Transactions on Computational and Scientific Methods | Vo. 4, No. 12, 2024
ISSN: 2998-8780
https://pspress.org/index.php/tcsm
Pinnacle Science Press

Development and Assessment of an Automated Obstacle Avoidance System Based on Laser Ranging Technology

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Abstract:

The increasing demand for water operations has driven the adoption of small unmanned vessels as essential tools due to their flexibility, compactness, and labor-saving capabilities. However, these vessels face challenges in navigating complex water conditions, where obstacles can cause significant damage. This study develops an automatic obstacle avoidance system leveraging laser ranging technology to provide accurate, low-cost, and robust obstacle detection and navigation for small unmanned ships. The system determines the relative position and velocity of obstacles, enabling proactive avoidance. Testing demonstrated its effectiveness in detecting and evading obstacles, ensuring safe operation. While the system performs well in accuracy, response speed, and robustness, future work will address its adaptability to diverse sea conditions, vessel types, and the recognition of obstacle size, shape, and motion state.

Keywords:

Automatic Obstacle Avoidance; Laser Distance Measurement; Microcontroller.

1. Introduction

As the demand for water operations is gradually increasing, small unmanned vessels are being widely used as an important water operation tool because of their advantages of miniaturization, flexibility and substitution of manual labor[1]. However, small unmanned ships face complex water conditions when performing special tasks and can cause irreparable damage if they encounter obstacles without timely avoidance.

At present, the collision avoidance systems used on large ships at home and abroad mainly include automatic radar mapper ARPA, automatic ship identification system AIS, etc[2,3]. However, due to the expensive price of such obstacle avoidance equipment, it is not suitable for application to small unmanned ships. The current science and technology is constantly updated, laser technology is maturing and has gradually penetrated from high-tech products to our daily life. Laser technology has a wide range of application fields, including medicine, industry, communication and many other fields, and its unique advantages have been widely used in these fields. Nowadays, laser ranging technology has been popularized and can be used to measure the distance between ships[4]. The speed between ships can be calculated by the pulse interval time emitted from the laser rangefinder, and thus the relative position and distance of the measured object can be obtained. Therefore, it is necessary to develop an automatic obstacle avoidance system with high accuracy, low price, good stability, and also able to realize obstacle avoidance initiative during the navigation of small unmanned ships[5].

1.1 System Design Ideas

The main design idea of this system is to use STM32F103ZET6 MCU as the main control chip, for the problem that laser detection has one-way, the thesis uses stepper motor as the electric head to drive the laser sensor to realize 180° area scanning, through the laser sensor constantly emits laser pulses to detect the information of obstacles around the unmanned ship, the MCU will process the collected information, if the distance between this ship If the distance between the ship and the obstacle is less than the safety distance set by the system, the alarm unit will issue an alarm, and the microcontroller will drive the rudder for evasion. The block diagram of system composition is shown in Figure 1.

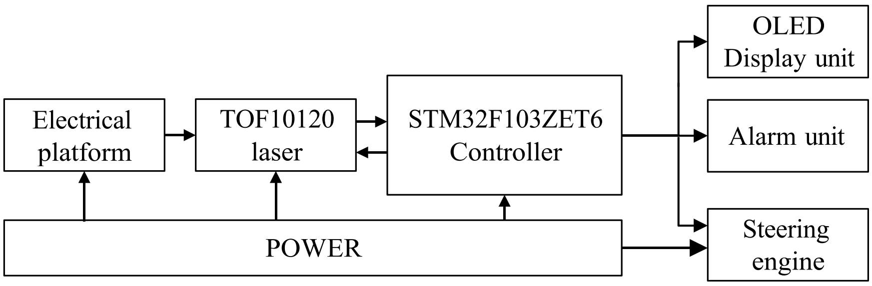

Figure 1. Block diagram of system composition

2. Laser Distance Measurement Principle

Laser distance measurement is achieved by using a laser as a light source for distance measurement. Compared with other tools used for distance measurement, laser has many advantages, such as single color, stability of direction, high brightness, high measurement accuracy, and long range[6]. Now it has been widely used in electric power, water conservancy, communication, land transportation, sea transportation, etc.

