Intelligent Control Design Using S12 Microcontroller: A Student Design Workshop

Christopher Carroll, Marian S. Stachowicz, Laboratory for Intelligent Systems,
Department of Electrical & Computer Engineering, University Of Minnesota Duluth, USA,
ccarroll@d.umn.edu, mstachow@d.umn.edu

Abstract - *In the last decade, the topic of mobile robots has become a very attractive to engineering students. It has been shown that students working in this problems show more interest in learning digital electronics, microcontrollers, and analog circuits; this is because they see an immediate application of the subjects they are learning.*

This paper describes the Design Workshop course offered at the Electrical and Computer Engineering Department (ECE) at the University of Minnesota Duluth (UMD). This workshop course is one mechanism by which students completing the ECE program at UMD can satisfy the requirement for a senior design project. The design workshop topic for the spring 2010 was the use of fuzzy logic to control mobile robots. In this workshop, students worked in small groups and were required to design, build and program a mobile robot with intelligent behaviors using fuzzy logic. In this workshop no formal lectures are taught, however the students receive an intensive review covering the topics of the 68HC12 microcontroller, principles of mobile robots, sensors, and Fuzzy Logic Control. Fuzzy Logic has emerged as a practical alternative that provides a convenient method to implement nonlinear controllers. Fuzzy controllers work differently than conventional controllers; expert knowledge is used instead of differential equations to describe a system. This knowledge can be expressed in a very natural way using linguistic variables, which are described by fuzzy sets. Fuzzy Logic has been used primarily on large-scale computing systems and personal computers. The introduction of Motorola's MC68HC12 microcontroller, which incorporates several Fuzzy Logic primitives in its instruction set, has made possible the implementation of fuzzy controllers in microprocessor-based systems. All concepts covered are illustrated with examples from course ECE 4951 Design Workshop – Spring 2010 – Intelligent Control Design Using S12 Microcontroller

Index Terms - *Fuzzy Logic, Intelligent Control, Microcontrollers, Mobile Robots.*

INTRODUCTION

The "Design Workshop" course umbrella under which the course described here was offered is one of two paths that students can use to complete their capstone senior design experience. The other option is an independent "Senior Project" format. In both settings, students complete a design project in small teams of two or three students. In the Senior Project format, the team is advised independently by a faculty sponsor for the project. In the Design Workshop format, a collection of design teams work in a class environment, sharing a common topic or theme for their designs. The faculty member teaching the Design Workshop course supervises all team designs completed in the course.

The two paths for completing the capstone senior design experience are appropriate for different groups of students. If a design team has a good idea for a project about which they are excited, the Senior Project format is the better choice, since the design team already has motivation to complete the project due to an existing interest in the topic. Ideas for Senior Projects often arise from student team members' hobby or professional interests outside school. Developing the idea for a design project, however, is usually the hardest part of the task, and students often have trouble settling on an appropriate topic for their design experience. For these students, the Design Workshop format is ideal, since the topic area is chosen by the faculty member offering the course, and specific project ideas arise as natural tasks within that topic arena.

Recent topics for Design Workshop courses have been wide-ranging. One Workshop involved using the low-power versions of PIC microcontrollers to implement various applications that operated on "coin-cell" batteries, emphasizing the low-power qualities of the circuit design. Another recent workshop used an early home computer game system as a foundation. Students designed software implementing games using the various features of the system. In that Workshop, students were asked to design their games to be marketable as plug-in cartridges for the computer game system in its day. Some Workshops have been designed around national or regional design competitions. The focus of the competition became the arena within which students designed their projects.

The Design Workshop topic for the course offering described in this paper was "Intelligent Control using the Freescale S12 Microcontroller."

The S12 microcontroller is uniquely suited to this workshop because it includes fuzzy logic capabilities.

Several of the primitive instructions in the S12 instruction set implement basic fuzzy logic operations, making this processor a natural choice for applications implementing intelligent control using fuzzy logic. A variety of projects was completed in this Workshop, including voice recognition, robotic control, and environmental monitoring.

This Design Workshop offering demonstrated the unique characteristic of the Workshop path to providing a capstone design experience to students. It introduced a topic, intelligent control using fuzzy logic, and established an environment within which student teams completed design projects on various topics. The nature of the Design Workshop course allowed students to complete their independent projects working in teams of two, while maintaining a classroom environment in which the teams could collaborate and share ideas. It was an environment that encouraged and stimulated learning.

Fuzzy Logic on the S12 Microcontroller

Three specific instructions in the instruction set of the S12 microcontroller are designed to implement fuzzy logic primitive operations. These instructions are MEM (membership), REV (rule evaluation), and WAV (weighted average). These three instructions are described briefly here.

