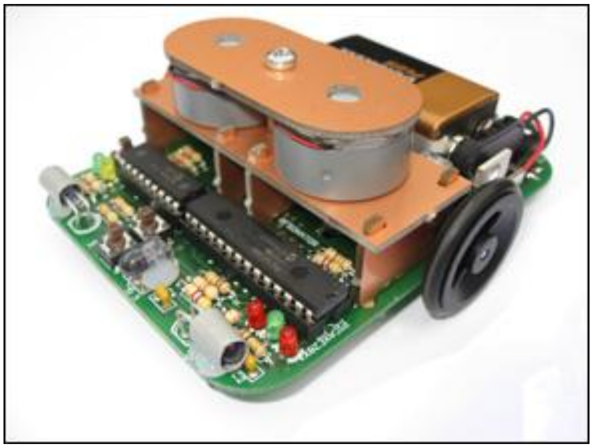
PICOne

(a.k.a. "PICAXE Micromouse")



Hardware

Chassis

The PICOne ("pick one") is built around a printed circuit board that serves as a chassis. The board and all of the standard parts arrived from the UK in an unassembled state; the parts all needed to be soldered on or otherwise connected to the printed circuit board. Using the board as the chassis is clever since it saves weight and allows the components to be accessed easily for repairs or modification. The wiring on the circuit board was modified in a few places during the 2009-2010 school year. These modifications will be described in other sections.

The mounting pieces for the motors are simply un-masked circuit board material plated with copper. They are light and rigid, good properties for their purpose. However, they give the PICOne a characteristic look and would need to be removed if a team wanted to pass the robot off as a "homemade" one versus a kit. The circuit board would likely have to be changed out also since it bears the names of Derek Hall and Jim Chidley, the original designers of the PICOne.

Power Source

Modification - Li-Ion Batteries and Custom Connectors

The original PICOne manual calls for a 9V ("PP3") battery. In general this type of battery does not seem to have adequate capacity for continuous operation over the course of a few hours, which is especially important when spending a few hours doing testing. A total of 5 lithium-ion batteries were purchased from Mouser.com. These have a nominal operating voltage of 3.7 V and a capacity of 1800 mAh. Two of them must be connected in series to power the PICOne, so two "packs" were created and one battery is a spare. This type of battery has an extremely low internal impedance. This allows them to drive lots of current. However, it also means that **they are dangerous when shorted.** They tend to puff up and explode.

Custom connectors were installed on the battery packs and on the chassis by Kadi, the lab tech in the OU Avionics Engineering Center. Other connectors (Japan Solderless Terminal connectors - "JST") were bought from Sparkfun.com. These connectors are useful for connecting things like batteries and motors to the circuit board since those parts sometimes need to be removed.

An even better solution than the 1800 mAh batteries may be a pair of batteries from a cellular phone. These are slightly smaller and have less capacity than the ones bought from Mouser electronics; however, they would still most likely be able to run the robot for an extended period of time. Some rudimentary tests revealed that when moving forward and with motors operating at 5 V regulated from a 9 V battery, the PICOne uses around 200 mA.


JST Header **JST Female Connector and Wires**

The short, stubby pins of the header get soldered into holes in a circuit board. The header is partially-shrouded.

The batteries are charged one-cell-at-a-time by a Triton 2 battery charger made by Great Planes. This charger was provided by Maarten Uijt de Haag. It takes 12 VDC (we used 14.4 V to simulate a car alternator) input from a lab power supply. If this charger is still around, the manual is very well-written and should be consulted before charging the batteries. If it is not used properly, a Li-Ion battery will violently explode. There are YouTube videos that demonstrate this type of explosion. The cells can’t be charged as a pack unless a balanced charger is used. The Triton 2 is not a balanced charger.

