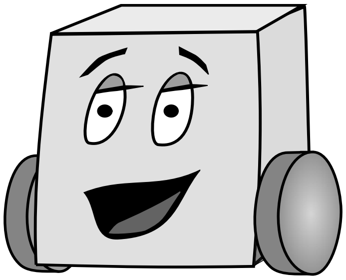


E11: Autonomous Vehicles

Fall 2010

Harris & Lape with Keeter & Ong

Lab 1: Mudduino Assembly

Introduction

Arduino is a popular open-source system built around an Atmega328 microcontroller with analog and digital inputs and output ports to interface with the real world and a USB port to interface with a PC or Mac. The Mudduino is a custom version of the Arduino system developed at HMC for E11. It includes LEDs, a speaker, an H-bridge (for motor control), and an area for prototyping add-on circuitry.

In this lab you will assemble and test your Mudduino board. You will be using this board for the remainder of the semester, so it is important to assemble it properly. But don't worry! If you damage parts on your board, you may ask your instructor for spare parts.

Soldering Background

Soldering is a process in which two metal items are fused together by melting an alloy between them. For this lab, you will be soldering together the pins of the electrical components in your kit to the electrical contacts on the board. There are two types of components on the Mudduino: through-hole and surface-mount. The surface-mount parts (the serial-to-USB chip and fuse) only attach to one side of the board. These have already been soldered on to the Mudduino for you because they are difficult to solder without creating solder bridges (unwanted links between pins). You are responsible for soldering on the through-hole components.

Before beginning the board assembly, make sure to familiarize yourself with the components in the component dictionary. It might be helpful to also skim through the lab to get an idea of the steps involved. If you have any questions, feel free to ask for help. You may also find that borrowing an additional hand or two to hold components may save you some trouble. We also included a parts glossary at the beginning to help you get acquainted with the various components in your kit.

Component Dictionary

This dictionary will help you identify the components that you will be using.

Resistors

Resistors are identified with four color bands. The first three indicate the value, in ohms (Ω). The fourth indicates the tolerance; it is typically gold, indicating +/- 5%.

The values are determined using the following color codes:

0	Black
1	Brown
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet
8	Grey
9	White

This can be remembered using the mneumonic "**B**ad **b**eer **r**ots **o**ur **y**oung **g**uts **b**ut **v**odka **g**oes **w**ell".

The first two bands are read as a two digit number, and the third is a power of ten multiplying the number. For example, red – black – brown – gold indicates 201, meaning $20 \times 10^1 = 200\ \Omega$, with a 5% tolerance. Brown – black – orange – gold indicates 103, meaning $10 \times 10^3 = 10{,}000\ \Omega$ (written 10 k Ω).

10kΩ

Capacitors

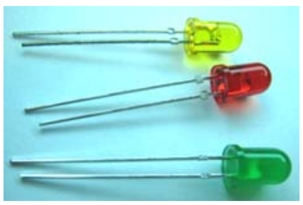
Capacitors are notoriously difficult to read. Usually large-valued electrolytic capacitors have their value written on the side. For example, a 10-microfarad (10^{-3} F) capacitor is labeled 10 μF. Small capacitors are sometimes labeled with a 3-digit code indicating their value in picofarads (10^{-12} F) in a fashion similar to resistors. For example, 104 means 10×10^4 pF = 10^{-7} F = 0.1 μF. A 2-digit code just indicates the value in picofarads. For example, 22 means 22 pF.

Ceramic – 22pF Ceramic – 0.1uF Electrolytic – 10uF

LEDs

Light-emitting diodes have two terminals. They long terminal is the positive side, called the *anode*. The short terminal, usually marked with a flat edge on the lens, is the negative side, called the *cathode*.



