An Integrated Undergraduate Research Experience in Control, Power Electronics, and Design using a Micromouse

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Abstract - **This paper presents a Micromouse project - integrated with the power electronics undergraduate curriculum - as part of a complete undergraduate research experience. The project had several objectives: a) challenge the programming skills of the students, b) teach team integration for an efficient hardware and software development, c) solve engineering problems in order to have a better Micromouse design. Undergraduate student participation is further ensured by linking the Micromouse project to microprocessor programming, electromechanical applications, and other classes. After this research experience the undergraduate students will expand their knowledge on software, hardware, and design using an entertaining but fairly complicated project. Finally, the project will benefit the department in enhancing classroom instruction as well as student retention, graduate school recruitment, and a hands-on experience.**

Index Terms - Nonholonomic Robots, Micromouse, Flood-Fill Algorithm, and Undergraduate Research.

INTRODUCTION

On the Micromouse project it is expected that the students will improve their skills in software, hardware, and control systems using tools and devices commonly used in applications like this one. The students will develop software that can solve a stated problem. By the end of the project, the students should have successfully built and tested a fully autonomous robot in order to compete in a Micromouse competition [1].

The goal of the competition is to design a robot car (Micromouse) that will find the shortest path to the center of a maze similar to the one showed in Figure 1. The contestants are given 10 to 15 minutes to make multiple runs [1], throughout which the robot should be capable of programming itself - "learning" the maze as it "discovers" it [2]. Once the robot successfully maps the maze, it has to choose the shortest way to the center. The winners are selected using certain criteria like shortest time, fully autonomous, and less crashing.

The Micromouse is a fully autonomous nonholonomic robot. Nonholonomic robots have been used in various research experiments. An application example could be a Mars robot used to explore the unknowns of the planet. Just like the Micromouse, a robot used to explore Mars should be completely autonomous, should be able to avoid obstacles, and reach a determined destination. It should also be able to "remember" the route taken so that it can go back to the start.

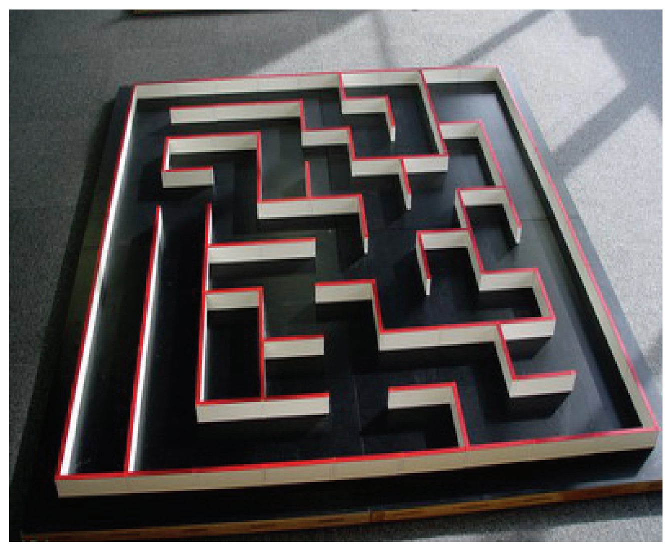

FIGURE 1
EXAMPLE OF THE TYPE OF MAZE USED ON THE MICROMOUSE CONTEST

The Micromouse is not just a competition, it's also an innovative project that challenges the students' ability to solve problems and relates them with actual projects. Some actual projects related to nonholonomic robots can be found in [3], [4], [5], [6], [7].

There are various difficulties that need to be taken into consideration in the design process in order to have the better robot (e.g. imperfections in the maze). Several algorithms and control systems are used to ensure overall performance and stability.

