The Inception of Chedda:

A detailed design and analysis of Micromouse

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Abstract

The Micromouse competition is an annual contest hosted by the Institute of Electrical and Electronics Engineers (IEEE). A small autonomous mobile robot, called a Micromouse, must navigate through an unknown maze and locate the center. The Micromice are judged by the time it takes them to find the center. The robot that makes the fastest timed run from the start to the center of the maze is declared the winner of the competition.

The Micromouse encompasses a vast range of engineering fields which can be divided into two categories: hardware and software. With the technology available for robotics today, the Micromouse competition has become increasingly more complex since its inception several decades ago. Advanced microcontrollers and microprocessors have transferred much of the complex logic that used to be implemented in hardware to software. The hardware is responsible for perceiving the surrounding environment and moving about the maze. The software, on the other hand, is responsible for navigating the maze, interpreting the environment, and sending control signals to the different hardware subcomponents.

The hardware has been further subdivided into components of a more manageable size. The different hardware components are: power, sensors, control, and drive train. The power system consists of the battery pack and voltage regulation scheme in the circuit. The sensors are the means through which the Micromouse detects walls and traverses the maze with proper alignment in the center of a pathway. The drive train includes the motors and motor controllers, which produce the motion of the robot. Finally, the control unit is responsible for controlling each of the other

components. Each of these parts in our project underwent a thorough process of design, analysis, and component selection.

The focus of the software has been on the selection and development of algorithms for solving mazes since finding the center of the maze is the primary goal of the Micromouse. The algorithms that we analyzed in detail are Wall Following, Depth-First Search, and Flood-Fill. Wall-Following is a trivial algorithm that is usually unsuccessful if implemented for IEEE Micromouse mazes, while Depth-First Search is an intuitive algorithm that also proves ineffective due to wasted time searching the entire maze. As such, the Flood-Fill algorithm and its many variations result in the best searching techniques.

Problem Statement

The main objective of this project is to design and construct an autonomous robot to compete in the annual IEEE Micromouse competition. The design of the Micromouse is subject to several constraints, as follows:

- **Cost** – The total bill of materials must be under $500.
- **Size** – The robot must be small enough to fit within a maze cell that is 16 cm x 16 cm. There is no height restriction.
- **Time** – The robot is limited to a period of 15 minutes, in which it must solve the maze and make as many speed runs to the center as possible.
- **Communication** – The robot must be fully autonomous, and no outside communication is allowed.
- **Maze Integrity** – The robot cannot cause damage to the maze or leave behind any debris in its path.

The significance of the project is that research in the field of robotics has a variety of far-reaching social implications, including advancements in biomedical engineering (e.g., miniature robots used to perform medical tests or aid in surgery), automation of tasks unsuitable for human beings, rescue operations, domestic applications, etc.

Background Information

History of Mazes

For thousands of years in our history, the concept of mazes and labyrinths has intrigued diverse cultures from around the world. A venture into the unknown, traversing a maze symbolizes mankind's own quest for truth or spiritual discovery.

Unlike the modern notion of a maze enclosing numerous false passages and dead ends, the ancient labyrinth usually featured a winding unicursal design with only a single entrance and exit ("A Short History"). Perhaps the most familiar story associated with the labyrinth is the Greek myth of Theseus and the Minotaur. According to legend, the Minotaur, a fierce half-man, half-bull beast trapped within King Minos' immense labyrinth on the island of Crete, devoured Athenian youth delivered to the King as tribute. Theseus was the celebrated young hero who volunteered to enter the labyrinth and vanquished the monster with the help of King Minos' daughter Ariadne, who provided him with a ball of string to find his way out of the labyrinth.

The design of the Cretan labyrinth, preserved on Cretan coins of the 1st century BC, has also been encountered in various other places in the world. For example, the symbol is present on a clay tablet from the Mycenean palace at Pylos in Greece, dated around 1200 BC, which is a much earlier time period. The Cretan labyrinth is also found on rock carvings in Spain, on an Etruscan wine jug from Italy, on a roof tile from the Greek Parthenon, etc. ("The History").

Maze designs flourished in various parts of Europe and Asia for many centuries. Scattered throughout the vast area of the Roman Empire at its height, there are over 60 known examples of Roman mosaic labyrinths ("The History"). In Scandinavia, over 600 stone labyrinths line the shores of the Baltic Sea. Their assorted names, including Julianís Bower and Maiden’s Bower, reveal further insight into their use as expressions of the pursuit of maidens, courtship, the birth of new life, etc. (“A Short History”). Religions such as Judaism, Sufism, Buddhism, and Taoism used symbols of mazes for marriage, fertility, birth, funeral, exorcism, wind-control, healing, protective ritual, or even as patterns to play games (“A brief history”). In addition, medieval Christianity also used maze designs on stone floors of churches to represent the tenuous path from death to salvation. Formal hedge maze gardens, enclosed to provide shelter for better cultivation and to protect against wild animals, soon began to be established throughout Europe (“A Short History”). Generally, the labyrinth seems to have been a symbol of the uncertainty of the path chosen through life (“A brief history”). Thus, the mystery surrounding mazes made an indelible mark upon many different areas of culture.

Eventually, this fascination with mazes began to transcend folklore and religious tradition and grew to influence the spheres of science and mathematics. The great Swiss mathematician Leonhard Euler was one of the first to study mazes scientifically. He worked on the famous Konigsberg bridge problem, which asks if the citizens of Konigsberg, a city comprised of two islands located on the Preger River and connected by seven bridges, could walk through their city while crossing each bridge only once. In studying the Konigsberg network, Euler founded the field of topology (“The Story”). His work had profound implications because various types of networks, from power and phone lines to computer systems and the Internet, are commonplace in our world today.

Moreover, in mathematics, finding the best path is known as critical path analysis (CPA). CPA can find the most efficient route for telephone calls or design the electrical paths of circuit boards. Computer programs that perform critical path analysis are called autorouters. Autorouters help to reduce the size and cost of electronics and have been a major factor in the development of today’s advanced information technology (“A brief history”). Being related to such work, many algorithms for solving mazes have been created throughout the years.

History of the IEEE Micromouse

In 1977, the Institute of Electrical and Electronics Engineer's *Spectrum Magazine* first introduced the idea of the autonomous Micromouse robot as a maze solving device. Soon after, the first IEEE Amazing Micromouse Maze Contest was held in New York in June 1979. Out of over 6000 entries received, fifteen Micromice competed, from which the eventual winner was Moonlight Flash, a non-intelligent wall follower mouse. Since the aim of the competition was to invite "intelligent" mice that utilize microprocessor technology, Moonlight Flash entered on a loophole in the contest rules. Competition rules were subsequently amended, with mazes being specifically designed to prevent wall-following strategies from succeeding ("The amazing").

Popularity of the Micromouse grew from there, and competitions were soon held all around the world. The first European Competition took place in London in 1980, and the first World Micromouse Competition, open to contestants from across Europe and the United States, was held in Tsubuka, Japan in August 1985. From the early 1990s, Micromouse clubs started to appear in schools and universities around the world ("History"). The IEEE Micromouse Competition now enjoys great popularity among undergraduate and graduate student organizations of computer and electrical engineering departments everywhere.

Micromice have undergone an astounding metamorphosis in the last several decades. Early Micromice were far less technologically and electronically advanced compared to those of today. Moonlight Flash, the winner in 1979, was a crude mechanical mouse that simply employed a feeler along the walls to navigate its way to the goal ("The Micromouse"). Moreover, several of the other mice at the competition did not include microprocessors in their design, instead opting to use simple IC logic. The top motor speed at that competition was 52 centimeters per second from a mouse using then-sophisticated stepper motors for its motion (“The amazing”).

In contrast, today’s Micromice are extremely evolved, electronically refined robots. Current microprocessor technologies allow the mice to perform computations not conceivable twenty-five years ago. As a result, the robots can be programmed to use more sophisticated algorithms to find the center of the maze. Motors, sensors, integrated circuits, and other components have greatly improved features to assist the robot designer. Depending on the maze design, mice can now run at speeds of up to 3 meters per second (“Micromouse”). Overall, Micromice are now smaller, faster, and smarter than their earlier counterparts.

Hardware

Block Diagram

The hardware for the Micromouse is composed of five subsystems: Power, Sensors, Control, Communication, and Locomotion (see Figure 1). Each of the aforementioned subsystems will undergo analysis and design. It should be noted that while these systems appear independent, they are in fact very intertwined

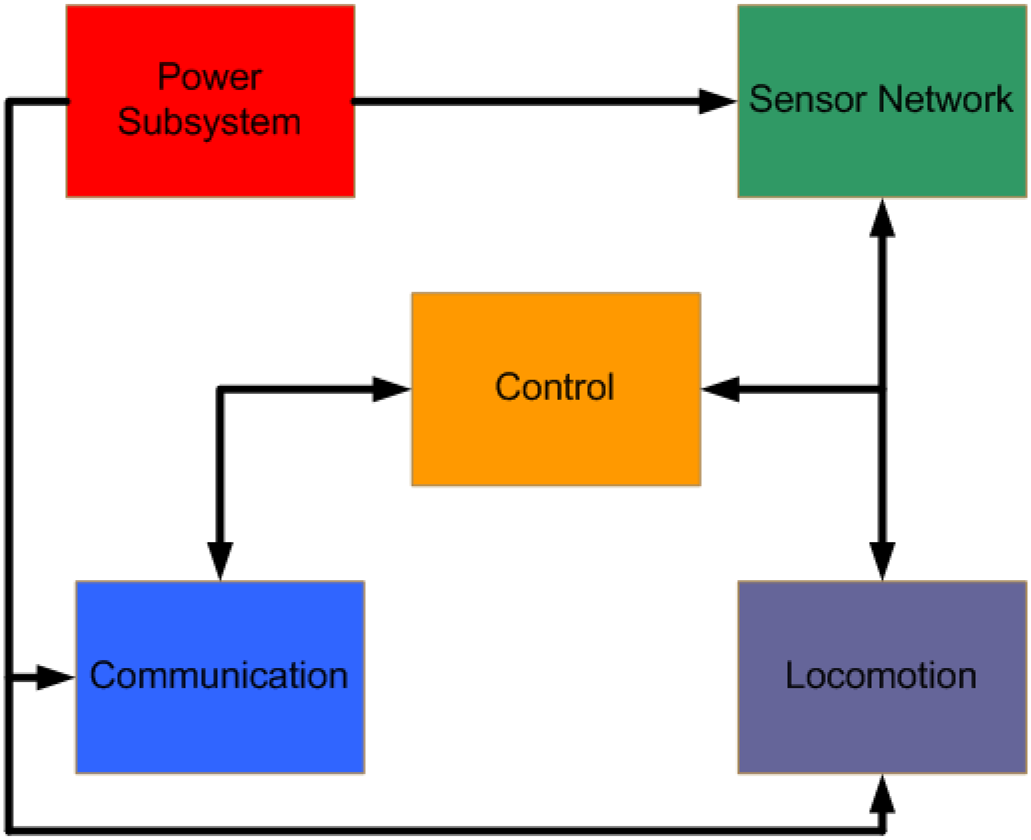


Figure 1

Motors

The movement mechanism of a mobile robot is known as its drive train. The motors and motor controllers constitute the most important part of the robot drive train. The process of choosing a motor for a robot is a significant undertaking because the motor ultimately selected has an impact on many other aspects of the robot. Most notably, motors comprise the largest and bulkiest components of the robot, and their power requirements usually dictate the design of the power system.

There is an immense array of motors available for various industrial and hobby-related uses, but we will quickly narrow our focus to direct current (DC) electric motors. DC electric motors are the most appropriate for robotics applications because they are reliable and easy to use, come in small sizes suitable for robots, and are powered by readily available self-contained DC electric batteries. Alternating current (AC) motors may be suitable for large industrial robot applications, so we will not concentrate on them herein.

The fundamental elements of the motion in different DC motors are similar in nature. The motion created by these electric motors is a result of several important common physical principles, including the Lorentz Force law and electromagnetic induction. When a conductor carrying current is placed in a magnetic field, a force known as the Lorenz Force is created orthogonal to both the magnetic field flux and the flow of current. This force pushes the conductor downward, as shown in Figure 2.

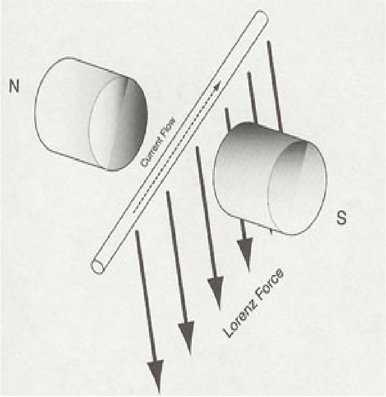


Figure 2

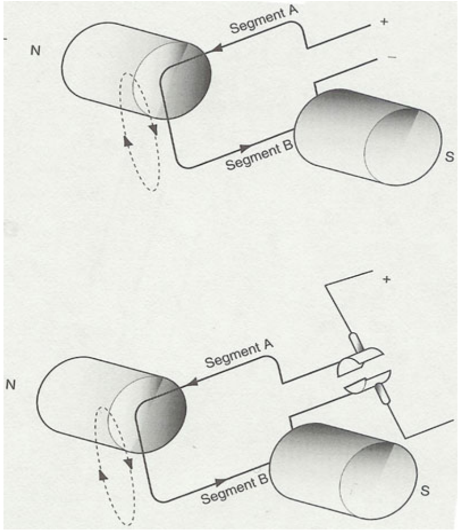


Figure 3

Rotary motion is achieved by placing a simple one-turn coil or loop of wire in a magnetic field. In Figure 3, as segment B is forced down, segment A is forced up because the current through A is flowing in the direction opposite to that of B. Reversing the polarity of the current through the coil at the moment when A and B reach their highest and lowest points, respectively, reverses the direction of the Lorenz Forces on both segments, and the coil continues to rotate in a full circle. The process of alternating the current through the coil as described above is known as *commutation* and is commonly achieved through the use of a brush arrangement attached to the power supply. Real motors use coils with more than one turn to increase the overall torque (or rotational force) on the armature, ensure that the armature never becomes stuck in a state of equilibrium with the magnetic field, and achieve greater efficiency in the design (Clark 8-11).

There are three basic types of electric motors commonly found in robots, which we discuss below:

- ***Continuous DC Motor*** - A continuous permanent magnet DC motor contains a stator which is an arrangement of two permanent magnets that provide a magnetic field in which the armature rotates. The armature, positioned in the center of the motor, has an odd number of poles that have windings connected to a contact pad on the center shaft known as the *commutator*. Brushes provide power to the windings of the armature so that they are alternately attracted to and repelled from the permanent magnets of the stator. As the Lorenz Force propels the coils, torque is transmitted through the shaft and causes the armature to turn in a circular motion. Numerous varieties of DC motors are commonly available, but they can be somewhat expensive. They are also very powerful and require a gearbox to control their fast speed (Clark 10, 29).