Clock/Oscillator

16 MHz

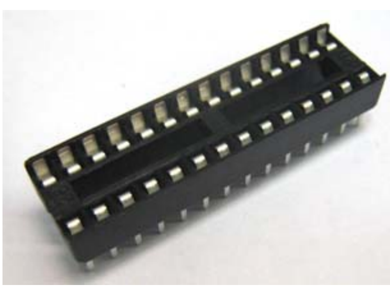
Push Button

Speaker

Voltage Regulator

Jumper

IC Sockets



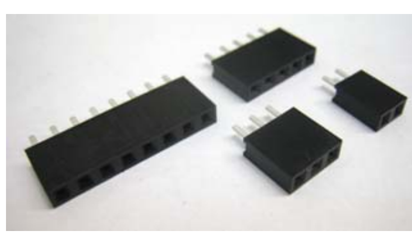
28 pos DIP socket

16 pos DIP socket

USB Jack

Male Header Pins

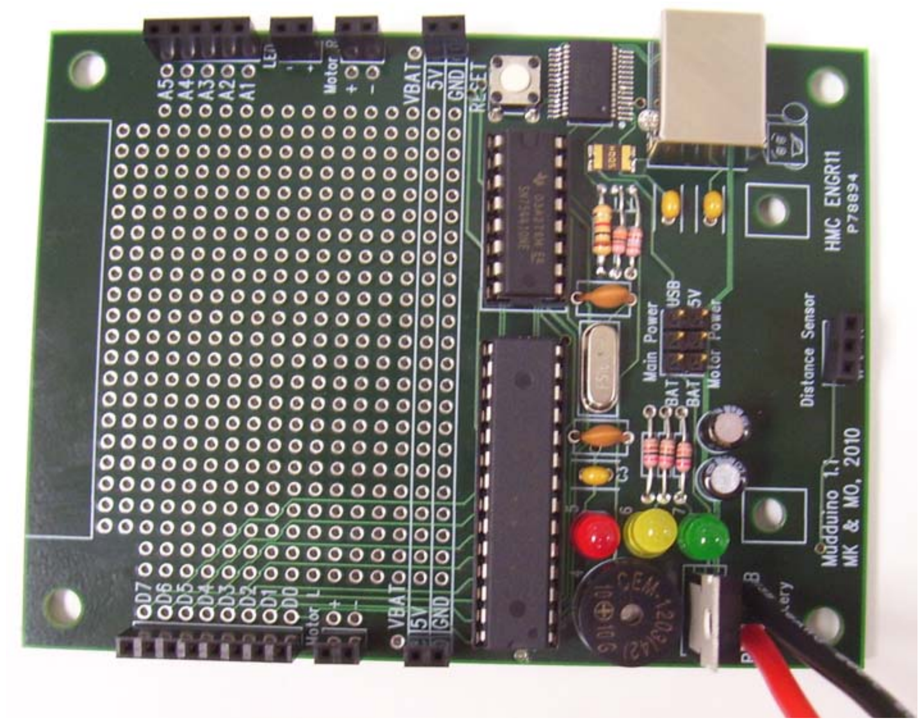
Female Header Pins



Right-Angle Header Pins

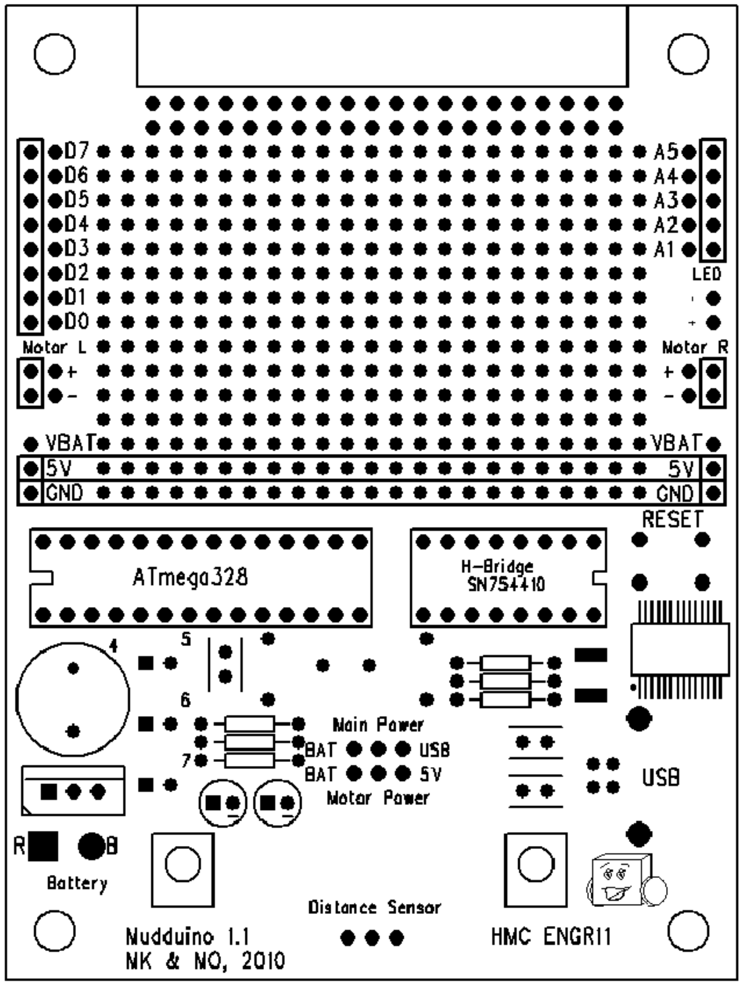
Assembling the board

This section guides you through soldering your Mudduino board. The steps work from the thinnest components upward to make assembly easier. When you are all done, your board should look like the one below.



