

# **E11: Autonomous Vehicles**

# Lab 1: Mudduino Assembly

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 the printed circuit board). 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 starting on page 6. 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.

### **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.

Digital Pin #	Analog Pin #	Notes
0		Serial TXD – don't use
1		Serial RXI – don't use
2		Header D2
3		Team ( $0 = \text{green} / 1 = \text{white}$ ) 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

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

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);  $0 \le angle \le 180$
- 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() reads the voltage at the specified analog pin number



### **Bill of Materials for Mudduino 1.3**

Image of the state of	Subsystem/Part	Quantity	Supplier	Part Number	Cost (bulk)	Total Cost
Meditaria 12 Printed Carulis Park         P66.4         9.5.5         9.5.5           20.0 Ferral berder         2         Polativ         Monto 200         50.3         51.25           rent verifi         1         Dighty         Monto 200         60.011						
12.00 Frenzie kender         2         Polu         1030         50.33         51.33           2.2 prostorker         2         Digkky         142.994-400         60.111         50.27           2.1 prostorker         2         Digkky         142.994-400         60.111         50.27           2.1 prostorker         1         Digkky         75.1145-401         60.113         50.27           Seers from 1.0         1         Digkky         75.1145-401         60.313         50.34           6 pin misk hander         1         Digkky         54.1153-401         62.227         50.14           8 pin misk hander         1         Digkky         54.1153-540         52.272         50.14           8 pin misk hander         1         Digkky         67.117300CT-M0         50.02         50.02           2 Digkky         CPL-117300CT-M0         50.02 <td< td=""><td></td><td></td><td></td><td></td><td></td><td></td></td<>						
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a ja na kasader         1         Digkey         SAM031-SAM0         9:272         52.12           kight angle franke hader         1         Digkey         3554-10         52.12         52.75         52.23           a pin franke hader         1         Digkey         39:524-10         52.21         52.75         52.23         52.77         52.72         52.77         52.80 <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>						
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160 Om resistor       1       Digkey       CF41T200RT-ND       50.022       50.04         Buzer       1       Digkey       CF41T200RT-ND       50.022       50.04         Buzer       1       Digkey       10.1135-ND       50.025       50.02         Buzer       1       Digkey       A100210-ND       50.025       50.03         16-pin DPI bridge socket       1       Digkey       A100210-ND       50.23       50.03         15-pin DPI bridge socket       1       Digkey       CP110-ND       50.47       50.04       50.04       50.04       50.04       50.04       50.05       50.0	L293D H bridge	1	Digikey	497-2936-5-ND	\$2.72	\$2.72
p200 Dram resistor         Pipely         CF31200CT-MD         S0.022         S0.002           Batzer         1         Digkey         AL021N3 MD         S0.76         S0.77           28-jni DPH Mingle Sockt         1         Digkey         AL020N4 MD         S0.286         S0.30           7805 SV Voltage Regulator         1         Digkey         AL020N4 MD         S0.488         S0.47           3005 spt side switch         1         Digkey         G31.108 AD         S0.38         S0.38           3005 spt side switch         1         Digkey         CP102A-MD         S0.505         S0.53           Atmega 282 chip (preprogrammed with Uno)         1         Sparkfun         R.8.4V10.860         S1.48         S1.49	10k resistor	2	Digikey	CF14JT10K0CT-ND	\$0.029	\$0.06
Buzzer         1         Digikey         102-103-40         53.767         65.775           25-pin DP Hondge sockt         1         Digikey         A100210-M0         59.266         59.30           15-pin DP Hondge sockt         1         Digikey         A100210-M0         59.265         59.33         59.35	160 Ohm resistor		Digikey	CF14JT160RCT-ND		\$0.02