The students learned about existing algorithms which allow the Micromouse to solve the maze [2], [8], [9]. The key is to implement them in such way that it will ensure the mouse to reach the center of the maze. Some of these are:

- The Wall Followers (left or right wall)
- The Flood-Fill Algorithm
- Combinations of the previous

HARDWARE

The Micromouse requires a microcontroller that can execute the maze solving algorithm. When working with a microcontroller, the student must be capable of understanding the required specifications. Namely the microcontroller should have enough memory to retain the code and memory matrices that it may need. It should be able to receive signals from all the different transducers, be them analog or digital signals, and it should be able to send signals to the different drivers and controllers. The students must be able to tell whether every component is compatible with the microcontroller. The technology (TTL, CMOS, LVCMOS, etc.) between the different devices must be compatible. Affordable microcontroller devices that satisfy the needs of the Micromouse project are the PIC® series from Microchip.

The Micromouse project requires several transducers to detect position and surrounding elements. One of the many possible transducers to facilitate detection of obstacles, such as walls, is an infrared sensor. These transducers have many applications, and the students may need to perform several tests to learn about their performance and detection ranges. They may be used as binary sensors to determine whether an obstacle is present or not, or, they may be used as analog sensors to determine the proximity to an object. The students will have to learn about reflecting and incident waves and angles of incidence. It will be necessary to take these effects into consideration when designing the system.

The students will need to determine the position of the Micromouse to be used with some form of memory to find its way through the maze. One way of doing so is the use of rotary optical encoders linked to the wheels of the Micromouse. The students will have to learn how to use encoders and the different techniques used to determine position and speed.

For the project, the students may learn about the different types of motors available for the use of little projects. The students will have to learn about Brushless DC Motors as well as Brushed DC Motors, Stepper motors, amongst several others, their advantages and disadvantages. The use of the appropriate motor is essential and must be made taking into consideration different factors such as the weight of the Micromouse and the energy source power capacity.

After the appropriate motors are selected, the Micromouse must be able to use them to move forward, turn right and turn left to find his way through the maze. In order to control the direction of rotation of the motor the students need to learn how to use motor drivers. Typically motors are controlled using an H-bridge configuration that can change the motor between on and off, or change the direction of rotation.

The students may have a case where a voltage supply exceeds the rated values of the motor or of other devices. If a higher voltage than the rated value is supplied to the devices, they will be damaged. To avoid this, the students must learn about power electronics, and use something like a buck converter, which can reduce the voltage supplied with high efficiency.

The actual structure of the Micromouse will have to be carefully thought through. Not only must the mouse comply with specific dimensions for the competition, but it is necessary to take into consideration the weight of every component, which additionally adds to the inertia of the Micromouse. Usually, the less components used or the smaller and lighter the components are, the better it is for the Micromouse to move around the maze and less energy is used to power the motors. Figure 2 and Figure 4 show the structural designs for two Micromouses, and Figure 3 and Figure 5 show their implementations, respectively.

