Design of a Distributed Ultrasonic Detecting System Based on Multi-processor for Autonomous Mobile Robot*

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Abstract: - To improve the real-time and accuracy performance of the environment detecting system for autonomous mobile robots, and robustness of robot control, a new distributed real-time ultrasonic detecting system for autonomous mobile robot based on multi-processor is designed and manufactured. This system consists of a high-level work method control module and an intelligent ultrasonic sensor array acted as the subsystem. In the sensor array, each sensor is controlled by an individual micro-processor which completes the functions such as real-time data processing, interference rejection, malfunction alarm, parallel communication, and etc. Based on different control strategies, the high-level work method control module decides the sensors at different sides can be grouped to work in parallel way. In this system, data processing adopts “Threshold Comparison”, “Advanced Data Shift Average Filter” and EERUF methods. These methods have improved the real-time, precision performance, reliability of the system, and robustness of mobile robot control. The simulation and experimental results show the proposed system has high validity and reliability.

Key-Words: - ultrasonic sensor, multi-microprocessor, distributed system, interference rejection, autonomous mobile robot

1 Introduction

A fast, accurate and robust environment detecting system is always a critical part of robotic tasks such as map building, localization, target tracking, and collision avoidance [1]. The detecting system usually can be classified into two categories: active and passive sensing approaches. Active sensing approaches usually employ sensors such as laser finders, stripe light ranging, short-wave radar and ultrasonic range sensor (URS). Passive sensing methods always adopt stereo vision and passive infra-red sensors [2]. The active sensing approaches offer advantages in accuracy, robustness and simplicity. Where, URSs are widely used in many mobile applications due to their low cost and simplicity.

Mobile robot is usually equipped sonar ring to obtain the nearly entire information of the environment because of URSs’ limitation of the beam angle. In the traditional sonar detecting systems, the real-time performance was not high on account of all or most sensors that were controlled

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by one processor and the data processing was tackled by the same processor. At the same time, the interference among the URSs influenced the reliability of the systems badly. To improve the real-time and accuracy performance of the environment detecting system, some researchers have achieved corresponding researches [1~4]. The traditional approaches were comparatively complex both in hardware and software system. Therefore, we have designed and manufactured a new distributed real-time ultrasonic detecting system for autonomous mobile robot based on multi-processor. It has some advantages such as low cost, simple software and hardware, high real-time performance, and better reliability.

2 Origin of design thought

Distributed Control System (DCS) is an advanced control system developed from the 1970's. It is a high tech product which consists of compute, communication, and automatic control technology. The system has obviously advantages in following aspects: large application area, better expansibility, high control speed, easy systemic modularization, easy of maintaining, strong capability for single point malfunction resisting, and so on. Distributed control architecture is the application of multi-agent technology in the research domain for mobile robot. In the distributed architecture, each functional module can not only autonomously select in/output objects and its function but can work in parallel mode, and a scheduler can correspond the whole system concurrently working.

The idea of DCS has been introduced to the ultrasonic detecting system, which simplifies the design of hardware and software, and lowered the cost of the system.

3 Hardware design of the detecting system

The detecting system adopts two-layer (high-level and low-level) distributed control architecture, the block diagram of the systematic architecture is presented in Fig.1.

3.1 High-level working mode control module

The central element of the high-level working mode control module is the AT89S52 produced by Atmel. AT89S52 is a low-power, high performance CMOS 8-bit microcontroller (μC) with 8K bytes of In-system Programmable Flash Memory (ISPFM).

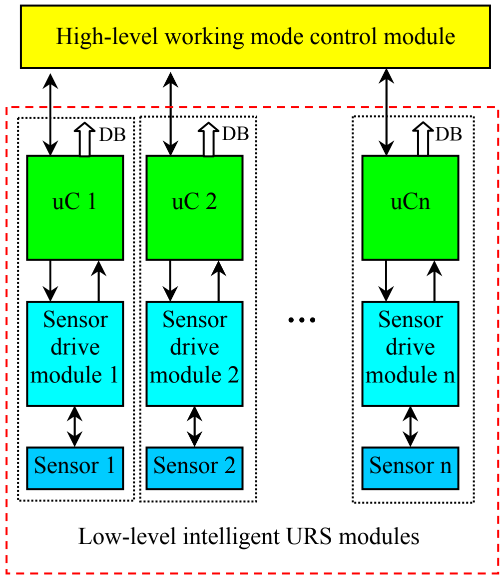


Fig.1 Architecture of the ultrasonic detecting system

The functions of the high-level working mode control module are: 1) to decide the sensors at different sides to be grouped and work in parallel method based on different control strategies. 2) to accept and process the data from the URSs array, and output the results of the ranging system by serial and parallel communication mode. 3) to provide power (DC5V) for the URSs array. So, the low-level URSs and the high-level control module can be connected by plat circuitry cables, which simplify the hardware architecture. The architecture of the high-level control module is shown in Fig.2.

