

Appropriate introduction of computer control to mechanical engineering students

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Introducing mechanical engineering (ME) students to microcomputer applications in data acquisition and control areas needs to be done appropriately. It would not be the type of training suitable for ME students if excessive hardware associated details are involved. This paper describes the development of a subject with such 'appropriateness' in mind. The subject, as an elective, has been welcomed and enthusiastically participated in by a larger percentage of the final year (i.e. fourth year) and postgraduate students during the last few years. This is in a way indicative that the approach taken is appropriate for ME students.

INTRODUCTION

The introduction of the knowledge and skills of computer control to mechanical engineering (ME) students is essential for their future professional engineering career [1, 2]. However, if excessive hardware-associated details are involved, ME students would be discouraged as a result. In an undergraduate subject for computer control [3] reported in 1985, students are required to learn the hardware details of microprocessors and write software in assembly language and machine code.

The authors of this paper would argue that the changing computer hardware/software technology has enabled us to avoid most hardware details and tedious assembly language while preserving the necessary insight to the topic. 'Computer control of machines and processes' is an elective subject developed for the fourth year students in the Department of Mechanical Engineering at University of Wollongong. Students are required to develop software from scratch for simpler tasks such as digital input/output while take advantage of the communication library often supplied with commercial interface cards for more involved

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tasks, such as analogue to digital conversion. In this way, students are relieved from many hardware related details while the benefit of insight into the problem is retained. The C language, which has become very popular for computer control applications and widely supported by most commercial computer data acquisition and control systems, provides ME students the opportunity of having a second computing language skill other than Fortran. Students are greatly encouraged when they find themselves able to accomplish with ease both conventional and more sophisticated control of systems such as robots, liquid level, autonomous vehicle, etc. Widely used analogue and digital sensory and actuation technologies are also incorporated as an integral part of the subject. Based on feedback received through the teaching evaluation system sponsored by the Centre for Staff Development at University of Wollongong over the last few years, the subject has proved to be a valuable learning experience appropriate to mechanical engineering students. The subject has been welcomed and enthusiastically participated in by a larger percentage of students as an elective at both the final-year undergraduate level and the postgraduate level.

THE AIM AND SCOPE OF THE SUBJECT

The subject, 'Computer control of machines and processes' (Mech412), is an elective for those students who have taken a core subject 'Control system I' (Mech361) which covers the classical control theory. After completing the subject Mech361, the students have only obtained some abstract concepts of control theory. The introduction of Mech412 is aimed at introducing the students to the knowledge of digital computer control and providing them an opportunity, through a number of practical control projects, to apply the control theory and concepts to practical machines and processes. The subject is structured to cover:

- (a) Analysis, synthesis and implementation of digital control systems for practical machines and processes.
- (b) Discrete modelling techniques including system response and discrete controller design.
- (c) Use of control computers and microprocessors, computer interfacing and C language.
- (d) Exposure to advanced and intelligent control techniques, such as expert system-based control and fuzzy logic control.

DESCRIPTION OF THE PROJECTS WITHIN THE SUBJECT

Three control projects at different levels are designed to provide step-by-step training to students. Two commercially available hardware/software packages were used in the projects. Schematic diagrams for the computer control systems using these two packages are shown in Fig. 1 for PCL812 data acquisition card and Fig. 2 for Mini Board. Their details are listed in the appendix.

The projects designed for the subject are outlined below.