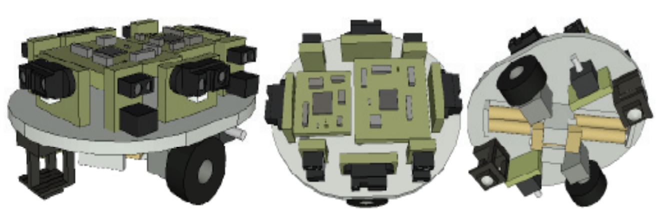

FIGURE 2
STRUCTURAL DESIGN FOR THE MICROMOUSE

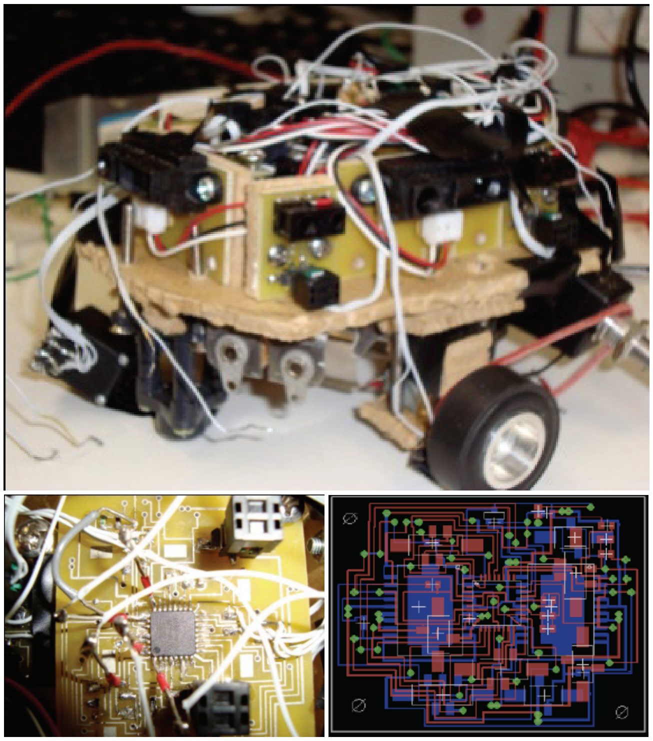

FIGURE 3
STRUCTURAL IMPLEMENTATION FOR DESIGN IN FIGURE 2

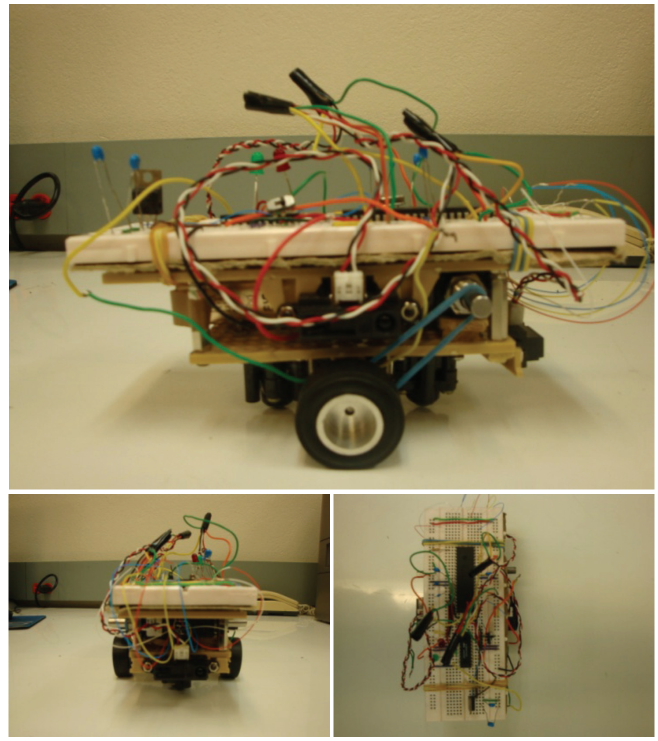

FIGURE 5
STRUCTURAL IMPLEMENTATION FOR DESIGN IN FIGURE 4

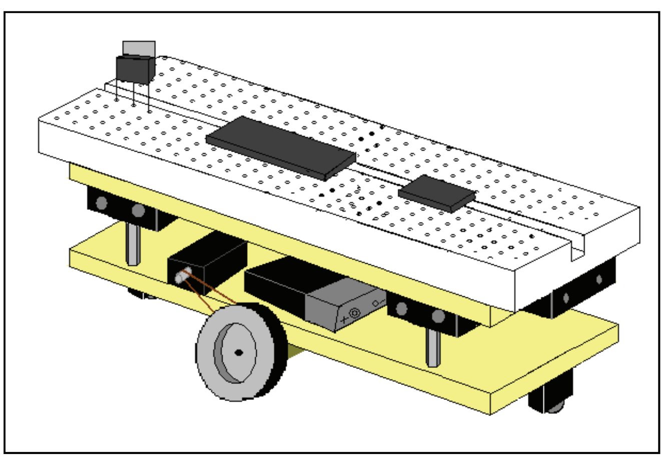

FIGURE 4
ANOTHER STRUCTURE DESIGN FOR A MICROMOUSE

SOFTWARE

To ensure that the Micromouse will reach the center of the maze in the shortest possible time, the students will have to develop new algorithms or implement existing algorithms that will determine the route to take. These algorithms will be carried out by the microcontroller and so everything must be designed in accordance with the controller's capabilities. The implementations of the algorithms will be done in high level languages, such as C. The high level code will then have to be translated into something the microcontroller can utilize and uploaded into it, as shown in Figure 6.