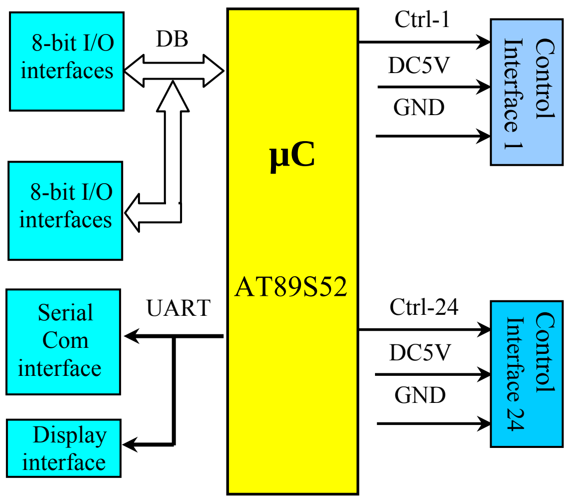


Fig.2 Architecture of the high-level working mode control module

AT89S52 has 32 programmable I/O pins. 24 pins of them are used to control 24 low-level intelligent URS modules. Each control interface includes 3 signals: DC5V, GND, and Ctrl.

The high-level control module has been extended many parallel interfaces. Each interface can accept the ranging result from the low-level intelligent URS modules. The data can be supervised by the static LED display interface during the period of debugging. The result of the detecting system can be out through the serial communication interface.

The ultrasonic detecting system has been equipped on the self-realization RIRA-II mobile robot, the detecting system configuration of RIRA-II mobile robot is shown in Fig.3. The sensors in the detecting system can be divided 4 groups: Front, Backward, Left, and Right (namely F, B, L, R). The sensors of each group can adopt individual cycle work mode (for example : F1→F4→F2→F5→F3 →F6→F1→F4→…), and two-sensor parallel work cycle mode (for example: [F1,F4]→[F2,F5]→ [F3,F6]→[F1,F4]→…). To enhance the real-time performance of the detecting system, we can make the sensors in the corresponding direction to work when the robot moves in different directions. For instance, the F group sensors can work when robot moves forward, and the F and L group sensors can work when robot turns left, etc.

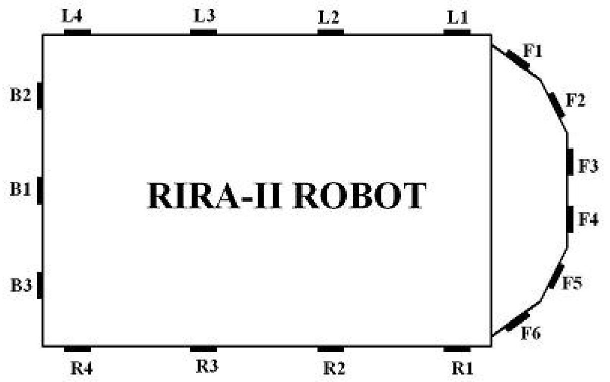


Fig.3 Ultrasonic detecting system configuration of RIRA-II ROBOT

3.2 Low-level intelligent URS modules

In the ultrasonic detecting system, we have adopted 600 Series Smart Sensors produced by SensComp. Inc. The Smart Sensor consists of ultrasonic transducer and the drive module. The drive module has two functions. One is producing high frequency (49.4 kHz) surge signal to drive the ultrasonic transducer. The other is amplifying the echo signal for making up the attenuation of ultrasonic transmission. The detecting rang of 600 Smart Sensor is 50cm~5m.

The 600 Series Smart Sensor have been rebuilt to an intelligent sensor by the approach that each sensor is controlled by a micro-processor and the data processing is tackled by the same micro-processor. AT89C4051 produced by Atmel is chosen as the micro-processor. AT89C4051 is a low-power, high performance CMOS 8-bit microcontroller with 4K bytes of Flash Programmable and Erasable Read-Only Memory (FPEROM). The μC has been chosen due to it's low cost, small dimensions and ease of programming. It is a powerful microcomputer which provides a highly-flexible and cost-effective solution to many embedded control applications. The architecture of intelligent sensors is shown in Fig.4.