Identify the component side of your board

Your Mudduino board has two sides: the component side and the solder side. Through-hole components are placed on the component side with their legs extending through the holes to be soldered on the solder side. If you do not place all of your components on the component side, you will make your future self very unhappy. All the soldering should be done on the solder side of the board. The component side is the one with the text and component shape outlines. The solder side has additional traces but no component outlines.



Component side

Make your board unique!

In order to keep your board from getting mixed up with other students' boards, write your name on the solder side. Sharpie will be the best for this.

How to Solder

Before you begin soldering, moisten the sponge. When the iron first heats up, tin the tip by applying a generous amount of solder all over the tip, then wiping off the excess on the sponge. Periodically re-tin the soldering iron as you work to keep the tip looking silvery rather than black and blistered. This preserves the life of the tip and allows for better heat conduction during soldering.

Place each component in the board. Bend the legs so that the component stays in place without having to be held; they should make a good mechanical connection even without the solder. The solder serves to make a good electrical connection, but should not be necessary to hold the component. Some parts have polarity, meaning that they only work in one direction. Be sure to put them in the right direction or you'll have to chop them out and redo them later.

When you make a solder joint, touch the tip of the iron to the pad on the board at the same time it touches the lead of the component. Apply the solder to the junction of the lead and board that has been heated by the iron. The solder should smoothly adhere to the pad and the component pin rather than balling up on the component or the iron. The connection should appear shiny; a gray color indicates a possible unreliable "cold solder" joint.

When you have completed a set of joints, chop the leads off on the solder side with diagonal cutters. Hold the lead as you cut it so that the lead doesn't go flying into your labmate's eye.

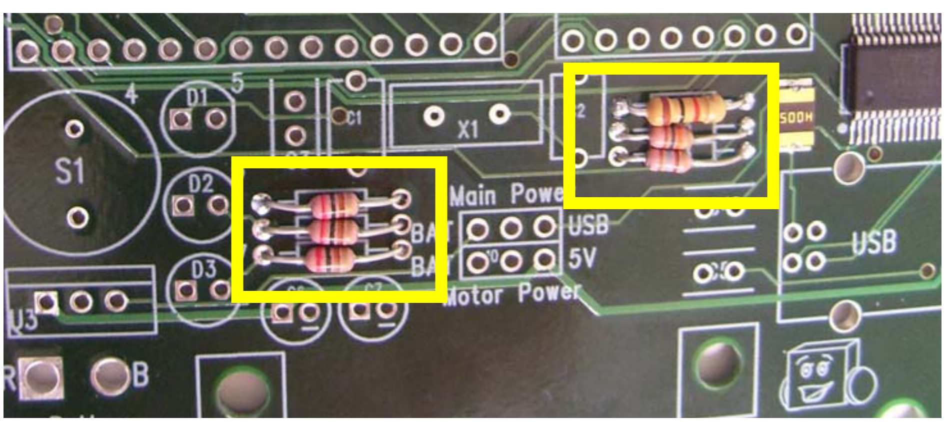
If you are in doubt about the quality of your solder joints, ask early on rather than doing all of them first and discovering that your connections are intermittent or unreliable. Some of the components will be soldered close to vias (the small holes through the board used to connect between wiring layers on the printed circuit board). Be sure excess solder does not bridge to the via, creating a short circuit. When you are done, tin the iron one last time to protect the tip before turning it off.

Place resistors

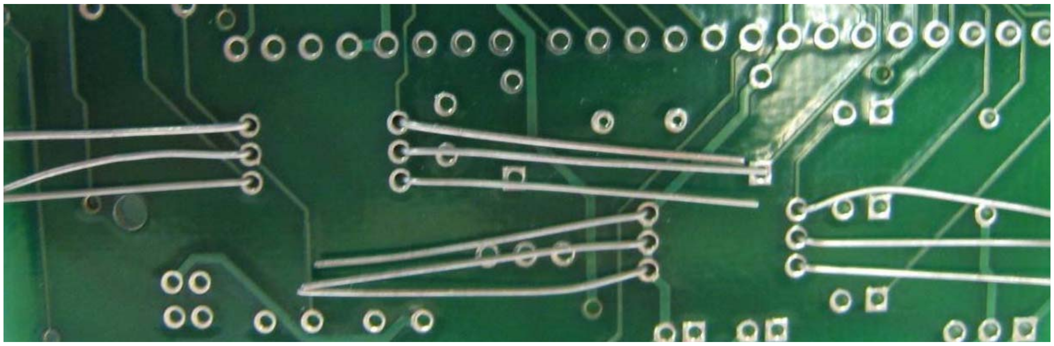
There are six resistors to place on the circuit board that limit current on the LEDs and set defaults on switches. Resistors to not have polarity; i.e. they can be inserted in either direction.

