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An Autonomous Ship for Cleaning the Garbage Floating on a Lake

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***Abstract*—Water pollution with floating garbage is getting more and more serious in many countries. The design of an autonomous ship for cleaning the garbage floating on a lake has been proposed. The ship is powered by a solar battery. Circuit for protection of the excessive charge and discharge of the battery system has been used. Ultrasonic sensors have been equipped to detect the distance between the ship and the bank of the lake. The position and the orientation of the ship can be determined by measuring the distance between the ship and the bank at two successive time, which is used for controlling the running direction of the ship to make the ship autonomously run in an annular zone of a short distance away from the bank. The ship has also been equipped with a system to detect the occurrence of obstacles and to bypass the detected obstacles. Two screw propellers have been installed at the two sides of the ship to drive the ship, which makes the ship change its direction nimbly. A photo-resistance has been used to determine if it is in daytime or nighttime. The ship circulates the lake only one time at nighttime to save power energy. Wireless remote control is also available, which makes the ship user friendly. Experiments have demonstrated the applicability of the design**

Keywords: autonomous; floating garbage; ultrasonic; cleaning ship; pollution

I. INTRODUCTION

Natural lakes and all kinds of artificial lakes make the living environment beautiful. However, with the increase of the activities of human being, the pollution of the floating garbage on the surface of the lake is more and more serious. Governing the pollution of the floating garbage on the surface of the lake is more and more urgent [1].

It can be seen by observation that the velocity of the water flow in the lake is very low. Sometimes it is almost zero. Most of the floating garbage distribute over an area near the bank of the lake [2]. At present, almost all these floating garbage is cleaned manually [3], which is time consuming, expensive in cost, and low in efficiency. To solve the abovementioned problem, we have designed an autonomous ship for cleaning the garbage floating on a lake. As shown in Fig.1, a model ship has been developed. Experiments have been conducted to demonstrate the applicability of the design.

Figure 1. The developed model ship

II. DESIGN OF THE CLEANING SHIP

The cleaning ship is powered by solar battery, which is economic, and can save energy and protect environment. The cleaning ship determines the position and the direction of it's own by taking the lake bank as the frame of reference. The ship runs around the lake bank by controlling itself running in a predefined distance away from the lake bank. At the same time, it automatically cleans the floating garbage. The ship can change direction if the equipped ultrasonic sensors have detected obstacles. Circuits for recognizing the daytime and the nighttime are designed too. The ship runs only once at nighttime to save electric energy. The circulating times of cleaning floating garbage at daytime can be determined according to the practical environment. A remote control circuit is designed, which makes manual control of the ship applicable. This is useful in some special circumstances, and thus can increase the practicability of the ship. A mechanism for collecting floating garbage is designed to realize automatic collecting floating garbage.

To realize the functions mentioned above, the designed cleaning ship should be controlled by a microprocessor. It should also have power supply system, keyboard and display, obstacles detecting system, ship position and orientation detection system, motion controlling system, circuit for recognizing daytime and nighttime, and remote control system, as can be seen in Fig.2.

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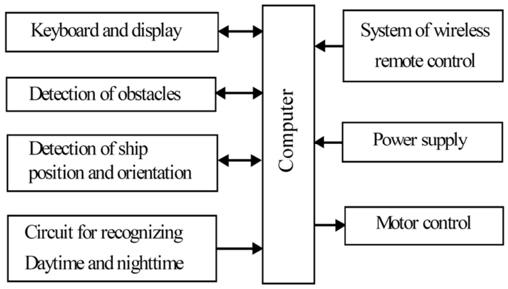

Figure 2. The structure of the cleaning ship

A. Design of the single-chip microcomputer (SCM) system

The main SCM system of the cleaning ship is made up of a SCM, a crystal oscillator, a watchdog timer. The SCM is AT89S52, produced by Atmel Corporation. It features 8k bytes of on-chip flash memory, 256 Bytes of on-chip RAM, two 16-bit timers/counters, two external interrupt, and one full duplex UART .The oscillating frequency of the SCM is 12 MHz. The Watchdog timer reset the computer system on power up, power failure, and other abnormity. The Watchdog circuit is MAX813, produced by Maxim Corporation, which is dedicated to production of integrated circuits for power-detection and Watchdog timer

