An Intelligent Robot Based on Sound Source Localization and Ultrasound Distance Detection

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ABSTRACT: In both industrial and research areas of electronic engineering, Sound Source Localization for robot control has always been an interesting subject to be further studied. Under some dangerous situation, especially when a special driver is required to implement a particular task, the device should be able to combine robotics control technology with Sound Source Localization, and take actions according to the different response patterns. In this research project, a multifunctional model driver, named "Mobile Island" , has been designed and built up by integrating the Emulator 8051 micro-controller, Intel 8255 interfaces, some components and other necessary devices. The intelligent Mobile Island implemented by C language programs can operate under three control modes. In the sound control Mode 1, the model driver can detect and track a target by Sound Source Localization and then turn and move toward the destination. In the keypad control Mode 2, it can be controlled by a manual keypad. In the free run Mode 3, Mobile Island can move and turn by itself. When finding an object in front, it will turn away before moving forward again, so that it can avoid crashing on the obstacle.

KETWORDS: circuit, interface, driver, motor control, sound source localization, ultrasound detection

1 Introduction

In some areas, especially in industry, to detect or supervise a dangerous equipment or site where people could not approach to, a special driver might be required to implement this task [1,2]. The special driver can be operated in manual control mode or in intelligent control mode in which it can automatically track an aim and/or move forward to an object. The intelligent control mode is based on some detection or measurement as well as some smart program embedded into a controller.

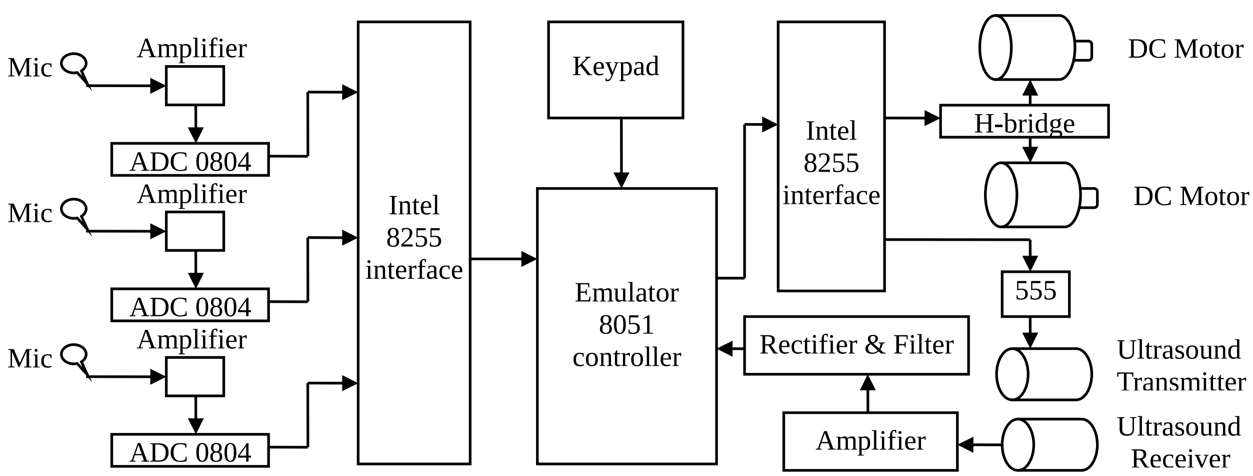

Fig.1. The architecture of Mobile Island

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Author's profile: The first 3 authors (non-prioritized) are the undergraduate students in Electrical and Computer Engineering at HKUST. They took part in the Oversea-Exchange Programs (2007-2008) in USA at the host institutions (respectively at Rice University, University of Illinois at Urbana-Champaign and Georgia Institute of Technology). The project is implemented under the conduct of instructors.

In this project, with a few kinds of components and devices combined with the program written in C language, we build a multifunctional sound control model driver[3]. The whole architecture of the Mobile Island is shown in Fig.1, which is set up in a bottom-up style. Implementation begins with basic modules that do not need other modules, i.e. we first made and test the circuits of sound amplification, ultrasound detection and motor driver, then worked towards analysis the signal from them.

The DC motor driver, the LEDs and the ultrasound control units are connected to an Intel 8255 programmable peripheral interface4, whose output chips are used to extend the limited amount of pins on Emulator 8051 micro-controller. The ADCs converting the analog sound signals to digital signals are connected to another Intel 8255 programmable peripheral interface which also links with a keypad for manual operation. For readers' convenient preview, the video of project is posted on You Tube (http://www.youtube.com/v/lgQ4HIu8d6E&hl=en&fs=1).