28-gin DP Horizes 228 socket         1         Digikey         A100206-M0         55.0276         55.0276           7805 XV ultage Regulator         1         Digikey         LM 20206-M0         55.013         50.33           7805 XV ultage Regulator         1         Digikey         631.108 M0         50.37         50.33           3pos gat side switch         3         Digikey         671.208 M0         50.376         50.326           2.1mm power jock         1         Digikey         CP.1028 M0         50.356         50.366           Atmage 328 this (preprogrammed with Uno)         1         Superfrighteds.om         R8-W110-350         51.89         51.89           Green 8mm ED         1         Superfrighteds.om         R8-W110-350         51.89         51.795           Sits OTTLFID Cable         1         Digikey         751.002 M0         51.91         51.91           Sits OTSTEPTO AD2YCKP Analog Distance Sensor (20-50 cm)         1         Digikey         751.002 M0         51.91         51.91           ORD11H effectance sensor         1         Digikey         CF1.012 M0         51.91         51.91           ORD11H effectance sensor         1         Digikey         CF1.012 M0         51.91         50.08	p200 Ohm resistor	2		CF14JT200RCT-ND	\$0.022	
16-bit Dirk bindge socket         10         Digkey         AU020eND         50.31.31         50.31.32         50.31.32         50.31.32         50.31.32         50.31.32         50.31.32         50.31.32         50.31.33 <td></td> <td></td> <td></td> <td>102-1153-ND</td> <td></td> <td></td>				102-1153-ND		
7805 SV oblage Regulator         1         Digikey         NURSEXCT-ND         \$0.486         \$0.477           3005 Sprt Lide switch         3         Digikey         67-1480-ND         \$0.570         \$52.35           2.1mm power jack         1         Digikey         CP-102A-ND         \$0.500         \$50.55           Attings 232 chip (preprogrammed with lino)         1         Sparkfun         Dicikey         \$4.350         \$51.488         \$11.88           Green Rmn LED         1         supertrightleds.com         RLB-W110-360         \$1.48         \$51.488         \$51.88         \$51.89         \$52.59         \$51.259         \$51.259         \$51.259         \$51.259         \$51.259         \$51.259         \$51.259						
16 MHz crystal         1         Digkey         63-1108-ND         50.375         50.383           2.1m power jack         1         Digkey         67-1240-ND         50.356           Armega 326 (higr programmed with lung)         1         Sparktun         DEV.1052.41         54.350           White Smn LED         1         supertrightleds.com         R38-650-850.45         51.489         51.89           Green Smn LED         1         supertrightleds.com         R38-650-850.40         51.49         51.79         51.795         51.23         51.31         51.31         51.31         51.31         51.31         51.31         51.31         51.31         53.13         51.31         53.13         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.32 <td></td> <td>1</td> <td>Digikey</td> <td></td> <td></td> <td></td>		1	Digikey			
apot sprit ulide switch         3         Digikey         67:140.N0         50.250         52.25           Armega 328 dujs (preprogrammed with Uno)         1         Spartfun         06:140.00         54.455           Mihe Barn LED         1         Superfrightleds.com         Rike Vital 3-60         51.48         51.49           Green Barn LED         1         Superfrightleds.com         Rike Vital 3-60         51.49         51.49           Green Barn LED         1         Spartfun         Del Second Second         51.49         51.259           Servord Servord         1         Poloin         1137         51.259         51.259           Servord Servord         1         Digikey         731.1020.N101         51.31         51.31           ORD114 Heflectance sensor         1         Digikey         C54.172.08CT AND         50.08         50.08           200 chn resistor         1         Digikey         C54.172.08CT AND         50.08         50.08           304 chn resistor         1         Digikey         C54.172.08CT AND         50.08         50.08           304 chn resistor         1         Digikey         C54.172.08CT AND         50.02         50.03           304 chn resistor         1         Digikey						
2.1mm power jack         1         Digkey         C + 102A+ND         50.560         50.556           White Sam LED         1         Sparkfund         DEV-LOS2A         54.360         54.369           Green Sam LED         1         Superbrighteds.com         RB2-650-360         51.489         51.898         51.89         51.89         51.89         51.89         51.89         51.89         51.795         51.235         51.335         51.31         51.31         51.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.31         53.33         53.30         53.30         53.30         53.30         53.30         53.30         53.30         53.30         53.30         53.30         53.33         53.30						-
Atmega 328 chip (preprogrammed with Uno)         1         Sparkfun         DV 10524         94.950         54.189         54.129         54.125         55.125         55.125         55.125 <t< td=""><td></td><td>-</td><td></td><td></td><td></td><td></td></t<>		-				
