E11: Autonomous Vehicles

Fall 2011

Harris & Harris

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 soldering: through-hole and surface-mount. Surface-mount parts only attach to one side of printed circuit board; but, in our case, we'll only be working with through-hole components. You'll be 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.

Mudduino Overview

The schematic and layout for the Mudduino board are shown on the following pages.

Take some time to learn to read the schematic and familiarize yourself with the contents of the board.

As you work with your Mudduino in later labs, you'll find the following table of pins helpful.

| Digital Pin #	Analog Pin #	Notes
0		Serial TXD – don't use
1		Serial RXI – don't use
2		Header D2
3		Team (0 = green / 1 = white) read only
4		Header D4, Buzzer
5		Header D5 / green LED / programming indicator
6		Left Motor Enable
7		Right Motor +
8		Left Motor -
9		Left Motor +
10		Header D10 / Servo (use servo.write)
11		Right Motor Enable
12		Right Motor -
13		Header D13 / red LED
14	0	Distance Sensor
15	1	Header A1
16	2	Header A2
17	3	Header A3
18	4	Header A4, Reflectance Sensor
19	5	Header A5, Phototransistor

Notes:
- Atmega operating voltage: 5 V
- Maximum output current: 40 mA
    - A short circuit exceeding this current may destroy the Atmega output pin
- Digital pins 2 and 3 support external interrupts using `attachInterrupt()`
- Digital pins 3, 5, 6, 9, 10, and 11 may be operated as pulse-width modulated analog outputs using `analogWrite()`. Pins 6 and 11 are already devoted to adjustable motor power in this fashion.
- Pin 10 servo: `servo.attach(10)` then `servo.write(angle)`; $0 \leq angle \leq 180$
- Digital pins 14-19 / analog pins 0-5 may be operated as analog inputs or digital I/Os
- `pinMode()`, `digitalRead()`, `digitalWrite()`, and `analogWrite()` refer to the digital pin number
- `analogRead()` refers to the analog pin number

Mudduino Schematic

Title block:

COMPANY:	HMC	
TITLE:	Mudduino Schematic	
CODE: ENGR11	SIZE: B	DRAWING NO: Mudduino
		REV: 1.2
SCALE:		SHEET: 1 of 2

DRAWN: MK & MO — DATED: Summer 2010
UPDATED: GF, SP, VR, JU, KV, JV — DATED: Spring 2011
QUALITY CONTROL: — DATED:
RELEASED: — DATED:

REVISION RECORD
LTR | ECO NO: | APPROVED: | DATE:

Schematic components (labels): U2 2.1MM_BARREL, VBAT, U3 LM7805, C5 10 uF, SW1 Power Select Switch 3POS_SWITCH, VCC_USB, SW2 3POS_SWITCH, VMOTOR, C6 10 uF, C3 0.1 uF, SW3 3POS_SWITCH, D3 LED, D3 LED DN, R3 160, R2 10 k, H7 HEADER_DISTANCESENSE, H1 HEADER_SERVO, D14, D10, H11 HEADER_FTDI, C4 0.1 uF, R1 10 k, X1 HC49S, C1 22 pF, C2, RESET_SWITCH B1, D13, D5, LED, R5, R4 200, U1 ATMEGA328, IC1 H-BRIDGE, D4 BUZZER S1, H4 HEADER12 HEADER_L, H2 HEADER_L, H3 HEADER12 HEADER_R, H5 HEADER_R, MOTOR_L+, MOTOR_L-, MOTOR_R+, MOTOR_R-