B. Design of the keyboard and display module

ZLG7289 has been applied in both the keyboard circuit and the display circuit in our cleaning ship, which was produced by Zhouligong Corporation situated in Guangzhou. A ZLG7289 chip can drive 7-segment numeric LED displays of up to 8 digits, bar-graph displays, or 64 individual LEDS, and a keyboard of up to 64 keys. It communicates with the SCM through the serial peripheral interface (SPI) [4], which takes only three I/O pins of the SCM to save its limited resources. The key pin of the ZLG7289 becomes low when a key is pressed. The SCM identifies the number of the keystroke by SPI bus when reading the low level signal. There are eight 7-segment numeric LED displays and six keys. 7-segment numeric LED display the distance value obtained from the distance-detection system. Six function keys are used for setting the control parameters of the cleaning ship.

C. Design of the motion control system

The motion control system controls the cleaning ship to move in a lake. Two slave systems detect the distances between the bank and the cleaning ship, and sent the distance values to the main control system through the asynchronous serial port. The main control system determines the position and orientation of the cleaning ship according to the two distance values. Ultrasonic range sensors are used to measure the distance in the system. Ultrasonic ranging is a method that uses reflective ranging method [5]. The distances to be measured are calculated according to the time period between the time at which the system transmits ultrasound waves and that at which the system receives the echo. Every ranging system is controlled by an independent SCM to transmit the ultrasound and to receive its echo [6]. The dedicated integrated circuit LM1812 fulfills the task of transmitting ultrasound waves. While the task of receiving the echo is fulfilled by the infrared receiver module CX20106. When the control signal of the transmission of the ultrasound is sent, the internal timer of the SCM is being started at the same time. The integrated circuit CX20106 will send a low-level signal through which the external interrupt of the SCM is triggered to stop the timer when the echo is received. The distance between the ship and objects can be calculated from the data in the timer. The ship is equipped with two ultrasonic ranging systems. One of which is at the front of the ship, marked as “A”. Another is placed at the ship’s right side, marked as “B”.

The two sensors measure the distance between the ship and the bank of the lake once every two seconds. The position and orientation of the ship relates to the bank of the lake are determined according to the distances at two successive times. There are several different situations as described in the following

The first situation is that the distances measured by A at both the first and the second times are over range. That is to say that the distance is more than 3 meters. And the distances measured by B are the same, about 60 centimeters, at this time, the ship is considered to be parallel to the bank of the lake, (see Fig. 3 time 2).

The second situation is that the distances measured by A at both the first and the second times are over range. Therefore, there are no obstacles in front. However, the first distance measured by B is smaller than the second one, which suggests that the bank turns to the right, (see Fig.3 time 3).

The third situation is that the distances measured by A at both the first and the second times are over range. While the first distance measured by B is lager than the second, which suggests that the bank turns to the left, (see Fig.3 time 4). The last situation is that the distances measured by A are less than two meters while the distances measured by B are the same. In this situation, obstacles may exist in front of the ship or the bank takes a right-angle turn to the left (see Fig.3 time 5). The motors will be controlled correspondingly to make the ship move around the bank of the lake.

