INTELLIGENT CONTROL OF AUTONOMOUS MOBILE ROBOT: A DSP IMPLEMENTATION

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Abstract: This paper presents the fuzzy logic controller of an autonomous mobile robot which is a member of a cooperative robot team. The controller is implemented on TMS320F2812 DSP by Texas Instrument, which is one of the most efficient digital signal processor for control. The DSP is very good platform for complex control system implementation, where the real-time working is one of the most important and difficult process.

Keywords: Robotics, Fuzzy control, Digital signal processor.

1. INTRODUCTION

This paper presents an autonomous mobile robot (AMR) that has multi-sensor system i.e. reflective infrared sensors for line tracking, go around obstacles, etc. The AMR has an on-board complex control system which is built on base of TMS320F2812 DSP card. We developed a hierarchical fuzzy control algorithm which controls the whole system from motion to communication.

Because this AMR is a member of a cooperative robot team it has to communicate and work together with other members of the team, but this paper presents only the autonomous system of AMR i.e. "edge of world" sensors and control which fend off the fall down from the table with.

The control algorithm is implemented on an ezDSP TMS320F2812 DSP starter kit by Spectrum Digital Inc. This card is a very efficient development and evaluation environment for reasonable price. It is directly programmed and debugged from Code Composer Studio as we will see below.

Now we will see the hardware and software systems of our AMR.

2. AMR HARDWARE SETUP

The Figure 1 shows the AMR which is built-up on a light weight chassis and has two RC-servo drives and a free ball wheel. There are two levels; on the ground level are the accu-pack and power supply, the sensors and the driving system. Above these are the TMS320F2812 control board, daughter boards and connections.

2.1. The Power Supply

This is a highly autonomous system so we should use a durable on-board power supply which can power up the DSP board, motors and all the electrical systems. We use a 7.2 V 900 mA accu-pack which is regulated down to 5 V and can drive the AMR about one hour between to charge.

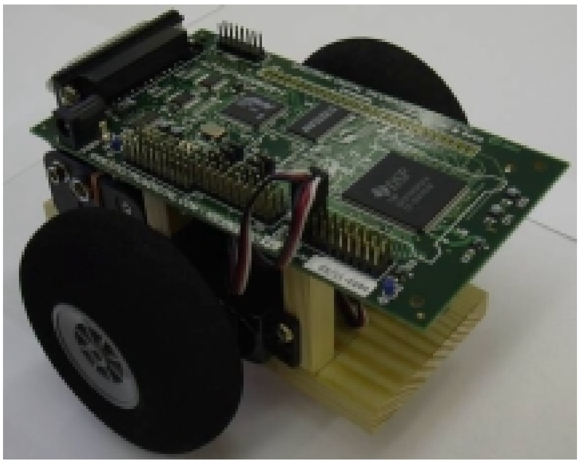

Fig. 1. The setup of Autonomous Mobile Robot (AMR)

2.2. *The RC-servo drive*

Driving the AMR two Conrad ES-030 RC-servos are used. The RC-servo is originated from radio-controlled model system but nowadays is used many control, robot and research system. The big benefits of these driving servos are the relative low price and the fully integrated electrical, mechanical and feedback system. The small black box contains:

- DC motor,
- gears with an output shaft,
- position (speed) -sensing mechanism,
- control and feedback circuitry.

We only need a PWM signal (one digital pin) to control the speed and the direction of one RC-servo.

The PWM cycle-time is 20 ms, the pulse widths and their effects are shown in Table 1. The pulse width is adjustable continuously between the lower and upper limits.

Table 1 The PWM pulse width and its effect

pulse width	speed and dir.	comment
0.6 ms	max. forward	min. pulse length
1.5 ms	zero	centre pos.
2.4 ms	max. backward	max. pulse length

2.3. *The Sensors*

We use four LTH 209-01 reflective infrared sensors that are situated on the four corner of AMR. The sensors send signal about the distance between the chassis and the ground, if the compared sensor signal is fall into the “gap” category the AMR stop or do something to fend off falling in the gap.

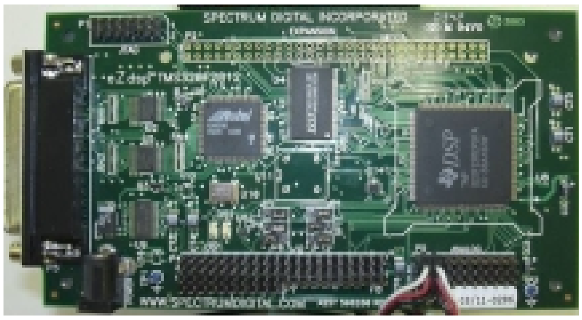

Fig. 2. The TMS320F2812 DSP Board

2.4. *The TMS320F2812 DSP Board*

The TMS320F2812 DSP board is a powerful processor produced by Texas Instrument (Fig. 2). It is supreme for control application. In this experiment, the board is served as the controller for AMR. This board can be programmed and debugged using CCS (Code Composer Studio). The compiled source code can be straight away load into the board through the parallel port connection from the pc to the board (Alter, 2003).