Project 1: Open-loop digital control of a stepping motor driven robot arm

Project 1 is designed to provide the students a basic understanding of computer control involving digital input and output only. Shown in Fig. 3(a) is a two-axis robot arm driven by stepping motors. The objectives of the Project 1 are:

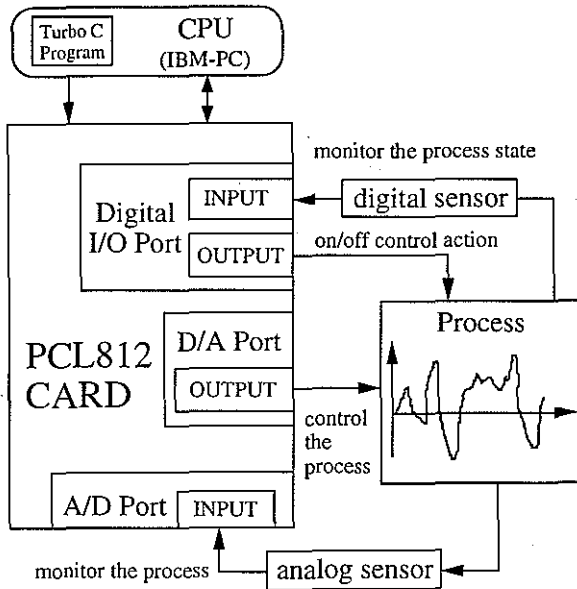


Fig. 1. A computer control system with the use of PCL812 data acquisition card.

- Develop understanding of the concepts involved in computer control which requires digital input/digital output (DI/DO) only.
- Gain insight into the concepts involved in computer control without using any provided input/output subroutines.
- Develop necessary programming and debugging skill in C language to implement the above.

Project 2: Closed-loop PID control systems

The main aim of Project 2 is to provide students with the basic skills in using a computer data acquisition and control card to perform PID control tasks, such as (a) a two-tank liquid level system shown in Fig. 3(b) and (b) a two-fan windmill system shown in Fig. 3(c). Given below is the outline of the objectives of this project.

- Develop understanding of the concepts involved in computer control which requires analogue to digital conversion (A/D) and digital to analogue conversion (D/A).
- Develop understanding of the concepts involved in computer control by taking advantages of the provided input/output subroutines.
- Develop further appreciation of the concepts involved in computer control of dynamic systems.
- Develop necessary programming and debugging skill in C language to implement the above.

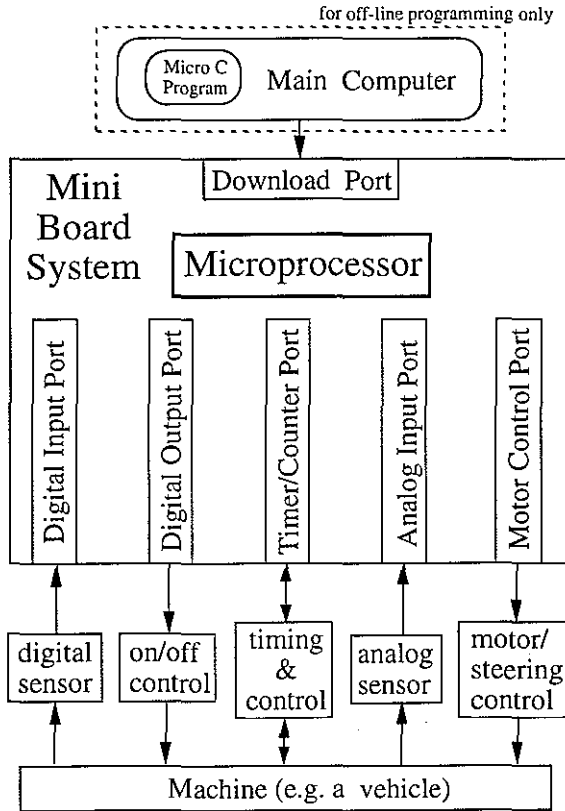


Fig. 2. A Mini Board-based computer control system.

Project 3: Microprocessor (Mini Board) based autonomous vehicle

The introduction of Project 3 is to train students in developing a relatively more sophisticated control system, such as an autonomous vehicle shown in Fig. 3(d), by taking advantages of commercially available microprocessor-based motor control packages (Mini Board). The objectives of the project are described as follows:

- Develop understanding of the concepts involved in various functions built in a microprocessor-based motor control system, such as analog and digital inputs, timer/counter input and output, and motor control unit.
- Develop understanding of the concepts involved in fuzzy logic control for a multiple sensor-based control task.
- Develop necessary programming and debugging skill in Micro-C language to implement the above.