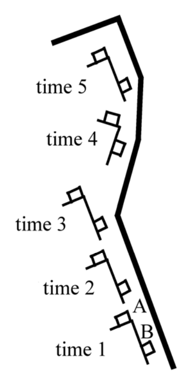

Figure 3. Ship motion control strategy

D. Design of the bypassing obstacles system

When moving in the lake, the cleaning ship may encounter obstacles. Therefore, it should be able to automatically bypass obstacles, and then return to its original orbit. Whether there exist obstacles or not is determined based on the data the two ultrasonic sensors measured. The preliminary decision of an obstacle or a turning of the bank in front of the ship is similar to the method for deciding the right-angle turn to the left. That is to say that the distances measured by A are two meters, and the distances measured by B are the same. In this situation, an obstacle or a turning of the bank is considered to be in the front, and therefore the ship should be controlled to make a right-angle left turn (see Fig.4 time 1). When the distances measured by A are larger than 3 meters and the distances measured by B are 60 centimeters, the ship starts to go straightly. If the ship has made a right-angle turn to the left, the distances measured by B will not change (see Fig.4 time 5).If the ship has encountered an obstacle, the distances measured by B will become bigger than the distances measured before. The reason is that obstacles are arc-shaped or rectangular-shaped. The ship will turn to right accordingly (see Fig.4 time 3). Not until that the distances measured by B are 60 centimeters, will the ship go straight. The ship will turn left at right angles after the bank of the lake is detected (see Fig.4 time 3). Finally, the ship will go back to the confined orbit as the distances measured by A are lager than 3 meters and the distances measured by B are 60 centimeters.

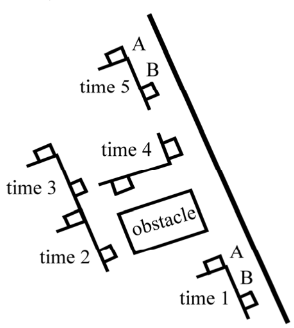

Figure 4. Strategy for the ship to bypass an obstacle

E. Design of the circuit for recognizing daytime/nighttime

Using a photosensitive resistance, which will have different resistance values under different light intensity, the system is able to recognize daytime and nighttime. When light is strong, its resistance value is small. On the contrary, resistance value will increase at low light. In the recognizing circuit, fixed resistors and photosensitive resistor are used to divide up the fixed voltage, and referenced voltage has been adopted. A voltage comparator is used to determine the output voltage. If the voltage divided up is smaller than the referenced voltage, the recognizing daytime and nighttime system determines it is at nighttime, otherwise it is considered at daytime. During the daytime, the frequency of the cleaning circulation can be set. While at nighttime, the cleaning ship circulates only one time.

F. Design of the motor control system

The power of the cleaning ship, including the conveyor belt of the refuse collection and transmission, and the two propellers which drive the ship and change its direction nimbly, are all powered by DC motors. The two high speed DC motors used to drive two propellers, and the motor used to drive the conveyor belt with gear case, are all controlled by special ICs Numbered TA8050P. Five controlling scenarios are designed which include going straight, turning to the left, turning to the right, turning to the left at right-angle and turning to the right at right-angle. The speeds of the two high-speed motors are controlled running at the same speed when the ship is going straight. The ship is turning left when the right side motor speeds up while the speed of the left side motor remains unchanged The left side motor speeds up while the speed of the right side motor keeps unchanged will lead to the ship turning right, which can result to a larger turning radius. The ship is turning left at right angle when the left side motor stops while the right side motor runs at the original speed. In the opposite situation, the ship is turning right at right angle.

G. Design of the remote control system

Besides the keyboard and display circuit, the remote control system is also designed to achieve manual control of the cleaning ship. Radio frequency signal, which can be radiated around and cannot be warded off by obstacles, is used as carriers to transport the remote control message. The remote controller can control the ship in a distance of up to 500 meters. It has 8 keys, including the key to switch between the manual mode and automatic mode, the keys to control the moving directions, and the key to control the motor that drives the conveyor belt.

H. Design of the power supply systems

The control system needs a 12-volt power supply, which is used for powering the ultrasonic transmitter and the DC motors. It also needs a 5-volt power supply used for powering the single-chip control system. The power comes from a solar battery of 15Watts rated output, which is used to charge a 12V/7AH maintenance-free lead acid battery. The latter is then used to power the system. During charge process, the battery voltage is monitored by the power system to avoid overcharge and over-discharge. The 5-volt power supply for the SCM is stabilized by a three-terminal voltage regulator. In order to avoid the motor starting/stopping operations influencing the control circuit, a DC-DC power conversion circuit is designed for power supply isolation.