R1 is a 1 kΩ resistor (Brown Black Red)
R2 is a 10 kΩ resistor (Brown Black Orange)
R3 is 160 Ω resistor (Brown Blue Brown)
R4, R5, and R6 are 200 Ω resistors (Red Black Brown)

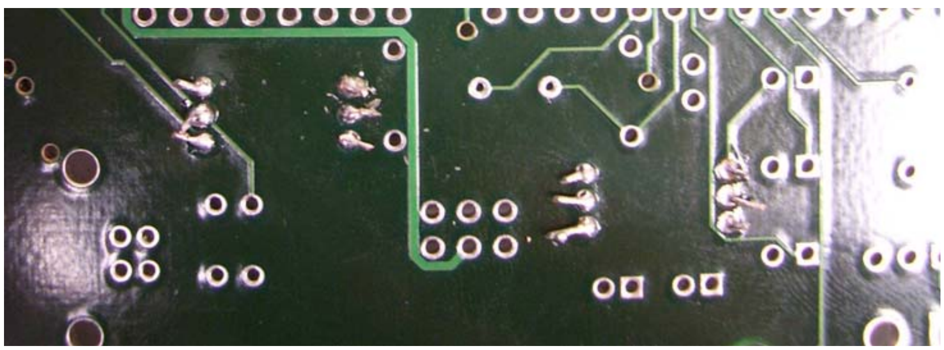
Bend the leads and insert in the diagram positions as shown below. Be sure to pull the leads all the way through the board to the resistor lies flat against the board. Turn the board over and bend the leads outward to hold each resistor in place then solder.



(note that your R1 will be smaller than the one shown in this image)



Clip the leads off when you are finished. Cut as much off as possible, as the board will need to lie flat in later labs. When you are done, the board should look like



Place right-angle female headers

There are a long set of female headers that sit at a right angle to the leads. These are one of the shortest components. These headers will serve to be the connection point for the off-board sensors: IR reflectance sensor and phototransistor. You want the black plastic to be on the component side of the board. Turn the board upside down so you can access the leads on the solder side of the board. The weight of the board should help keep the pins in place while you are soldering.

Place ceramic capacitors

The next step is to insert the five small ceramic capacitors and the clock oscillator. These, like the resistors, are not polarized and can be inserted in either direction. Solder these on in the same way the resistors were. Two of the 0.1 μF capacitors are bypass capacitors that stabilize the power supply on the board, and the third is used in the reset circuit. The 22 pF capacitors are used to store energy in conjunction with the clock crystal.

C1 and C2 are the larger brownish 22 pF capacitors.
C3, C4, and C5 are the small yellow ceramic 0.1 μF capacitors.

Place the clock crystal

X1 is the 16 MHz quartz crystal. It has no polarity.

Place the reset button

The reset button restarts the microcontroller when pushed. It will take a little extra pressure when pushing the leads through the circuit board. It has no polarity

Place IC Sockets

Integrated circuits (ICs, better known as chips) are sensitive to heat and other damage. It is prudent to place them in sockets so that you do not overheat them during soldering and can easily remove them in case of damage.

There are two sockets; one has 28 pins, the other has 16 pins. Make sure to match the socket's notch with the footprint's notch on the board. Bend the legs in the opposite corners of the sockets to hold them in place before you solder.

Place electrolytic capacitors

The voltage regulator supplies current sufficient to meet the average demand of circuits on the board. However, whenever there are spikes of current at high frequency, the voltage briefly droops in order to keep up with the current demand, just as the lights in Metropolis dim as the evil genius closes the switch on his giant antimatter ray gun. Electrolytic capacitors store charge and provide current to keep the voltage at the desired level during the spikes. They are called bypass capacitors because they provide another path for the current to flow.