Before the implementation of the code can be done, the correct algorithm must be selected. It is suggested that the students write flowcharts or some other form of visual aid so that the process of implementing the desired algorithm can be performed in an easier fashion. Organization and a good, clear design of the algorithm before the students begin implementing the code will consume some time at first, but will save the students a lot of time in the end.

Once an appropriate microcontroller device is selected, the students must program it. Most microcontrollers only accept machine code. For this reason, the students must

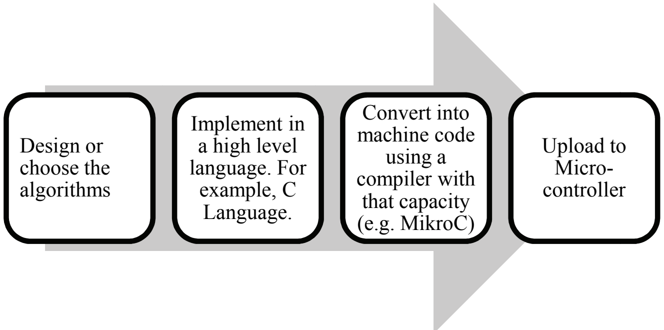

FIGURE 6
FLOWCHART OF ALGORITHM IMPLEMENTATION BY SOFTWARE

familiarize themselves with compilers or assemblers that will turn the high-level languages or assembly code into machine code. Several C-based compilers are available to provide translation between languages. Some of these are CCS PIC C-Compiler, MikroC Advanced C compiler for PICs, and Hi-Tech PIC C-Compiler. These are very popular compilers, and there is a cornucopia of open-source code available through the internet which can be modified to fit the needs of the students.

To write algorithms a high-level language must be used so that it may be changed into machine code afterwards. For this reason students must familiarize themselves with some high-level language. A highly used language for this kind of application is C, and several compilers are available to aid the students in the design of the algorithms. The students must familiarize themselves with several basic functions that the language can provide and will be used.

ALGORITHMS

The use of more than one algorithm will not only make the model more efficient, but it will also allow the Micromouse to have more control. For example, problems encountered when using the wall follower algorithm, either left wall or right wall follower, are solved by the flood fill algorithm [9].

Some of the algorithms the students may use are the Left Wall Follower and the Modified Flood-Fill Algorithm. The Left Wall Follower logic works on the rule of following the left wall continuously until it leads to the center. The Flood Fill algorithm is the most commonly used algorithm in the Micromouse competition because of its efficiency. This algorithm was selected because, based on various tests, it ensures that the mouse will reach the center of the maze in the shortest possible time. A flow chart explaining the Flood-Fill Algorithm is shown in Figure 7. The algorithm involves assigning values to each of the cells in the maze where these values represent the distance from any cell on