- ***Servo Motor*** - A servo motor is a closed-loop device consisting of a continuous DC motor, gearbox, and motor controller assembly housed inside a plastic outer casing. The built-in circuitry allows for precise control and positioning of the motor. Inexpensive hobby servos come in a great variety and are easy to interface. However, they have a significantly low weight capabilities (Clark 30).
- ***Stepper Motor*** - A stepper motor is a brushless, non-continuous DC motor in which the permanent magnets are located on the shaft or *rotor*, and the windings are in the *stator* (the can of the motor). As current is applied to the stator windings and they are energized in sequence, the rotor is attracted to opposite magnetic poles in the stator, and the motor turns. Stepper motors are capable of precise incremental shaft rotation and can hold their position and resist turning. The incremental stepping movement of the rotor gives the name *stepper motor* (Clark 30).

To compare the three types of electric motors, we discuss the relative advantages and disadvantages of each with respect to the Micromouse. First of all, there is an immense variety of commercially available continuous DC motors and it would not be too difficult to find one that closely meets the size and weight requirements of the Micromouse. However, the significant drawback to DC motors is the fact that they require gearing. With the vast number of components already required for the robot, we do not want to deal with the added complication of a gearbox. DC motors may also be too powerful for our robot's needs, and we might have a difficult time working out proper speed controls. Furthermore, the relative merit of hobby servos is that they contain a DC motor, gearbox, and control circuitry all in one prepackaged unit. Even though this convenience is very helpful, the lack of power of servo motors is a serious disadvantage. We have to ensure that the motors we ultimately select are capable of meeting the torque requirements of the Micromouse. Finally, the great advantage of stepper motors over the other two types is their precise movement control. The fact that steppers can move in very small incremental steps, as well as hold their position and resist turning, makes them perfect for our application. The only shortcoming of stepper motors is their complex control requirements. Fortunately, this control can be easily accomplished through one of the numerous stepper motor controllers that are widely available. Thus, we conclude that the stepper motor is the most suitable motor for our Micromouse.

Let us now consider the stepper motor in further detail. To reiterate from above, the defining characteristic of stepper motors is fact that the shaft rotates in angular steps corresponding to discrete signals fed into a controller. The controller converts these signals into current pulses that are switched to the motor coils in a specific sequence, and the motor acts as an incremental actuator, which converts digital pulses into analog output shaft rotation. The speed of the rotation depends on the pulse rate and the motor's incremental step angle whereas the angle of rotation depends on the number of pulses fed to the motor and the incremental step angle.

There are three basic types of stepper motors, namely permanent magnet (PM), variable reluctance (VR), and hybrid, which contains elements from the previous two.

The rotor of a PM motor is usually a solid cylinder magnetized in a two, four, six or eight-pole configuration. The laminated, slot wound stator usually has two, three, or four phases. The rotation of the motor shaft is achieved by switching currents between coils to create a change in the electromagnetic field alignment. When the stator is not energized, the PM rotor tends to remain in the same position as when last energized, known as the detent torque. In contrast, the rotor of a VR motor is not a permanent magnet. It is formed of soft iron material with a number equally-spaced poles, which form paths of minimum reluctance in the overall magnetic circuit. With the rotor not magnetized, polarization is only determined by the stator excitation, and the step angle is a function of the number of rotor poles compared to stator pole, often not the same number. Compared to the VR motor, the PM motor develops a higher torque due to the magnet flux strength and has a better axis of alignment due to the polarized rotor. Even though the VR motor has a lower static torque rating than that of the PM motor, the absence of the permanent magnet in the rotor allows a higher speed range to be achieved for similar input. The detent torque of a VR motor is almost zero, and so the motor can be moved freely when not energized. Since there is not a problem of demagnetizing the rotor, the torque output can be uprated for short duty within certain practical limits.

The hybrid motor combines the design of PM and VR motors in that its rotor has a permanent magnet core with soft iron end pieces. While its principle of operation differs from the other two, the generation of torque is still due to the forces involved in aligning the rotor teeth with stator pole teeth, and rotation is also controlled by switching the current to the coils in a particular sequence. The most common configuration of a hybrid stepper motor is a four-phase wound stator and fifty-teeth rotor with a step angle of 1.8 degrees.

The most readily available steppers are the hybrid unipolar and bipolar motors. The unipolar is called four-phase because there are four windings to energize. Unipolar motors are also known as bifilar since they contain two coils that are oriented in polar opposite directions while wrapped on the same core with a center tap. Also, the current flows in only one direction in each winding. On the other hand, the bipolar motor is so named because the windings are energized in both directions such that each winding can be either a north or south pole. It is called two-phase because it contains only two separate windings. It is also known as unifilar since each pole has a single winding. Finally, bipolar steppers are stronger than unipolar steppers of the same size and weight because they have two times the field strength in their poles (single windings without a center tap). Since space and weight are important constraints for the Micromouse, we will opt to use a bipolar hybrid stepper motor.

At this point, we are ready to view manufacturers' websites and catalogs for a suitable stepper motor. The following design matrix (see Table 1) shows several motor candidate possibilities and their scores for important design criterion (see Table 2). Based on the analysis, we have decided to use the 39BYG401A bipolar hybrid stepper motor available from Jameco Electronics.

Part	Cost ($)	Step Angle (°)	Detent Torque (g-cm)	Weight (lbs)	Voltage (V)	Current (mA)
42BYG4023	17.95	1.8	2100	0.5	12	400
35BYG005	15.95	1.8	1.5	0.37	12	500
39BYG401A	19.49	1.8	200	0.44	14	400

Table 1

Part	Size	Detent Torque	Weight	Voltage	Current	Total
42BYG4023	4	7	2	5	5	23
35BYG005	8	0	6	5	5	24
39BYG401A	6	5	4	7	5	27

Table 2

Stepper motors require fairly complex driving circuitry. A complete stepper motor controller requires several different circuit blocks: a driver to handle the high current demanded by the motor windings, a sequencer or translator to produce the sequence of pulses needed to drive the motor, a stepper or oscillator to produce the pulses at a rate that determines the motor speed, and a controller to act on the other circuit blocks to brake, speed up, slow down, or reverse the direction of the motor (Braga 142).

We have studied a number of reference texts that include the circuits for the individual blocks or combinations of the blocks described above. However, with so many elements involved in controlling the motor, proper sequencing of all the blocks in combination may become too complex. It makes greater practical sense to simply use one of the integrated circuits devised by manufacturers to control stepper motors.

Stepper motor controllers basically come in two major designs, namely the L/R type and the chopper type. Both of these methods try to efficiently handle the problem of supplying voltage to a stepper motor's coils. To be precise, they each use a different technique to force the maximum rated current into the coils as quickly as possible because the faster the maximum current is provided to the coils, the sooner full torque is available. The reason for the difficulty is that the inductance L (measured in henrys) and the resistance R (measured in ohms) of the stepper's coils combine to place an upper limit on how quickly current can build up at a given voltage. The L/R constant determines the time in seconds that is required for the current to reach its maximum value.

The L/R type controller tries to offset the L/R time constant by increasing the value of the resistance. For example, if the resistance in each motor coil measures 15 ohms and we were able to double that value somehow, the time constant would suddenly become L/2R, or one-half of its original value. That would allow the maximum rated current to reach the motor's coils twice as fast. Since rewinding the motor's coils with smaller wire to achieve a higher resistance is not possible, most L/R drivers simply add a bucking power resistor in series with each coil. The downfall of this scheme is that greater driving voltages are required for the coil to see its rated voltage, and the power resistors dissipate a great deal of heat. The advantage of the method is that it is fairly inexpensive.

In contrast, chopper controllers take a more efficient approach to the problem of quickly getting the rated current into the coils. The basic principle of the chopper controller is to supply a large voltage well in excess of the rated voltage into the coil and then monitor the coil's current. Whenever the coil's current reaches a set limit, usually below the rated value, the chopper controller temporarily shuts off the voltage but continues to monitor the current. When the current drops below a lower bound, the controller turns the voltage back on and the process starts all over again. This repeated cycle allows the chopper controller to maintain full current in the coils for a longer period than is possible with a simple L/R controller. Ultimately, this allows the stepper motor to run faster and with greater torque (Lunt 188-189).

After researching various motor controllers from many different manufacturers, we narrowed our list to three (see Table 3): Motorola’s MC3479, Allegro Microsystems’

A3967SLB, and SGS Thompson's L297. The following design matrix (see Table 4) compares the three, and clearly shows the superiority of the 3967 for our application.

Part	Cost ($)	Max Current (mA)	Max Voltage (V)	Current Control	Step Pattern
MC3479	3.68	350	16	No	1/2, ¼
Allegro 3967	2.56	750	30	Yes	1/2, 1/4, 1/8, Micro
SGS Thompson L297	4.89	3000	50	Yes	No Translator

Table 3

Part	Max Current (mA)	Max Voltage (V)	Current Control	Step Pattern	Package	Total
MC3479	3	7	0	5	4	27
Allegro 3967	6	7	7	7	8	43
SGS Thompson L297	9	7	7	0	2	25

Table 4

Power

The power system of a robot is a critical part of its overall design. Simply stated, a robot needs power to run. Therefore, the power system must include a power source that stores enough energy for the robot to run for a predetermined time period without having to be replaced or recharged. In addition, power must be provided at a constant voltage through a particular voltage regulation scheme in order to ensure the proper operation of all circuitry and components (Jones 265).

Most small mobile robots consume electric power supplied by self-contained batteries. Although other sources of electric power do exist, batteries are currently the most practical option for the majority of such applications. For instance, photovoltaic cells (commonly known as solar cells), which produce electric power from sunlight, are usually not a viable option due to their inefficiency. Much of the solar energy is lost as heat, and a typical solar cell is only able to provide a voltage of around 0.7 volts and a few milliamps of current (Iovine 23).

There are hundreds of different types of batteries. With such a large variety available for use, it is important to consider the following list of properties in order to distinguish among their differences:

- ***Voltage*** - Single cells of each battery type are rated to supply a different nominal voltage. However, the actual voltage outputted from a cell may vary from the rated value depending on its state of charge (or discharge). Most batteries are considered dead when their output reaches around 80 percent of the rated value. To realize higher output voltages, cells may be connected in series so that the equivalent voltage is the sum of all the individual cell voltages.

- ***Capacity*** - Battery capacity, typically rated in amp-hours (AH) or milliamp-hours (mAH), is the amount of power that the battery can deliver in a specified period of time. The term “amp-hour” indicates that the battery can provide the rated current for one hour before failing. For example, a battery with a rating of 5 AH implies that it can continuously provide up to five amps of current for one hour, one amp for five hours, etc. However, most battery types are likely to provide less current for a longer period than more current for a shorter period because manufacturers generally test the battery at a low or moderate discharge rate over a 10- to 20-hour period, and use this longer period to derive the rating. Consequently, batteries usually cannot provide the stated amps during the one-hour period. Thus, it is prudent to select a battery with an amp-hour rating that is 20 to 40 percent higher than is expected to be required to power the robot (McComb 193-196).
- ***Internal Resistance*** - All batteries have an internal resistance that acts as a current limiter, limiting both the maximum output current as well as the maximum discharge rate. Batteries with lower resistances are able to higher surge currents that may be necessary for certain applications. A battery with a lower internal resistance will be able to provide more power in a specified interval of time than one with a higher internal resistance.
- ***Energy Density*** - Energy density is a property that specifies the maximum amount of energy per unit mass stored in a particular battery type. This value is usually expressed in either watt-hours per kilogram (Wh/kg) or joules per kilogram (J/kg).

- ***Rechargeability*** - A battery that cannot be recharged is known as a primary battery, while one that can is known as a secondary battery. Rechargeability is an important property for batteries in a mobile robot because nonrechargeable batteries, although initially less costly, are both expensive and inconvenient to replace over time. Each rechargeable battery type has a different number of allowable charge/discharge cycles (Clark 17-18). Most batteries are recharged very slowly, over a 12- to 24-hour period, because a recharge interval of 2 to 10 times the discharge rate is recommended (McComb 195). Another issue associated with rechargeability is the memory effect. Certain battery types are prone to the memory effect if they are repeatedly recharged before they have been completely discharged. Over time, the battery forms a "memory" of the usual recharge level, and it becomes difficult to discharge the battery past that remembered level (199).
- ***Shelf Life*** - Over time, batteries will lose charge even though no external load is applied. Shelf life is a measure of how quickly this loss of charge will occur (Jones 266).

As stated previously, there are hundreds of different battery types in use today. However, we can narrow down the vast array of choices to a small list of possibilities, from which we will select one for our project, based on the design constraints of the Micromouse in relation to the battery properties discussed above as well as other practical considerations including temperature dependence and cost.

First of all, most of the power consumption in the Micromouse results from the motors. The IC chips selected for the project require far less voltage and current in comparison. As such, if we choose a battery that meets the power needs of the motors, and include an additional margin of error for safety, the power requirements of the entire Micromouse should be readily attained.

To review, we will use two of the 39BYG401A bipolar hybrid stepper motors for our project. The 39BYG401A is rated at 12 volts DC and 400 milliamps. At very low speeds, though, each of the motors will probably draw closer to 500 milliamps of current. Current spikes when initially starting the motors, or if the motors become stalled, can be significantly higher. Fortunately, the motor controller selected for the project, the Allegro 3967, has a continuous drive capability of 750 milliamps with a peak of 850 milliamps and will help to keep power dissipation at a reasonable level. Moreover, we may find it necessary to apply voltages higher than the rated value of 12 volts if greater motor torque is required than can be provided through normal operation. Since the Micromouse needs to run at full operation for around 20 minutes at a time, a battery capacity of around 300 mAH is required. We would also prefer batteries with the smallest possible internal resistances to allow for the potential current surges.

Two other significant practical issues to take into account regarding the selection of batteries are their size and weight. The Micromouse must be physically compact enough to travel and maneuver inside the actual maze without hindrance from its size. Since the chassis of the Micromouse cannot be larger than around 8 cm by 14 cm and the size of the motors has already been fixed, space for the batteries is quite limited. To reduce the total number of batteries required, we need to select a battery type whose individual cells have a relatively higher voltage. The battery type must be smaller in size to reduce the area used on the chassis. The mass of the battery type should also have a lower weight to decrease the burden of the load on the motor torque. These goals may be accomplished by selecting a battery with as high an energy density as possible.

Finally, rechargeability is an important property of any battery we select for the Micromouse. Even though primary batteries have a lower initial cost, secondary batteries are clearly the superior choice for our project because we will have to operate the robot for extended periods of time for testing.

From the discussion above, we compiled a preliminary list of battery types: zinc, sealed lead-acid, alkaline, nickel-cadmium, nickel metal hydride, lithium ion, and lithium polymer. We now analyze these different batteries' suitability for use in the Micromouse:

- ***Zinc*** - Zinc batteries are available in two different chemical forms, namely carbon zinc (or "regular-duty") and zinc chloride (or "heavy-duty"), of which only the zinc chloride type is practical for robotics applications. Zinc chloride batteries are low cost and are readily available in a number of different voltage ranges, but they provide too low current and cannot be recharged more than a few times.
- ***Sealed Lead Acid (SLA)*** - Lead acid batteries are of the "wet cell" chemical type. They contain caustic, corrosive liquids inside and should be sealed for safety purposes. The most common form of SLA batteries are gelled electrolyte ("gel-cell") batteries. SLA batteries are rechargeable and can provide high current for a considerable amount of time. However, drawbacks to these batteries are their relatively large size and weight.
- ***Alkaline*** - The life expectancy of alkaline batteries is 300 to 800 percent higher than that of zinc batteries. They are inexpensive and commonly available in both

non-rechargeable and rechargeable types. A significant disadvantage to alkaline batteries is their inability to deliver high currents.