The principle of laser pulse ranging is shown in Figure 2, The transmission through the medium enables the transmission of laser pulses with a specific frequency to the optical elements. All surfaces have a reflection effect as well as a scattering effect of the laser. The optical element is then transmitted to the receiving circuit using the reflection principle, and the time difference of the reflected wave is used to obtain an accurate distance.

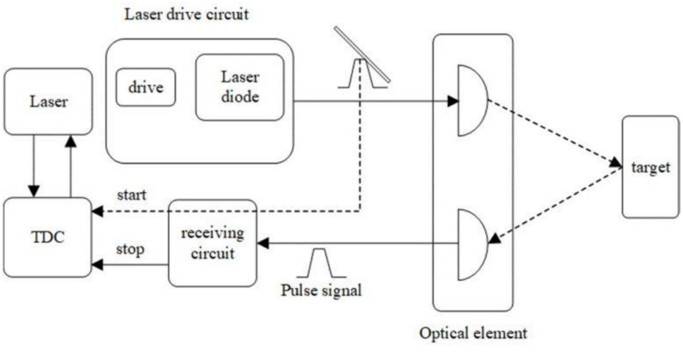

Figure 2. Laser pulse distance measurement principle

The distance between the target and the sensor is set as *S,* the time interval between the laser pulse from emission to round trip is *T,* and the propagation speed of light in vacuum is $C=3\times 10^8\ m/s$

This leads to:

$$S=\frac{1}{2}C_0T$$

Assuming that the modulation frequency of the laser pulse is f and the number of clock pulses in time t is N, the distance to the target D is obtained as follows.

$$D = \frac{C_0}{2} NT = \frac{C_0}{2f} N$$

3. System Hardware Design

3.1 STM32F103ZET6 Minimum System Design

The STM32F103ZET6 features a 72 MHz CPU speed and up to 1 MB of flash memory. It includes motor control peripherals as well as CAN and USB full-speed interfaces. STM32 series ARM Cortex-M3 32-bit flash microcontrollers operate with low power, low voltage, and combine excellent performance with real-time functionality. Therefore, the STM32F103ZET6 is selected as the main control chip in this paper.

The STM32 microcontroller minimum system design system contains the basic functions such as power supply, reset and clock. The power supply provides power to the entire system and ensures the normal operation of the system. The reset role is for the reset and reset of the system, the external operating principle is that a specific state to let the circuit initialize, its equivalent to the conversion to an empty state, for the internal is the reset and reload of the microcontroller, registers and storage devices preset values for the manufacturer. And the clock circuit provides the appropriate frequency for the operation of the microcontroller. Figure 3 shows the composition of the minimum system design.

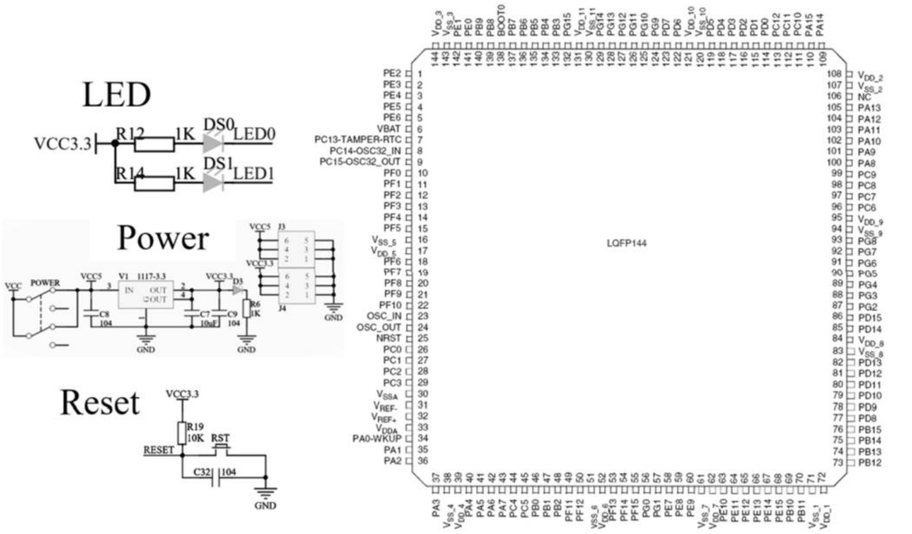

Figure 3. STM32F103ZET6 minimum system design

3.2 Data Acquisition Unit Design

The biggest advantage of the TOF10120 laser module is the long range measurement and simple operation is shown in Figure 4. The program simply needs to send a command string to the module serial port through the microcontroller to send back distance data to the microcontroller. If you send a string command for automatic distance measurement, the module will automatically send back data according to a certain frequency, and the relevant physical quantities can be set by the command string. The sensor only needs the serial port to be implemented[7,8].

