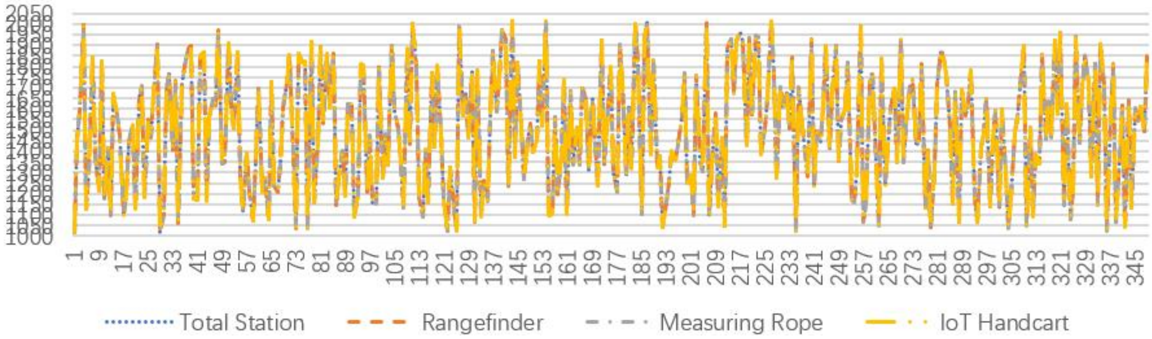

Figure 5. Comparison of Four Tools

5. Conclusion

In conclusion, the handcart-style distance measuring system, controlled by the STM32F103 microcontroller, demonstrates an innovative approach to calculating distances based on the angle changes of the cart's wheels. This design enables accurate distance measurements for handcart movement and facilitates the transmission of distance information via WiFi to a terminal for real-time display and storage. Through comparative analysis with established measurement tools, the system's effectiveness and reliability have been successfully verified.

Despite its promising features, the system does exhibit several shortcomings that warrant attention. Firstly, the hardware and software components of the system may face limitations due to economic constraints, potentially affecting performance and scalability. Additionally, the overall size of the system may be considered excessive, impacting portability and practicality in certain applications. Furthermore, the system's modular integration could be improved to enhance ease of maintenance and future upgrades. Addressing these identified shortcomings is crucial for enhancing the overall performance and applicability of the system. By investing in more robust hardware and optimizing software algorithms, the system can achieve higher levels of accuracy and efficiency in distance calculations. Moreover, efforts to reduce the system's size and enhance modularity can enhance its usability across various settings and scenarios.

With these improvements implemented, the handcart-style distance measuring system holds significant potential for broader applications in the future. Its ability to provide accurate distance measurements, coupled with wireless data transmission capabilities, makes it suitable for diverse industries such as logistics, transportation, and urban planning. By addressing the existing limitations and refining its design, the system can pave the way for enhanced efficiency and precision in distance measurement applications, contributing to its widespread adoption and utility in various fields.

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