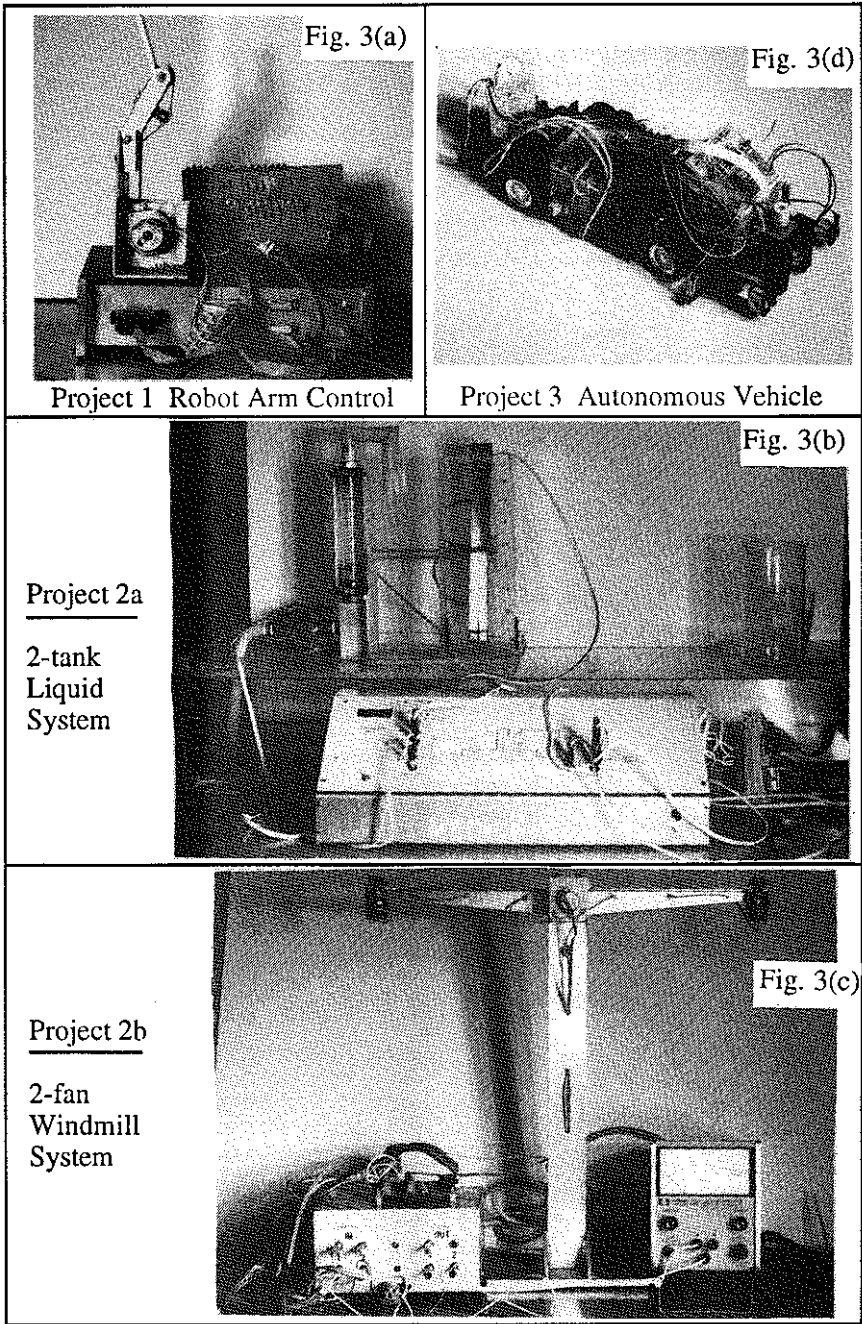


Fig. 3. Projects designed for the subject of computer control.