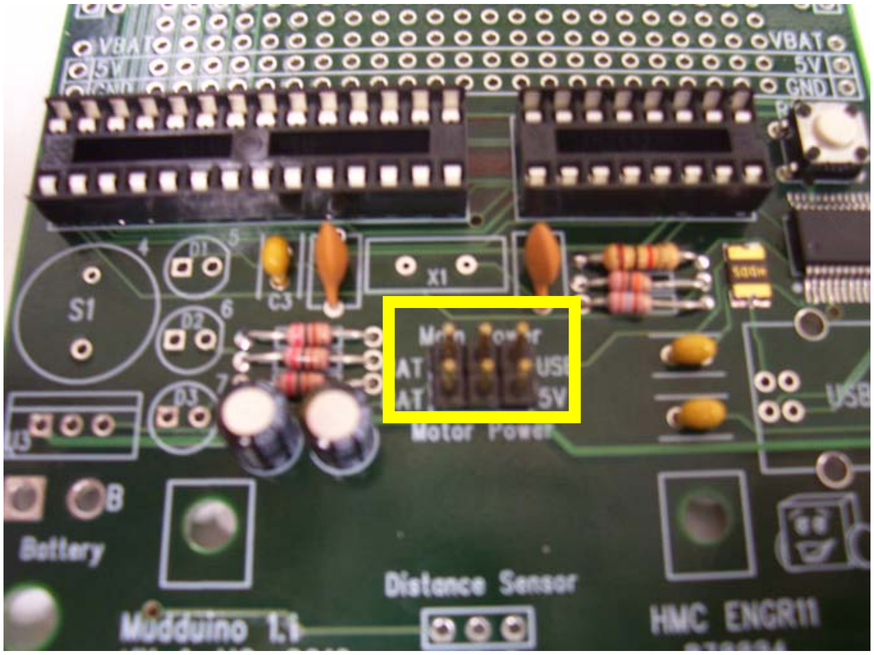
Electrolytic capacitors, unlike the ceramic ones, are polarized. This means it **matters** what direction they are put in. There are two ways to determine the polarity. If the leads on your capacitors are uncut, the longer of the two leads is the positive (+) terminal and goes in the hole with square copper plating. The other way is to look at the capacitor and find the stripe going down one side. This points to the negative (-) lead. This lead then goes in the hole with circular copper plating. If you install an electrolytic with the incorrect polarity, it could leak or explode.

C6 and C7 are both 10 μF caps.

Place male header pins

The male header pins are used in conjunction with jumpers to select whether you power the board off an RC car battery (BAT) or the USB cable (USB). They also determine whether the motor receives its power from the battery (5V) or 5V regulator (BAT) – the silkscreen is printed incorrectly. The pins are gold-plated to provide a better contact.

You will have to cut two two sets of three header pins from the long strip of headers using your diagonal cutters. The long side will be pointing up from the component side of the board, with the **short pins going through the hole**. The longer gold-plated pins and the black plastic strip should stay on the component side.



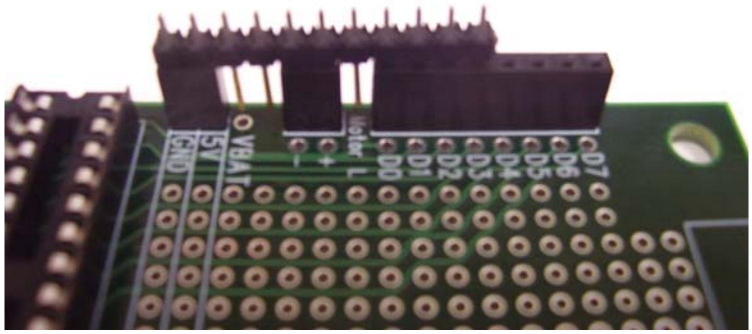
Remember: the labels for Motor Power are reversed. BAT and 5V are switched. The labels for Main Power are correct.

Place female header pins

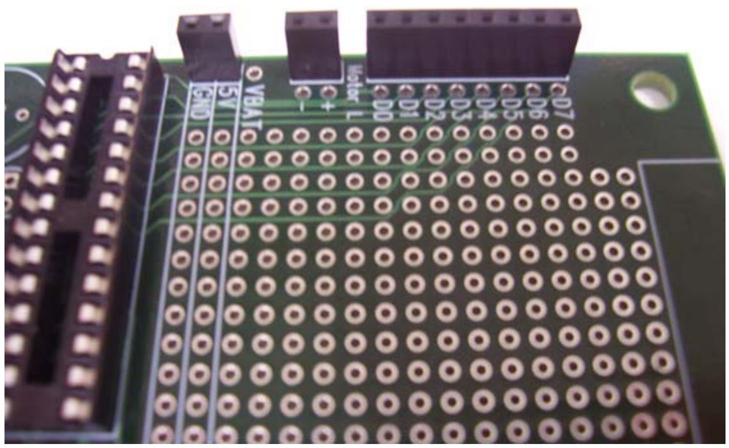
The female header pins provide convenient receptacles for the Mudduino input / output (I/O) ports. You should have five 2-pin, one 3-pin, one 5-pin and one 8- pin female header. They will be spread out along the edge of the board for ease of access.

You'll notice that two edges of the board will have a series of female header pin in a row. One way of attaching the header pins is by soldering each jack individually. However, the header pins will probably not be oriented straight. So, you can save time (and prevent future frustration) by cleverly using the male header pins to keep the pins straight.

The left side of the board has a 2-pin header for 5V and GND, a 2-pin header for the left motor, and an 8-pin header for the digital I/Os. Place the female header pins on the component side of the board. Then use a row of male header pins to temporarily lock the female headers in place.



Solder on the pins, making sure to keep the black plastic of the female headers flush with the board. After all the pins have been soldered, remove the male header pins. Your female headers should be beautifully straight on the board's edge.