- ***Nickel cadmium (Ni-Cad)*** - Nickel cadmium batteries are ideal for many robotics applications because they are among the least expensive and most readily available, have a high capacity, and can be recharged up to 500 or more times. They exist in all the standard sizes as well as special purpose sub-sizes. Unfortunately, they suffer from the memory effect and are extremely toxic.

Figure 4

- ***Nickel Metal Hydride (NiMH)*** - Nickel metal hydride batteries are about the same size and weight as nickel cadmium batteries, but they can deliver much higher currents due to a lower internal resistance and are less prone to the memory effect (see Figure 4). Furthermore, they are more environment-friendly since they do not contain any cadmium. They can also be recharged 400 or more times at a more aggressive rate than Ni-Cads can. Despite these advantages, they lose their charge faster than most other battery types, and cannot be stored for more than days at a time.

Figure 5

- ***Lithium ion (Li-Ion)*** - Lithium ion batteries are popular in consumer electronics and laptop computers due to their small size and exceptionally high energy density (see Figure 5). They can retain their charge for months or even years and have a steady discharge rate. Lithium ion batteries are relatively more expensive than the other battery types previously considered (McComb 190-192).
- ***Lithium Polymer*** - The new lithium polymer batteries are the most advanced technology for cellular phone batteries. They have all the benefits of lithium ion

batteries but can last up to twice as long. Their chemical composition allows for the most compact battery cells available today. However, lithium polymer batteries are quite expensive ("Battery").

After considering all the battery options above, we have concluded that the lithium polymer battery is the most suitable for our project. Even though they are not widely available and are considerable expensive, their relative advantages outweigh their disadvantages. The weight of the load on the Micromouse chassis is a matter of great concern for us since the aim of the robot is to maneuver quickly through the maze. Lithium polymer batteries are small and compact and have the highest energy density of any currently available battery.

To charge lithium polymer batteries, we can either purchase a ready-made commercial charger or construct a charging circuit of our own. Creating our own charger is probably the more cost-effective alternative, but it can create unforeseen problems later. Even though the circuitry for a charger is fairly uncomplicated and several manufacturers make special integrated circuits for recharging batteries, there are many variables such as surge currents that have to be closely monitored and regulated to avoid destroying the batteries. Also, due to the extensive breadth of this project, there are many more areas where we can more efficiently use our time rather than build a charger that can be easily purchased.

We completed a comprehensive search of several lithium polymer battery manufacturers' websites (see Table 5) and found the batteries analyzed using the following design matrix (see Table 6). Based on the analysis, we see that E-TEC's batteries most closely meet our needs.

Part	Cost ($)	Capacity (Ah)	Voltage (V)	Max Current (A)	Size (in x in x in)
2LP1500	39.95	1.5	7.4	7.5	3.35 x 1.97 x 0.36
KOK1250HC2S	48.95	1.25	7.4	18	Unknown
E-TEC	28.95	1.2	7.4	10	2.54 x 1.38 x 0.59

Table 5

Part	Capacity	Max Current	Size	Total
2LP1500	9	6	3	18
KOK1250HC2S	8	8	0	16
E-TEC	7	7	8	22

Table 6

The next juncture of our power system design consists of a decision on whether to use a single common battery pack for the entire robot or two separate battery packs, one for the motors and one for the electronics. In general, the motors distribute a great deal of electrical noise through the power lines when the current is switched on and off, such as when using pulse width modulation to control the motor speed. The noise-sensitive microprocessors and other circuitry connected to the same power supply as the motors may periodically reboot, lock up, behave erratically, and even become permanently damaged due to the huge voltage and current spikes that are created (Clark 23). Specifically, whenever a coil in the motor loses voltage, the magnetic field it was generating collapses and creates a reverse voltage back to the driving circuit through induction (Wise 31). Furthermore, when a motor first starts or changes direction, it draws a great deal of current from the power supply, which can cause significant dips in the power supplied to the rest of the circuit, and as a result the circuitry may cease proper functioning (Clark 23).

A straightforward solution to the problem is to use a separate power supply for the motors and another for the rest of the circuit. An advantage to this method would be that two different voltages (i.e., 12 volts for the motors and around 5 volts for the IC chips) can be provided without the use of a voltage regulator or some other voltage division scheme. Unfortunately, the use of two different battery packs significantly increases the weight of the load and takes up additional space on the Micromouse chassis. Since one of our main concerns is to keep the load as light as possible, using separate battery packs in not practical for our project.

On the other hand, the option of using a single battery pack and including various measures to reduce the amount of electrical noise from the motors is a far better alternative. A common battery pack may create problems for unprotected circuitry, but we will make certain that all components are thoroughly shielded from electrical noise, and so the robot should function properly. For one thing, the Allegro 3967 motor controller itself has a current-decay scheme that results in decreased motor noise and power dissipation. Also, we can include a number of additional components in the circuit to reduce the detrimental effects of motor noise. Placing filtering capacitors across the positive and negative rails of all the subsystems in the robot will help to absorb excessive current spikes and noise. Filtering capacitors must be positioned as close to the batteries and other sources of noise as possible. The value of these capacitors needs to be quite large, around 10 uF or so. In addition, smaller capacitors with values around 0.1 uF, known as decoupling capacitors, should be added to the positive and negative power rail wherever power enters or exits the circuit board, especially across the power and ground of the IC chips in the circuit (McComb 202-203). Along with the capacitors, we can also add series inductors to help filter out any current transients (Predko 8).

Another precaution to reduce the effects of stray magnetic fields from the motors is to use what is known as a single-point ground. The power distribution traces on the printed circuit board must be laid out so that no ground loops are formed because the changing magnetic fields can induce a voltage in any wire loops they may encounter. As a result, components connected to different parts of a ground loop will not see a common reference ground voltage. It is also good engineering practice to position the power supply in between the motor and other electronic components (Jones 279-280).

Sensors

Sensors give a robot the means to perceive its environment. The robot processes the information received from its sensors and reacts in a predetermined manner according to the design of the control system. For our project, the robot needs to sense the surrounding walls of the maze in order to keep track of possible routes to the center as well as dead ends, and to keep itself aligned in the center of a pathway.

To achieve its goal of traveling to the center of the maze, the Micromouse may require the sense of sight and/or touch, depending on the sensor technology (or combination of technologies) used. Sight is simulated through light and sound sensors, while touch is simulated through pressure sensors. Infrared (IR) sensors are a type of light sensor, ultrasonic or sonar sensors are a type of sound sensor, and touch or bump sensors are a type of pressure sensor. Light and sound sensors may give either proximity or distance detection. Proximity sensors only detect whether or not an object is within a predetermined range from the robot, while distance sensors determine the actual distance between the object and the robot (McComb 570). We first take a general look at each of these sensor technologies:

Figure 6

- ***Infrared (IR) Sensors*** - An infrared sensor consists of an infrared transmitter that sends out an invisible beam of light into the environment and an infrared receiver that absorbs the beam of light that is reflected back (see Figure 6). The angle of the reflected beam indicates the proximity of the infrared receiver to the object that is reflecting the light. The microprocessor of the robot uses the changes in angle to measure the distance of the robot from the object ahead.

- ***Ultrasonic or Sonar Sensors*** - Sound, in addition to light, can be used for object detection since the speed of sound traveling through air is considerably slower than the speed of microprocessor circuits. In a sonar sensor (see Figure 7), an emitter transducer projects high-frequency sound waves outside the range of human hearing into the environment, which then bounce off possible objects ahead, and return to a receiver transducer. The time it takes for the sound wave to return to the receiver is used to determine the robot's distance from the object (Martin 271).

Figure 7

- ***Touch or Bump Sensors*** - Touch sensors operate by engaging a switch located on the fender or feeler of a robot when it is pressed or bent by an object (see Figure 8). The microcontroller processes the contact and then responds accordingly (McComb 581-583).

Figure 8

Before deciding on a sensor technology to use for our project, it is also important to keep in mind a few additional principles. First of all, simplicity, although an extremely relative term, should be a central goal of the sensor system. We should only use the level of sensor sophistication appropriate for the project because adding too many complex sensors will not necessarily give us any more useful data. Along the same lines, sensor redundancy must be handled carefully. Same sensor redundancy relies on the use of two or more sensors of an identical technology, and the received data is compared to detect potential errors. On the other hand, complementary sensor redundancy relies on two or more sensors of different technologies, and the received data goes through a process of interpolation since the data from one sensor is more reliable for certain objects while the data from the other sensor is more reliable for other objects (571-572).

We now discuss the relative advantages and disadvantages of the sensor technologies discussed above. To begin, relying solely on touch sensors is clearly not a reasonable option because the robot needs to detect a wall with enough time to adjust its position and avoid crashing into the wall. Touch sensors may be included, however, to guide the robot when making precise movements such as turning.

Choosing between infrared sensors and sonar sensors is more difficult. An advantage to sonar sensors is that sound is not sensitive to objects of different colors and light-reflecting properties. However, certain materials do reflect sound better than others while some absorb sound completely (McComb 579). Sonar systems are extremely susceptible to electrical noise in the power circuit because of the high amplification involved (Martin 275). Also, there can be problems with transducer ringing. After outputting the sound wave, the transmitter transducer may have residual vibrations or ringing that false trigger the receiver transducer (273). A problem associated with infrared sensor technology includes the fact that the IR receiver is sensitive to ambient light. However, the frequency at which the IR beam is modulated helps to avoid interference effects from common indoor lighting sources such as fluorescent lights (234). Also, the effects of ambient light can be mitigated by taking two readings, one with the IR sensor’s emitter light source on and one with it off, and subtracting the values to yield a more accurate measurement (125). Unlike sonar sensors, IR sensors are not subject to electromagnetic interference (Braga 241).

Finally, another advantage of infrared sensors is that they are usually somewhat less expensive than sonar sensors.

Based on the discussion above, we conclude that infrared sensor technology is the most appropriate for the Micromouse. Having selected infrared sensors for the robot, we now closely examine IR sensors

An infrared proximity sensor includes an infrared emitter (the source of infrared light) and an infrared receiver (the detector of infrared light). The emitter is usually an LED made from gallium arsenide, while the receiver may be a photoresistor, photodiode, or phototransistor (Jones 127).

The presence of light significantly alters the resistance of a photoresistor (also known as a photocell). In the dark, photoresistors have very high resistances in the 100K to 1M ohm range, while in bright light the values are several orders of magnitude lower. Unfortunately, the response time of photoresistors is somewhat slow (Martin 121). Photoresistors are typically cadmium sulfide (CdS) cells (Iovine 64).

Photodiodes and phototransistors are similar in construction since both have a light-sensitive PN junction. When light strikes the PN junction, current flow begins. Photodiodes possess great light sensitivity, respond rapidly to changes in illumination, and produce a linear signal over a wide range of light levels (Jones 121). However, a relative advantage of phototransistors over their diode counterparts is that they can provide amplification of the light signal (Iovine 64). Phototransistors are also superior to photoresistors because they provide a greater sensitivity to light (Jones 121).

We can cheaply create a proximity detector on our own by using an IR LED and one of the IR detectors mentioned above, with a minimal amount of hardware and testing. The problem with using such a proximity detector is that we can only find out whether or not a wall is within some threshold distance. We require the actual distance from the walls in order to properly correct for misalignment and smoothly steer the Micromouse through the maze. Therefore, an infrared distance sensor, which is far too complex to construct on our own, is more suited to our needs.

In the infrared distance sensors, the distance to nearby objects is measured through a process known as triangulation. First, the emitter of the unit illuminates a small spot ahead with modulated IR light. The emitter and receiver must have a shield between them or the receiver would be flooded with light regardless of the presence of obstacles to reflect the light from the emitter (Jones 132). The IR light is modulated at around 40 kHz because the frequency is high enough to reduce the interference effects of common indoor light sources. The light from the illuminated spot is focused by a special lens onto the detector element, which is a charge coupled device (CCD) array, and a triangle is formed between the emitter, the spot of illumination, and the detector. Depending on the distance between the sensor module and the target surface, the angle of incidence of the reflected light will change, and the light will strike a different point along the position-sensitive detector. Thus, the location of the spot on the sensor directly corresponds to the distance from the sensor to the object ahead (Martin 234, 280-281). The distance is outputted as an analog voltage, which is then sent to the microcontroller for analog-to-digital conversion and further processing.

There are a great variety of high-quality infrared sensors readily available, including those manufactured by Sharp Electronics. The following design matrix (see Table 7) compares several of the Sharp sensors, as well as one manufactured by Vishay, and a sensor unit composed of discrete parts. Based on the scores (see Table 8), we have decided to use several of Sharp's GP2D120 short-range infrared sensors for sensing distance to the walls of the maze. These IR sensors output a voltage relative to the distance of the sensor from an object ahead.

Part	Cost ($)	Interface	Range (cm)	# of external components
Sharp GP2D02	19.00	Serial	10-80	0
Sharp GP2D120	12.50	Analog	4-30	0
Sharp GP2D05	19.00	Serial	10-80	0
Vishay TCRT 1000		Analog	0-5	3+
Discrete	3.00	Analog	Variable	5+

Table 7

Part	Interface	Range (cm)	# of external components	Reliability	Total
Sharp GP2D02	4	1	7	8	20
Sharp GP2D120	8	6	7	8	29
Sharp GP2D05	4	1	7	8	20
Vishay TCRT 1000	8	8	4	6	26
Discrete	8	10	1	3	22

Table 8

The final task of our design of the sensor system consists of devising a scheme for odometry, which affects both control and navigation of a robot. Theoretically, we should be able to measure the distance traveled by the robot based on the number of steps moved, a current tally of which is kept by the microcontroller. However, the stepper motor is not perfect and may miss a small percentage of steps, which would lead to an incorrect assessment of the distance traveled. Therefore, it is important to include a separate, independent means of odometry.

A very common method of odometry in robotics is through the use of a shaft encoder, which is a special sensor that measures the position or velocity of a rotating shaft. Shaft encoders are generally mounted on the output shaft of a motor (Jones 150). Absolute encoders are a type of shaft encoder that measure only the position of the shaft, while incremental encoders actually measure the velocity (i.e., speed and direction) of the shaft. An incremental encoder generates a pulse train that corresponds directly to the rotational speed of the shaft, as well as direction in the case of quadrature encoders (Clark 227). Specifically, the output of the shaft encoder changes from low to high or vise versa whenever the shaft turns a small amount, and so the rate of the pulse varies directly with the rate of the turning shaft (Jones 150).

For a photointerrupter incremental shaft encoder (also known as a beam interrupter or break beam encoder), a disk with slots cut into it is attached to the motor shaft and spins with it. A near-range infrared LED is place on one side of the disk's slots and a phototransistor is placed on the other side. When the motor moves and the disk spins, the light from the IR LED passing through the disk is interrupted by the moving slots, and a pulse train is produced at the output of the phototransistor. The microcontroller then counts the pulses to determine how far the wheels have rotated (and thus how far the robot has traveled). The greater the number of slots, the more precise is the encoder measurement (150-151).