2 The Sound Control Mode

2.1 The Principle of Sound Source Localization

The Principle of human and animal sound source Localization has always been an interesting and abstruse topic, in which many uncertainties remain to be further investigated. From the early 20th century, scientists have been taking efforts trying to find out the mechanism about how human and animals can localize a sound source[5]. Through lots of experiments, they researched the relationships involving human sound source localization with two ears and brain system. It is generally believed that human and animals could track a sound source by recognizing the tiny difference of intensity of the sounds separately received by the two ears, the difference of time the sounds take to travel form the source to the two ears, as well as the difference of timbre between two ears. But at the present time, we are not quite clear yet about how the ears and brain can so correctly detect, measure and compare the tiny differences mentioned above[6].

In the research program, to avoid establish a complex sound source localization system, the Mobile Island does not compare the time and the timbre, but only compare the intensity of sounds received by microphones which function as human ears. To distinguish the sound source from front or rear, instead of two mics, the model driver receives the sound with three mics which are symmetrically placed on the Mobile Island as shown in Fig.2.

The three mics are about 25cm apart from each other, from which the responses are denoted as mic1, mic2 and mic3 in the program. In order to let the model driver perform sound source localization in different environments which could bring about a variety of background noise[7], three threshold values corresponding to three microphones are computed, and each of the microphone responses will be compared to its threshold value plus a predetermined bias value.

In the sound control mode, when a voice source is located by the sound modules, the Mobile Island will turn to the direction and move forward.

Note that the bias valves are three parameters that should be determined during test trails. If the properties of three microphones are somewhat different, the three bias values tend to be obviously different, either.

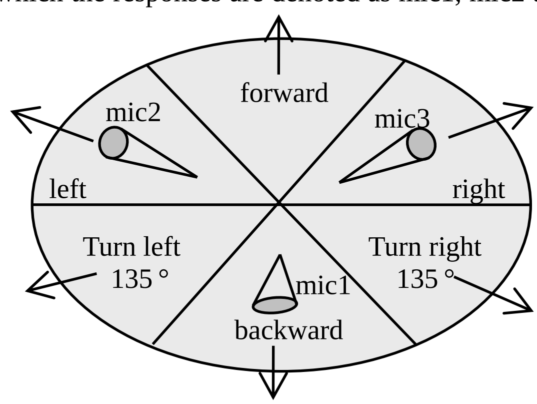

Fig.2 Sound source localization scheme

2.2 The Circuits related to Sound Control

We chose the electret condenser mics (capacitor mic) for the sound control mode. To achieve a output voltage range from 0 to 5V, three operational amplifier (LM324) are connected in series and provide a total amplify ratio about $15^3 \approx 3400$. A capacitor (103) across the op-amp is used to filter out jitters in the received signal. Without the capacitor, the received signal would jump to a large value easily even there is no perceivable sound source existing. The amplifier signal will pass through a rectifier (IN4148) and a low pass filter and output to the input of A/D convertor (ADC0804).

The signal lines of three ADCs are wired together, so to ensure the A/D conversion start at the same time. The precision of conversion can be adjusted by a variable resistor. The smaller the resistor, the higher the precision is, however, the conversion range will be reduced.

2.3 The Program for Sound Control

The whole flowchart of Mobile Island control program is shown in Fig.3. For the part of sound control, some emphases are put forward as below.