One-way and two-way ranging techniques are the main methods for traditional ranging techniques. In a better modulated signal level or in a non-line-of-sight environment, the RSSI (Received Signal Strength Indication) ranging method is superior[9]. This method uses the time of flight of the data signal shuttling back and forth between a pair of transceivers to measure the distance between two points. Since the beam has a certain amount of dispersion, the energy becomes weak, and when the distance is measured at a long distance, only the stability of the laser pulse with a high density of light intensity distance measurement is guaranteed. The dispersion can be solved by increasing the light intensity through the stability of the directionality and the singularity of the light color, and effectively improving the signal-to-noise ratio of the receiving system, in addition to being able to accurately determine the position direction. Due to the short round-trip time and fast speed of light. To obtain accurate measurements, the round-trip time must be greater than the light pulse.

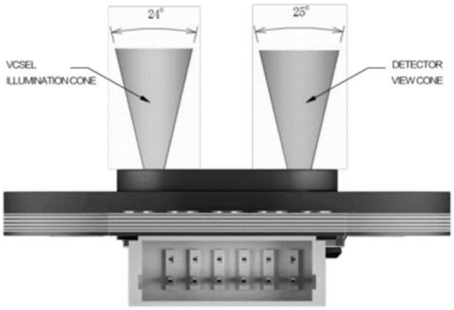

Figure 4. TOF10120 range measurement schematic

3.3 Display Unit Design

OLED (Organic Light Emitting Diode), known as organic light emitting diode. It is mainly made of a glass substrate and a very thin polarization layer. With selfluminous, wide viewing angle, and energy saving, no backlight characteristics, its relative to other displays, high contrast, thin, and wide viewing angle, fast response time, the use of temperature light, can be used for flexible panels, its structure and manufacturing simple is shown in Figure 5.

The OLED display controller software is based on the STM32 microcontroller written in C language. It mainly configures the STM32 microcontroller pins, implements the display functions, transmits the required display information to the OLED display controller chip, controls the OLED display, performs chip selection and reset, and performs display and display clear operations.

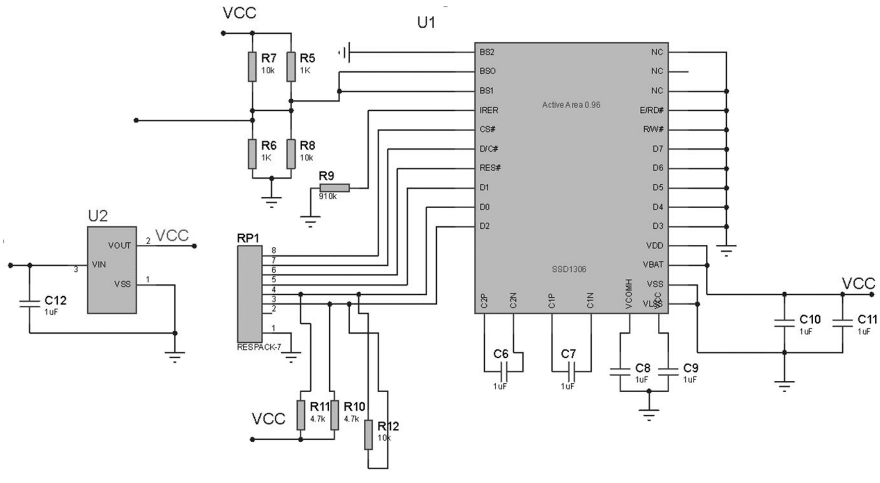

Figure 5. TOF101OLED schematic

3.4 Alarm Unit Design

When the measurement distance of the small unmanned ship obstacle avoidance system exceeds its set value, the alarm circuit will immediately issue an alarm at this time, and its unique intuitive nature can quickly give audible and visual feedback to the operator indicating that the obstacle is about to be avoided, and this setting greatly reduces the probability of unmanned ship collision with the obstacle and guarantees the navigation safety. In this paper, we mainly use the active peak alarm and LED light as one alarm, as Figure 6. shows the schematic diagram of the sound and light alarm.