Another type of shaft encoder known as a photoreflector shines light from a near-range IR LED onto a striped wheel (as shown in Figure A), which then reflects the light back onto a phototransistor. The wheel is a palette of radially alternating white and black stripes that reflect and do not reflect light back to the phototransistor, respectively, which yields a pulse-train similar to that of a photointerrupter (see Figure 9). Again, a greater number of stripes results in better resolution in the measurement (151).

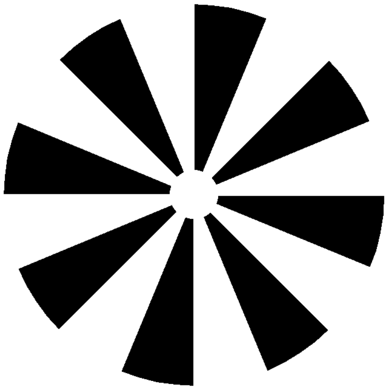


Figure 9

Quadrature encoding is a very popular technique but comes with increased complexity and cost. It requires two sensors to be positioned on the striped encoder wheel so that when one sensor encounters a black and white boundary, the other

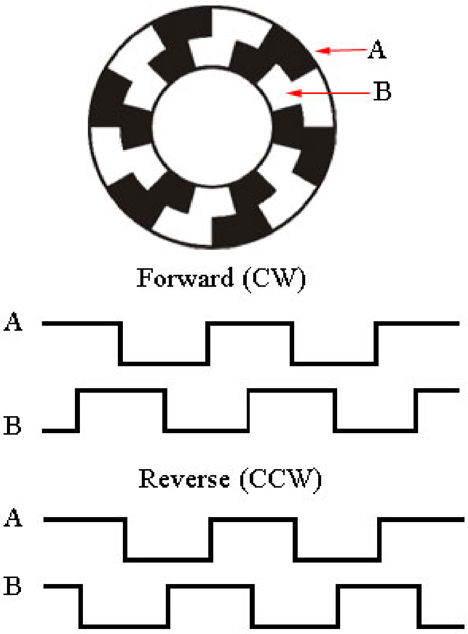


Figure 10

sensor is exactly in the middle of a black or white stripe. The resulting pulse trains from the sensors are 90 degrees out of phase with respect to each other. By identifying the leading transition, the direction of the wheel can be determined. Looking at Figure 10, if the output of sensor B goes high to low after the output of sensor A goes high to low (or if B goes low to high after A goes low to high), then the disk is moving in the clockwise direction. Conversely, if the output of sensor B goes low to high after the output of sensor A goes high to low (or if B goes high to low after A goes low to high), then the disk is moving counterclockwise. In addition to direction sensing, a relative merit of quadrature encoding over the regular methods of shaft encoding is doubled encoder resolution (Clark 248-249).

There are also non-optical approaches to odometry that have the advantage of being immune to noise from ambient light. One such method is the Hall Effect switch, which is based on magnetic principles. Other methods include the mechanical rotary encoder or the analog tachometer.

Chassis

The chassis holds all of the other hardware components together and provides a stable framework. There goals of the chassis design include making it as lightweight as possible while also making it durable and rigid. These two goals are competing and a balance has to be established. The chassis will be made of polyvinyl chloride (PVC) plastic because it has a good weight to strength ratio (see Figure 11 & Figure 12).

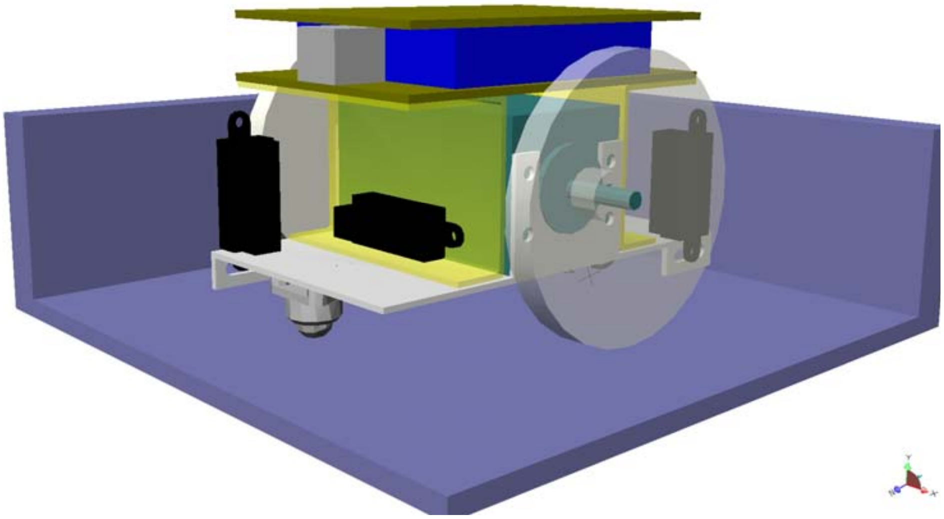


Figure 11

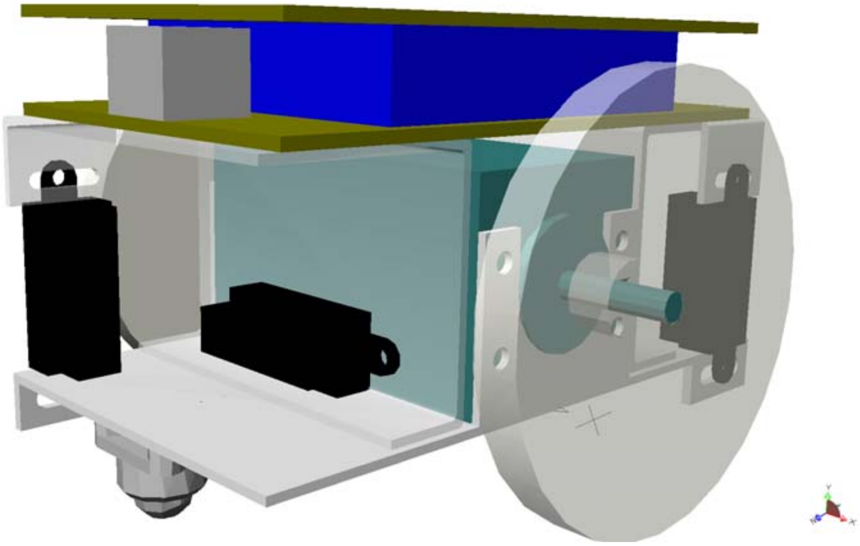


Figure 12

Software

Flowchart

The primary purpose of the software is to maintain control over the hardware at all times and determine where to move by solving the maze (see Figure 13). Controlling the hardware consist of reading the sensors, setting the motor speed, and communicating with any external peripherals. Since each of the motors speeds are controlled independently, alignment corrections can be made by increasing or decreasing the speed of a single motor.

In addition to controlling the hardware, the software must also keep track of the current position within the maze and determine where to move based on the selected algorithm.

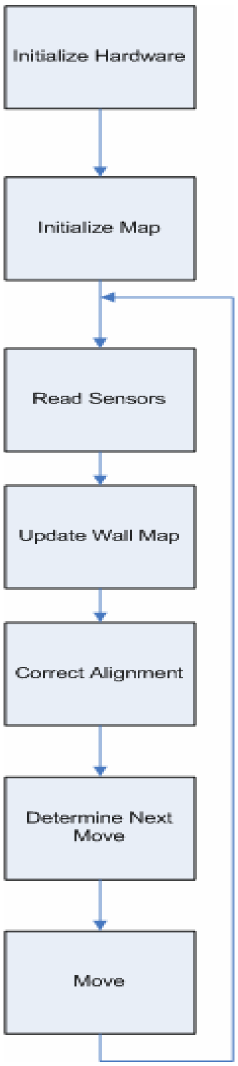


Figure 13

Algorithm

The principal goal of the Micromouse is to solve the maze and find its center as quickly as possible. To accomplish this task, the Micromouse uses a particular maze-searching algorithm.

A vast amount of research on searching techniques already exists and is currently being undertaken. Mathematicians in the fields of topology and graph theory have been studying maze creation and maze solving algorithms for several centuries. However, the algorithms they have developed are not feasible for Micromouse applications due to the memory and speed limitations of most Micromouse microcontrollers. Moreover, since searching through data is a fundamental function of computers, computer scientists have also devised a number of different searching techniques throughout the last few decades. Again, while these algorithms are highly effective and efficient for computers built with a sophisticated microprocessing unit, they cannot be practically implemented in the less advanced microcontrollers utilized for Micromice. As a result, Micromouse robots generally use some variation of the following three searching algorithms: Wall Following, Depth-First Search, and Flood-Fill.

Wall Following is a trivial algorithm in which the mouse chooses a wall, either left or right, and then always keeps the chosen wall on its side as it moves through the maze. This algorithm is very simple to implement in code, but unfortunately it is inefficient and does not work for IEEE mazes because they are specifically designed to prevent

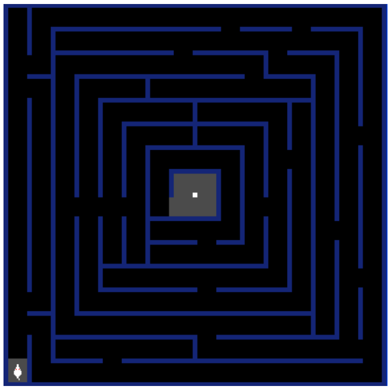


Figure 14

wall-following mice from succeeding (i.e., they are not perfect mazes). For instance, the maze in Figure 14 is an example of a one in which a left wall-following mouse would end up circling the outer perimeter and never travel further into the maze.

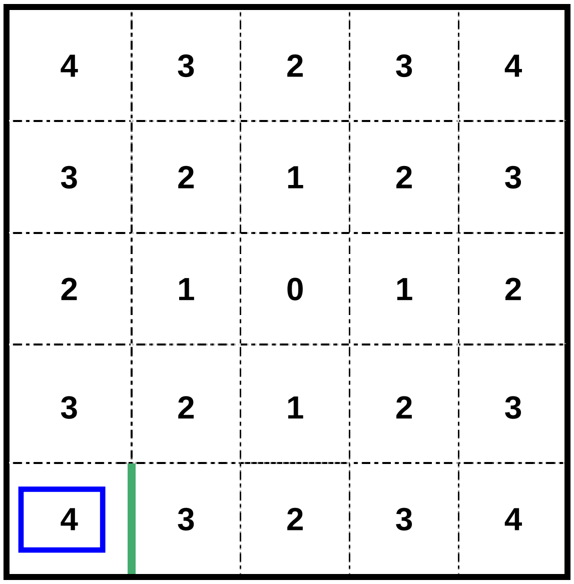
Depth-First Search is an intuitive algorithm for searching a maze in which the mouse first starts moving forward and randomly chooses a path when it comes to an intersection. If that path leads to a dead end, the mouse returns to the intersection and choose another path. This algorithm forces the mouse to explore each possible path within the maze, and by exploring every cell, the mouse eventually finds the center. It is called “depth-first” because, if the maze is considered a spanning tree, the full depth of one branch is searched before moving onto the next branch. The relative advantage of this method is that the Micromouse always finds a route. Unfortunately, the major drawback is that the mouse does not necessarily find the shortest or quickest route, and it wastes too much time exploring the entire maze.

Flood-Fill is better suited to the Micromouse than the two algorithms discussed above. This algorithm, also known as Bellman’s algorithm, uses a sophisticated system of distance and wall information to refine a short path to the center of the maze. Since the maze has a fixed size already known to the Micromouse, namely 16 cells by 16 cells, it must first assign a value to each cell in the maze representing the distance from that cell to the center and store these values in an array. The Micromouse must also store a wall map which will be continually updated with information as the sensors detect new walls in the maze. At each cell, the Micromouse performs the following steps:

1. Check for new walls and update the wall map.
2. “Re-flood” the maze with new distance values and update the distance array.
3. Move to the neighboring cell with the lowest distance value.

Flood-Fill is called a “breadth-first” algorithm because, if the maze is considered to be a spanning tree, an entire level is searched before exploring the whole depth of a particular branch. The major advantage of the Flood-Fill algorithm is that it always finds the shortest path to the center of the maze. It is important to note that the shortest path is not necessarily the quickest path since a path filled with turns will take a longer time to traverse than one primarily composed of forward-going moves. The relative disadvantage of this algorithm is that more memory is required for execution.

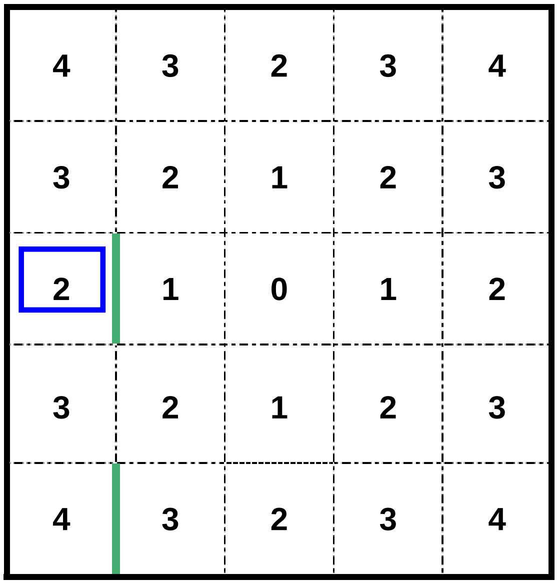
Several modifications of the Flood-Fill algorithm may be implemented to increase efficiency. For example, Modified Flood-Fill is a derived version of regular Flood-Fill in which only those values which need to be changed are actually updated when searching the maze rather than re-flooding the entire maze as in regular Flood-Fill. This method is considerably faster than regular Flood-Fill because entire maze does not need to updated each time the Micromouse moves to a new cell (“Software”). The following diagrams are a pictorial illustration of the Modified Flood-Fill algorithm:



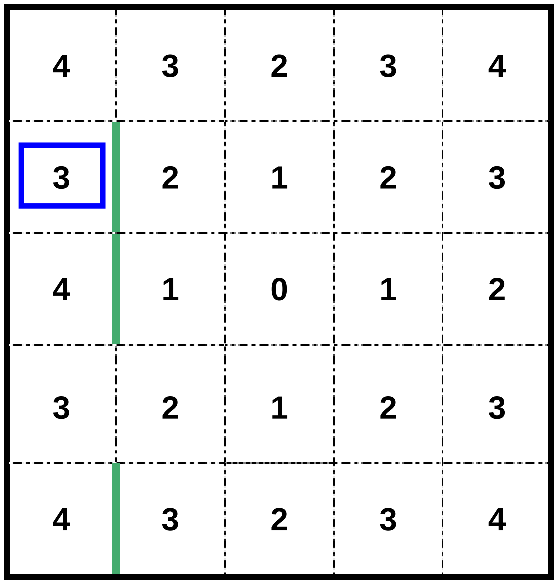
4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

1. Here we have a smaller version of the maze for illustration purposes. No prior wall information is known to the Micromouse. The mouse begins at the bottom left corner and sees a wall to the right and goes forward to the cell of lower distance.