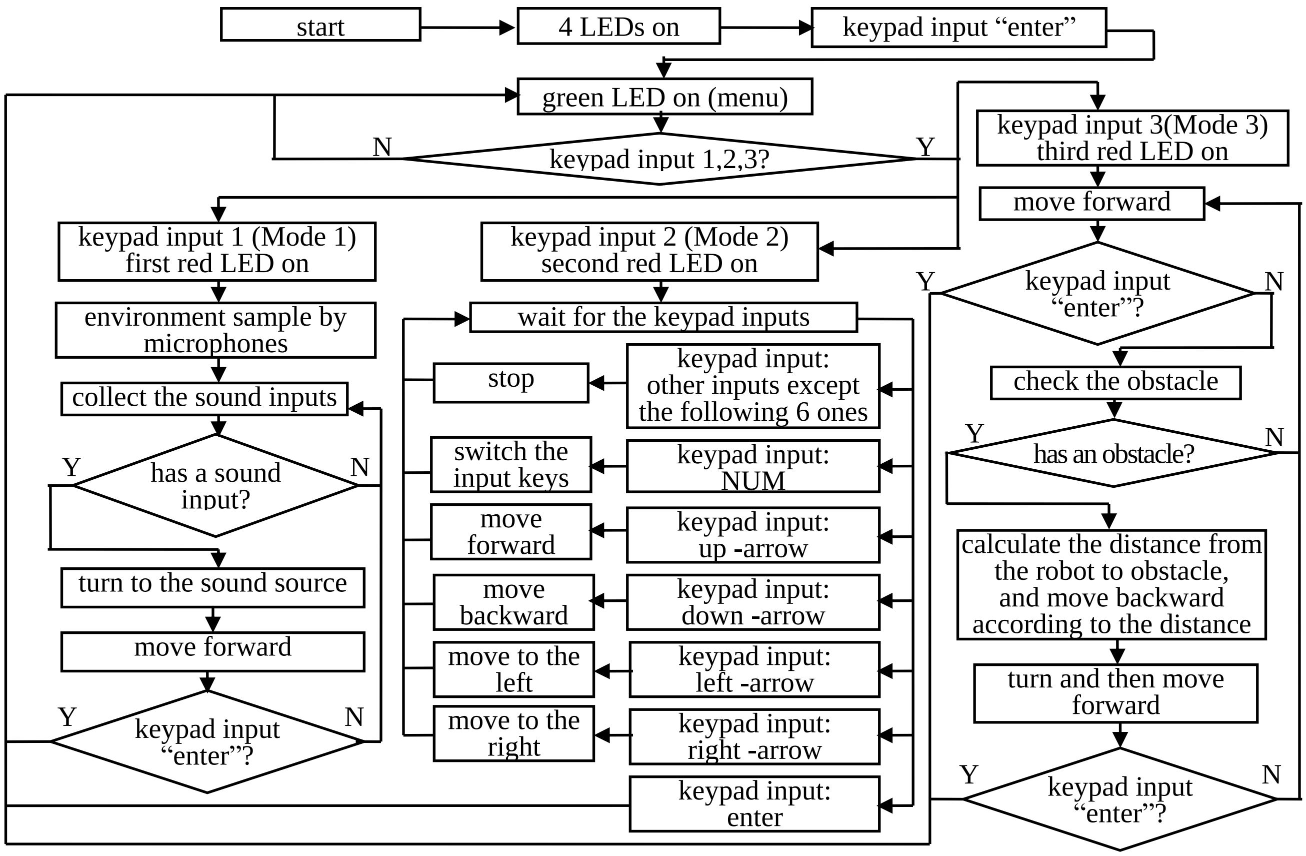

Fig.3 The flowchart of Mobile Island control program.

1) Environment Sampling: the mics sample the environment and set the threshold as the maximum value obtained during sampling[7].

2) Collect the Sound Inputs: the A/D conversion starts at the same time for three microphones, however, the data collections are performed one by one.

3) Sound Source Localization: after A/D conversion, the received signals from the three electric condenser microphones are analyzed and proper action is triggered[8]. Our model driver can achieve 30 degrees of resolution in sound source detection.

3 The Keypad Control Mode

3.1 Keypad Interfacing

We use standard PS/2 keypad in this project. The PS/2 protocol is applied for communication between the keypad and the emulator 8501. The CLK line of the keypad is connected to P3.2 (external interrupt 0) of 8051 and the DATA line of the keypad is connected to P3.1 (normal input pin) of 8051.The keypad implements a bi-directional protocol. The keypad can send data to the host and the host can send data to the Keypad. The host has the ultimate priority over direction[9].

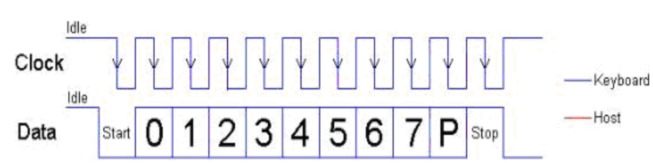

Fig.4 Timing diagram for keypad to host

The timing diagram for keypad to host is shown as Fig.4. It takes 11 clock cycles to transmit each byte. The data should be sampled on the data bus at each falling edge of the clock. Bit 2 to 9 of the transmitted packet is the data. In each falling edge of the clock, the external interrupt will occur and the bit will be recorded. When it counts to a total 11 bits, the data will be stored in a buffer waiting for decoding. Decoding process will be called in the main function. After decoding process, the data will be deleted from the buffer. The keypad to host protocol is used to get keypad values.

Reversely, the host to keypad protocol is initiated by taking the keypad data line low, and it is used to turn on and off the NUM-Lock LED.

There are two kinds of code in a PS/2 keypad. They are the make code and break code. Make code is an 8 bit data and break code is 0xF0 plus the previous 8 bit data. We need to detect the two codes to determine the key status.