The advantage of using TMS320F2812 as motor controller is that it has 12 PWM output pins, plus 4 programmable PWM output pins. Therefore, motor control can be done with the setting of PWM along the board. No extra circuitry is needed to generate PWM signals for controlling the motor. Another advantage for using this board is that it has build-in analog to digital converter, which allows the feedback signals from the sensors to be digitized and stored in the DSP board for further process.

As shown in Figure 3, only two PWM pins (PWM1 and PWM2) are being used for the RC-servo control. Four ADC pins (ADCINA0, ADCINA1, ADCINA2 and ADCINA3) are reserved for the four RIR sensors. The 12-bits ADC samples the voltage values given by the sensors and stored the digitized value in each corresponding buffers. The value is then being used to decide the next movement of the AMR.

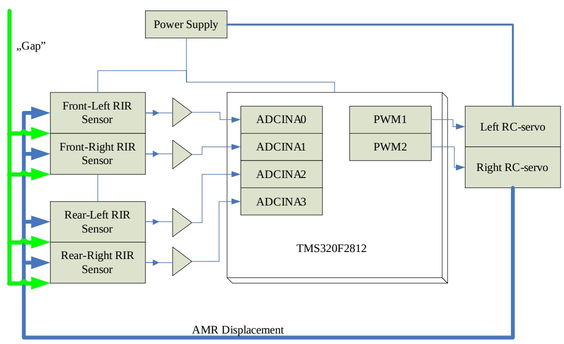

Fig. 3. The block diagram of controller hardware

3. FUZZY LOGIC

When the new concept of fuzzy sets and fuzzy logic was proposed by Zadeh (Zadeh, 1965), he was motivated by control and systems engineering aspects. Conventional control theory can cope with only a restricted class of systems, where linear, or at least, analytical input-output models can be constructed, or obtained by the eventually numerical, approximative solutions of the partial differential equation system describing the connection between input and output state variables (those being often dependent from each other).

Another major problem is the real-time application. Real-time control means that between two sampling times, the optimal solution for the action must be determined, and applied, where the frequency of sampling is predetermined by the frequency spectrum of the process (by the system itself), especially by Shannon's sampling theorem (Marks, 1991). Often, the system is known, and there are exact ways to determine the optimal conclusion (action); however, the computational complexity of the solution is too high, so it is merely a hypothetical possibility.

The question is now "How is it possible that well trained experts/operators can often cope with very complex systems (even though they cannot find the optimal solution in the exact sense), while high-speed and high-capacity computers fail with real-time digital control?" The answer lies somewhere in the ability of humankind to extract the most important elements of a problem, to find approximative solutions, to come to conclusions where no exact model is known, merely by reasoning on the analogy of known cases, and so on.

Fuzzy logic has a great advantage in comparison with discrete formal logical systems: it can approximate very well, it is suitable for the construction of approximative models that have any desired degree of exactness- or unexactness, and, by giving up the absolute goal of obtaining exactly optimal solutions, it is suitable for the construction of computationally effective algorithms of reasoning and control (Kosko, 1992). However, it is important to note at this point that good approximation does not necessarily mean precise approximation; in many applicational contexts, it is better to approximate as roughly as the concrete problem on hand allows it as preciseness of the approximation usually must be traded off for convenient computability (both in the sense of space and time complexity).

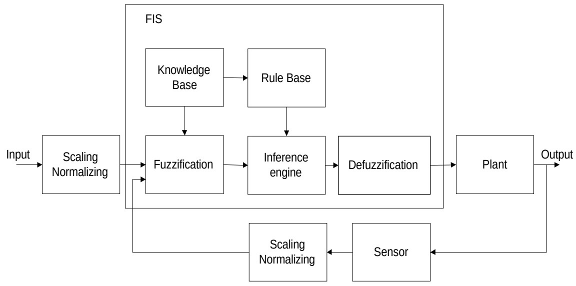

Fig. 4. The Fuzzy Inference control system

3.1. The Fuzzy Controller

The block diagram of the rule based fuzzy controller or fuzzy inference system is seen in Fig. 4.

The rule base is built upon fuzzy rules, which contain knowledge that states something exactly for a certain domain of the input space (this domain might be a single point, like in the case of the nonfuzzy systems) while for the fuzzy neighbourhood of this exact domain (core), vague knowledge is given (that has a decreasing degree of truth when going farther from the core) for a certain neighbourhood of these domains (Driankov, 1993).

In fuzzy controller this rule base is used by inference engine to get the fuzzy output from fuzzified measured and set value to defuzzified crisp control signal.

4. AMR'S FUZZY CONTROL ALGORITHM

Our fuzzy control algorithm runs on the DSP board as shown in Fig. 3. There are four sensors which send analog signals to the DSP about the distance from ground. Every sensor's input has three membership functions as is seen in Fig. 5.