Bill of Materials for Mudduino 1.3

Subsystem/Part	Quantity	Supplier	Part Number	Cost (bulk)	Total Cost
Mudduino					
Mudduino 1.3 Printed Circuit Board	1	Advanced Circuits	P66545	9.55	$9.55
12-pos Female header	2	Pololu	1030	$0.63	$1.26
reset switch	1	Digikey	SW400-ND	$0.211	$0.21
22 pF capacitor	2	Digikey	1429PH-ND	$0.111	$0.22
10 uF capacitor	2	Digikey	P828-ND	$0.089	$0.18
0.1 uF capacitor	2	Digikey	399-4266-ND	$0.117	$0.23
Red 5mm LED	1	Digikey	751-1141-ND	$0.373	$0.37
Green 5mm LED	1	Digikey	751-1153-ND	$0.337	$0.34
6 pin male header	1	Digikey	SAM1031-50-ND	$2.272	$0.28
3 pin male header	1	Digikey	SAM1031-50-ND	$2.272	
Right angled female header (20 pos)	1	Digikey	S5456-ND	$1.276	$1.28
H bridge	1	Digikey	296-9911-5-ND	$1.875	$1.88
H bridge socket	1	Digikey	A100206-ND	$0.131	$0.13
10k resistor	2	Digikey	CF14JT10K0CT-ND	$0.029	$0.06
160 Ohm resistor	1	Digikey	CF14JT160RCT-ND	$0.020	$0.02
200 Ohm resistor	2	Digikey	CF14JT200RCT-ND	$0.022	$0.04
Buzzer	1	Digikey	102-1153-ND	$0.767	$0.77
Atmega 328 socket	1	Digikey	A100210-ND	$0.296	$0.30
Voltage Regulator (5V)	1	Digikey	LM7805ACT-ND	$0.468	$0.47
16 MHz crystal	1	Digikey	631-1108-ND	$0.375	$0.38
3pos spdt slide switch	3	Digikey	679-1840-ND	$0.750	$2.25
2.1mm power jack	1	Digikey	CP-102A-ND	$0.560	$0.56
Atmega 328 chip (preprogrammed)	1	Sparkfun	DEV-09217	$4.950	$4.95
White 8mm LED	1	superbrightleds.com	RL8-W110-360	$1.89	$1.89
Green 8mm LED	1	superbrightleds.com	RL8-G50-360	$1.49	$1.49
Sensors/Servos					
Sharp GP2Y0A02YK0F Analog Distance Sensor	1	Pololu	1137	$12.59	$12.59
BPW77NA Phototransistor	1	Digikey	751-1020-ND	$1.91	$1.91
QRD1114 Reflectance sensor	1	Digikey	QRD1114-ND	$1.31	$1.31
3-pin JST PH-style cable	1	Pololu	117	$0.89	$0.89
220 ohm resistor	1	Stockroom			
330 kOhm resistor	1	Stockroom			
10 kOhm resistor	1	Digikey	CF14JT10K0CT-ND	$0.029	$0.03
4-pin male header	1	Digikey	SAM1031-50-ND	0.19	0.19
Omron Snap Action Switch	1	SparkFun	COM-00098	$1.95	$1.95
Servo	1	HobbyPartz	Servo_TPro-SG90	$2.77	$2.77
Drive Train					
Tamiya 89918 Double Gearbox Kit - Clear	1	Pololu	1677	$7.85	$7.85
Brushed DC Motor: 130-Size, 6V, 11.5kRPM, 800mA Stall	2	Pololu	1117	$1.31	$2.62
Tamiya 70145 Narrow Tire Set (2 tires)	1	Pololu	63	$6.75	$6.75
Pololu Ball Caster with 3/8" Metal Ball	1	Pololu	951	$2.39	$2.39
Tools and Utilities					
400-point breadboard	1	Pololu	351	$3.38	$3.38
Diagonal cutter	1	Jameco	179902	$3.59	$3.59
Wire cutter/stripper, 10-30 AWG	1	Jameco	78992	$3.49	$3.49
Chip puller (yellow)	1	Jameco	16838	$1.49	$1.49
Precision screwdriver set	1	Jameco	226094	$2.95	$2.95
Toolbox	1	Stockroom		Cheap	
Wire 22AWG solid wire (100ft spool)	1	Jameco	36881	$5.59	$5.59
Power System					
NiMH 7.2 V Battery	1	BatterySpace.com	RC-HAA6R1WR22	$15.95	$15.95
Tamiya Battery Charger	1	BatterySpace.com	CH-UN123	$18.95	$18.95
2.1 mm power cable	1	Digikey	CP-2213-ND	$3.33	$3.33
Chassis					
3D printed chassis	1	HMC	N/A	$20.00	$20.00
Aluminum Female Threaded Hex Standoff, 1/4" Hex, 1-1/2" Length, 8-32 Screw Size	4	Mcmaster	91780A202	$0.71	$2.84
Multipurpose Aluminum (alloy 6061), 1/2" Square, 6' Length	1	Mcmaster	9008K23	$15.08	$0.30
Zinc-pltd Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length	9	Mcmaster	90272A194	$2.85	$0.26
Multipurpose Aluminum (Alloy 6061) .063" Thick, 12" X 12"	1	Mcmaster	89015K37	$15.77	$0.47
2-56 x ¼" Phillips pan head machine screw	2	Mcmaster	90272A077	2.28/100	0.05
4-40 x ¼" Phillips pan head machine screw	2	Mcmaster	90272A106	1.30/100	0.03
2-56 nut	2	Mcmaster	91841A003	2.77/100	0.05
4-40 nut	2	Mcmaster	91841A005	2.75/100	0.05
2-56 x 3/16" pan-head straight slot black nylon machine screw	2	Mcmaster	94735A176	4.96	0.10
				Total Cost =	$162.31