DESIGN OF A LEARNING PROCESS

Step 1—Learning control via digital I/O only

In Project 1 for digital control of a two-axis robot arm, students learn how to interactively specify which axis to control and whether they would like to move it up or down. Based on the PCL812 data acquisition card, the students are required to write C program to move the robot arm using two digital output ports and to remotely stop the robot using a digital input port, as shown in Fig. 4.

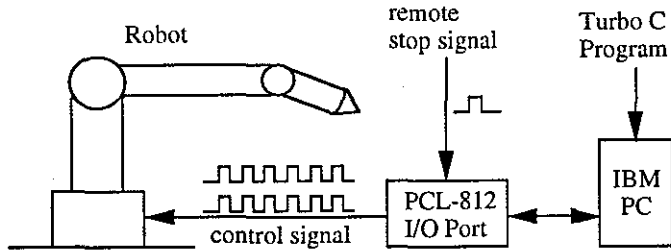


Fig. 4. Schematic diagram for a two-axis robot arm control (Project 1).

Step 2—Learning PID control via A/D and D/A interface

In Project 2, students implement the proportional-integral-derivative (PID) control strategy for a two-tank liquid level system and a two-fan windmill system. The PCL812 interface card provides the input subroutines for data conversion (A/D) from sensors and the output subroutines for control action (D/A) to outside actuators. By using transform techniques, students translate the continuous PID control algorithm into a discrete one for computer control purpose, as shown below:

Continuous PID control algorithm:

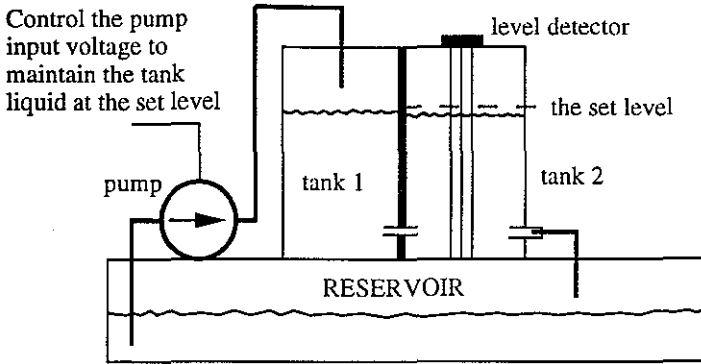
$$m(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (1)$$

Corresponding discrete PID control algorithm:

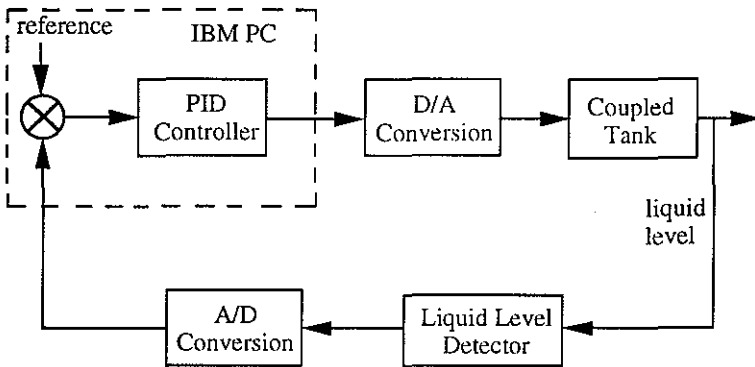
$$m_n = K_p e_n + K_i \sum_{j=1}^n T e_j + K_d \left(\frac{e_n - e_{n-1}}{T} \right) \quad (2)$$

where K_p is the proportional gain, K_i the integral gain, K_d the derivative gain and T the sample time interval.

The working principles and control systems for Project 2 (a and b) are shown in Figs 5 and 6 respectively. Students learn how to use the provided PCL812 subroutines to perform the A/D and D/A operations and how to implement PID control algorithms. Fig 7 gives a general flow chart for PID control used in Project 2.