2. The Micromouse continues to follow the lowest distance number path and finds a wall to east. The neighboring cells all have a higher number, so it must adjust its current distance number to 1 higher than lowest neighbor.

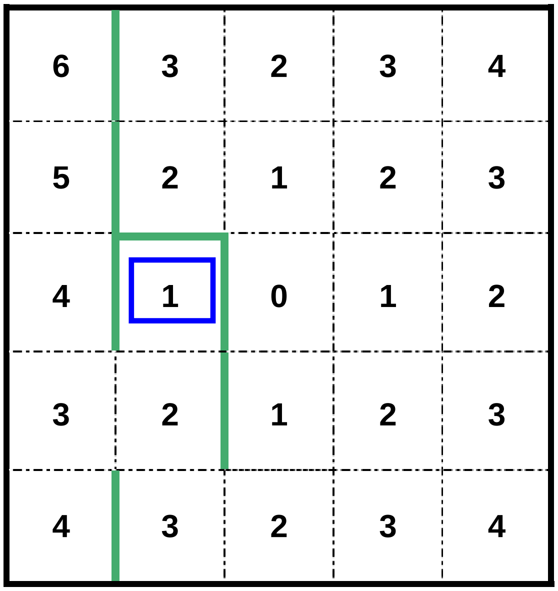


4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4



4	3	2	3	4
3	2	1	2	3
4	1	0	1	2
3	2	1	2	3
4	3	2	3	4

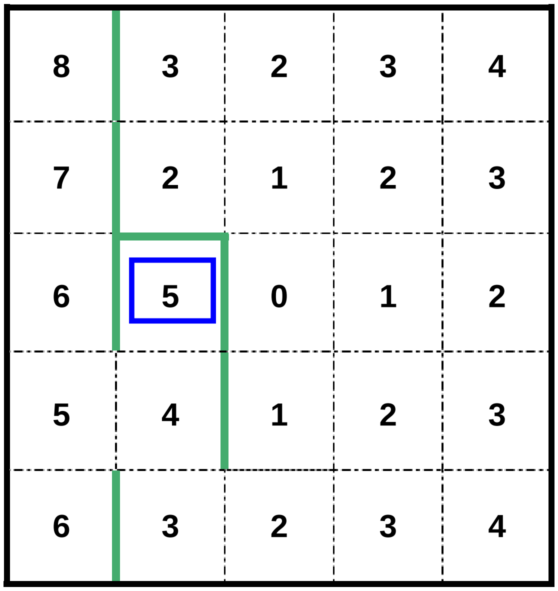
3. The Micromouse finds another wall to the east and updates the wall map. It also re-floods the distance array with the new values.



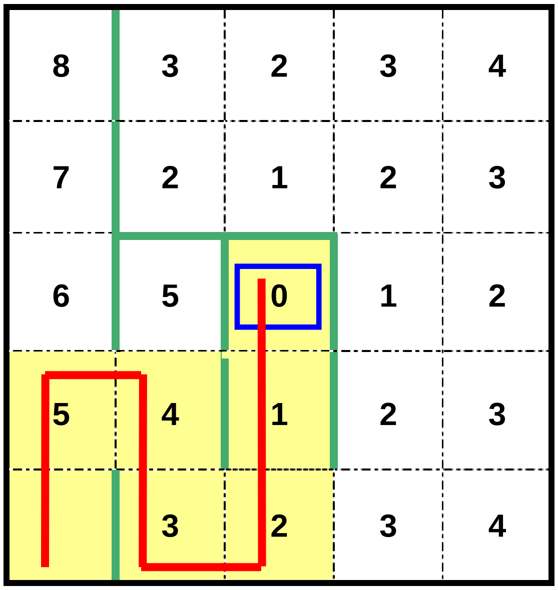
6	3	2	3	4
5	2	1	2	3
4	1	0	1	2
3	2	1	2	3
4	3	2	3	4

4. The Micromouse continues exploring up to the top left corner, updates wall and distance information as required, and then follows the lowest distance path towards the center of the maze. At its current position, cells to south have incorrect distance information, so they must be updated.

5. In order to update the values, the distance array is changed as shown to the right.



8	3	2	3	4
7	2	1	2	3
6	5	0	1	2
5	4	1	2	3
6	3	2	3	4



8	3	2	3	4
7	2	1	2	3
6	5	0	1	2
5	4	1	2	3
	3	2	3	4

6. The shortest path has now been discovered. The Micromouse must simply follow number sequence in descending order from the start to the center of the maze.

Testing and Simulation

GP2D120 IR Distance Sensor

According to the data sheet provided by Sharp Electronics, the GP2D120 is supposed to detect objects in the range of 4 to 30 cm away. To verify this statement and to gain additional insight into how the sensor functions, we performed several laboratory tests using the sensor.

First, we placed the IR sensor facing a white sheet of paper straight on and measured the output voltage at several incremental distances from the sheet of paper measured with a ruler. Table 9 shows the results of the three trials conducted, as well as an average of the three:

Test #1 (180° with White Paper)

Distance (cm) *	$\text{Voltage}_{\text{Trial 1}}$ (V)	$\text{Voltage}_{\text{Trial 2}}$ (V)	$\text{Voltage}_{\text{Trial 3}}$ (V)	$\text{Voltage}_{\text{Average of Trials}}$ (V)
3	1.917	1.882	2.011	1.937
3.5	2.187	2.266	2.029	2.161
4	2.811	2.876	2.560	2.749
4.5	3.083	3.084	3.058	3.075
5	3.031	3.003	3.067	3.034
5.5	2.811	2.777	2.909	2.832
6	2.577	2.543	2.671	2.597
6.5	2.369	2.369	2.437	2.392
7	2.222	2.205	2.266	2.231
7.5	2.064	2.046	2.117	2.076
8	1.918	1.907	1.972	1.932
8.5	1.811	1.793	1.846	1.817
9	1.703	1.684	1.721	1.703
9.5	1.592	1.592	1.629	1.604
10	1.501	1.501	1.538	1.513
11	1.368	1.350	1.387	1.368
12	1.239	1.239	1.257	1.245
13	1.127	1.127	1.146	1.133
14	1.064	1.046	1.064	1.058
15	0.988	0.988	0.988	0.988

Table 9

Using the results above, we created the following voltage versus distance plot (see Figure 15).

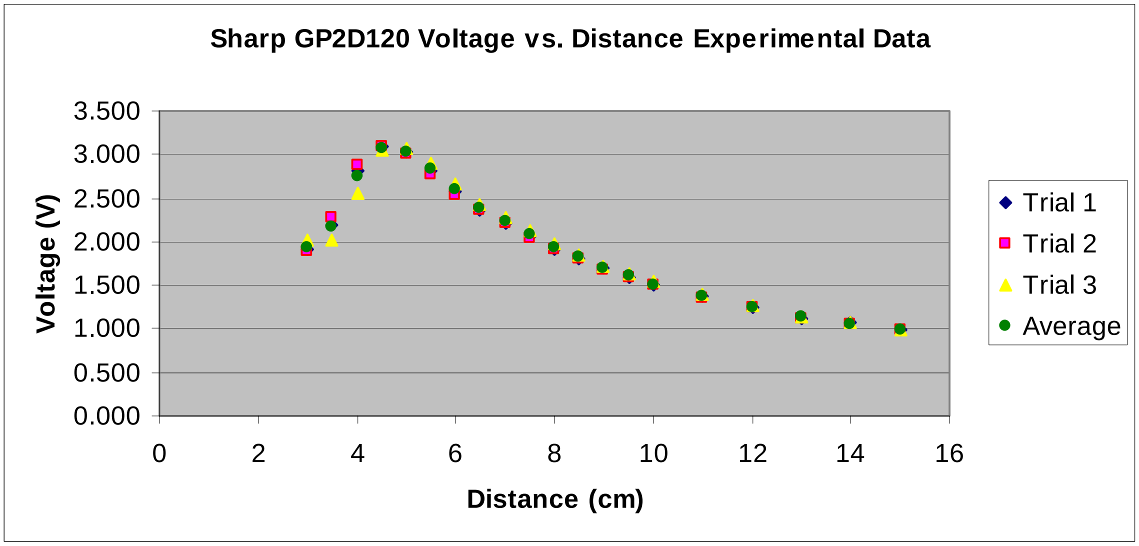


Figure 15

We notice that the output from the sensor is quite non-linear. This is due to the basic trigonometry within the triangle from the emitter to the illumination spot to the detector. Moreover, as expected from the device specifications, there is a range, namely closer than 4 cm to the wall, where the distance cannot be accurately measured. We must follow this constraint when placing the sensors on the robot.

Second, we placed the sensor at a fixed distance from the sheet of white paper, namely at 15 cm because that appeared to be the most consistent distance from the test performed above, and then varied the angle at which the sensor faced the paper using a protractor. Table 10 shows the results of the two trials performed.

Test #2 (Fixed Distance, Varying Angle with White Paper)

Angle (°)	Voltage$_{\text{Trial 1}}$ (V)	Voltage$_{\text{Trial 2}}$ (V)
60 (left to right)	0.895	0.913
65 (left to right)	0.894	0.913
75 (left to right)	0.894	0.913
80 (left to right)	0.894	0.933
85 (left to right)	0.895	0.894
90 (straight)	0.895	0.913
95 (right to left)	0.876	0.875
100 (left to right)	0.837	0.875
105 (left to right)	0.819	0.856
110 (left to right)	0.796	0.857
115 (left to right)	0.776	0.876

Table 10

We see that the data is somewhat inconsistent between the two trials. There appears to be greater error when the sensor is angled towards the right.

Button Debounce

The Micromouse requires external inputs via buttons and switches. The main problem associated with these mechanical devices is that they are susceptible to contact bounce. Without any additional circuitry, a single press of the button in the schematic (see Figure16) below results in the noise seen in Figure 17.

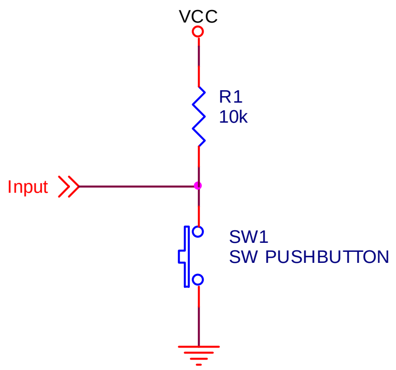


Figure 16

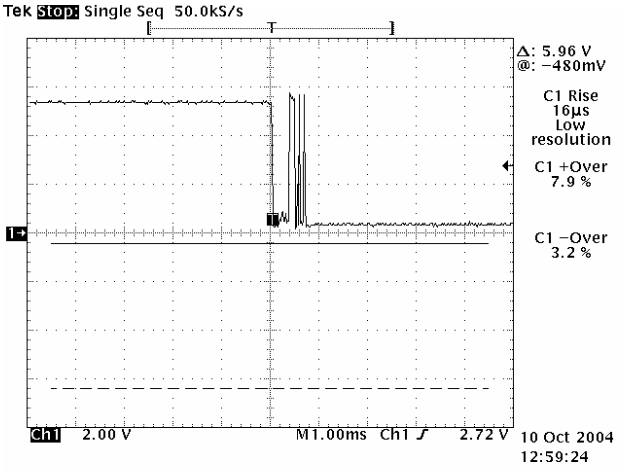


Figure 17

The debouncing can either be taken care of by hardware or software. In the interest of decreasing the software complexity as much as possible, the debouncing will be performed in hardware. The addition of a capacitor across the switch (see Figure 18) creates an RC circuit that eliminates all of the bounce (see Figure 19).

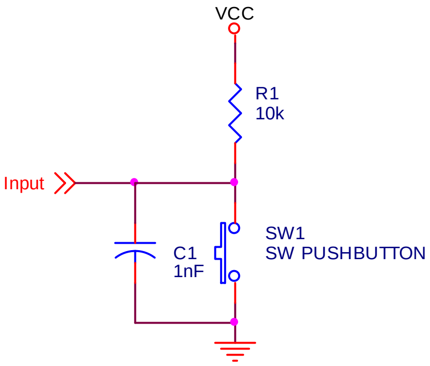


Figure 18

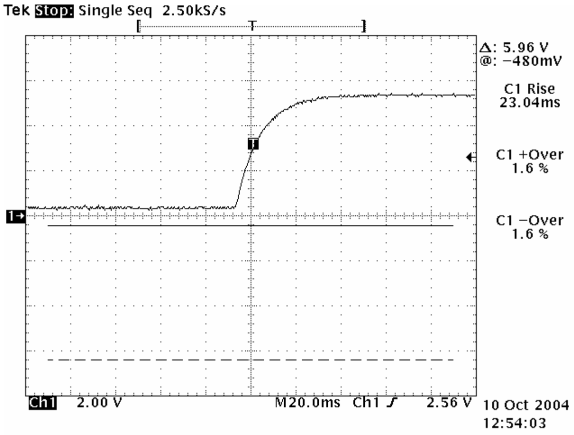


Figure 19

The slow rise time causes havoc on CMOS circuits; therefore, a Schmitt Trigger is introduced to remedy the problem (see Figure 20). The hysteresis of the Schmitt Trigger converts the slow rising exponential into clean square wave (see Figure 21). It should be noted that the value of the resistor and the value of the capacitor should exceed the maximum bounce time, thus RC > 20ms.

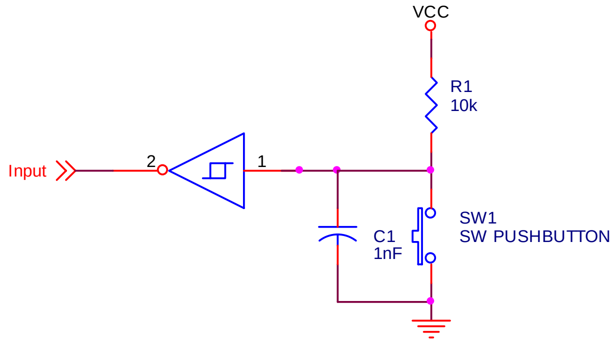


Figure 20

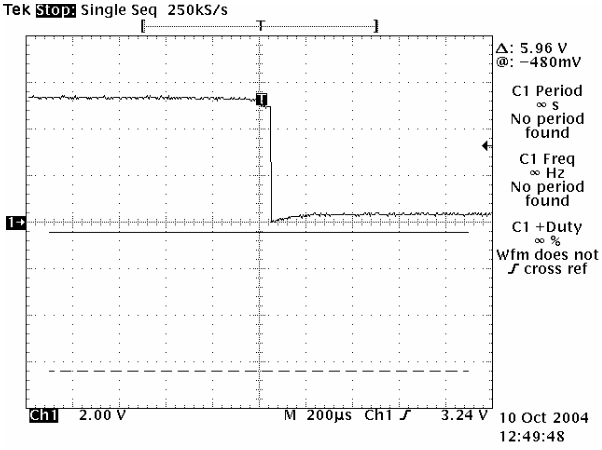


Figure 21

Since the inputs on the microcontroller have Schmitt Triggers built-in, the only actual component required to deobounce the switch in hardware is a single capacitor.