*** out of sync with master BOM. Update this one
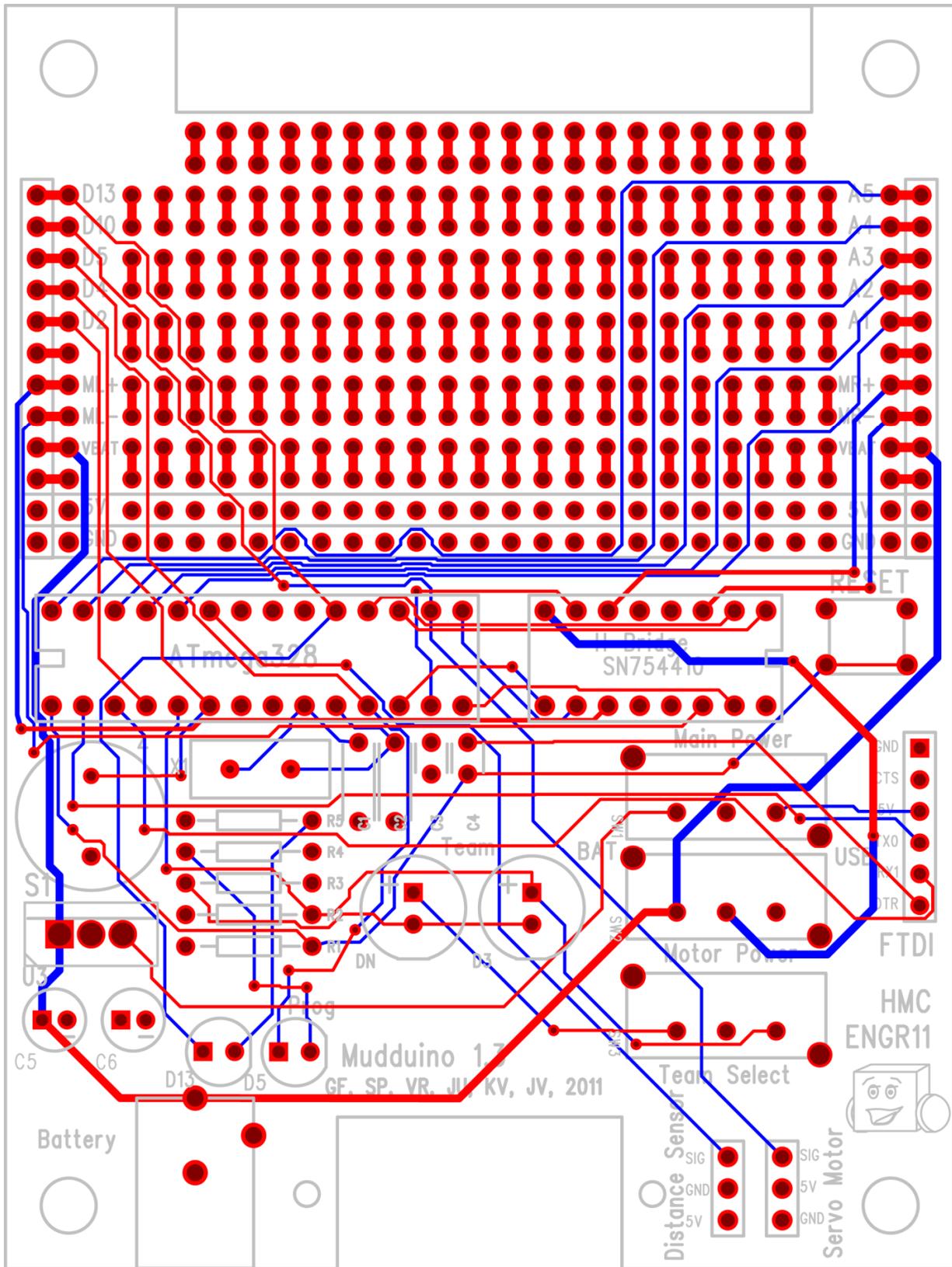
Mudduino Layout (component side wires