Motors and Drive System

<u>Motors</u>

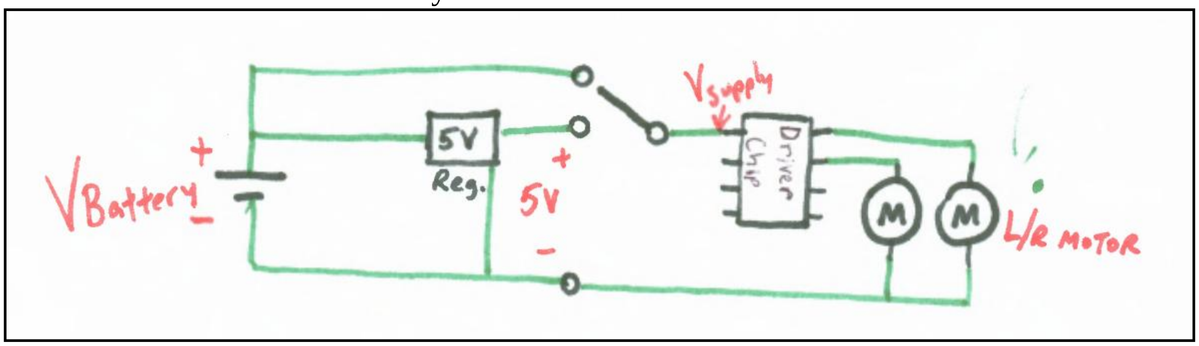
The two motors are brushed DC type. They are normally used in CD and DVD players. They have a nominal operating voltage of around 3V but have successfully handled up to 9V (PWM, so not continuous 9V) without issues. Some spare motors were ordered that are a similar model to the ones provided in the kit. In addition, two larger motors should be lying around that will fit onto the PICOne with minimal modification. The problem is that larger motors do not necessarily run faster. They may provide more torque at lower speed and higher rated operating voltage. This would require a change in gearing which, although not impossible, may be more work than it's worth.

<u>Drive Electronics</u>

Each motor is driven by a PWM output from the PICAXE 28X1 or 28X2. These chips have dedicated PWM pins that are controlled in software. The PWM output from a pin is fed into one channel of a 2-channel, single-direction driver chip that essentially operates as a relay. Each of these chips (4424YN) has 8 pins; two are for power and ground, two are signal inputs, two are high-current outputs controlled by those inputs, and two pins have no function. There are two of these driver chips onboard the PICOne: one for the motors and one that operates the IR LED "headlights" and the right-motor-reversing-relay.

Modification – Increasing Driving Speed

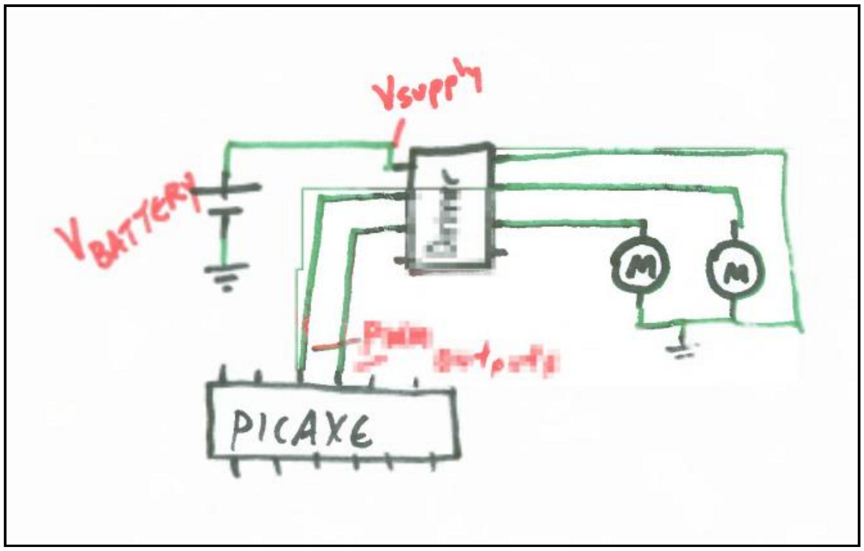
Out of the box, the driver chips are supplied with 5 VDC from the PICOne's voltage regulator. In order to drive the motors faster, however, a switch was installed that allowed the motor driver chip to be supplied either with regulated 5 V or $V_{battery}$, which is simply the un-regulated battery voltage. This switch has two positions labeled "1" and "2". Position 1 gives the driver chip 5 V and position 2 gives $V_{battery}$. Note that the other driver chip should not have its voltage supply modified as this would not be very useful.



Modified Motor Driving Circuit

Note that there is actually a large capacitor between the 5 V regulator output and chassis ground.