The right side of the board has a 2-pin header for 5V and GND, a 2-pin header for the right motor, a 2-pin header for the robot identification LED, and a 5-pin header for the analog I/Os. Assemble these headers in the same way.

Finally, place the 3-pin distance sensor header at the bottom of component side.

Place LEDs

The LEDs, like the electrolytic capacitors, are polarized. The positive terminal has a longer lead. The lens of the LED has a flat edge next to the negative terminal. Insert the LEDs in the board with the positive terminal in the square hole. Bend the legs and solder.

D1 is red. D2 is yellow. D3 is green.

Place buzzer

The buzzer, S1, will be useful for debugging and for amusing yourself by playing random tunes. You'll notice the speaker has polarization markings on the bottom. However, because the speakers are not of the best quality, the direction you put it in won't affect the sound. If you really care, the negative terminal points to ground (lower half of the board).

S1 is the speaker.

Place USB Jack

The USB Jack has two mechanical mounting holes in addition to the four terminal holes. We'll be soldering the mounting holes, even though they are not electrically connected to anything, to increase the stability of the component. The part should snap into place with the mounting pins. Although the mounting pin holes do not have a large pad to solder to, the inside of the large hole is plated, giving the solder plenty of area to adhere to.

Place Voltage Regulator

The voltage regulator, U3, is the tallest component so we saved it for last. It drops the 7.2 V battery voltage down to a steady 5 V, which is the ideal operating voltage for the microprocessor and sensors. The component outline matches the eagle eye view of the part. This means the tall metal portion lines up with the skinny rectangle of the component's footprint. The regulator has polarity, so it must be oriented correctly. **Note:** the regulator will not sit flat against the board because of the flanges on the leads.

Place Battery Jack

Add the battery jack. Cut the red and black wires down to 2 or 3 inches. Strip a quarter inch of insulation off the end of each wire. Twist the strands so that they don't fray. Insert the red and black wires into the holes labeled R and B, respectively. Solder the reverse side.

Insert the ICs

Place the SN754410 H-Bridge motor driver in the smaller socket. The notch on the chip should be aligned with the notch at the right end of the socket. You may need to carefully bend the legs of the chip to fit it in the socket. One way is to press the legs against a flat surface such as a lab bench so that the legs all bend uniformly. Take care because the legs will break if you bend them more than about twice.

Then place the ATMEGA328 microcontroller in the larger socket. Note that the notch is on the left side for this chip.

Insert the Power Jumpers

Place a jumper between the center and right (USB) header pins on the Main Power row. This supplies power from the USB port.

The Mudduino has a label error on the motor power row: the BAT and 5V labels are reversed. Place another jumper between the center and left (BAT) header pins. This actually powers the motor off the 5V supply for testing purposes. Later, you'll move this jumper to the other side to power the motors from the more powerful battery.

Woohoo! Your board is assembled!

Celebrate by sounding your barbaric YAWP!

Testing

Once you're finished with the soldering, bring your Mudduino to the lab instructor. The instructor will visually inspect the board and check for shorts using a multimeter. Next, they will plug the board into a computer. If nothing starts smoking after a few seconds, the instructor will download a test program.

The instructor has two shields, which will plug into the left and right hand side of the board. These shields will allow us to quickly test continuity on the board.

Once the board is programmed with lab1_tester code, the instructor will attach the testing shields to your board and open a serial monitor on the computer. At this point, three LEDs should light up: the lower red LEDs on both shields, and the yellow team LED on the right shield. Press the reset button. If the board is working correctly, the following should take place:

- The board will print "Hello, world!" on the serial port.
- The speaker will play five tones.
- The eight digital pins on the left shield will flash in order.
- The lower two green LEDs on the left shield will flash on, off, on, off (together).
- The serial link will print whether the analog pins are working.
- The serial link will print whether the distance sensor plug is working.
- The lower two green LEDs on the right shield will flash on, off, on, off (together).

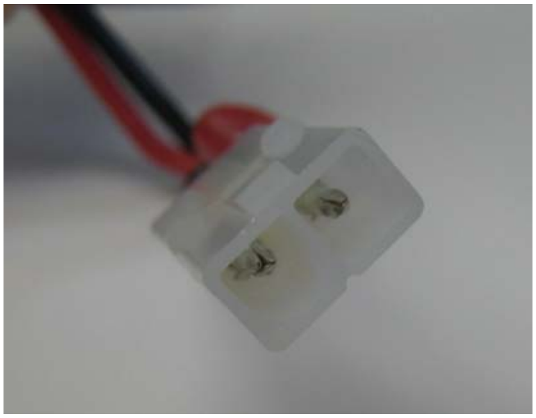
If all of these events take place, congratulations! Your board is complete! If not, the lab instructor will give you pointers on debugging your system.