Social Implications

The field of robotics is rapidly becoming one of the leading frontiers in engineering technology. While the emergence of robotics may appear to have stemmed from the development of computer technology, the idea of artificial people has long fascinated mankind. Computers have only provided a tool for the practical realization of the numerous sophisticated systems required to create an autonomous robot. Fueled by the rash of movies, television programs, and books about robots popularized in the mid-twentieth century, people at the time expected robots to become a regular part of their lives—in positions such as domestic workers, store clerks, bankers, and the like—by the end of the millennium. The progress of the field has occurred at a slower pace than perhaps was initially expected, but robotics is now at the forefront of technology. Robots offer us effective solutions for many global problems, and they are now coming to pervade more and more aspects of our daily lives.

Robots are currently being utilized in many different manufacturing and industrial applications. They are often used for work considered to be too dangerous or difficult for human workers. Robots are also able to perform repetitive tasks that are tedious for humans with great precision and accuracy. For example, automobile manufacturers commonly use robots for welding and painting applications, semiconductor companies use robots for inserting integrated circuits onto printed circuit boards and soldering chips, etc. In addition, manufacturing companies often use computer-aided design (CAD), computer-aided manufacturing (CAM), and computer numerical control (CNC) machines to produce designs, make components, and assemble machines. This technology allows engineers to design a component using CAD and then quickly manufacture the design using robot-controlled equipment. Robots help to raise the overall profit margin of companies due to increased productivity and higher quality products, savings which can then be passed onto consumers (Iovine 7).

Medical robots are ideal for various diagnostic testing and surgery applications. For instance, laboratory testing is often a manual task requiring an analyst to examine a sample under a microscope for abnormal conditions (see Figure 22). This procedure is well-suited to robot automation. Surgeons use robots to perform delicate surgeries that were once considered impossible. In the future, researchers hope to use nanotechnology to create microscopic robots that are injected into human beings to perform actions such as removing fatty deposits from blocked arteries and destroying cancerous cells in tumors (9).

Figure 22

Another vast area of research and development is robot-based space exploration. The National Aeronautics and Space Administration (NASA) arguably has the most sophisticated robotics program in the world today. NASA often sends unmanned robot explorers on missions impossible for human explorers to accomplish. In addition to the risk involved with sending a human being into outer space, humans also require a substantial support system for their space travel, including breathable atmosphere, food and water, heat, living accommodations (see Figure 23). Robots, on the other hand, require far less support and can be abandoned if necessary (3-7).

Figure 23

Robots are particularly useful for performing hazardous duty services. They can easily perform hazardous work without risking human life or limb. For instance, they are used in many bomb squads around the country. Resembling small armored tanks, these robots are usually guided remotely by personnel using video cameras attached to the front of the robot. Similar robots can also help with handling or cleaning up toxic waste. They can work unimpeded in all types of polluted chemical environments, including ones so dangerous in which an unprotected human being would quickly die. In fact, the nuclear industry was the first to develop and use robotic arms for handling radioactive materials. Currently, there is research being done in developing fire-fighting robots that can detect a fire anywhere in a building, travel to the location, and put out the fire (8-9).

In addition, robots are becoming increasingly indispensable in war and weaponry. Militaries around the world are developing sophisticated robotics programs to keep watch on enemies and help ensure their victory if the need for war should arise. In modern warfare, drone aircraft tracks enemy movements and keeps the enemy under close surveillance. Other examples of intelligent weaponry are “smart” bombs and cruise missiles (11).

There are also many different applications for domestic robots. While labor-saving devices such as washing machines, clothes dryers, dishwashers, ovens, and the like have been computerized for some time now, most people would not characterize them as robots but rather as machines, since they do not autonomously gather the materials they need to perform their functions. Although it may be a while yet before we all have “Rosie the Robot” maids to perform various household duties, current research in the development of domestic robots is in the area of greater autonomization.

The social impacts of robots are significant and varied. While there are some obvious and indisputable advantages to using robots for performing certain functions or duties, there are also considerable ethical concerns involved with their other uses or misuses. As with the advent of any new technology, there are fears of domination by the technology we created. Specifically, there are concerns that the advanced development of robots may be used to do harm to human beings. Considering all the robotics war and weaponry applications, these fears are perhaps not unfounded. It is also true that many humans have already been and will continue to be replaced by robots in certain jobs.

Many also question the right of scientists and engineers to “play god” and attempt to create autonomous robots that have the ability to reproduce and exist outside of human control, or even to make humanoid robots in man’s image. Some people are wary of the possibility of robots having anthropomorphic traits and real human emotions. Clearly, the assimilation of humanoid robots into our everyday lives and interactions may take some time. Non-humanoid robots, on the other hand, may gain acceptance more easily since, according to definition, robots are already all around us in washing machines and other automated machines and devices. Looking back in history, we see that computers were initially looked upon with great suspicion, but are now almost universally accepted for ordinary applications.

Thus, the social implications of robots involve a complex interplay of their palpable benefits to mankind and the substantial ethical concerns associated with their rapidly increasing sophistication. The question of whether robots can provide some good to humanity is one as old as technology itself. There have always been doubts and questions raised when new technologies have been introduced. At this stage, it is uncertain if engineers will ever be able to develop robots to the point that some people fear. Nevertheless, given the current level of research in robotics, one point is clear: robots will be a force to reckon with in the future.

Safety and Ethics

Constructing a Micromouse robot is an extensive project that involves a wide expanse of electronics and controls engineering. As such, there are a number of varied safety and ethics issues to be considered throughout the development of the robot. Safety and ethics are in general key areas of concern for all electronics applications, but there are a number of these issues unique to the Micromouse.

In regards to personal safety, we always need to take proper precautions when handling potentially dangerous electrical equipment or other hazardous materials. While working in the laboratory, we must wear personal protective gear whenever required. For example, when soldering components onto a board, we should have safety goggles to protect our eyes, and work in a well-ventilated area to avoid ingesting excessive amounts of solder flux. It is also extremely important to wash hands thoroughly after handling soldering materials or other items that may contain lead or other toxic substances. In addition, we must be cognizant of the high voltages and currents that may be drawn by a circuit board, and never touch components unless power to the circuit has been turned off. Finally, we should be aware of how to shut off power to the lab in the event of an emergency, and know the location of the fire extinguisher in case a fire erupts.

Electromagnetic Interference, also known as EMI, is a disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics or electrical equipment. The design of the Micromouse has taken several measures to minimize the amount of EMI radiated. Most notably, the use of any ground loops has been strictly avoided. Instead, the grounding is replaced by a ground plane. The ground plane is a continuous plane layer on the PC Board, thus eliminating any possibilities for ground loops to exist.

The batteries used to power the robot are Lithium Polymer (LiPo) cells. These batteries are known for their compact size and high charge density. LiPo cells also exhibit extremely high discharge rates, up to 10 coulombs. With this high discharge rate, precautions have been taken to avoid direct shorts which would cause the batteries to overheat and possibly explode. Due to the high-risk nature of the problem, two safety measures are employed. First, the design contains a fuse to prevent high current discharge. Second, the connectors on the batteries have been changed to prevent any accidental shorting.

As far as ethics are concerned, one major area of focus should be environmental responsibility. The use of lead free (Pb-free) integrated circuits (ICs) has been utilized whenever available. Lead is a naturally occurring element that is commonly used within the electronics industry to enhance soldering. Lead additives in solder help lower the melting point, reducing the risk that the semiconductor will be damaged during the soldering process. However, lead is classified as a hazardous and toxic material by the World Health Organization. Lead has been eliminated from many commercial products in the recent years, such as paint and water pipe solder. Lead has been confirmed to hamper neurological and physical development, making it most harmful to children. Since most large IC manufactures have begun offering Pb-free ICs, there is no reason not to use them in our design.

Finally, another topic related to ethics involves intellectual property rights and the issue of scholastic honesty. We must perform a great deal of research in order to complete this project. While the sharing of ideas is encouraged and necessary for the advancement of the field, proper credit must be given. In writing our report, we have to include proper references wherever we use others' ideas or research. Also, since our project involves a considerable amount of programming, we will need to cite references if we utilize code already developed by others.

To conclude, we mention that the discussion above is only a general synopsis of the safety and ethics concerns regarding the Micromouse. We expect many other issues to come up as we further develop our project. However, having received adequate safety and ethics training in various classes we have already taken as well as ECG 497 itself, we will be able to address these issues in a responsible manner.

Economics

Part of the project constraints is a limited budget because the project must be produced for under $500. This figure includes the actual amount that free samples and gifts would cost to purchase from a reputable vendor. The price listed below is for low volume purchases (see Table 11). If the project was to be mass produced, these prices would be reduced significantly. Namely, the price of the circuit boards would drop significantly from two hundred and fifty to around a few dollars.

Qty	Part Description	Unit Cost	Total Cost
1	Microchip PIC18F6621	12.95	12.95
2	Allegro 3967	2.56	5.12
2	Lithium Polymer Batteries	32.00	64.00
2	H39BYG401A Stepper Motors	19.49	38.98
4	Sharp GP2D120 IR Sensors	12.50	50.00
1	National Semiconductor LM2675	4.00	4.00
1	4 Layer PCB Board	250.00	250.00
1	Misc Components (resistors, capacitors, inductors, ...)	50.00	50.00
1	Chassis	20.00	20.00
		[redacted]	[redacted]
		Total:	$495.05

Table 11

Future Work

Although we have made a significant amount of progress in the design of the Micromouse during this semester, we still have a considerable amount of work remaining in the implementation of the robot. First, we have to assemble all our parts and construct the actual robot chassis. We have to do the PC Board layout and construction. We must also code the maze-solving algorithm into the microcontroller. Associated with all of these tasks is an extensive amount of testing, for which we need to obtain or construct at least part of a life-size maze.

Conclusions

This project has been an incredible learning experience. It is a daunting task to undertake a project of such huge magnitude and wide breadth, but we were able to meet the challenge by diligently working on the design the entire semester. The Micromouse project is of great value to our future academic goals due to its broad engineering nature. By completing this project, we will gain a great deal of experience in several areas of computer and electrical engineering only briefly studied in our courses. In addition, the development of the searching algorithm will allow us to incorporate aspects of our mathematics backgrounds. Furthermore, the project has a research aspect which is strongly in accordance with our future career aspirations.

Acknowledgements

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Mr. Jamil Renno
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Dr. Venkatesan Muthukumar
Dr. Dolores Tanno
Dr. Stephen Rosenbaum
Mr. Kevin Forcade

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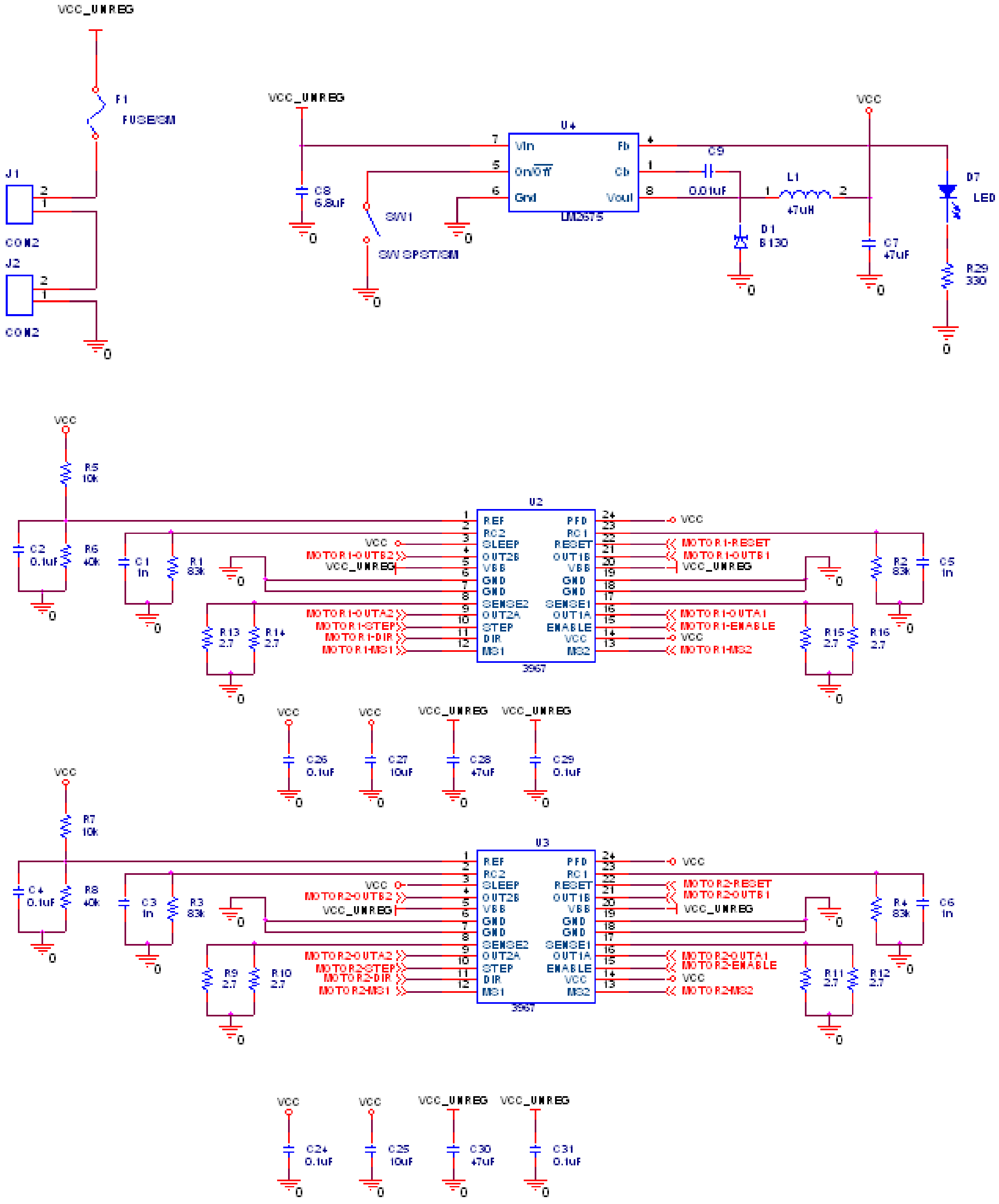
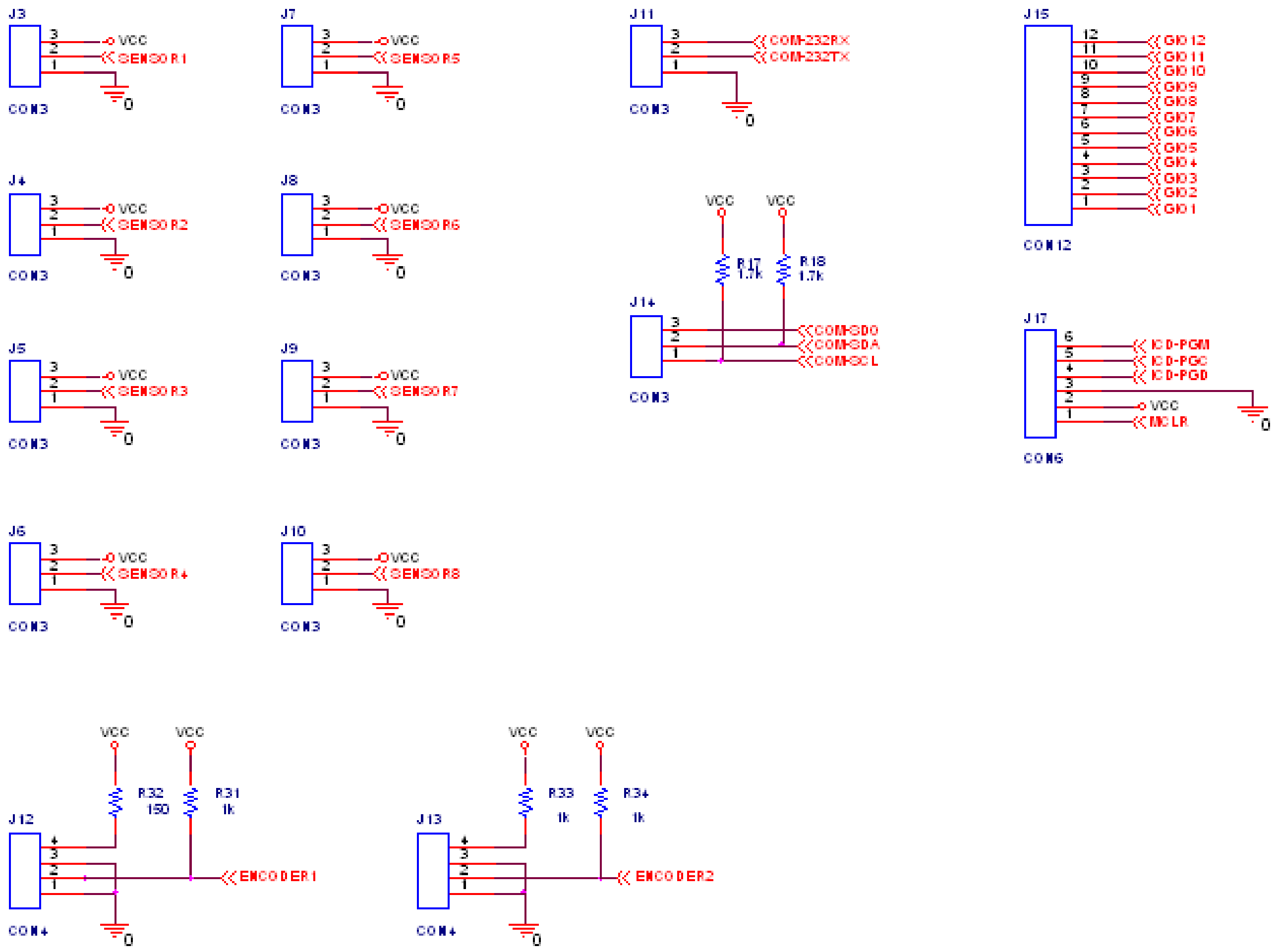
Appendix