White same LED         1         superbrighteds.com         RL8-W110-360         51.89         51.89           Green Barn LED         1         Sparhfun         RL9-650-860         51.49         51.795           Green Barn LED         1         Sparhfun         DEV-09718         512.795         517.795           Sharp GP2XP042Y06 Analog Distance Sensor (20-150 cm)         1         Polou         1137         512.59         512.59           BPW77NA Phototramsitor         1         Digikey         751-100-ND         51.31         51.31           GRD1114 Reflectance sensor         1         Digikey         C71417300CT-ND         50.08         50.08           230 Ohm resistor         1         Digikey         C71417300CT-ND         50.08         50.08           30 KOhm resistor         1         Digikey         C71417300CT-ND         50.08         50.08           30 KOhm resistor         1         Digikey         C71417300CT-ND         50.08         50.05           5069 Servo         1         Bopaf-YD         COM-0098         51.57         57.85           Sorger Servo         1         Pololu         1677         57.85         57.85           Drive Train         1         Pololu         1677						
Green Rm LD         1         Superdrighteds.com         R18-569-360         51.49           USb to TLL FDI Cable         1         Sparkfum         DEV-9718         \$17.95         \$17.95           Sensor/Servos         1         Digitey         751-020-400         \$12.95         \$17.95           Sharp GP270A02YK0F Analog Distance Sensor (20-150 cm)         1         Digitey         751-020-400         \$13.13           BWW77NA Phototramsitor         1         Digitey         GPA10114 Reflectance sensor         \$10         Digitey         GPA10120KCT+ND         \$50.08         \$0.08           32 0hn resistor         1         Digitey         GF141720KCT+ND         \$50.08         \$50.08           320 ohn resistor         1         Digitey         GF141720KCT+ND         \$50.08         \$50.89           30 Khm resistor         1         Digitey         GF141720KCT+ND         \$50.08         \$50.93           10 khorts         Starfsfram         COM-00098         \$1.35         \$1.55         \$51.55           500 Servo         1         HobbyPartz         Servo_TPro-SG90         \$2.77         \$2.77           Drive Train         1         Pololu         117         \$1.31         \$2.62           Tamiy 20450 Anotox Kt-Clear <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>						
USB to TLFTDI Cable         1         Sparkfun         DPL-09718         \$37.95         \$37.95           Sensor/Servos         I         Polou         1137         \$12.59         S12.59           Sharg GP2Y0AD2Y0F Analog Distance Sensor (20-150 cm)         1         Digikey         751-1020-ND         \$13.91         \$13.91           GRD 114 Relectance sensor         1         Digikey         CF14/T220RCT-ND         \$0.08         \$0.08           230 K0hm resistor         1         Digikey         CF14/T220RCT-ND         \$0.08         \$0.08           230 K0hm resistor         1         Digikey         CF14/T30KCT-ND         \$0.08         \$0.08           200 form resistor         1         Digikey         CF14/T30KCT-ND         \$0.08         \$0.08           200 form resistor         1         Digikey         CF14/T30KCT-ND         \$0.08         \$0.08           200 form resistor         1         Digikey         CF14/T30KCT-ND         \$0.02         \$0.03           200 form resistor         1         Digikey         CF14/T10KCT-ND         \$0.02         \$0.03           200 morn Sap Action Switch         1         Digikey         CF14/T10KOT-ND         \$0.27         \$2.77           Drive Train         1						
Sensor/Servos         Image						
Sharp G2Y0AQXYK0F Analog Distance Sensor (20-150 cm)         1         Pololu         1137         \$12.59         \$12.59           BWY7TAR Photoramistor         1         Digikey         QRD1114 Reflectance sensor         \$1         Digikey         QRD1114 ND         \$1.31         \$5.131           37b1137 H-style cable         1         Digikey         QRD1114 ND         \$0.88         \$0.88           20 ohm resistor         1         Digikey         CF1407230CT-ND         \$0.08         \$0.08           30 kDhm resistor         1         Digikey         CF140730CT-ND         \$0.02         \$0.03           4-pin male header         1         Digikey         CF140730CT-ND         \$0.02         \$0.03           0mron Snap Action Switch         1         Saparksun         COM-00098         \$1.95         \$1.95           5690 Servo         1         HobbyPartz         Servo_TPro-S690         \$2.77         \$2.77           Drive Train         1         Pololu         117         \$5.131         \$2.62           Tamya 8918 Double Gearbox Kit - Clear         1         Pololu         117         \$7.131         \$2.62           Tamya 8918 Double Gearbox Kit - Clear         1         Pololu         1137         \$3.38         \$3.38     <	USB to TIL FIDI Cable	1	Sparktun	DEV-09718	\$17.95	\$17.95