(a) Working Principle



(b) Control System

Fig. 5. Schematic diagram for a two-tank liquid level system (Project 2a).

Step 3—Learning more sophisticated control and the use of microprocessor-based control pack

In Project 3, students first develop skills in using various types of sensors to build up an autonomous vehicle. For instance, six digital infrared reflectance (IR) sensors are mounted near the four wheels of the vehicle to detect any sharp edges. Two analogue infrared reflectance sensors mounted on the front of the vehicle are used for detecting any obstacles during the movement and the distance to these obstacles. A compass sensor is used to check the direction of vehicle movement. A photodiode sensor is used to give a stop command when the vehicle approaches the goal outlet. Shown in Fig. 8 is the requirements in this project for such an autonomous vehicle which is controlled by the Mini Board.

Next, students learn how to utilize some common functions, which are built in most commercially available computerized motor control packages, to perform a sophisticated task. Equipped with these functions, students are set to implement some forms of more advanced control techniques, such as fuzzy logic control. For example, by sensing the

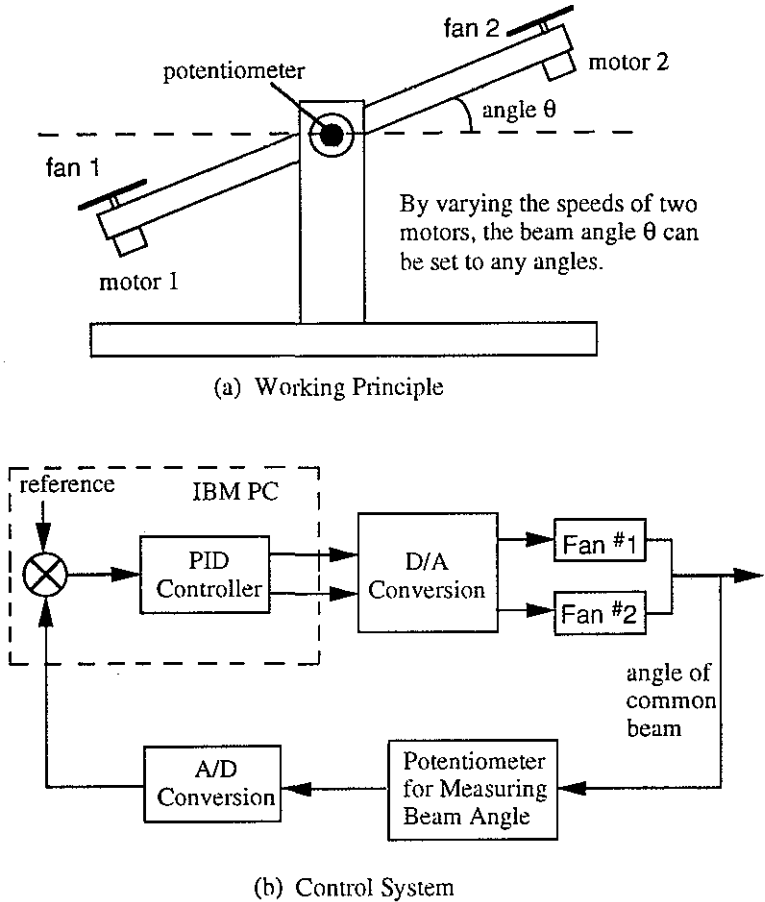


Fig. 6. Schematic diagram for a two-fan windmill system (Project 2b).

the distance between the vehicle and an obstacle, a fuzzy logic controller could be developed to control the steering. Shown below are three fuzzy knowledge rules of doing this:

- Rule 1: IF distance is close THEN steering angle is maximum.
 Rule 2: IF distance is middle THEN steering angle is medium.
 Rule 3: IF distance is far THEN steering angle is minimum.