3.2 The Program for Keypad Control

For the keypad controlled mode, the PS/2 is connected to the emulator directly. Referred to previous description on keypad interfacing, the program involved to keypad control mode[8] is shown in the flowchart of Fig.3.

4 The Free Run Mode

4.1 The Principle of Ultrasound Detection

Though infrared is a more robust way to detect object compared to ultrasound, however, the distance information is difficult to obtain from infrared sensor. For obstacle detection in the Free Run mode, we employ an ultrasound circuit.

The distance detection[5] is based on the time interval between ultrasound transmission and reflection. Referred to Fig.1, the ultrasound is generated by a transmitter which converts electrical energy into mechanical energy of ultrasound wave. Actually, the receiver is structurally the same as a transmitter, but with an inversed function, converting mechanical energy into electrical energy.

4.2 The Circuits of Ultrasound Transmitter and Receiver

As shown in Fig.5, the whole ultrasound transmitting and detecting circuit is operating under a 9V voltage supply. The transmitter’s pulse frequency is set to 40kHz by a adjustable resistor R13, and it is turned on or off by software through the pin 1 of the NE555 timer in Fig.5 (a). The ultrasound transmitter can only work at a frequency around 40 kHz, which means the amplitude of the ultrasound generated by the transmitter is maximized under the specified frequency.

As for the ultrasound receiver, the operating frequency is the same as that of the transmitter. The Circuits of Ultrasound Receiver is illustrated in Fig.5 (b). After the ultrasound is detected by the receiver, it will be transformed into a sinusoidal waveform at the very beginning. This sinusoidal signal is then amplified by 1100 times, which is achieved by using two operational amplified in the chip LM324N. Through each of the op-amps, the magnitude of this signal is multiplied by a factor of 33.

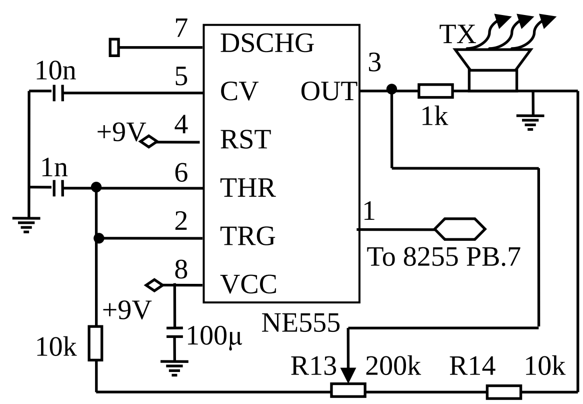

Fig.5(a).
The ultrasonic receiver and transmitter circuit

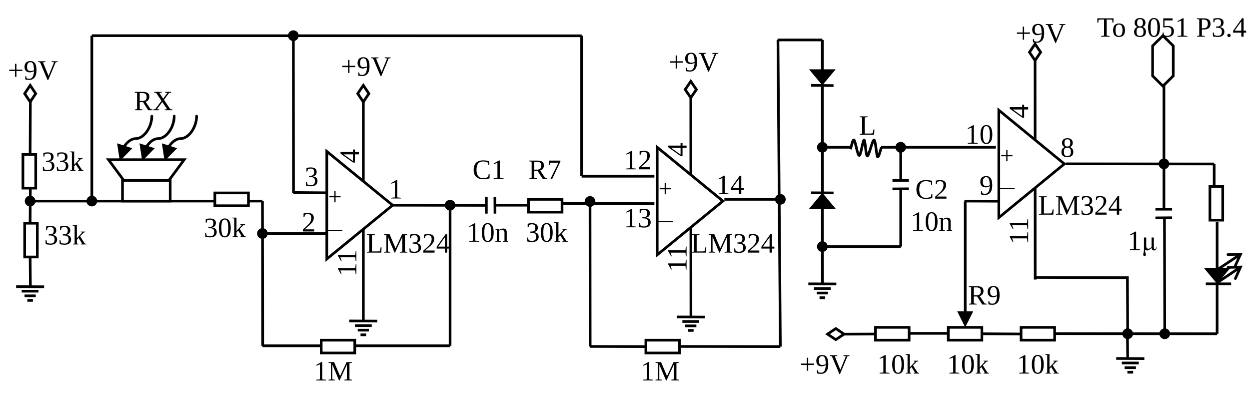

Fig.5(b). The ultrasonic receiver and transmitter circuit

A diode is then acting as rectifier to transform rectifier the AC signal into a DC one. For the convenience of signal detection, the DC signal is filtered by a low-pass filter to make the fluctuating signal a stabilized one, which is either 7V or 0.