I. Design of programs

According to the process of the work of the cleaning ship, the programs of the main SCM system and distance measurement systems are designed in a modular structure. The programs of the main SCM system consist of the following modules: the program for managing the power system, the program for the remote control, the program for communicating with slave distance measurement systems, the program for controlling the moving directions, and the program for controlling the motors. The flow chart of the main SCM system is showed in Fig.5. The main works of the two slave SCM systems are realizing ultrasonic ranging and serial communication to send the measured distances to the host computer.

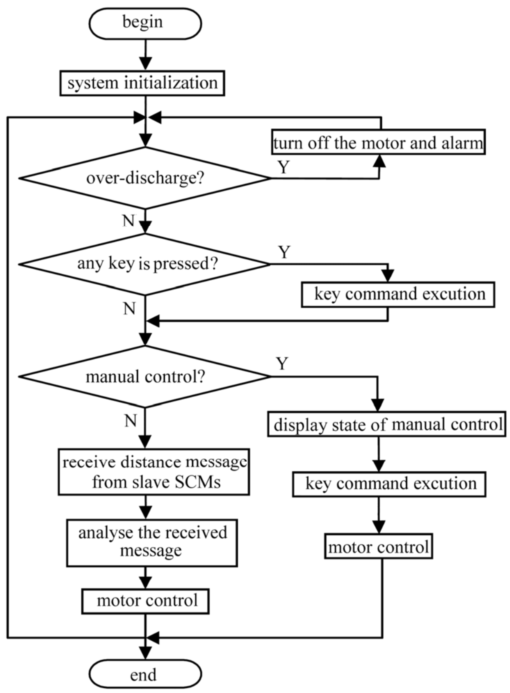

Figure 5.Flow chart of master single-chip

The working process is as follows: The first is the detection of battery energy. If the voltage is lower than the threshold value, the ship stops and a low-energy warning signal is sent through a LED flashing. If the voltage of the power supply is normal, it will check to see if there is a key pressed or not. The keyboard is designed to set the circulation frequency of the cleaning ship. Then the ship will work accordingly. If the working mode is automatic, the corresponding LED automatically displays working status. Afterwards, the system checks whether there is data sent by the slave SCM systems, and receive the data. The received data will be calculated by the main computer system to control the motors. If the ship works in the manual mode, it will show the manual state, and perform control of the ship in accordance with the keystroke of the keyboard of the remote controller.

III. EXPERIMENTAL RESEARCH OF THE CLEANING SHIP

We have carried out running experiments, which include the test of ultrasonic ranging, manual operation, and automatic operation. Compared with a measurement of the standard mechanical scale, the measurement accuracy of the ultrasonic sensors is about 1 centimeter when the measuring distance is between 25 centimeters and 300 centimeters. Since the path the ship runs around is formed on the basis of the measured distance, the ship can't leave far away from the bank of the lake. Experiments show that the sensors fulfill the need for the running of the ship. Higher accuracy is not required for the running of the ship. In addition, the ship is able to go straight, turn left, turn right, turn left at right angle and turn right at right angle manually or automatically. Detection of obstacles and bypassing of the detected obstacles have also been successfully performed. However, there are still some disadvantages. On the one hand, the ship advances forward well. On the other hand, in case there is large curvature radius of the bank of the lake, the ship may turn left slowly at first and then turn left at right-angle when the ship is going to hit the bank. Thus, the path may not be smooth.

IV. CONCLUSIONS

In this paper, the structure and working principle of an autonomous ship for cleaning the garbage floating on a lake has been proposed. The ship can both be manually operated and run automatically. A motion control strategy based on ultrasonic distance measurement is put forward. By analyzing the distribution characteristic of the garbage floating on a lake, a method for cleaning up floating garbage round the bank of the lake has been brought forward. Two ultrasonic ranging systems are used to obtain the positioning and the orientation of the cleaning ship and for path planning. As only five situations have been programmed, the motion path of the ship is not very smooth. Analyzing more situations on the basis of the five mentioned situations will make the path of the ship more perfectly parallel to the bank of the lake. Experiments have already demonstrated that the design of the autonomous cleaning ship for cleaning floating garbage on a lake is applicable.

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