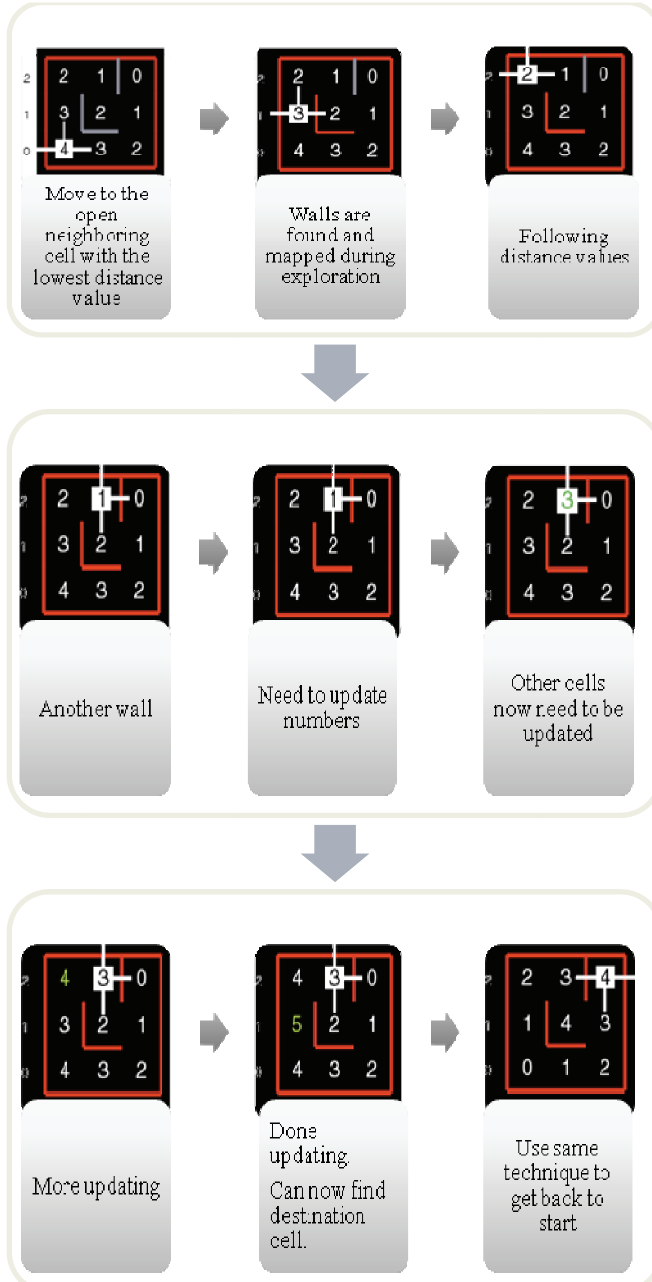

FIGURE 7
FLOOD-FILL ALGORITHM STEP-BY-STEP SIMULATION

the maze to the destination cell. The destination cell, therefore, is assigned a value of 0. If the mouse is standing in a cell with a value of 1, it is 1 cell away from the goal. If the mouse is standing in a cell with a value of 3, it is 3 cells away from the goal [9]. These are the most common algorithms used in the Micromouse competitions because of their efficiency. It is possible that the mouse will have a response for every possible case it can encounter by implementing both algorithms at the same time.

CONTROL SYSTEM

In addition to the control system needed to move the Micromouse, there are other problems that could be encountered for which the students will need additional control systems. There are certain difficulties that are to be taken into consideration in the design process, namely the maze's imperfections. Even dust particles and dirt on the maze will make the Micromouse unstable. Officials try to make the maze as smooth and as flat as possible, but this is virtually impossible to achieve. If no control system is implemented, instead of traveling in a straight path, the Micromouse would shift to either wall and eventually crash.

In order to compensate for these imperfections, a control system is required. One way to do so is the use of analog sensors to measure the distance between the Micromouse and the walls. Different distances mean that the Micromouse is starting to shift to either side. The written software should control the actions of the Micromouse based on the sensors readings. If at some point the sensors detect a difference in distances, the microcontroller must determine the duty cycle of a dc to dc converter to deliver the required voltage to the correct motor in order to maintain the Micromouse in a straight path.

SKILLS DEVELOPED

During the time spent on the Micromouse project, it is expected that the students will develop several valuable skills that will aid them in their careers. The majority of these skills comply with the criteria of evaluation from the Accreditation Board for Engineering and Technology (ABET) [10]. Some of the skills expected that the student will develop during the research are:

- Ability to apply mathematical and physics concepts. – In order to design a build a fast robot, physics concepts had to be taken into consideration.
- Ability to design and conduct experiments, as well as to analyze and interpret data. – While testing the different algorithms, the students had to be able to make a decision based on their interpretation of the results.
- Ability to design the system, components, and processes that meet the contest specifications.
- Ability to comply with realistic constraints such as economical, ethical, safety, and physical.
- An understanding of professional and ethical responsibility. – The students needed to realize that the project will be a success only if the integrity of the team is kept.
- Ability to identify, formulate, and solve engineering problems using techniques learned in previous courses.
- Ability to communicate effectively with others.
- Knowledge of contemporary issues, technologies and techniques. – The more time spent on the project, the more reading needed to be done, and the more knowledge is acquired by the students.
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. – Techniques like soldering and circuit building were acquired through the project.
- A recognition of the need for, and an ability to engage in lifelong learning, through different means like web searches, library references, journals and papers, and software and hardware tools. – Before the students started on the project they had to search for information on related topics in order to have a better background.