red, solder side wires blue, silk screen gray)
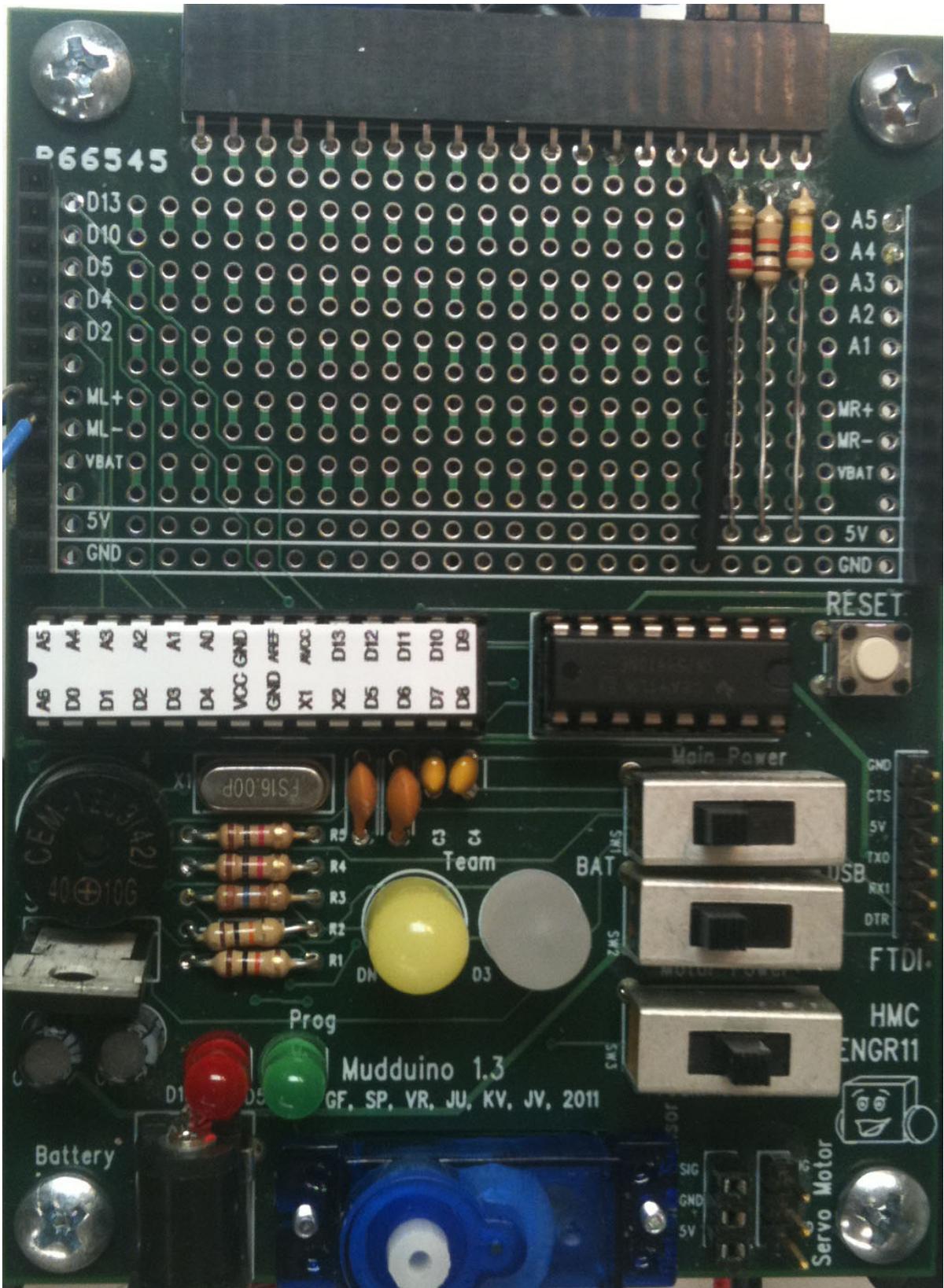
Photograph of Assembled Mudduino Board

