Research Article

High speed micromouse servo controller based on DSP and FPGA

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ABSTRACT

Micromouse is an intelligent walking robot using embedded technology, depending on sensors for navigation, which consists of the ability to collect and gather information of the complex "maze" after forward and backward searching without human inspection. The micromouse memory the information automatically and select the shortest path, use smart algorithm to reach destination quickly. Servo controller based on single-chip microcomputer can not meet micromouse system special requirements of high speed and high stability. Hardware and software of servo controller based on DSP and FPGA was discussed and realized, and experimental results are also presented.

Key words: micromouse; embedded technology; searching; DSP; FPGA
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INTRODUCTION

Autonomous robot can be used in the future as to venture into dangerous area, or to perform critical tasks, instead of having a human life as stack. Autonomous robot will be a trend in the future. More and more autonomous robots were being applied in hospital, airport and factory[1-3]. Micromouse is an autonomous robot, which is completely autonomous that is able to find their way from a predetermined starting position to the central area of the maze unaided. The robot will need to keep track of where it is, discover walls as it explores, store the maze and detect whether it has reached the goal. After it reached the goal, the robot will typically perform additional searches of the maze until it has found an optimal route from the start to the center. Once the optimal route has been found, the robot will run that route in the shortest possible time[4-6].Micromouse maze is made up of 256 squares arranged in a 16x16 grid of cells, and set up the maze using a standardize wall which will be different in different events[5-12], for examples Singapore's competition will be using the wall shown in Figure 1,where as Japan competition will be using the wall show in Figure 2.

Fig.1:Wall for Singapore competition maze

Fig.2:Wall for Japan competition maze

Because there are few domestic manufacturers and research institutes research and design the robot, and misunderstand international competition rules, micromouse designed based on MCS-51 with stepper motor, ability and function of the micromouse relative simple, which can not satisfy the micromouse special requirements: high

speed and high stability. To ensure that this project can be completed, there exists two sections that must be done which is hardware and software. Micromouse design of the analog circuits and as well as the digital circuits based on dual core DSP and FPGA is discussed (as shown figure 3).
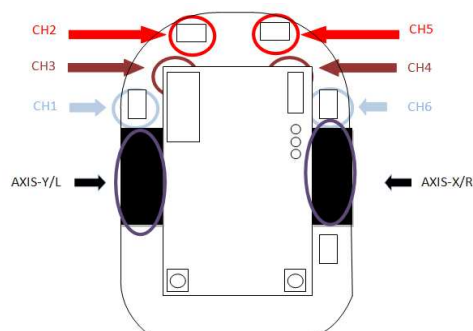
Fig.3: Top view of the Micromouse

Although there is a lot research has to be done, the author willing to spend all time so that the performance of the robot fully satisfactory. Shining Sunshines Global PTE LTD co-operate with the author to complete this project.
The objectives of this project are listed below:
1) To build and assemble an autonomous robot.
2) To learn, design and troubleshoot the analog/digital circuits design based on DSP+FPGA.

HIGH SPEED MICROMOUSE INTELLIGENT SERVO SYSTEM
In this paper, in order to overcome micromouse based on a single chip can not meet the stability and high speed requirements, abandon the domestic micromouse's single chip operating mode, refer to foreign advanced design ideas, micromouse based on dual core DSP and FPGA was designed, intelligent servo system of the micromouse searching and tracing maze principle as shown in Figure 4.
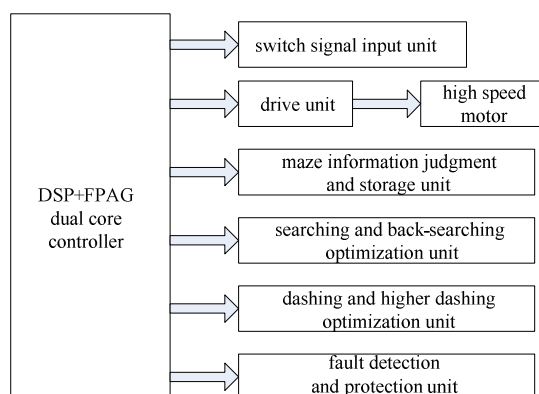
Fig.4: Principle of smart micromouse servo controller

Micromouse intelligent servo system mainly includes: switch signal input unit, motor driving unit, maze information judgment and storage unit, searching and back-searching optimization unit, dashing and higher dashing optimization unit, and fault detection and protection etc.. This management system take FPGA(A3P250) as the core, realize synchronous servo control of two axis DC motor, free the DSP from the complex work, only handle sensor signal logic ,a part of the intelligent algorithm and the control of FPGA.