SUGGESTED COURSES

The students are encouraged to take several courses before working on the Micromouse project. Table 1 provides examples of several university courses that could aid the design and development of the Micromouse project. Circuit analysis knowledge is required to understand the electrical behavior of the devices that will be used for the project. The students will need to understand and use basic electrical components from resistors, capacitors and inductors, to more sophisticated ones like diodes, transistors and integrated circuits. Power analysis should be done to understand how much power is required. The delivery of excessive power should be avoided, and power losses should be minimized.

Power electronics knowledge will be needed after understanding the amount energy to be delivered to some devices. If a higher voltage than that which the source can supply is needed for a device, a boost converter may be used. On the contrary if a lower voltage is needed then a buck converter may be use. If the voltage needed in an application varies, a buck-boost converter may be use to lower or raise the voltage.

The students will need to have some background in programming to be able to implement the algorithms. Learning to program in C is highly convenient because of the high volume of available resources in said language. In order for the Micromouse to find the center of the maze, the students will have to develop a new algorithm or modify existing ones, which is why they must familiarize themselves with writing algorithms and finding the most effective way to find solutions.

For the students to be able to implement good algorithms they must be aware of how a microcontroller works and know it's limitations. The students must be aware of the memory capacity of the microcontroller. If for example the students need to save a memory matrix, they must be aware of how much space it will consume and take into consideration other applications that consume memory, like the machine code itself.

TABLE I
SUGGESTED COURSES EXAMPLES

Course Number	Course Name	Course Description
INEL 3105	**Basic Circuit Analysis**	Analysis of direct current and alternating current linear electric circuits; laws and concepts that characterize their behavior.
INEL 4102	**Intermediate Circuit Analysis**	Networks functions; Circuit analysis by Laplace Transforms and Fourier series; Two-port Networks; Butterworth and Chebyshev Filters; Computer-aided Analysis of these systems.
INGE 3016	**Algorithms and Computer Programming**	Development of algorithms and their implementation in a structured high level language. Programming techniques applied to the solution of engineering and mathematical problems.
INEL 4505	**Introduction to Control Systems**	Analysis of Control Systems and their mathematical models; analysis and design of Control Systems for single-input single-output plants; Computer solution of problems will be emphasized.
INEL 4201	**Basic Electronic Circuit Analysis**	Semiconductor device characteristics: Semiconductor Diodes, Bipolar Junction Transistors and Field Effect Transistors; analysis of basic digital circuits; analysis and design considerations of Transistor Amplifiers; introduction to Integrated Circuits.
INEL 4416	**Power Electronics**	Design of circuits for rectification, inversion, frequency conversion, direct current and alternating current machines control, and other non-motor applications using solid state power devices.
INEL 4206	**Microprocessors**	Architecture, organization and operation of microprocessors and their supporting devices; design of microprocessor based systems.

CONCLUSIONS

Undergraduate research is an excellent source of knowledge for students. A lot of topics are learnt while working on a research project that students do not cover in class. Sometimes there is just not enough time in class to finish a topic, and through research it is possible to fully explore topics and even learn about other associated topics, which provides a richer learning experience.

The Micromouse project provides the opportunity for students to expand their knowledge in several fields. From the abstract, like algorithms and software, to the physically solid, like motors and electronic components, students get a taste of multiple fields. The Micromouse provides a fairly difficult, but fun project that helps students reach academic goals and develop useful researching skill.

ACKNOWLEDGMENT

M_{inds}^2 CREATE Team: Daniel Soltero, Nelson Vázquez, Eric Sánchez, Andres Salazar-Llinas, Dr. Eduardo I. Ortiz-Rivera

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