Preparing the distance sensor

The distance sensor is meant to be plugged into header pins at the rear of the board. Look in your kit for a distance sensor and a white/black/red wire that plugs into the bottom of the sensor. Plug in this connector to the sensor. Strip a small amount from each of the three wires. Break off three pins from your male header strip. Wrap each of the three wires around the top (short) end of a male header pin and solder it in place. The middle pin is most difficult. Make sure that the wires do not touch and create a short circuit.

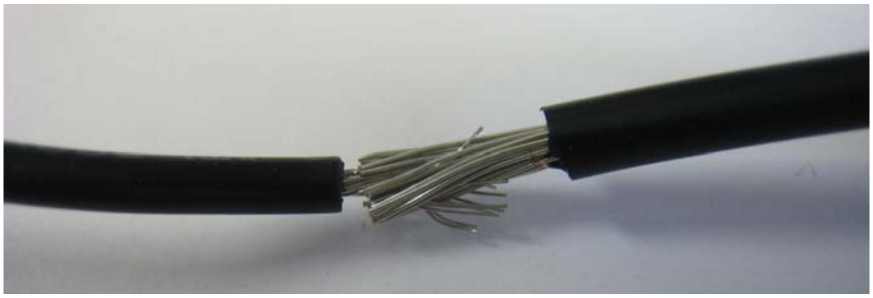
Preparing the battery

The robot is powered by a 7.2V RC car battery. Before it can be used, you need to solder a male Tamiya connector to the battery wires. The male connector has metal prongs inside plastic sheathes:



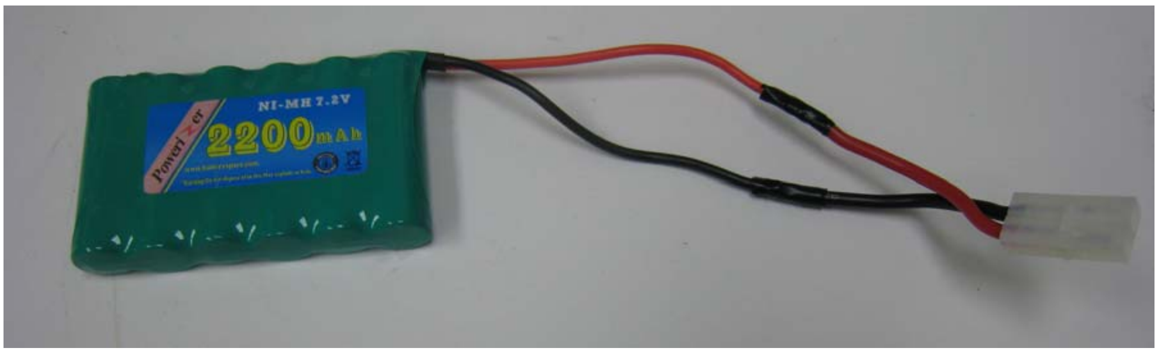
WARNING: The battery is designed for high current output. If you accidently create a direct path between power and ground, the battery will start smoking in about four seconds. There is also the possibility of sparking between power and ground, which can cause small burns. If you take care to keep power and ground separated, you won't have any problems.

Now that we've gotten the scary warnings out of the way, here's how to attach the connector. Cut the wires so that about 4" emerge from the battery, and 2.5" emerge from the connector. Strip about 1/3" off of the black wires. Intertwine the wires, like so. Make sure you have a good mechanical connection before you solder.



Heat the junction, and apply copious amounts of solder. Make sure that the solder is actually soaking into the connection, rather than just wetting the surface (if this isn't happening, keep heating the wires   You should also flip over the wires and solder the other side. You want to make a very strong electrical and mechanical connection.

Once you're satisfied, clean up any stray wires with the cutters and wrap electrical tape around the junction. Then, do the same thing with the red wires. You should end up with the following:



Write your initials on your battery pack.