Schematic

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CON3
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GIO11
GIO10
GIO9
GIO8
GIO7
GIO6
GIO5
GIO4
GIO3
GIO2
GIO1
CON12
J4
SENSOR2
J8
SENSOR6
VCC
VCC
R17
4.7k
R18
4.7k
J14
COM-SDO
COM-SDA
COM-SCL
CON3
J17
ICD-PGM
ICD-PGC
ICD-PGD
VCC
MCLR
CON6
J5
SENSOR3
J9
SENSOR7
J6
SENSOR4
J10
SENSOR8
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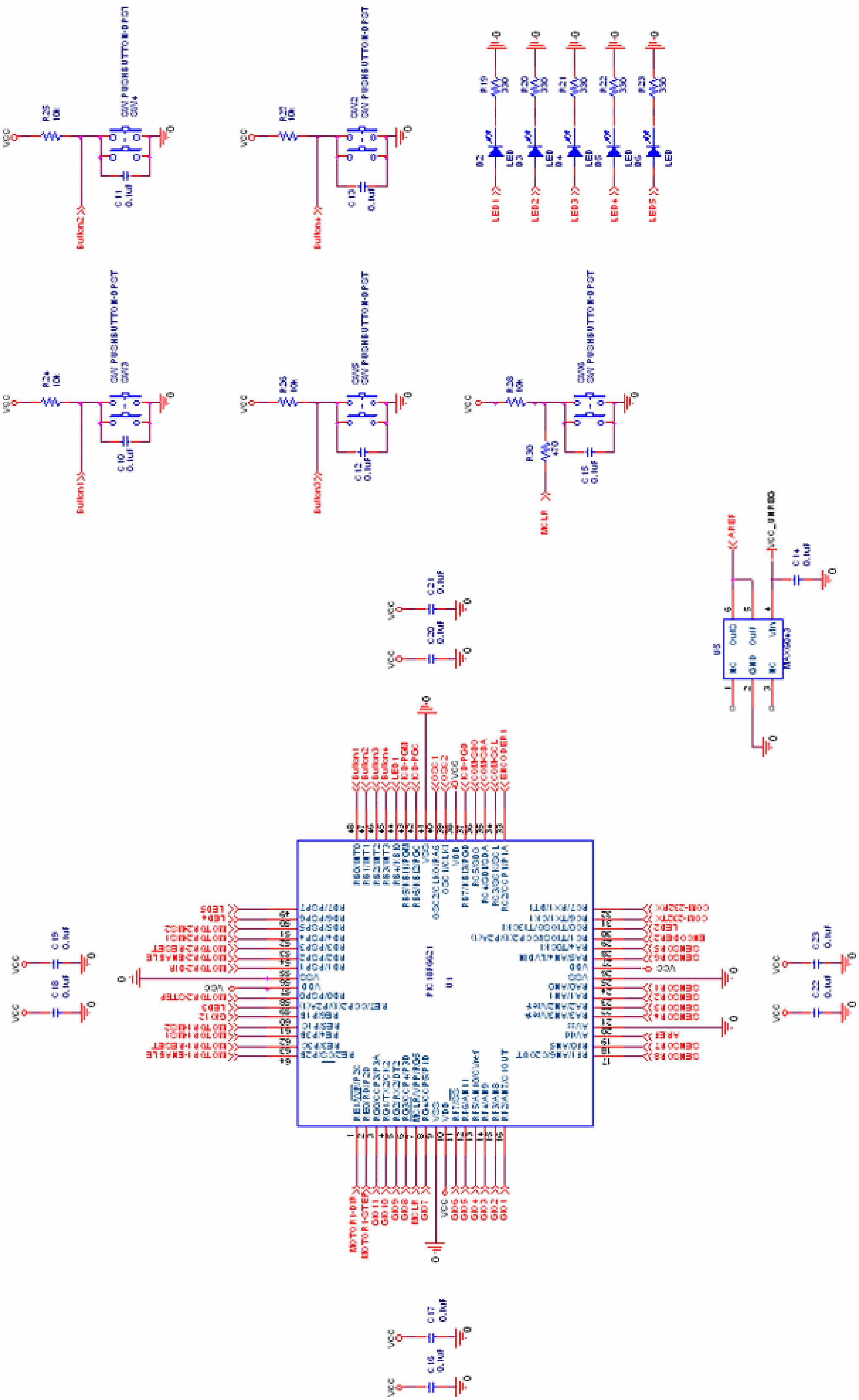
R33
1k
R34
1k
ENCODER2
CON4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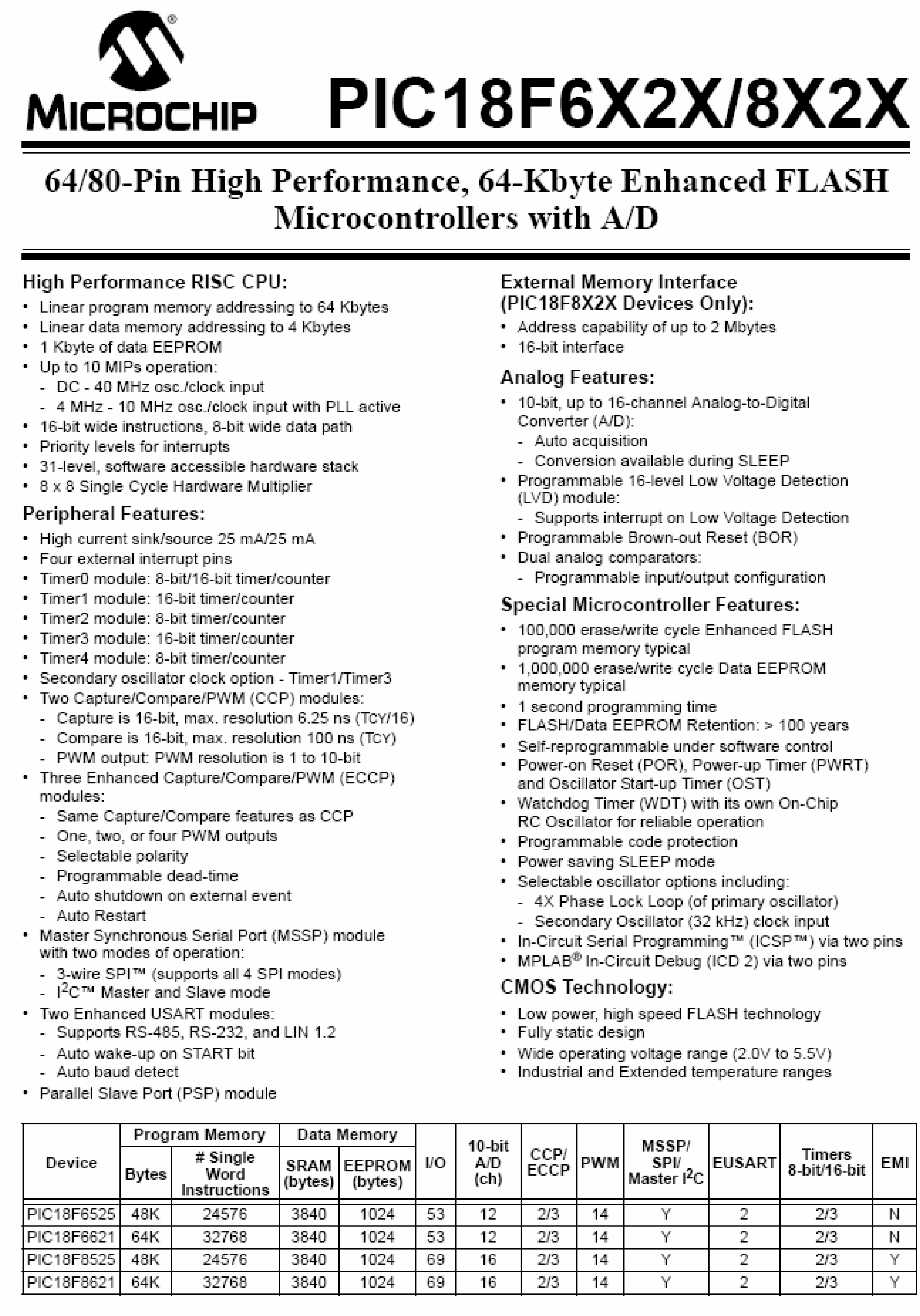
10k
SW PUSHBUTTON-DPST
SW4
C11
0.1uF
Button2
R27
10k
SW2
C13
0.1uF
Button4
R19
R20
R21
R22
R23
330
D2
D3
D4
D5
D6
LED
LED1
LED2
LED3
LED4
LED5
R24
10k
SW3
C10
0.1uF
Button1
R26
10k
SW5
C12
0.1uF
Button3
R28
10k
SW6
R30
470
C15
0.1uF
MCLR
C20
0.1uF
C21
0.1uF
U5
AREF
VCC_UNREG
C14
0.1uF
U1
C16
C17
C18
C19
C22
C23
0.1uF
0

Datasheets



MICROCHIP

PIC18F6X2X/8X2X

64/80-Pin High Performance, 64-Kbyte Enhanced FLASH Microcontrollers with A/D

High Performance RISC CPU:

- Linear program memory addressing to 64 Kbytes
- Linear data memory addressing to 4 Kbytes
- 1 Kbyte of data EEPROM
- Up to 10 MIPs operation:
  - DC - 40 MHz osc./clock input
  - 4 MHz - 10 MHz osc./clock input with PLL active
- 16-bit wide instructions, 8-bit wide data path
- Priority levels for interrupts
- 31-level, software accessible hardware stack
- 8 x 8 Single Cycle Hardware Multiplier

Peripheral Features:

- High current sink/source 25 mA/25 mA
- Four external interrupt pins
- Timer0 module: 8-bit/16-bit timer/counter
- Timer1 module: 16-bit timer/counter
- Timer2 module: 8-bit timer/counter
- Timer3 module: 16-bit timer/counter
- Timer4 module: 8-bit timer/counter
- Secondary oscillator clock option - Timer1/Timer3
- Two Capture/Compare/PWM (CCP) modules:
  - Capture is 16-bit, max. resolution 6.25 ns (TCY/16)
  - Compare is 16-bit, max. resolution 100 ns (TCY)
  - PWM output: PWM resolution is 1 to 10-bit
- Three Enhanced Capture/Compare/PWM (ECCP) modules:
  - Same Capture/Compare features as CCP
  - One, two, or four PWM outputs
  - Selectable polarity
  - Programmable dead-time
  - Auto shutdown on external event
  - Auto Restart
- Master Synchronous Serial Port (MSSP) module with two modes of operation:
  - 3-wire SPI™ (supports all 4 SPI modes)
  - I^{2}C™ Master and Slave mode
- Two Enhanced USART modules:
  - Supports RS-485, RS-232, and LIN 1.2
  - Auto wake-up on START bit
  - Auto baud detect
- Parallel Slave Port (PSP) module

External Memory Interface (PIC18F8X2X Devices Only):

- Address capability of up to 2 Mbytes
- 16-bit interface

Analog Features:

- 10-bit, up to 16-channel Analog-to-Digital Converter (A/D):
  - Auto acquisition
  - Conversion available during SLEEP
- Programmable 16-level Low Voltage Detection (LVD) module:
  - Supports interrupt on Low Voltage Detection
- Programmable Brown-out Reset (BOR)
- Dual analog comparators:
  - Programmable input/output configuration

Special Microcontroller Features:

- 100,000 erase/write cycle Enhanced FLASH program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- 1 second programming time
- FLASH/Data EEPROM Retention: > 100 years
- Self-reprogrammable under software control
- Power-on Reset (POR), Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own On-Chip RC Oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options including:
  - 4X Phase Lock Loop (of primary oscillator)
  - Secondary Oscillator (32 kHz) clock input
- In-Circuit Serial Programming™ (ICSP™) via two pins
- MPLAB® In-Circuit Debug (ICD 2) via two pins

CMOS Technology:

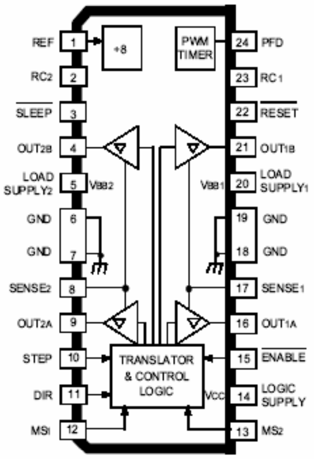
- Low power, high speed FLASH technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Industrial and Extended temperature ranges

Device	Program Memory		Data Memory		I/O	10-bit A/D (ch)	CCP/ ECCP	PWM	MSSP/ SPI/ Master I^{2}C	EUSART	Timers 8-bit/16-bit	EMI
	Bytes	# Single Word Instructions	SRAM (bytes)	EEPROM (bytes)								
PIC18F6525	48K	24576	3840	1024	53	12	2/3	14	Y	2	2/3	N
PIC18F6621	64K	32768	3840	1024	53	12	2/3	14	Y	2	2/3	N
PIC18F8525	48K	24576	3840	1024	69	16	2/3	14	Y	2	2/3	Y
PIC18F8621	64K	32768	3840	1024	69	16	2/3	14	Y	2	2/3	Y

3967

Data Sheet
26184.24C

MICROSTEPPING DRIVER WITH TRANSLATOR



Dwg. PP-075-2

ABSOLUTE MAXIMUM RATINGS at T_A = +25°C

Load Supply Voltage, V_{BB}	**30 V**
Output Current, I_{OUT}	
Continuous	**±750 mA***
Peak	**±850 mA**
Logic Supply Voltage, V_{CC}	**7.0 V**
Logic Input Voltage Range, V_{IN}	
(t_w >30 ns)	**-0.3 V to +7.0 V**
(t_w <30 ns)	**-1 V to +7.0 V**
Sense Voltage, V_{SENSE}	**0.68 V**
Reference Voltage, V_{REF}	**V_{CC}**
Package Power Dissipation, P_D	**See page 8**
Operating Temperature Range, T_A	**-20°C to +85°C**
Junction Temperature, T_J	**+150°C**
Storage Temperature Range, T_S	**-55°C to +150°C**

* Output current rating may be limited by duty cycle, ambient temperature, and heat sinking. Under any set of conditions, do not exceed the specified current rating or a junction temperature of 150°C.