HARDWARE
Hardware circuit of the servo system mainly includes: switching circuit, power supply circuit, the motor and its drive circuit, quadrature encoder circuit, infrared sensor circuit etc.

SWITCH CIRCUIT
In order to realize the function of start, reset, searching and dashing, micromouse in this paper has 4 independent input switch buttons. To reduce negatively impact of the external interference, switch signals were shaped by the
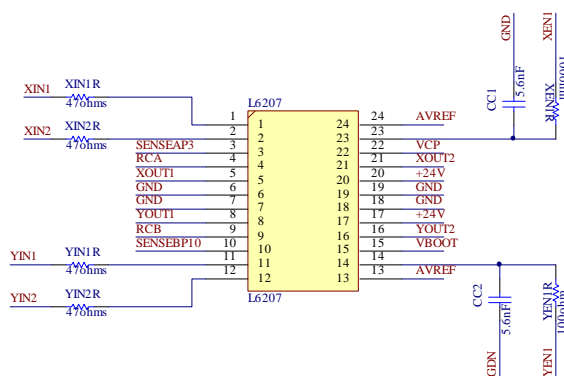
74VC14 then were input to DSP(TMS320F2812), respectively, Their circuit principles are similar, one specific circuit principle of start as shown in figure 5.

Fig.5: Switch circuit

POWER CIRCUIT

In this system, micromouse is powered by rechargeable lithium-ion battery, the average voltage of the system is 11.1V, and the highest voltage is up to 12.6V. In order to meet the requirement of dual core controller, the DC bus voltage through step-down voltage chip L5973D, then the voltage is reduced to 5V, 5V voltage is changed to 3.3V to meet DSP and FPGA requirement, where 5V power supply circuit as shown in figure 6.

Fig.6: Power circuit

MOTOR AND ITS DRIVE CIRCUIT

DC motors convert electrical energy into mechanical energy. DC brushed motors contain internal brushes for commutation. They have a positive terminal and a negative terminal through which external power is supplied. They are usually fitted with encoders for closed-loop position feedback.

DC motor speed control has excellent characteristics, such as speed can be changed smoothly, speed adjustment range is wide, DC motor can realize a frequent quick starting and braking, and overload capacity is strong, these characteristics can meet fast dashing micromouse special requirements in a complex maze. DC motor (T006SR+IE2-512) is used in the system. Its parameters as shown in table 1.

Table1. Parameters of motor

Voltage	6 V	Weight	35 g
Power	4 W	Diameter	22 ±0.5 mm
Efficiency	85 %	Length	24±0.5 mm
Speed	7500 rpm	Shaft diameter	2 ±0.1 mm
Torque	10 mNm	Encoder	512 lines

Pulse width modulation (PWM) is a technique to control the analog circuits with a processor's digital output, this project will be using the FPGA to generate the output instead of microcontroller. PWM can be seen as a way of digitally encoding analog signal levels .By using a high resolution counters, the duty cycle of a square wave is modulated so that it will encode a specific analog signal level on it. The PWM signal is in the form of digital pulse as the full DC supply is either totally on or off at any given instant of time. DC supply will be applied to the load during the on-time and switched off in the off-time. It can also be treated as a person in charge control the power supply by deciding the actual on time for the motor to rotate, so by turning on and off, the motor will rotate at different speed. Advantage of using PWM is that the power loss in the switching devices is very low.

In this paper, the micromouse is driven by two wheels, needs X and Y axis two motors to be used in the system, In order to simplify the drive circuit, double DMOS full bridge driver L6207D is adopted, the drive circuit principle as shown in figure 7.