Based on the rules, students develop fuzzy logic control algorithms by using the fuzzy membership functions for the 'distance' and 'steering angle', and the fuzzy min-max operations [4, 5].

Shown in Fig. 9 is a flow chart for the control strategy of the autonomous vehicle system developed in Project 3.

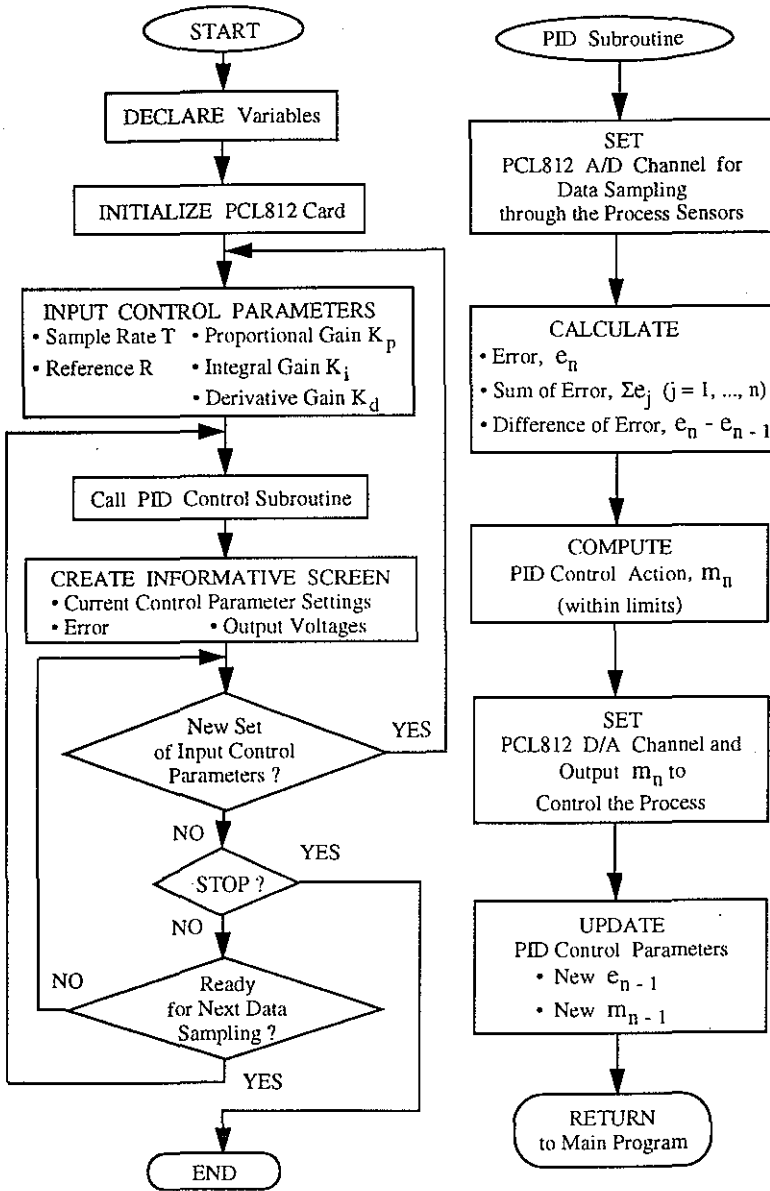


Fig. 7. A general flow chart for PID control.

CONCLUDING REMARKS

Through taking the project MECH412, ‘Computer control of machines and processes’, students from mechanical engineering have learned how to use computer hardware/software