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 mnemonic "**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^{-5} 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 – 0.1 µF   Electrolytic – 10 µF

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*.
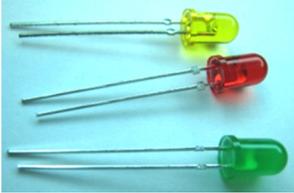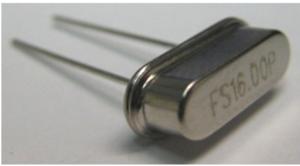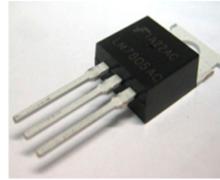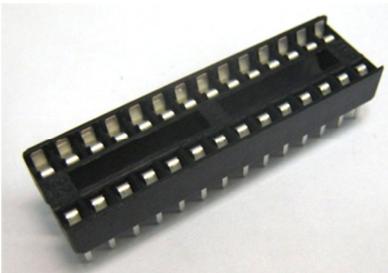

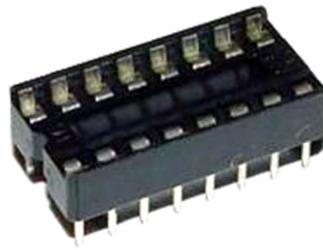| **Clock/Oscillator** | **Push Button** | **Speaker** | **Voltage Regulator** | **Jumper** |

IC Sockets   **USB Jack**
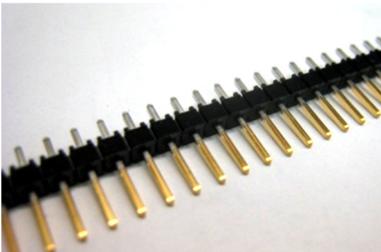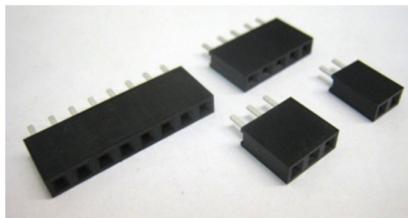

28 position DIP socket   16 position DIP socket
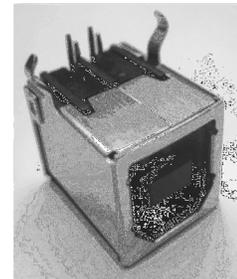
Male Header Pins   **Female Header Pins**   **Right-Angle Header Pins**

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 (except that this picture is missing the right angle female headers).