There is actually a way to drive the motors faster that still allows a choice between "fast" and "slow" but allows more torque when operating in "slow mode". If the circuit instead looked like so (the pins on the driver chip aren't necessarily correct):



Proposed Motor Driving Circuit (pins may not be correct)

then the switch could be used to control an input pin on the PICAXE control chip - say, low for "slow" and high for "fast". The PWM values in the software could then be scaled by a certain factor based on the state of that input pin. This method allows more torque output from the motors at slower speeds due to the fact that they receive high voltage during the "on" time of the PWM signal. This allows the inductance of the motor coils to be overcome more quickly.

Another option to increase the mouse's speed is to use larger wheels or "gear up" the transmission system. However, the control software strongly relies on the original gear ratio and wheel size. This approach is therefore more labor-intensive than increasing power to the motors or replacing the motors altogether. Also, the original wheels seem to have excellent traction on the painted maze surface; any larger wheel should try to preserve this friction coefficient as much as possible.

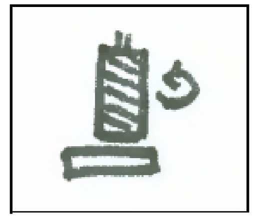
<u>Relay</u>

This motor-reversing relay (GS-SH-205D) simply serves to reverse the direction of the right motor when a certain pin is driven high in the software. The reversal of the right motor allows the robot to make zero-radius turnarounds when it gets into a dead end. The relay can be heard to click when the right motor reverses directions.

<u>Feedback</u>

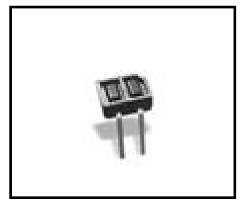
Bottom of Worm Gear

The motor control loop is closed using reflective encoders. The worm gears attached to the motors have black and white half-circles on the bottom. Attached to the circuit board are two sensors called photomicrosensors. These are the black, 4-pin sensors that "peek" up through the circuit board and face the bottom of the worm gears. These have two parts inside of them: one is an infrared LED and the other is a photo-sensitive bipolar junction transistor, the base current of which is controlled by the amount of light that enters the sensor's aperture. The PICAXE chip uses the collector current of this BJT (via a pulldown resistor network – see circuit diagram) to judge whether the sensor is looking at the white or black half-circle. Each transition from white to black indicates an entire revolution of the worm gear, which corresponds to a certain amount of wheel rotation and therefore distance travelled by the micromouse. When the robot is travelling straight ahead, each time the left encoder makes a black-to-white transition is when the infrared "headlights" (wall detectors) get pulsed on – so the IR headlights get pulsed faster as the mouse is driven faster. See the section on wall-sensing for more information.

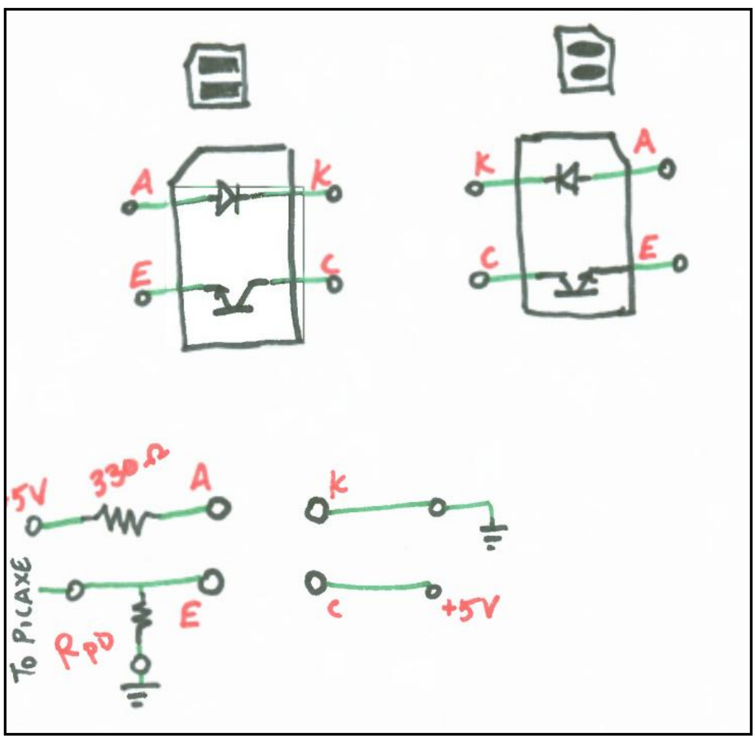


Worm Gear and Photomicrosensor (bottom)