The first step in fuzzy logic calculations involves "fuzzification," in which the crisp input variables to the system are assigned degrees of membership in various fuzzy sets. In the S12 microcontroller, fuzzy sets are described as trapezoidal functions that identify the degree to which a particular crisp value is a member of the set. These trapezoidal functions are described in a data structure in the microcontroller memory, and that data structure is used by the MEM, membership, instruction to calculate the degree of membership in each fuzzy set for a given crisp input value. The resulting degrees of membership in each fuzzy set, or fuzzy inputs, are stored in the microcontroller memory for use in the next step of processing.

Following fuzzification, the fuzzy inputs are combined using a list of "rules" for producing fuzzy outputs of the system. The rules each say "If A and B and C and… then output is XX." The "and" operator is implemented on the fuzzy input variables using a "minimum" operation, and the results of various rules are combined using a "maximum" operation, producing a set of fuzzy output variables that record the degree to which the variables belong to certain classes of output. The instruction in the S12 instruction set that accomplishes this operation is REV, rule evaluation. There is another instruction REVW, or weighted rule evaluation, that can be used instead for the situation where some rules are weighted differently than others in producing the fuzzy outputs. The result of this core processing is a collection of fuzzy output variables, again stored in the microcontroller memory.

The final step of processing involves "defuzzification" in which the fuzzy output variables are converted to crisp outputs that can then be used in the system under study. This process involves calculating a weighted average of the possible values of the crisp outputs, using the fuzzy output values as weights in the calculation. The WAV, weighted average, instruction in the S12 instruction set implements this process, completing the fuzzy logic calculations. WAV produces crisp output values that can then be displayed or used in the rest of the system.

These instructions, MEM, REV (or REVW), and WAV, form the heart of the fuzzy logic processing capabilities of the S12 microcontroller. They are included as primitive operations in the microcontroller's instruction set. They ease the process of designing fuzzy logic applications by implementing the core parts of the processing in a compact and easily used package.
In the next sections the objectives, description, and organization of the workshop are described. Some of the student projects are shown, and conclusions and further improvements are presented.

OBJECTIVES

In order to include several of the ABET EC2008 a-k criterions, the objectives established for the Design Workshop are:

- Expose students to team-based design and experience team learning,
- Expose students to engineering problems with realistic constrains, and use their creativity, knowledge, and skills acquired in previous courses to solve the problems,
- Exercise their oral and written communication skills, and improve them by presenting written reports and oral presentations during the semester,
- Expose students to the knowledge of contemporary issues, and made them realize of the need to engage in life-long learning,
- Since no formal lectures are given, the students exercise their own self-learning and research skills.

WORKSHOP DESCRIPTION

The Design Workshop course is offered each year during the spring semester and the topic of the course varies depending on the expertise of the instructor(s) teaching the course. Usually a team of two faculty members teaches this course, and the main role of the instructors is to guide and advise the students in order that they can develop a real engineering project.

In order to make the Design Workshop more interesting for the students, during the last years we have selected topics in areas that are not typical or that are not usually covered in normal courses. For example in the past three years the topics were: Intelligent Toys, Fuzzy Mobile Robots, and Intelligent Mobile Robots.

For the implementation of the projects, a platform based on the Motorola M68HC12 microcontroller has been used. We have found the 68HC12 microcontroller very convenient for our capstone design projects because its large amount of I/O ports available to interface with sensors and motors, and the instruction set with fuzzy logic primitives are very useful in the implementation of intelligent controllers. Since all of our ECE students learned in previous courses the 68HC11 architecture and assembly language, they have the background necessary to start using the 68HC12. Due to the popularity of the Motorola microprocessors, the variety of development boards based on the 68HC12 family, and the large amount of information and examples available on the web, which can be accessed by the students, we have made this family of microcontroller our choice for the controllers in our design projects.

Since no formal lectures are taught in this workshop, an intensive review, covering important material related to the specific topic, is given at the beginning of the semester. In particular for the robotics, and intelligent systems topics, the reviewed material includes: the MC68HC12 architecture and assembly language, introduction to robotics, sensors for robotic applications, motors and drivers, and fuzzy logic. Several papers and references are given, and students are encouraged to read the material and exercise their self-leaning skills.

It is important to have in mind that since this is a capstone design, students should be able to apply the knowledge and skills that they have learned in previous courses to solve problems that will emerge during the development of the project.

WORKSHOP ORGANIZATION

In the workshop, teams of two or three students are formed. Each team is encouraged to develop ideas of their own and present a proposal for their project. All the proposed projects should fit into the selected topic, and should be reviewed and approved by the instructors. The students have fifteen weeks to do all the work, from the definition to the development and completion of the project. To secure that the proposed projects are developed on the specified time, the activities are planned as follows:

- Weeks 1 –3. Intensive review covering key topics for the projects. Typically the themes have been: The 68HC12 microcontroller, its architecture and assembly language. Principles of mobile robots. Sensors for robotic applications. Principles of fuzzy logic. Literature review.
- Week 4. Definition and specification of the proposed projects. Each team works on a formal written proposal for their project.
- Week 5. Students present the written reports and oral presentations of the project proposals.
- Week 6-7. Students work in the simulation part of their projects. They use Mathematica and its Fuzzy Logic Package.
- Week 8. Midterm written reports and oral presentations. Students present the results of the simulations. A formal oral presentation is required, and each student in the team has to participate.
- Weeks 9-14. Implementation of the systems. Students build their intelligent systems, using the 68HC12 microcontroller. Circuits and interfaces are designed and built to connect different sensors and actuators to the 68HC12.
- Week 15. Final written reports, poster, oral presentations, and demonstrations of the working systems.