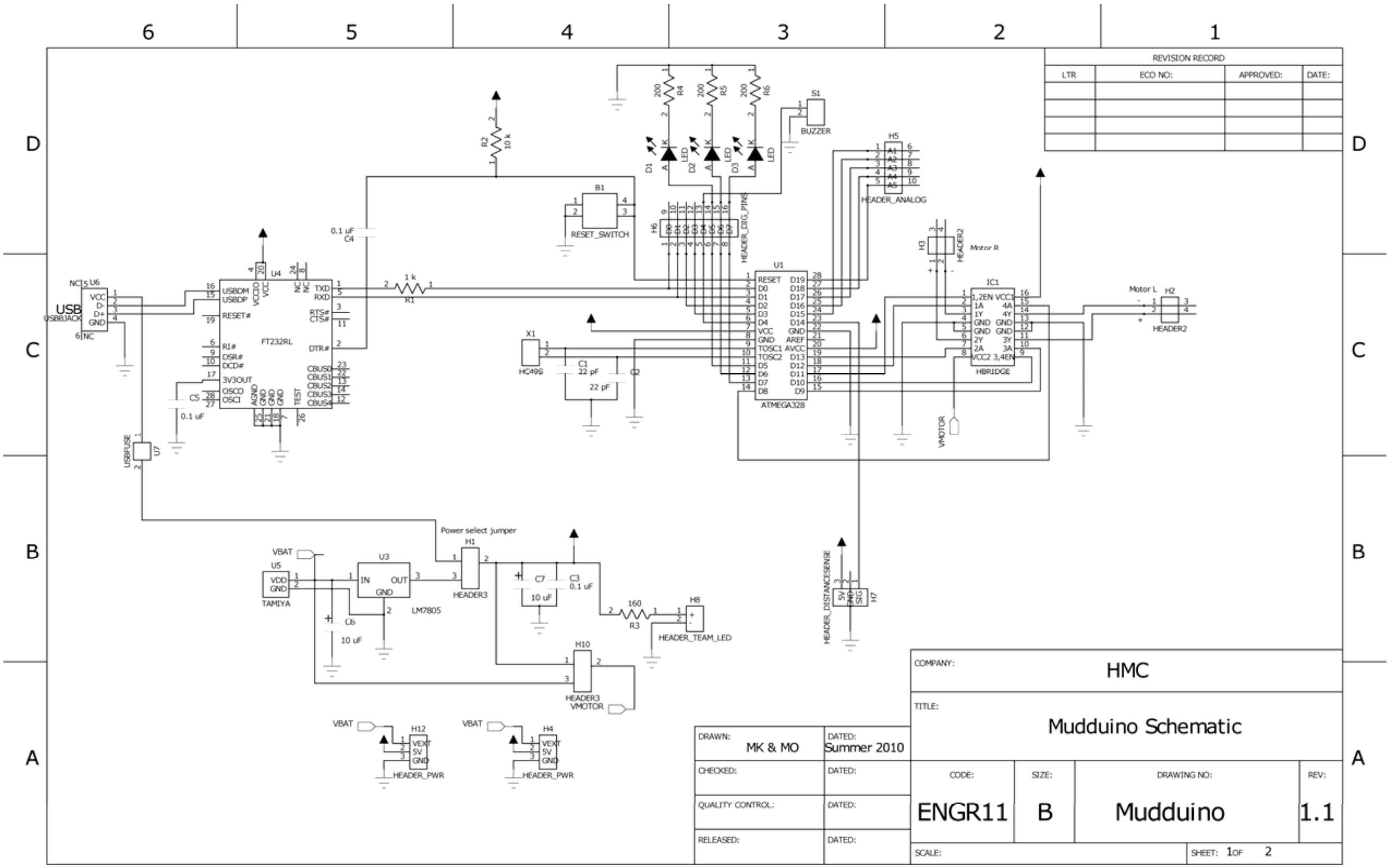
Plug your battery pack into the charger and the charger into the wall. You should see a red light on the charger indicating that the battery pack is charging. It is a good idea to recharge your battery before each of the future labs so that it remains at full strength.

Clean Up

Clean up your lab station. Discard the refuse you accumulated while soldering. Tin the iron and turn it off. Please clear the benches and keep the lab clean because we share the room with other classes.

Board Schematic

A schematic of your Mudduino board is shown below for future reference. The schematic shows how all of the components are connected together.



Arduino Pinout

As you work with your Arduino, you'll find the following table of pins helpful:

Digital Pin #	Analog Pin #	Notes
0		Header D0, Serial TX
1		Header D1, Serial RX
2		Header D2
3		Header D3
4		Header D4, Buzzer
5		Header D5, Red LED
6		Header D6, Yellow LED
7		Header D7, Green LED
8		Left Motor Black
9		Left Motor Red
10		Left Motor Enable
11		Right Motor Enable
12		Right Motor Black
13		Right Motor Red
14	0	Distance Sensor
15	1	Header A1
16	2	Header A2
17	3	Header A3
18	4	Header A4, Phototransistor
19	5	Header A5, Reflectance Sensor

Notes:

- Operating voltage: 5 V
- Maximum output current: 40 mA
    - A short circuit exceeding this current may destroy the output pin
- Pins 2 and 3 support external interrupts using `attachInterrupt()`
- Pins 3, 5, 6, 9, 10, and 11 may be operated as pulse width modulated analog outputs using `analogWrite()`
- Pins 14-19 may be operated as analog inputs or digital I/Os
- `pinMode()` refers to the digital pin number
- `digitalRead()` and `digitalWrite`() refer to the digital pin number
- `analogWrite()` refers to the digital pin number (!)
- `analogRead()` refers to the analog pin number