The photomicronsensors are an important part of the PICOne. One issue that was encountered during the 2009-2010 school year was that R_{PD} (see circuit drawing below) was too small – the voltage at the PICAXE input was being pulled very strongly to ground. The original R_{PD} that comes with the PICOne kit is 10 kΩ. Generally, a better value to use is 15 kΩ, but a value as high as 50 kΩ may be necessary. The goal is to allow the voltage at the PICAXE input to swing from 0.5 V (sensor sees black surface) to around 4.5V (sensor sees white). R_{PD} varies partly due to non-matched photo-sensitive BJTs.



Reflective Photomicronsensor



Photomicrosensor Circuits. **The top-left shows the new sensor that was purchased from Mouser.com (right-angle pins). The top-right shows the sensor that comes in the PICOne kit (straight pins). The bottom shows the circuit that drives the photomicrosensors. A = anode, K = cathode, E = emitter, C = collector. Extra sensors were purchased in case of damage.**

Processor

The original PICOne kit uses two PICAXE processors, a PICAXE 18X and a PICAXE 28X1. In general, a PICAXE processor is simply a PIC microcontroller that is programmed with low-level bootstrap code. This bootstrap program allows the chip to be programmed in BASIC (instead of assembly) while preserving the low-level bootstrap code. This solution sacrifices a small amount of extra cost and lost efficiency in return for ease of use. If one were to use a standard PIC programmer to load assembly code onto a PICAXE, the bootstrap program would be erased and the chip would revert to a standard PIC. Since PIC microcontrollers are cheaper than PICAXes, this is not recommended.

On the original kit, the PICAXE 28X1 runs a physical control and wall-sensing program while the 18X runs a maze-solving program. The chips communicate via RS-232 and both are usually run at 8 MHz, which is the maximum speed allowed with the chips' internal resonators.

<u>Modification – New Processor</u>

In 2010, both chips were replaced with a single PICAXE 28X2. This chip is an improvement of the 28X1 with higher clock speed capability, expanded memory (data, program, and RAM), and more programmable I/O pins. An external resonator was installed that allows the PICAXE 28X2 to run at 40 MHz. The resonator itself outputs 10 MHz, which is then multiplied via phase-locked loop (internal to the PICAXE) to 40 MHz. Both programs were combined into one (see software section) and loaded onto the 28X2 chip. This increased clock speed drastically shortens the time it takes the robot to stop and compute a new direction to move. Note that serial communication between chips does not have much of an effect on processing speed since only one byte is exchanged each time the mouse stops to calculate a new route.

The PICAXE 28X1 and 28X2 are pin compatible, but the "A" button and the two visible-light LEDs controlled by the 18X had to be re-wired in order to be controlled by the 28X2 chip. This is the reason for the thin white wires gracing the bottom of the main PICOne robot. The wires were simply taken from the original pins on the 18X socket to the new I/O pins on the 28X2 socket. A diagram of these new pin assignments is in one of the appendices.

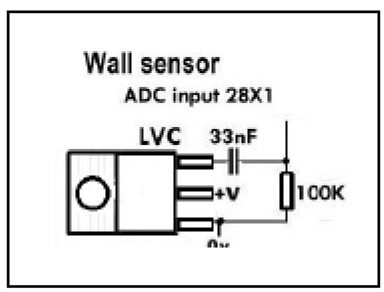
Sensors

Almost any sensor attached to the PICOne will have one of two purposes – wall sensing or odometry.

<u>Infrared Headlights</u>

There is one LED and phototransistor pair for each direction: right, left, and forward. There are two different situations in which these sensors are used.

The first situation is when the robot first enters a cell. The control program turns all three LEDs on (they are all driven using a single pin on the PICAXE 28X1 / 28X2 via a driver chip) and immediately reads the output of the phototransistors using the given circuit. The amount of light received by the sensor is a



IR Sensor Circuit (from manual)

function of distance from a wall. The 33 nF capacitor is present so that only the sensor's output due to the sudden pulse of light is read into the PICAXE – so, in effect, the capacitor helps reject any output from ambient light. The output voltage from each direction is stored in a separate register in software. In this case, the program decides whether a wall is present in each direction. This information is sent either to the PICAXE 18X or to a separate part of the program in the case of the 28X2.