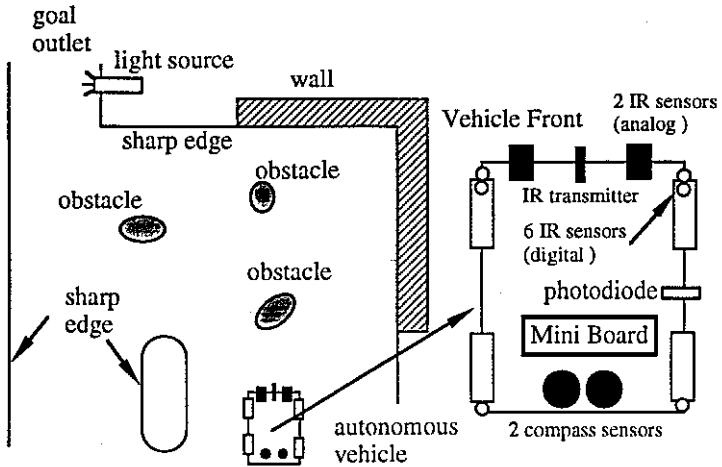


Fig. 8. Requirements for control of an autonomous vehicle (Project 3).

technology to perform various control tasks. They have also learned how to apply sensory and actuation techniques to practical systems.

Directly benefiting from commercial interface cards and the associated supporting software subroutines, students can concentrate on the problem in question by being relieved from related hardware details, while the insight to the area is preserved by a proper design of the subject. This approach is in agreement with the current trend in the development of computer software/hardware technology which has put fewer requirements on the users' knowledge into electronic hardware details.

The subject has been run for three years and a large percentage of the final-year (fourth year) and postgraduate students has participated. The teaching evaluation sponsored by the Centre for Staff Development at University of Wollongong has shown that the subject is well received by the students. This is reasonably indicative that the design of this subject is appropriate for mechanical engineering students.

APPENDIX: HARDWARE DETAILS

(1) PCL812 enhanced Multi-Lab card

The PCL812 is a low-cost multi-function data acquisition and control card, from Advantech Co., Ltd (Taiwan) for IBM and compatible computers, suitable for a wide range of applications in industrial and laboratory environments. The PCL812 also provides powerful and easy-to-use software subroutines which can be called from several common computer languages, such as Basic, Fortran and C. The key features of PCL812 are as follows.

- 16 single-ended analogue input channels.
- An industrial standard 12-bit successive approximation converter (HAD574Z) to convert analogue inputs. The maximum A/D sampling rate is 30 kHz in DMA mode.
- Switch selectable versatile analogue input ranges. Bipolar: $\pm 4V$, $\pm 2V$, $\pm 5V$, $\pm 10V$.
- Three A/D trigger modes: software trigger, programmable pacer trigger and external trigger pulse trigger.