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.

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 lab-mate'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 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 in terms of height off of the board. They also have several joints perfect for warming up your soldering skills. These headers will serve to be the connection point for the off-board sensors: IR reflectance sensor and phototransistor. Place the part at the top of the board as shown below
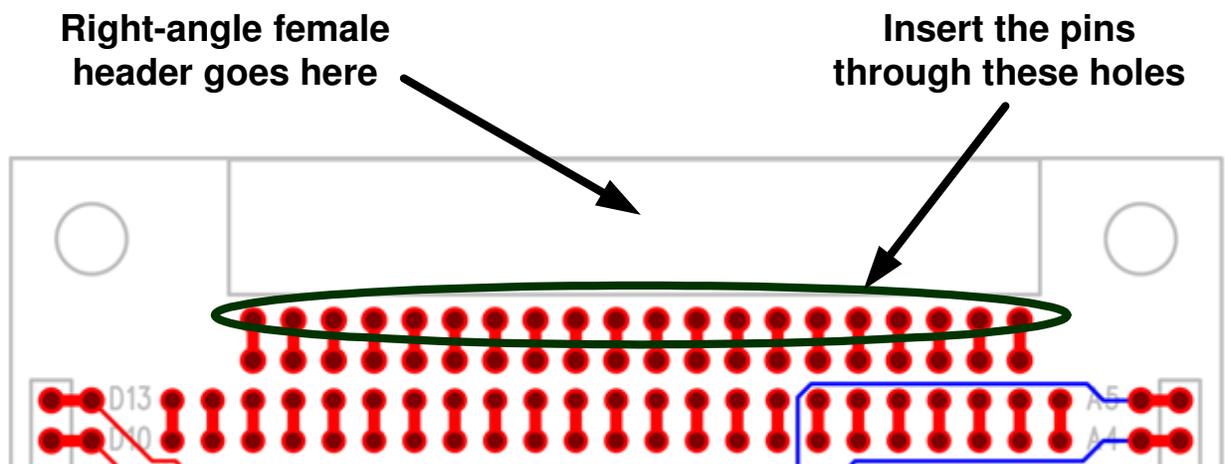
You want the black plastic to be on the component side of the board. Turn the board upside down so you can access the leads on the solder side of the board. The weight of the board should help keep the pins in place while you are soldering.

Place the Resistors

There are five resistors to place on the circuit board that limit current on the LEDs and set defaults on switches. Resistors also do not have polarity. Gently insert a resistor into the slot, turn the board over and bend the leads outward to hold the resistor in place; then, solder. Note, the labeling on the board goes down, R5 to R1.
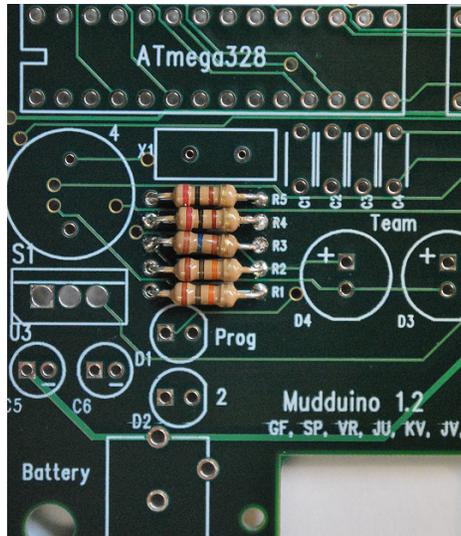
R1 and R2 are 10 kΩ resistors (Brown Black Orange)
R3 is a 160 Ω resistor (Brown Blue Brown)
R4 and R5 are 200 Ω resistors (Red Black Brown)

The characters *R1*, *R2*, etc., have been printed on the PCB to indicate the placement of the resistors.