Fig.7: Motor drive circuit based on L6207D

In the above circuit, XIN1, XIN2, YIN1, YIN2 represents motor X and motor Y PWM positive and negative signal respectively, generated by FPGA (A3P250) according to the parameters transferred by DSP, from the method, PWM signal of DC motor speed regulation is realized by hardware circuit, which improves the micromouse's handling date ability greatly.

QUADRATURE ENCODER
An rotary encoder is an electromechanical device that can be used to measure the motion or position of a device by converting the angular position or motion of a shaft to an analog or digital code. An incremental rotary encoder are widely used in industrial controls, robotics, computer input devices such as micromouse.

An incremental rotary encoder will be used in this project. It has two outputs which are normally known as Channel A and Channel B in this project and the quadrature outputs can be either mechanical or optical. Figure 8 shows the components which are needed for the optical encoder. The disk is mounted on the rotating shaft and has patterns of opaque and transparent sectors coded into the disk. The theory behind is that while the disk is rotating, the opaque segments block the light and the light only pass through when the glass is clear and thus generate a square-wave pulses.
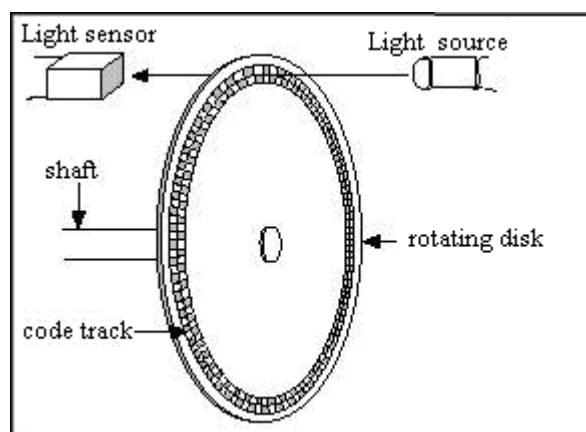
Fig.8: Optical encoder components

Instead of using only one set of pulses, it could not indicate the direction of rotation, so by adding in another set of pulses which positioned 90^0 out of phase with the previous pulses (Figure 9) now the two outputs channels indicate both direction and position of rotation. Just a simple notation, in this case, if Channel A leads Channel B, the disk rotate in a clockwise direction, and in the other way round, if Channel B leads Channel A, the disk will rotate in an anti-clockwise direction. By using the incremental encoders, it is not possible to determine the absolute position of a device but only the changes in position.

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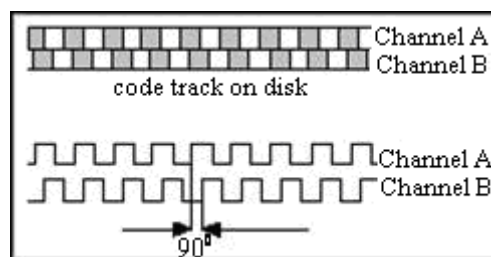
Fig.9: Quadrature encoder output Channel A and Channel B

INFRARED SENSOR CIRCUIT

Infrared sensor is an electronic device that emits infrared radiation and by detecting the reflection of the radiation through the receiver. Infrared sensors are easy to design and assemble because the components required are easy to come by [13-16].

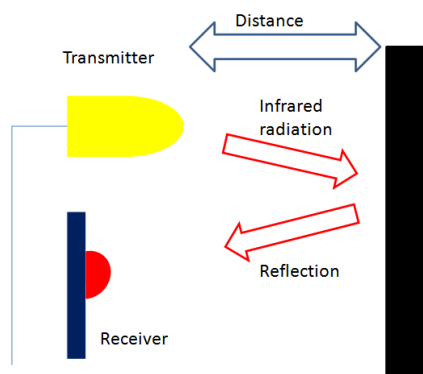The placement of the transmitter and receiver of the infrared sensor for the micromouse is shown in the figure below.

Fig.10: Placement of infrared sensor

The red color arrows show the infrared radiation and after it hit the wall, it will reflect back to the receiver. By measuring the voltage produced by the receiver, the distance between the sensors can be approximated. By placing a resistor between the power supply and the infrared emitter can manipulate the intensity of the emitter so that the receiver would not get saturated easily by detecting large amount of infrared radiation.