It is important to emphasis that during all the semester, students and instructors meet once a week. Students talk about their progress, and problems that they are having in the projects, and the instructors give suggestions.

HARDWARE DESCRIPTION

For the actual implementation of the projects, each team is giving an evaluation board based on the Motorola MC68HC12 microcontroller. The boards that we have been using include the Motorola M68EVB912B3 evaluation board [8], the NMT MRK board [9], and the Wytec MC9S12 MiniDRAGON+ Development Board [11].

To meet the necessities of each specific project, different types of sensors and motors are available to the students. Some of the components available are photocells, thermistors, small microphones, micro switches, infrared and ultrasonic rangers, small digital cameras, DC motors, servomotors, and step motors. A variety of hardware material such as PVC, acrylic, wood, metal, bolts, screws, etc. is available too.

PROJECTS DESCRIPTION

At the beginning of the semester suggestions about possible projects are given to the students. However students are encouraged to develop ideas on their own as well. One of the projects was to create an intelligent hovercraft mobile toy that would navigate by itself without bumping into obstacles and searching for a specific goal. A fuzzy control was implemented to create a rule-based controller to select the proper fan speed and steering angle using input distances. In another project the goal was to implement an intelligent greenhouse. In this project a fuzzy control was used to control the climate of one or a few plants automatically. A racecar robot was another project. The goal in this project was to create an autonomous racecar capable of driving itself around a closed-course race-track, adjusting speed for proper cornering. For the implementation of the racecar robot, a remote control car was modified, adding a Motorola 68HC12 evaluation board, and a sensor system to perform the control of the car. A fuzzy control was implemented to select the proper wheel speed, and steering angle using input distance sensors. The racecar robot was capable of wall avoidance, speed adjustment, and corrective steering. Another project was a fuzzy controlled insect behavior robot. The objective of this project was the design and implementation of an insect behavior robot. In this project fuzzy control was used to implement the avoidance of light, sound, and obstacles. This robot utilized five photocells for the detection of light, five small microphones for the detection of sound, three infrared proximity sensors (Sharp GP2D12), and two touch sensors for the detection of obstacles. The object avoidance was the highest priority, and the robot would always avoid objects before running from sound or light. Several interfaces were designed and implemented to connect the different sensors to the 68HC12. The titles of other projects were: the Color Recognition for Tracking Robots, Path Tracking Vehicle with Fuzzy Control, Voice Activated Control of a Direct Current Motor.

CONCLUSIONS

During the three years that we have been offering the Design Workshop course on intelligent systems, and robotics, we have found that students get more motivated in learning fuzzy logic theory and microcontroller programming by applying them to the design and implementation of mobile robots and intelligent toys [12] - [14]. From the oral presentations, written reports, poster, and demonstration of the projects, we can say that the students gain an excellent understanding in both disciplines: microcontrollers and fuzzy logic control.

The organization of the activities kept the students working in the projects during all the semester, and as a result, most of the projects were able to meet the original goals. Students are also exposed to team learning experience and team-based design, and have the opportunity to exercise and improve their written and oral communication skills.

FURTHER IMPROVEMENTS

Future improvements to the Design Workshop course include the following: having multidisciplinary teams including students from different engineering disciplines (electrical, mechanical, industrial) and computer science. Also, student should address as part of their final reports any environmental, ethical, and economical issues that are affected by their projects.

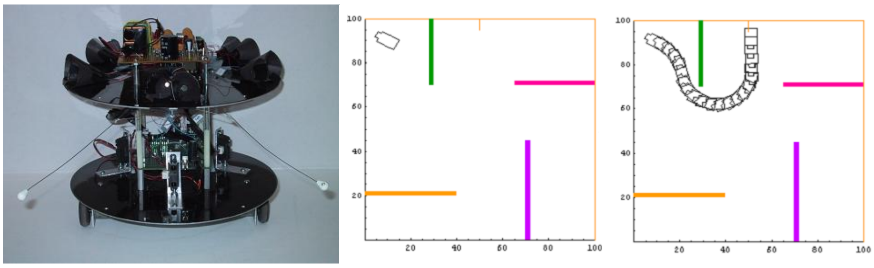

FIGURE 1
THE RACE CAR ROBOT AND *MATHEMATICA* SIMULATION: MOBILE ROBOT TRAJECTORY WITH OBSTACLE AVOIDANCE

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