Place the clock crystal

X1 is the 16 MHz quartz crystal. This is the means by which the Mudduino keeps time. It has no polarity, which means you can solder it in either way. Solder the clock crystal as done for the resistors.
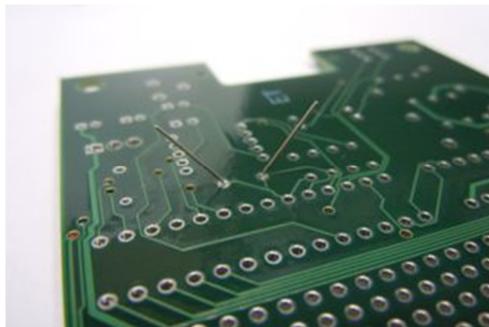
Place ceramic capacitors

The next step is to insert the four small ceramic disc capacitors. These are not polarized and can be inserted in either direction. Solder these on in the same way the resistors were. The two 0.1 µF capacitors are bypass capacitors that stabilize the power supply on the board. The 22 pF capacitors are used to store energy in conjunction with the clock crystal.
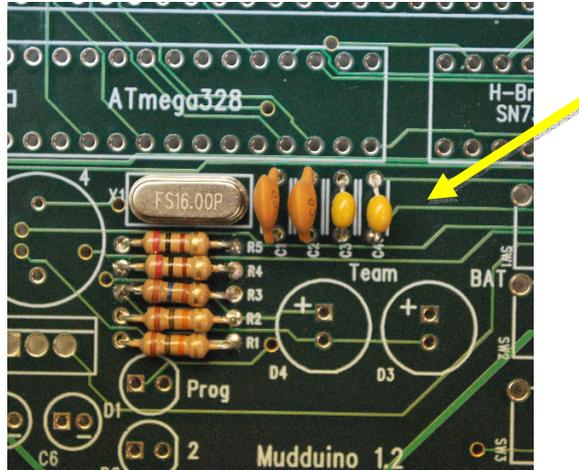
Bend the leads and insert in the diagram positions as shown below. We advise that you solder each component one by one. Be sure to pull the leads all the way through the board to the resistor lies flat against the board.

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 as the picture above

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

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.
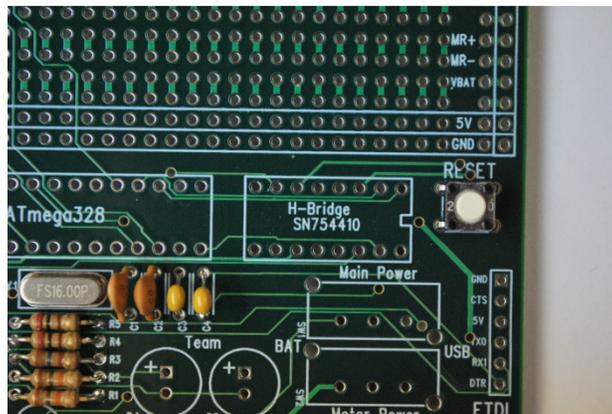
Place IC Sockets

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. Again, 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.

C5 and C6 are both 10 µF caps.

Place the 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. Notice that the holes where the LEDS are placed are shaped differently. Insert the LEDs in the board with the positive terminal in the square hole. Bend the legs and solder. Insert all LEDs in the board *__before__* soldering one or else they may not lie flat on the board next to each other.

We have four LEDs that come in two different sizes.

> 5mm LEDs: D5 is green. D13 is red.
> 8mm LEDs: D3 is yellow-colored, (but glows white), and DN is translucent-white tinted (but glows green).