The robot has 6 pairs of infrared transmitters and receivers, so that it can detect the walls. Its principle is shown in figure.11.
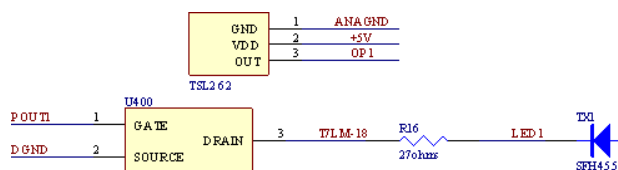
Fig.11: Infrared sensor transmitting and receiving circuit

In the circuit, SFH4550 emits the infrared light, change the value of R16 can change the intensity of the reflected light,TSL262 accepts the reflected infrared light and convert it, then input the value to MCU.

SOFTWARE

With the development of microelectronic technology and computer integrated technology, the integration and calculation capacity of digital signal processor (DSP) has been greatly improved, which not only has been widely used in various communication and video signal processing system, also are gradually applied to various advanced motor servo control system. TMS320F2812 is a chip of TI company product has the advantages of low cost, low power consumption, high processing capacity, the instruction execution speed up to 150MIPS, with independent

arithmetic logic unit, which increases its powerful digital signal processing ability. In addition, large capacity RAM are integrated into the chip, which can greatly simplify servo system circuit design, reduce system cost and complexity, but also greatly improve the storage capacity of data processing.

Field programmable gate array (FPGA) is just based on the standard unit array, it does not have a general integrated circuit function, but according to different needs, the user through a software can change its internal connectivity, in a relatively short period of time can realize specific integrated circuit function, and can secondary develop and change the software, so as to reduce the cost and shorten the cycle of product development. Due to the design of FPGA circuit uses traditional software ideas, which makes system design based on FPGA has a good reusability and modification, and greatly improved the calculation speed of the system. The new design concept just meets the high performance multi axis servor control system requirements, so in this paper micromouse intelligent servo system chooses TMS320F2812 and A3P250 as the core, PWM control signal of two axis motors completed generated by A3P250.

According to the requirements of the system, principle of dual core intelligent servo system based on DSP and FPGA was shown in Figure 12.
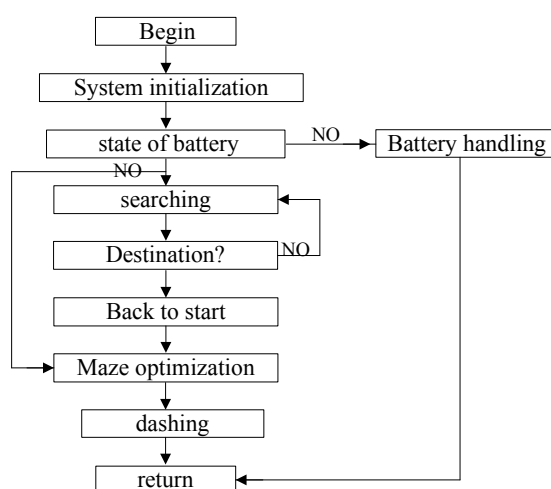
Fig.12: Flow chart of smart management system software

EXPERIMENT SECTION

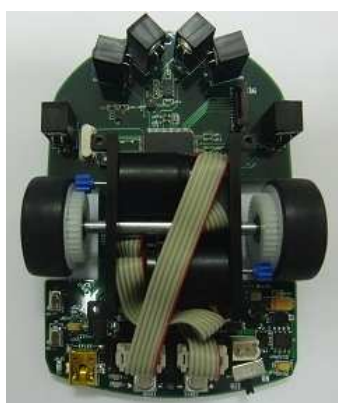The experimental micromouse prototype is shown in figure 13.