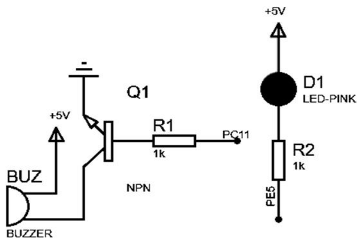

Figure 6. Schematic diagram of the audible and visual alarm

3.5 Motorized Head Design

Since a laser rangefinder emits only one laser beam, it can only measure a narrow point in front of it and cannot reach a wide detection range. Therefore, in order to increase the sensing range of the laser sensor, this thesis designs a free platform that can be rotated horizontally to expand the sensing range of the environment. The stepper motor has excellent start-stop and reversal response, high reliability, speed proportional to pulse frequency, and a relatively wide speed range. So the stepper motor is chosen as the drive for the motorized head design. The combination of the laser distance sensor and the rotary stage allows the stepper motor to rotate and perform horizontal scanning, which extends the control range of the whole system. The physical diagram of the motorized head in the test is shown in Figure 7.

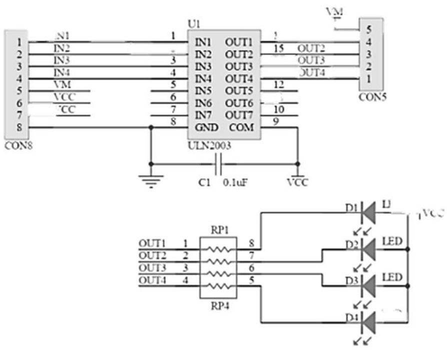

Figure 7. Motorized head schematic

3.6 Correction Circuit Design

In this paper, the rudder is used as the correction module of the ship's obstacle avoidance system. The operation principle is to modulate the rudder by PWM (Pulse Width Modulation), and thus a stable voltage can be obtained.

The input/output of the microcontroller is controlled to produce a signal with a certain pulse width and sent to the servo to match the servo output with the deflection angle until another signal with a new pulse width is sent to the processor to change the output angle again[10]. It is also able to compare the voltage of the DC with the voltage of the potentiometer, which in turn produces a relative value in the output of the voltage difference. The forward and reverse rotation of the servo uses the positive and negative voltage difference received by the motor control chip. Until the next pulse signal is sent from the main control module, the angle of the rudder is issued with a corresponding change. Figure 8 shows the rudder.

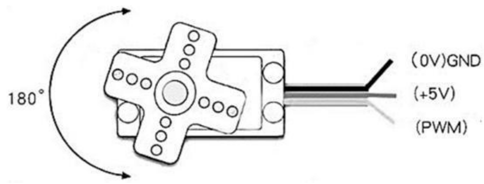

Figure 8. SG90 Servo

3.7 Overall Circuit Design

Figure 9 shows the overall circuit design of the ship obstacle avoidance system, as shown in the figure, the whole circuit diagram mainly consists of the main control module STM32ZET6, TOF10120 laser distance measurement module, and ULN2003 drive module stepper motor electric head, OLED display module and sound and light alarm module.