Place the FTDI and servo header pins

You will have to cut one set of three male header pins (for the servo) and one set of six male header pins (for the FTDI connector) 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.

Place the remaining input/output female header pins

The female header pins provide convenient receptacles for the Mudduino input / output (I/O) ports. You should have two 12- pin female headers. They will be spread out along the edge of the board for ease of access.

Place the buzzer

The buzzer or speaker, 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).

Place the three 3-position switches

The switches govern three functions. The top switch will distinguish where the boards power supply is coming from (either USB or Battery). The middle switch will determine the source of motor power (either USB or Battery also). The bottom switch will select between two colors to distinguish the team color of the Mudduino. (More on this later!)

The switches (SW1-SW3) can only be inserted one way. We again recommend bending the leads of the switches in one direction such that the switch remains in the board while you solder.

Place the 2.1mm barrel jack

The barrel jack supplies external power to the board when you aren't connected to a computer via an FTDI cable. To solder this component a bit more easily, try bending the leads inwards on the solder side of the board before soldering.
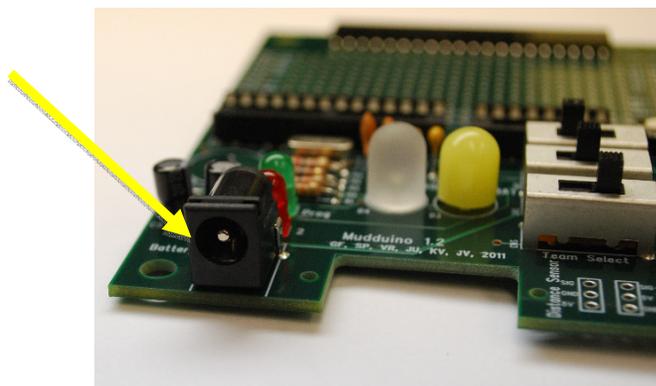
Place voltage regulator

The voltage regulator, U3, is the tallest component on the board. It drops the 7.2-8 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.
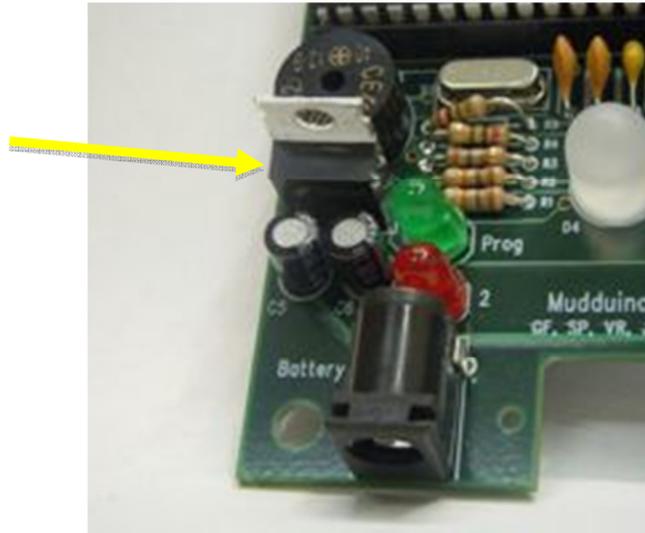
Attach the distance sensor cable

The distance sensor cable has three stranded wires and connector.

Strip ¼" of insulation off the end of each stranded wire. Insert the wires into the holes labeled Distance Sensor. The red wire is for 5V; the black is for GND, and the white is for signal (SIG). Solder and then cut off any excess wire.

Plug the connector into your black two-eyed distance sensor.

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 (which should be aligned with the image on the PCB). You may need to carefully bend the legs of the chip slightly 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.

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 digital pins will flash in order.
- The serial link will print whether the analog pins are working.

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.

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. Wash your hands with soap and water because solder contains lead.