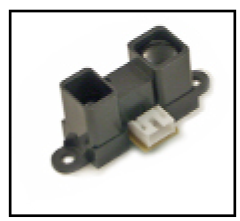
The second situation is when the mouse is travelling along a wall or between two walls. The "turn on headlights, read ADC values, turn off headlights" operation is done continuously (every time the left encoder makes a black-to-white transition, which is very frequent) in this case. The measured mouse-to-wall distances are simply used to keep the robot travelling straight.

There was an issue in April 2010 where the left-facing IR LED broke from the circuit board and had to be replaced. The team found that mismatched left and right LEDs have different light outputs and therefore cause the mouse to "lean" toward one side when moving forward. Although this can be compensated for in software, it may be easier to just make sure that the left and right LEDs are matched.

Another issue came in May 2010 when the main PICOne robot (there exists a backup) was dropped onto a tile floor. One of the side-facing phototransistors was bent and one of its leads broken; rather than desolder it from the board, however, the team bent it back into place, made sure that it worked, and applied a small dab of superglue to ensure that proper electrical contact was kept. Besides those on the spare PICOne robot, no spare phototransistors are on-hand at the moment. That phototransistor currently works properly.

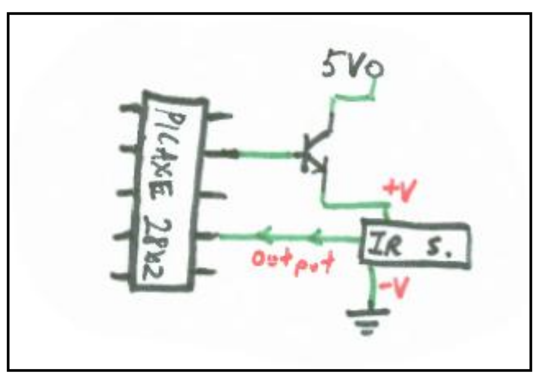
Long-Range Sensor

In the winter of 2010, a trade study was done and a long-range sensor selected that could detect the presence of – as well as measure the distance to – a wall forward of the robot up to 1 m away. The team ordered two of these sensors (GP2Y0A02YK made by Sharp). These estimate the distance to an object and output it as an analog voltage between approximately 0.6 and 2.7 V. The part contains an infrared LED that emits light in the forward direction. A lens then directs any returning light onto a linear CCD array (like a 1-dimensional camera) which detects the dominant angle of the incoming light. The distance to whatever object the light bounced from can then be computed using triangulation.



Sharp IR Sensor

The sensor draws around 30 mA, which is more than a single pin on a PICAXE is rated to handle. Since all 4 current-driver channels are already used on the PICOne, this sensor would need to be powered using a power transistor. The PICAXE would drive a certain output pin high; this would cause a collector current to flow in the transistor, powering the sensor. A biasing resistor network may have to be used (and maybe a



Basic Circuit for Using Sharp IR Sensor

pulldown resistor in the output), but the included circuit drawing presents a basic concept of how the device could be powered.

The output voltage of the sensor does not relate linearly to the distance from an object. One of the appendices should include results from a test done on these sensors; the test showed that sensitivity to changes in distance decreases as the object gets further away. The tests also showed that the sensors are not reliable inside ~6 cm. Also, consider that an 8-bit ADC with a range of 0 to 5 V only has a resolution of around 20 mV.

Odometry

The operation of the PICOne's standard encoders is described in another section. Another possibility exists for odometry, however, that is potentially more robust than the current one: a sensor from (or meant for) an optical mouse. These sensors work by continuously taking small photos of the surface under them and comparing the photo to the previous frame using digital signal processing. The device then outputs the distance travelled in the x and y directions since the last frame; it does this many times each second.

Whereas the current method of odometry is fooled when the wheels slip on the maze surface or when the mouse hits a wall (a common cause for a bad run), an optical mouse sensor is not affected by these error sources.

Although no such sensor was purchased during the 2009-2010 school year, Mouser Electronics was found to have several different viable models at modest prices.