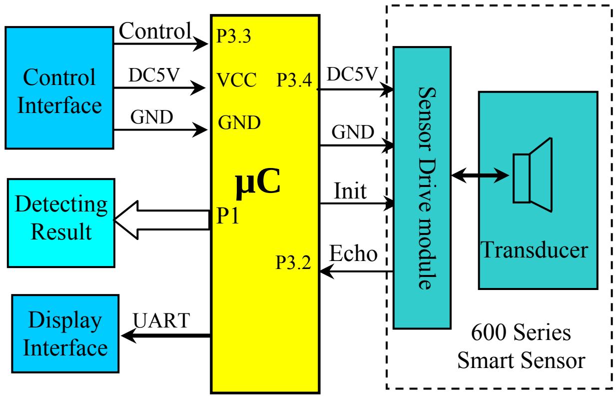


Fig.4 Architecture of sub-intelligent sensors

The μC emits signal "Init" to make the Smart Sensor to transmit ultrasonic through pin P3.4, and receives signal "Echo" from the Smart Sensor by the interrupt function of pin P3.2. Then, the μC completes detecting mission after getting signal "Control" through pin P3.3 from the higl-level working mode control module. The μC sends the detecting result through 8-bit parallel port P1. The display interface can be used to supervise the detecting result during the debugging for software of the low-level intelligent sensor. Furthermore, the low-level intelligent sensor processes the function of interference rejecting and malfunction alarm, which can easily carry out the fault diagnosing for a mobile robot. All low-level intelligent sensors have the same architecture of hardware and software, so we can expediently replace and substitute the low-level intelligent sensors, which simplifies the design of the whole system of a mobile robot.

4 The ranging information pre-processing

The theory of ultrasonic ranging is simple. Time of Flight (TOF) method is generally employed [6]. If we denote d as the distance between robot and the detected object and t as the time elapsed between emission and reception, then d can be calculated as

$$2d = vt \tag{1}$$

Where v is the signal speed of propagation, which is approximately 340m/sec.

There are three sources of ranging error in the ultrasonic detecting system: random interference, crosstalk among many URSs and phantom interference.

To obtain exact distance and position, the signals of detecting distance must be pre-processed. The signal pre-processing mainly includes random and crosstalk interference rejection.

4.1 The rejection for random interference

The random interference mostly comes from the ultrasonic interference of the environment, the systemic interference of robot hardware and noise interference produced by robot when it moves in high speed.

In the design of hardware system, we have dealt with the each power module especially the power module for servo motors by means of power filter. This can eliminate the noise resulting from the control system of the robot in a big degree.

In the design of software, we have adopted the "Threshold Comparison" method to reduce the noise interference. The last two ranging results of each sensor have a different value T_{err} due to the resolution of the sensor and the moving of mobile robot. Assumed a threshold value E_0, the difference of the last two virtual results must be less than E_0.

T_{err} is related with the speed of the mobile robot. We suppose the speed of mobile robot is v_1, and the scanning cycle of ultrasonic detecting system is T, therefore

$$D_T = v_1 T \tag{2}$$

In Eq. (2), D_T is the biggest distance of a scanning cycle. We generally choose the threshold value E_0 according as the experimental results:

$$E_0 = 1.5 D_T \tag{3}$$

Thus, we can decide weather the detecting result is effective or is random noise need to be abandoned by means of comparison the T_{err} and E_0. The experiment results show that "Threshold Comparison" can greatly improve the reliability of ultrasonic detecting system.

4.2 The rejection for crosstalk interference

Other work on sonar interference has analyzed the forming reason of the ultrasonic crosstalk, and put forward the EERUF (Error Eliminating Rapid Ultrasonic Firing) method to reject crosstalk interference [7]. We find a rule of forming crosstalk interference: the result of the sensing distance is less than the actual distance between sensor and barrier because of the crosstalk interference. Therefore, we employed the EERUF method in the control strategy for the sensors in the hardware design, at the same time, "Threshold Comparison" and "Advanced Data Shift Average Filter" is used in data processing for individual sensor. This can eliminate or reduce the ultrasonic crosstalk interference.

"Data Shift Average Filter" is a data processing method, which adopts N measurement results as a data alignment, the length of the alignment is N. When a new measurement result is accepted, it is put in the end of the alignment and the first data of the alignment is abandoned, and then take the average of the N data of the new alignment as the new measuring result. In the "Advanced Data Shift Average Filter", the N data are sorted and m minimal data are abandoned, and then take the average of the N-m data of the new alignment as the newest measuring result, where m and n is chosen by experience and experiment.

In the experiment of RIRA-II autonomous mobile robot rapid collision avoidance, N is 5, m is 2. This method can reduce the ultrasonic crosstalk interference, and can ensure the mobile robot has a mild and stable speed.