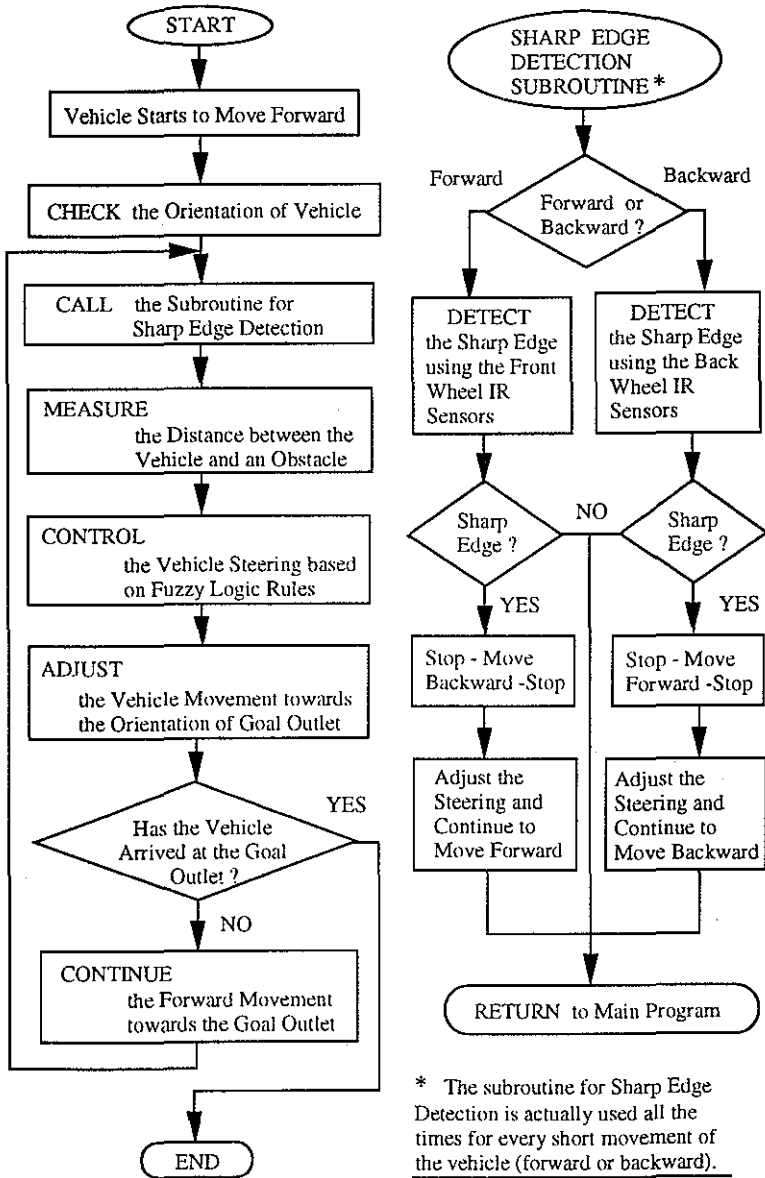


Fig. 9. A representative flow chart for the autonomous vehicle control.

- The ability to transfer A/D converted data by program control, interrupt handler routine or DMA transfer.
- An INTEL 8253-5 programmable timer/counter provides pacer output (trigger pulse) at the rate of 0.5 MHz to 35 minutes/pulse to the A/D. The timer time base is 2 MHz. One 16-bit counter channel is reserved for user-configurable applications.

- Two 12-bit monolithic multiplying D/A output channels. An output range of from 0 to +5 can be created by using the on board $-5V$ precision reference. External AC or DC references can also be used to generate other D/A output ranges.
- 16 TTL/DTL compatibles digital input, and 16 digital output channels.
- Expansion capabilities with a series of daughter boards, such as Amplifier/Multiplexer Board, Relay Output Board, Isolated D/I board, etc.

(2) Mini Board

The Mini Board is a single-board computer, from The Media Laboratory at the Massachusetts Institute of Technology, optimized for controlling small DC motors and receiving data from various electronic sensors. Its miniature size (about 7.5 by 5 cm), low power operation, and programmability make it ideal for control of a small, mobile robot or vehicle. It communicates with a desktop computer over a standard RS-232 serial port, making it suitable for PC-based control as well. The key features of the Mini Board 2.0 are listed as follows.

- Control of four DC motors, at voltages of 6 to 36 V and up to 600 mA of current. Using software-based pulse width modulations, motors may be controlled at 16 levels of speed from off to on in either direction.
- Eight analogue inputs for continuously varying sensor devices.
- Eight digital inputs for on/off type sensor devices.
- Three or four programmable counter inputs and four or five timer outputs. One of the timer pins is used to drive a piezo beeper for sound output.
- An RS-232 compatible serial port for communicating with desktop computers.
- A high-speed synchronous serial bus that may be used implement a network of Mini Boards. The network may be controlled by a single desktop computer or a single Mini Board, or it may have distributed control.
- Single power input for powering electronics and motors. On-board voltage regular allows board to be powered by an DC voltage source of 6 V or greater.
- Motorola 6811 8-bit microprocessor with 256 bytes of internal RAM and 2 Kbytes of electrically erasable programmable ROM (program memory).
- 6811 software libraries provided for stand-alone programming (embedded control) using an inexpensive C compiler.
- 6811 monitor program supplied for use of board as tethered controller operated by desktop computer.
- MS-DOS software provided for downloading 6811 programs to the board.

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