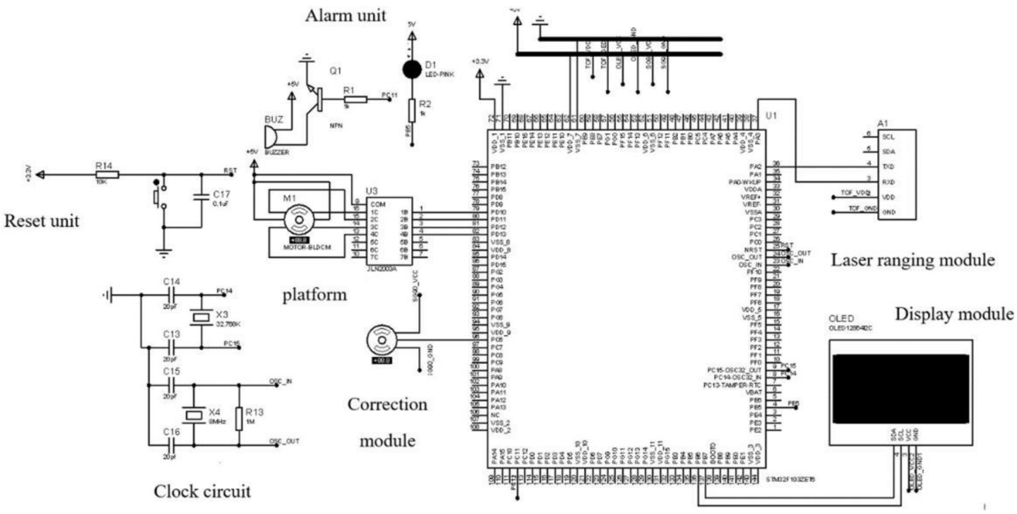

Figure 9. System general circuit diagram

4. System Software Design and System Commissioning

The software design includes the main program design, data acquisition program design, display program design, head design, alarm program design and correction program design. Figure 10 is the block diagram of the main program of the system, when the system is initialized, the motorized head will be rotating all the time, the laser sensor has a transmitter and a receiver, the measurement beam is sent from the transmitter and the receiver will receive this signal. The data processed by STM32ZET6 microcontroller will be displayed on the OLED display in real time, and the corresponding subroutine module will execute the obstacle avoidance function when the obstacle reaches a certain safety distance.

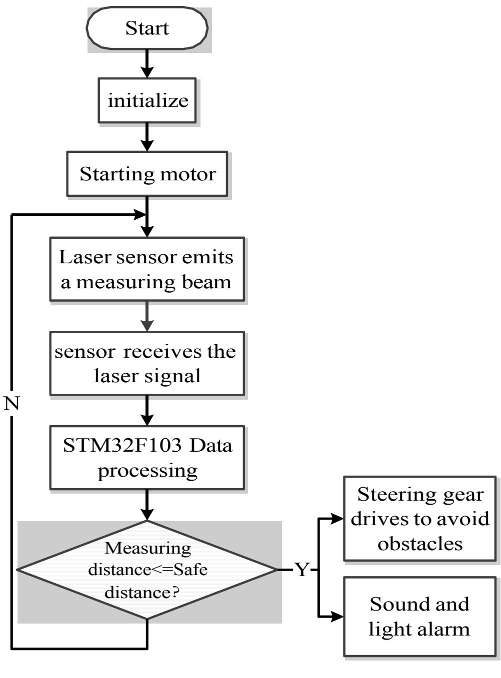

Figure 10. Flow chart of the main system program

After designing the microcontroller ship obstacle avoidance system, it will be tested according to its function used to verify its integrity. The system is mainly composed of main control module, correction module, distance measurement module, alarm module, display module and power supply module as Figure 11. The main control module troller as the main control chip, and the distance measurement module is mainly composed of TOF10120 laser sensor, which aims to measure the distance between the ship and the obstacle. The buzzer will sound an alarm and light up to warn after the first safe distance. After the second safety distance is smaller, the rudder will adjust the direction to make the ship complete the obstacle avoidance function. Considering the single problem of laser range receiving signal, in order to expand the detection of the surrounding environment, this paper will choose to use stepper motor to drive the electric head. The test results show that the design can realize the obstacle avoidance function of small unmanned ship and ensure the safe navigation.

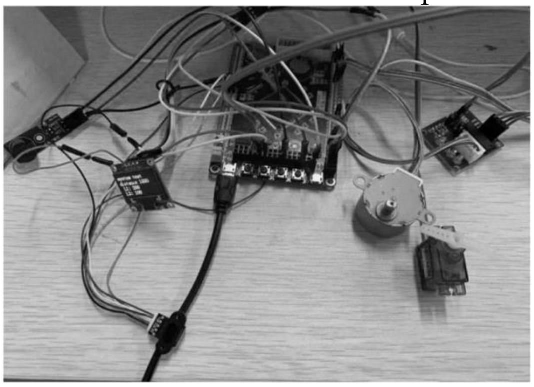

Figure 11. System commissioning

5. Conclusion

The study shows that the designed unmanned ship automatic obstacle avoidance system can effectively detect obstacles and automatically avoid them, thus ensuring the safe operation of small unmanned ships. Through testing and evaluation of the system, the performance indexes of the system, such as accuracy, response speed, robustness, etc., are derived. The feasibility and applicability of the design in practical applications need to be further explored, including the applicability to different sea conditions and different ship types, and the ability to recognize the size, shape and motion state of obstacles.

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