Fig.13: Micromouse prototype

The simulation results of FPGA for filter AB are shown in figure 14. Because the ChA leads ChB, so the filter AB will generate an up count signal (active high) together with Cnt signal which is shown in the white oval.
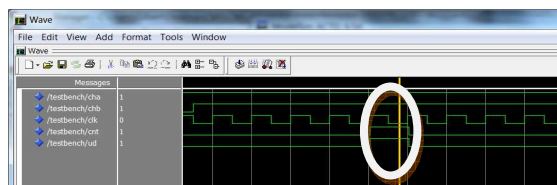
Fig.14: Simulation results-ChA leads ChB

The PWM output from A3P250 as shown in figure 15, as can be seen, pulse of PWM output waveform from the FPGA is very small, and the duty ratio of PWM signal is constant, which reduces interference to drive circuit.
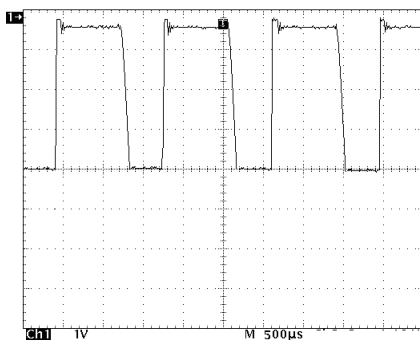

Fig.15: PWM waveform from FPGA

PWM signal to drive the X axis DC motor and Y axis DC motor in straight as shown in figure 16, as can be seen from the figure, the two DC motor PWM wave duty ratio is almost equal, which ensures that the two DC motor can walk at the same speed, ensures the accuracy of micromouse in straight navigation.
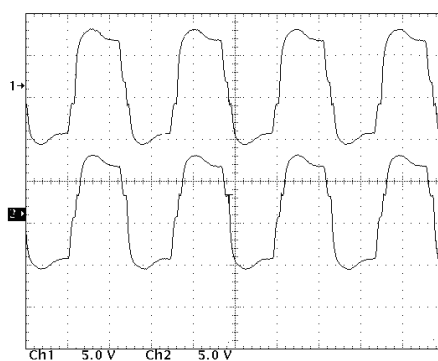
Fig.16: Input PWM waveform of motor

Electromagnetic torque of X axis DC motor and Y axis DC motor in straight accelerating stage as shown in figure 17. As can be seen from the graph, torque of the two DC motors in accelerating stage is almost the same, so that the two DC motors can increase its speed at the same acceleration, which ensures the accuracy of micromouse in straight acceleration.
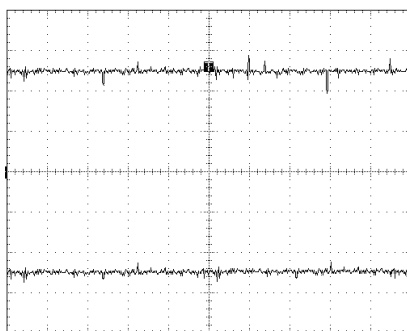

Fig.17: Waveform of motor torque

Increase the discharging current rapidly. The discharge current and discharge MOSFET gate drive signal as shown in figure 18.
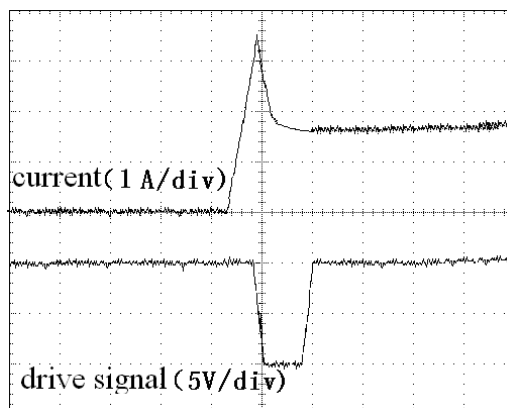

Fig.18: Current experiment

From the test waveform can be seen, when sampling current is too high exceed the limitation, MOSFET is shut off immediately, when sampling current recovery to the normal set value, MOSFET is automatically opened, which shows that current sampling circuit and protection circuit can work right, can effective protect of the test device and the system.

CONCLUSION

To meet the special requirements of high speed micromouse maze tracing, dual core micromouse based on DSP and FPGA is proposed. Intelligent servo system hardware and software is discussed and realized. Experiment result of motors show that the designed intelligent servo system can effectively realize two axis motor synchronous controls; Overcurrent test has proved that the system can effectively protect the power system.

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