Software

Maze-Solving Algorithm

During 2009-10 senior design, we did not spend much time trying to understand the PICOne's maze-solving algorithm more than was necessary to port the code from the PICAXE 18X to the 28X2. It works exactly like it's supposed to. Every issue that we observed was caused by poor control; the mouse would stray too far to the left or right, take a wall-configuration reading, miss one wall because it was too far away, and then the mouse would get confused when it had a different maze stored in memory than that in real life. It would sometimes crash into a wall, keep running the motors like nothing happened, and be unaware of its actual position in the maze.

Besides combining two programs and porting them to the PICAXE 28X2, not much work was done on the PICOne's software.

Control Program

The control program is centered around a set of pre-programmed values near the beginning of the code. These generally need to be modified in order to get the PICOne fine-tuned. Some notable clues to the operation of the control program are:

- While moving straight, reads the headlight sensors every time a black-to-white transition is detected on the left encoder. These readings are only used to straighten itself on the walls.
- Uses either the sudden absence of a wall on either side (if available) or a number of encoder counts to tell it's in a new cell. It does a sensor reading right here at the beginning of the cell. It sends this reading to the 18X (maze-solving) program (or subroutine) and that subroutine sends back a direction to travel in.
- Re-calibrates its position if it sees a wall head-on.
- When turning, only runs one motor and simply uses a set number of encoder counts that this turn should last. This number can be changed at the beginning of the code to calibrate the robot; ideally, the turn should be exactly 90 degrees.
- Does the same thing for a complete turnaround, which should be 180 degrees.

Modification – Combining the 28X1 and 18X Code

The newest software, which should be linked to at the end of this document, has a 28X2 conversion wizard. This will make all of the 28X1 code and most of the 18X code usable on a 28X2 chip.

Most of the work in the conversion was getting rid of the serial communication and making sure the program flowed exactly the same as it did with 2 different chips in place. This involved the deletion of some loops, especially the one that the 18X runs while it waits for communication from the 28X1.

The 28X2 is being run at a much faster clock speed than the previous 2 processors. This clock speed is slowed just before a sensor reading takes place; this should allow the ADCs on the PICAXE to settle somewhat before the values in the ADC registers are used.

Other Features

Both the original PICOne robot and the modified (28X2) version are capable of outputting their current maze configuration data to a computer running the appropriate software. The instructions for this are the same whether using the 28X2 robot or the 28X1/18X robot and are described in the PICAXE Micromouse manual on the CD.

In software, the 28X2 robot slows down its clock speed from 40 MHz while the serial upload to the PC is taking place; this is to make sure that the correct baud rate is used. This slowdown also takes place just before reading the ADC values associated with wall sensing – this is to help the analog voltage on the ADC pin settle before actually reading the ADC register.

Links

General micromouse info web site
http://www.micromouseonline.com/book/micromouse-book/sensors/odometry

Good parts supplier
www.mouser.com

Another good parts supplier
www.acroname.com

Yet another excellent supplier of electronics
www.sparkfun.com

PICOne motor (similar model) data sheet
http://www.mabuchi-motor.co.jp/cgi-bin/catalog/e_catalog.cgi?CAT_ID=rf_300fa

AIRAT II Review
http://www.micromouseonline.com/files/AIRAT%202%20review.doc

Video about calibration of PICOne
http://www.youtube.com/watch?v=TqTgMHo38xc&feature=related

2009-2010 FDR presentation
http://www.angelfire.com/oh4/thevault/Micromouse_FDR_Final.pdf

Long-Range Sensor Trade Study
http://www.angelfire.com/oh4/thevault/Sensor_Trade_Study.pdf

More documentation for our PICOne robot
http://www.angelfire.com/oh4/thevault/PICOne_Documentation.pdf

Spring 2010 quarterly report for senior design
http://www.angelfire.com/oh4/thevault/Spring_Report.pdf

Find the latest version of the PICAXE programming software here (note – must still use one of the programs on the PICOne CD to upload maze data from the robot)
http://www.rev-ed.co.uk/picaxe/software.htm

Bill's Project Notebook (Also contains data for long-range IR sensors)
http://www.angelfire.com/oh4/thevault/WD_Micromouse_Project_Notebook.pdf

Pinout diagrams related to 28X1 + 18X2 => 28X2 processor switch
http://www.angelfire.com/oh4/thevault/Pinout_Switch.pdf