Therefore we have four sensors and three terms, for dense rule base we should use 81 rules, and because we have a strong computational processor, a DSP, there is no problem for complexity. Afterwards, if the scale of system is grow up maybe we should use sparse or hierarchical rule base to reduce the time and space complexity of the fuzzy system (Kóczy, 1993).

The output signal has three fuzzy sets per servo, which is shown in Fig. 6. It is a reduced fuzzy output system; the speed variable is ignored, which would increase the system complexity significantly. However the speed variable is an important signal in a mobile vehicle, this level of our project it has no significant effect. Nevertheless the speed is not constant, between the output fuzzy signals are smooth transitions; there are no rigid boundaries.

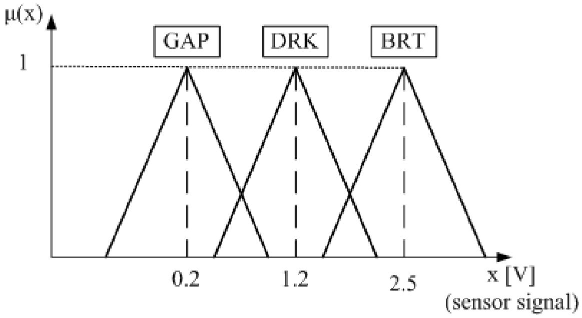

Fig. 5. The input fuzzy variable of one sensor

Table 2 Input fuzzy variable

Term	Definition
GAP	gap on ground
DRK	dark ground colour
BRT	bright ground colour

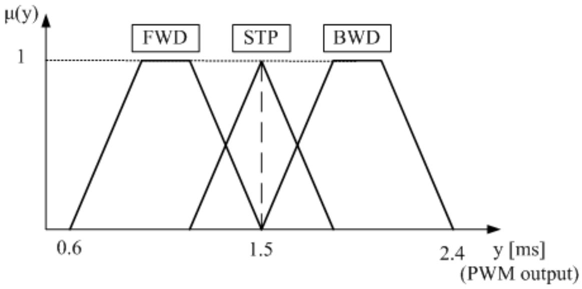

Fig. 6. The output fuzzy variable of one RC-servo

Table 3 Output fuzzy variable

Term	Definition
FWD	the motor rotates forward
STP	stop the motor
BWD	the motor rotates backward

The fuzzy variables and rule base are implemented as look-up table in the DSP memory. We use only linear membership functions (triangular and trapezoid), so the DSP has to calculate the series of linear functions to get the aggregated fuzzy output set. The crisp PWM outputs for RC-servos are calculated through centre-of-gravity defuzzification method by DSP.

4.1. The results of implementation

The quality of AMR control depends on the accurate decision making in real-time. For accurate control we need a dense and well built rule base. If there is not dense rule base, either no enough knowledge or no enough memory for store knowledge, we could use some interpolation methods (Kóczy, 1993). The TMS320F2812 has much more resources then we need in this level of our project.

For the properly sampling the sensors voltage the sampling rate is set to be around 400 Hz in TMS320F2812 ADC, while the fuzzy computation on DSP takes around 15 ms for one decision cycle. Hence the computational speed of controller board is enough of real-time working.

5. CONCLUSION

In this paper we present the implementation of a fuzzy controller on TMS320F2812 DSP, which is a control system oriented platform from Texas Instrument Inc. The DSP is very good platform for complex control system implementation, where the real-time working is one of the most important and difficult process, because it has strong computational capacity, enough working memory, and numerous direct system inputs and outputs (ADC, PWM, etc.). Therefore the idea come to test a fuzzy controller, which has high space and time complexity, on a DSP based system.

Our implementation done a good performance and realised a high speed real-time system, which can control more complex systems than this AMR.

The presented model is not a high scale system, but it was only one slice of a complex cooperation model team that is the main stream of our research project.

REFERENCES

Alter, M.D. (2003). *Thermoelectric Cooler Control Using a TMS320F2812 DSP and a DRV592 Power Amplifier.* Application Report SPRA873. Texas Instrument, New-York, USA.

Drainkov, D., H. Hellendoorn and M. Reinfrank (1993). *An Introduction to Fuzzy Control.* Springer-Verlag, Berlin, Germany.

Kóczy, L.T. and K. Hirota, (1993) Interpolation and size reduction in fuzzy rule base. *TR 93-94/401, LIFE Chair of Fuzzy Theory*, Tokyo Inst. Technology, Yokohama, Japan.

Kosko, B., (1992) Fuzzy systems are universal approximators. in *Proc. IEEE Int. Conf. Fuzzy Syst.* pp. 1153-1162, San Diego, CA.

Marks, R.J., (1991) Introduction to Shannon Sampling and Interpolation Theory. Springer-Verlag, Berlin, Germany.

Zadeh, L.A., (1965) Fuzzy Sets. *Inform. Contr.*, **vol. 8**, pp. 338-353.