Eventually, comparing the stabilized signal with a voltage around 4.5V by a comparator in the LM324N chip, the circuit is able to tell whether an ultrasound signal is detected just by checking whether the output is high[6].

4.3 The Program of Ultrasound Detection

Fig.3 show the flowchart of ultrasound control mode. By using ultrasound, the model driver gets the information of how far the obstacle is from the front of the model driver (the sampling period is adjustable) and modify its retreating step size according to it[8].

When the ultrasound is transmitted, the Timer starts to count. If no ultrasound response is received in a certain time interval, the Timer will be reset and the model driver goes forward continue. If an obstacle is detected, the Timer will measures the time the ultrasound takes to run from the transmitter to receiver, and then the program can calculate the distance based on the time interval. If the Mobile Island gets too close to an object, it will move backward for a longer distance, following with a turn, and then keep running forward.

5 DC Motor Control

Two DC motors are used to move the model driver forward, backward, left and right. The two DC motors are controlled by a motor driver LS293D. So the control to the motors is actually the control to the motor driver[10].
The program will enable the two DC motors at the very beginning. When motor functions are called, the values on the controlled pins of the motor driver will be changed in order to spin the DC motor. The motor driver LS293D uses a separate +9V power source as the two DC motors consume a lot of power.

6 Overview of Software

The whole program is written in C language by using Keil uVision[7] IDE. After the segments for each of control mode are completed, they are eventually integrated in a main file[11]. The overall program description mainly in forms of flowchart is illustrated in Fig.4. The total lines in source files are 1026. The size of compiled .hex files is about 8KB. The whole software package contains the following files.

1) main: main.h, main.c ; 148 lines for demonstration
2) mic: mic.h, mic.c ; 151 lines for sound source localization and sound control mode
3) keypad: keypad.h, keypad.c ; 233 lines for keypad control mode
4) ultrasound: ultrasound.h, ultrasound.c ; 106 lines for obstacle detection and control mode
5) motor: motor.h, motor.c ; 186 lines for motor driver control[12]
6) setting8255: setting8255.h, setting8255.c ; 144 lines for using 8255 chip controlling motors, LEDs and ultrasound control pin
7) delay: delay.h, delay.c ; 58 lines for time delays

7 Discussion.

The model driver could be further researched and developed by combining infrared detector for localization, which could identify the dangerous equipment from its temperature.

Here we also identified some limitation of the project. The model driver can not tell a human voice’s location when the sound source is far away from it. This is because the amplitude of capacitor microphone’s response falls rapidly as distance increases, as shown in Fig.6 (data collected from Speaker Nokia N5300), and then it might become very difficult for the program to recognize the difference between responses. This problem can be improved by replacing the component and increasing the distance between mics. As a result, the area of Sound Source Localization would still be further developed[13].

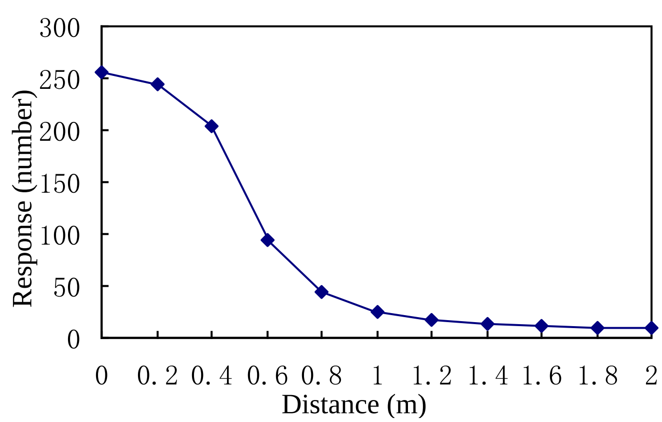

Fig.6 Amplitude vs distance

8 Summary and Conclusion

The project aims to build a intelligent Mobile Island with multiple control modes. In sound control mode, the model driver can lead itself toward the sound source. For example, if a person shouts at the left side of the model driver, it will turn left and proceed towards the person. This is also called Sound Source Localization [5]. In keypad control mode, the model driver will be guided by keypad. In free run mode, it will go straight forward unless it meets an obstacle. When the model driver runs too close to an object, it will move backward for a longer distance, then gets a turn and go straight forward again [3].

All these functionalities are achieved by using the Emulator 8051 micro-controller, Intel 8255 programmable peripheral interface and other necessary peripheral devices [12]. The project tests the abilities for implementation from planning, designing, integrating to testing, which are based on the related preparations for hardware and software [13].

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