4.3 The rejection for ultrasonic phantom

The specular reflection usually results in ultrasonic phantom when the ultrasonic sensors and the barriers have some angles because of the beam angle of the URSs. The sketch map of phantom is shown in Fig.5.

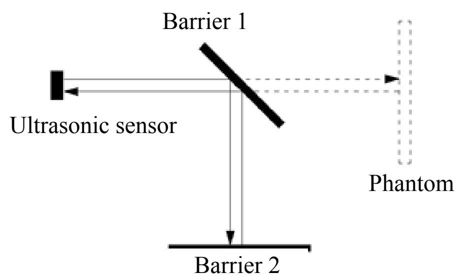


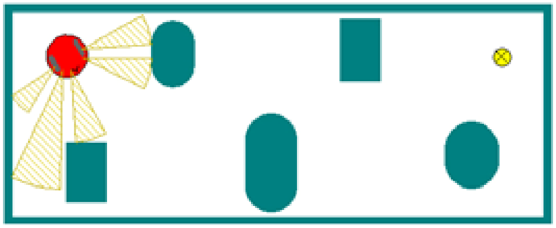
Fig.5 Sketch map of phantom

The mobile robot wrongly considers the distance between it and barriers is far due to the ultrasonic phantom, and then the robot maybe collide the barriers. The ultrasonic phantom rejection can not be accomplished in the data pre-processing of the sensor, and it must be processed with a special way. In this system, we have applied the following methods: adopting multi ultrasonic sensors in the design of hardware, and adopting hierarchical fuzzy control technology in the design of software [9~10]. This restrained the ultrasonic phantom interference effectively, and enhanced the robustness of robot control.

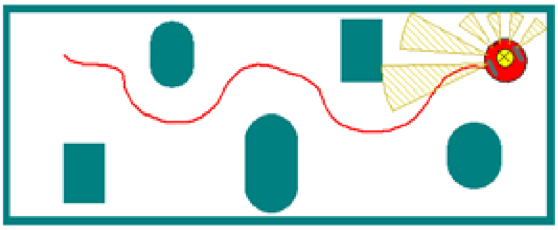
5 Simulations and experiments

We have adopted the software MotoSim[11] for simulation to validate the validity and reliability of the proposed ultrasonic detecting system .

6 intelligent sensors(F1~F6) have been built in the front of the mobile robot, the beam angle of the sensor is 15°. The results of simulation for robot collision avoidance are shown in Fig.6. The results prove that the hierarchical fuzzy controller merged with the information of the detecting system nicely, and can instruct the robot to arrive the setting goal in unknown environment.



(a)



(b)

Fig.6 Simulation results

The experiments have been finished on the experimental platform RIRA-II ROBOT which is manufactured for the research project "Behavior-control based on vision for autonomous mobile robot" sponsored by Shenyang Institute of Automation, Chinese Academy of Sciences. The appearance of RIRA-II ROBOT is shown in Fig.7. In this experiment, 6 intelligent sensors (F1~F6) is only been used, and the configuration of the ultrasonic detecting system is shown in Fig.3.

Diverse barriers have been put in the experiment environment, the experimental scene and the results are shown on Fig.8. The results validate that the design of the ultrasonic detecting system is rational, and the hierarchical fuzzy controller can control the mobile robot avoiding all barriers and reaching the setting goal successfully. Simultaneously, it also shows that the moving speed of mobile robot is mild and stable, the collision avoiding motion is flexible, and the mobile robot possesses high robustness.

Fig.7 The appearance of RIRA-II ROBOT

(a)

(b)

(c)

(d)

(e)

(f)

Fig.8 Experiment and Results

6 Conclusion

We have introduced the thought of DCS to the design of autonomous mobile robot, and manufactured a new distributed real-time ultrasonic detecting system for autonomous mobile robot based on multi-processor, which features low cost, simple software and hardware, high real-time performance, and better stability. The detecting system adopts the high-level and low-level two layer distributed control architecture. Based on different controlling strategies, the high-level work method control module decides the sensors at different sides to be grouped to work in different approaches. In this system, data processing adopted “Threshold Comparison”, “Advanced Data Shift Average Filter”, and EERUF method is adopted in hardware design. At the same time, we designed a hierarchical fuzzy controller.

The simulation and experiment results show that the proposed system has simple architecture, high reliability, and the system can improve the real-time and accuracy performance of the mobile robot, and can restrain effectively the ultrasonic crosstalk and phantom, which improves the control robustness of a mobile robot

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