The A3967SLB is a complete microstepping motor driver with built-in translator. It is designed to operate bipolar stepper motors in full-, half-, quarter-, and eighth-step modes, with output drive capability of 30 V and ±750 mA. The A3967SLB includes a fixed off-time current regulator that has the ability to operate in slow, fast, or mixed current-decay modes. This current-decay control scheme results in reduced audible motor noise, increased step accuracy, and reduced power dissipation.

The translator is the key to the easy implementation of the A3967SLB. By simply inputting one pulse on the STEP input the motor will take one step (full, half, quarter, or eighth depending on two logic inputs). There are no phase-sequence tables, high-frequency control lines, or complex interfaces to program. The A3967SLB interface is an ideal fit for applications where a complex µP is unavailable or over-burdened.

Internal circuit protection includes thermal shutdown with hysteresis, under-voltage lockout (UVLO) and crossover-current protection. Special power-up sequencing is not required.

The A3967SLB is supplied in a 24-lead SOIC with copper batwing tabs. The tabs are at ground potential and need no insulation. A lead-free (100% matte tin leadframe) version is also available.

FEATURES

- ±750 mA, 30 V Output Rating
- Satlington™ Sink Drivers
- Automatic Current-Decay Mode Detection/Selection
- 3.0 V to 5.5 V Logic Supply Voltage Range
- Mixed, Fast, and Slow Current-Decay Modes
- Internal UVLO and Thermal Shutdown Circuitry
- Crossover-Current Protection

Always order by complete part number:

Part Number	Package
A3967SLB	24-lead batwing SOIC
A3967SLB-T	24-lead batwing SOIC; Lead-free

National Semiconductor

April 2003

LM2675
SIMPLE SWITCHER® Power Converter High Efficiency 1A Step-Down Voltage Regulator

General Description

The LM2675 series of regulators are monolithic integrated circuits built with a LMDMOS process. These regulators provide all the active functions for a step-down (buck) switching regulator, capable of driving a 1A load current with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5.0V, 12V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include patented internal frequency compensation (Patent Nos. 5,382,918 and 5,514,947) and a fixed frequency oscillator.

The LM2675 series operates at a switching frequency of 260 kHz, thus allowing smaller sized filter components than what would be needed with lower frequency switching regulators. Because of its very high efficiency (>90%), the copper traces on the printed circuit board are the only heat sinking needed.

A family of standard inductors for use with the LM2675 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies using these advanced ICs. Also included in the datasheet are selector guides for diodes and capacitors designed to work in switch-mode power supplies.

Other features include a guaranteed ±1.5% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring typically 50 µA stand-by current. The output switch includes current limiting, as well as thermal shutdown for full protection under fault conditions.

To simplify the LM2675 buck regulator design procedure, there exists computer design software, ***LM267X Made Simple*** version 6.0.

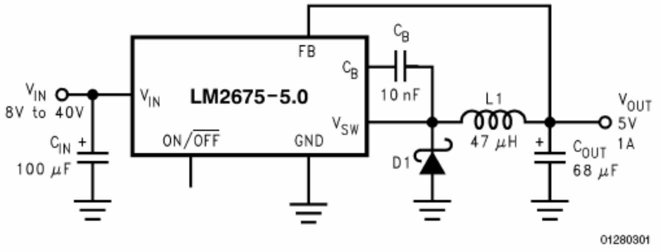
Features

- Efficiency up to 96%
- Available in SO-8, 8-pin DIP and LLP packages
- Computer Design Software ***LM267X Made Simple*** (version 6.0)
- Simple and easy to design with
- Requires only 5 external components
- Uses readily available standard inductors
- 3.3V, 5.0V, 12V, and adjustable output versions
- Adjustable version output voltage range: 1.21V to 37V
- ±1.5% max output voltage tolerance over line and load conditions
- Guaranteed 1A output load current
- 0.25Ω DMOS Output Switch
- Wide input voltage range: 8V to 40V
- 260 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- Thermal shutdown and current limit protection

Typical Applications

- Simple High Efficiency (>90%) Step-Down (Buck) Regulator
- Efficient Pre-Regulator for Linear Regulators
- Positive-to-Negative Converter

Typical Application



Rules

MICROMOUSE CONTEST RULES
REGION 6

These rules were revised November 30, 2001 and are valid for the **Spring 2004** contest. The 2001 revisions are: (1) The MicroMouse competition is intended to be a design contest, culminating the aggregate knowledge earned in a typical undergraduate degree. To support this, the participants will submit a report including a summary of the project, schematics, layout, Bill of Materials (with costs), and software code. The participants will present their design for review and answer questions from the judges prior to competing on the maze. The following rules were adapted from 1986 OFFICIAL RULES for NORTH AMERICAN MICROMOUSE CONTEST.

1. **OBJECTIVE**
    1.1. In this contest the contestant or team of contestants design and build small self-contained robots (micromice) to negotiate a maze in the shortest possible time.
2. **CONTEST ELIGIBILITY**
    2.1. All contestants must be an undergraduate IEEE student member at a Region 6 school from within the Area of Region 6 in which contest they will compete at the time of entry in the MicroMouse contest. Any student who graduates anytime during the Fall-Spring academic year in which the contest is held is eligible to enter the contest. A student graduating after competing in the contest still remains eligible to compete in succeeding Area, Region, and higher contests as an undergraduate student. Up to two graduate students per team are also allowed as stated in **Rule A.4** below, providing they meet all other requirements.
    2.2. All contestants must be an IEEE Student Members or must have submitted an application for membership (and have it accepted by their Student Branch Counselor) prior to entry in the Student Branch and/or Chapter Contest.
    2.3. The contestant(s) will submit their design in a document that will include a summary description of their mouse, schematics, layout, Bill of Materials (with associated costs) and code prior to the competition. This information will be presented, in five minutes or less, and the contestant(s) will answer any questions posed by the judges of their design.
    2.4. The MicroMouse entry may be the effort of an individual or a team. In the case of a team it should be possible to demonstrate that each individual made a significant contribution and that they are all IEEE members.
    2.5. A team may consist of up to five people. A team of four or five people may include no more than two graduate students. A team of two or three people may have no more than one graduate student. A team consisting of a single graduate student is not allowed.
    2.6. All entrants to the Student Branch Area contests must declare their intention to enter the contest at least 2 weeks before the date of the Area contest. This notice must be submitted to the current Student Activities Coordinator, appropriate Area, Region 6, by mail, email, or phone (see the names and addresses at the end of this document).

2.7. If the total number of declared mice, from all schools, is less than the number of eligible schools to compete in that Area, all shall be eligible to compete in the area contest. Two or more mice of near identical design from the same school are not allowed. If more mice than the number of eligible schools to compete are entered in the contest (ie., four mice from the same school), a qualifying competition will be held in the morning. A qualifying contest might involve, for example, having the mice transverse a specific numbers of cells.

3. RULES FOR THE MicroMouse

3.1. A MicroMouse shall be self-contained (no remote controls). A MicroMouse shall not use an energy source employing a combustion process.

3.2. A MicroMouse shall not leave any part of its body behind while negotiating the maze.

3.3. A MicroMouse shall not jump over, fly over, climb, scratch, cut, burn, mark, damage, or destroy the walls of the maze.

3.4. A MicroMouse shall not be larger either in length or in width, than 25 centimeters. The dimensions of a MicroMouse that changes its geometry during a run shall not be greater than 25 cm x 25 cm. There are no restrictions on the height of a MicroMouse.

3.5. The total cost of the mouse (in materials, labor is assumed to be free) may not exceed $500.00. This is judged on actual cost and market value of any donated materials used in the mouse. Contestants should be prepared to present a list of materials and their market values to the judges upon request. Since market values may vary from source to source, contestants should be prepared with catalogs or quotes to confirm unusual prices. The judge's decision shall be final in these matters.

3.6. Any violation of these rules will constitute immediate disqualification from the contest and ineligibility for the associated prizes.

4. RULES FOR THE MAZE

4.1. The maze is composed of multiples of an 18 cm x 18 cm unit square. The maze comprises 16 x 16 unit squares. The walls of the maze are 5 cm high and 1.2 cm thick (**assume 5% tolerance for mazes**). The outside wall encloses the entire maze.

4.2. The sides of the maze walls are white, the tops of the walls are red, and the floor is black. The maze is made of wood, finished with non-gloss paint.

4.2.1. WARNING: Do not assume the walls are consistently white, or that the tops of the walls are consistently red, or that the floor is consistently black. Fading may occur; parts from different mazes may be used. Do not assume the floor provides a given amount of friction. It is simply painted plywood and may be quite slick. The maze floor may be constructed using multiple sheets of plywood. Therefore there may be a seam between the two sheets on which any low-hanging parts of a mouse may snag.

4.3. The start of the maze is located at one of the four corners. The start square is bounded on three sides by walls. The start line is located between the first and second squares. That is, as the mouse exits the corner square, the time starts. The destination goal is the four cells at the center of the maze. At the center of this zone is a post, 20 cm high and each side 2.5 cm. (This post may be removed if requested.) The destination square has only one entrance.

4.4. Small square zones (posts), each 1.2 cm x 1.2 cm, at the four corners of each unit square are called lattice points. The maze is so constituted that there is at least one wall at each lattice point.

4.5. Multiple paths to the destination square are allowed and are to be expected. The destination square will be positioned so that a wall-hugging mouse will NOT be able to find it.

5. RULES FOR THE CONTEST

5.1. Each contesting MicroMouse is allocated a total of 10 minutes of access to the maze from the moment the contest administrator acknowledges the contestant(s) and grants access to the maze. Any time used to adjust a mouse between runs is included in the 10 minutes. Each run (from the start cell to the center zone) in which a mouse successfully reaches the destination square is given a run time. The minimum run time shall be the mouse's official time. First prize goes to the mouse with the shortest official time. Second prize to the next shortest, and so on. **NOTE**, again, that the 10-minute timer continues even between runs. Mice that do not enter the center square will be ranked by the maximum number of cells they consecutively transverse without being touched. All mice whom enter the center square within their 10 minute allotment are ranked higher than those who do not enter the center square.

5.2. Each run shall be made from the starting square. The operator may abort a run at any time. If an operator touches the MicroMouse during a run, it is deemed aborted, and the mouse must be removed from the maze. If a mouse has already crossed the finish line, it may be removed at any time without affecting the run time of that run. If a mouse is placed back in the maze for another run, a one-time penalty of **30 seconds** will be added to the mouse's best time.

5.3. After the maze is disclosed, the operator shall not feed information on the maze into the MicroMouse however, switch positions may be changed. See **Rule D.1**.

5.4. The illumination, temperature, and humidity of the room shall be those of an ambient environment. (40 to 120 degrees F, 0% to 95% humidity, non-condensing).

   5.4.1. **BEWARE**: Do not make any assumptions about the amount of sunlight, incandescent light, or fluorescent light that may be present at the contest site.

5.5. The run timer will start when front edge of the mouse crosses the start line and stops when the front edge of the mouse crosses the finish line. The start line is at the boundary between the starting unit square and the next unit square clockwise. The finish line is at the entrance to the destination square.

5.6. Every time the mouse leaves the start square, a new run begins. If the mouse has not entered the destination square, the previous run is aborted. For example, if a mouse re-enters the start square (before entering the destination square) on a run, that run is aborted, and a new run will be deemed begun, with a new time that starts when the starting square is exited.

5.7. The mouse may, after reaching the destination square, continue to navigate the maze, for as long as their total maze time allows.

5.8. If a mouse continues to navigate the maze after reaching the destination square, the time taken will not count toward any run. Of course, the 10-minute timer continues to run. When the mouse next leaves the start square, a new run will start. Thus, a mouse may and should make several runs without being touched by the operator. It should make its own way back to the beginning to do so.

5.9. The judges reserve the right to ask the operator for an explanation of the MicroMouse. The judges also reserve the right to stop a run, declare disqualification, or give instructions as appropriate (e.g., if the structure of the maze is jeopardized by continuing operation of the mouse).

5.10. A contestant may not feed information on the maze to the MicroMouse. Therefore, changing ROMs or downloading programs is NOT allowed once the maze is revealed. **However, contestants are allowed to**:

5.11. Change switch settings (e.g. to select algorithms)

5.12. Replace batteries between runs

5.13. Adjust sensors

5.14. Change speed settings

5.15. Make repairs

5.16. However, a contestant may not alter a mouse in a manner that alters its weight (e.g. removal of a bulky sensor array or switching to lighter batteries to get better speed after mapping the maze is not allowed). The judges shall arbitrate.

5.17. There is only one official IEEE MicroMouse contest each year in each Area or Region. All mice, whether or not they have competed in previous contests, compete on an equal basis. All mice must be presented to the judges by the original design team, which must meet all other qualifications. First prize will go to that mouse which travels from the start square to the destination square in the least amount of time. Second and third prizes will be awarded to the second and third fastest respectively. As stated in **Rule 4.1**, mice that do not enter the center square will be ranked by the maximum number of cells they consecutively transverse without being touched.

5.18. A rotating trophy is awarded to the first place mouse. Verbal recognition and certificates will be given to the top three mice among those who are competing for the first time. If you and your mouse are first-time contestants, be sure to so stipulate when you register for the contest and notify the contest judge at the time of the contest.

5.19. If requested, a break will be provided for a mouse after any run if another mouse is waiting to compete. The 10-minute timer will stop. When the mouse is re-entered, the 10-minute timer will continue. The judges shall arbitrate on the granting of such breaks.

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