Sharp G2Y0AQXYK0F Analog Distance Sensor (20-150 cm)         1         Pololu         1137         \$12.59         \$12.59           BWY7TAR Photoramistor         1         Digikey         QRD1114 Reflectance sensor         \$1         Digikey         QRD1114 ND         \$1.31         \$5.131           37b1137 H-style cable         1         Digikey         QRD1114 ND         \$0.88         \$0.88           20 ohm resistor         1         Digikey         CF1407230CT-ND         \$0.08         \$0.08           30 kDhm resistor         1         Digikey         CF140730CT-ND         \$0.02         \$0.03           4-pin male header         1         Digikey         CF140730CT-ND         \$0.02         \$0.03           0mron Snap Action Switch         1         Saparksun         COM-00098         \$1.95         \$1.95           5690 Servo         1         HobbyPartz         Servo_TPro-S690         \$2.77         \$2.77           Drive Train         1         Pololu         117         \$5.131         \$2.62           Tamya 8918 Double Gearbox Kit - Clear         1         Pololu         117         \$7.131         \$2.62           Tamya 8918 Double Gearbox Kit - Clear         1         Pololu         1137         \$3.38         \$3.38     <	C					
BPW7DNA Phototransizor         1         Digikey         751-020-ND         \$1.91         \$1.91           3-pin JST PH-style cable         1         Pololu         117         \$0.89         \$0.39           220 Ohn resistor         1         Digikey         CFL4172DRCT-ND         \$0.08         \$0.08           230 KDhm resistor         1         Digikey         CFL4173DRCT-ND         \$0.08         \$0.08           30 KDhm resistor         1         Digikey         CFL4173DRCT-ND         \$0.08         \$0.08           10 KDhm resistor         1         Digikey         CFL4173DRCT-ND         \$0.029         \$0.03           4-pin male header         1         Digikey         CFL4173DRCT-ND         \$0.029         \$0.03           590 Servo         1         HobbyPartz         Servo_TPro-SG90         \$2.77         \$2.77           Drive Train         1         Pololu         1677         \$7.85         \$7.85           Brushed C Motor 130-Size (X-1) SkPPM, 800mA Stall         2         Pololu         117         \$1.31         \$2.62           Tamiya 20145 Narrow Tire Set (2 tires)         1         Pololu         951         \$2.39         \$2.39           Tools and Utilities         1         Pololu         351<		1	Pololu	1127	\$12.50	\$12.50
0R01114 Reflectance sensor         1         Digikey         0R0114ND         \$1.31         \$1.31           3-pin JST PH-style cable         1         Pololu         117         \$0.89         \$0.30           220 ohm resistor         1         Digikey         CF1417320RT-ND         \$0.08         \$0.08           330 Khm resistor         1         Digikey         CF1417300CT-ND         \$0.08         \$0.08           330 Khm resistor         1         Digikey         CF1417300CT-ND         \$0.09         \$0.03           4-pin male header         1         Digikey         CF1417300CT-ND         \$0.09         \$0.03           5690 Servo         1         HobbyPartz         Servo_TPro-S690         \$2.77         \$2.77           Drive Train         1         Pololu         1677         \$7.85         \$7.85           Brunked DC Motor: 130-Size, 6V, 11.SkRPM, 800mA stall         2         Pololu         1117         \$1.31         \$2.82           Tamiya 89918 Double Gearbox Rit - Clear         1         Pololu         1317         \$3.8         \$3.38         \$3.38           Tools and Uitlites         1         Pololu         1317         \$3.8         \$3.38         \$3.38         \$3.38         \$3.38         \$3.38						
s-pin IST PH-style cable         1         Polou         117         \$0.89         \$0.39           220 ohm resistor         1         Digikey         CF14/T330KCT-ND         \$0.08         \$0.08           30 kOhm resistor         1         Digikey         CF14/T330KCT-ND         \$0.08         \$0.08           10 kOhm resistor         1         Digikey         CF14/T330KCT-ND         \$0.029         \$0.03           10 kOhm resistor         1         Digikey         CF14/T330KCT-ND         \$0.029         \$0.03           0mron Snap Action Switch         1         SparkTun         COM-00098         \$1.95         \$1.95           5600 Servo         1         HobbyPartz         Servo_TPro-5690         \$2.77         \$2.77           Servo Trann         1         Pololu         1677         \$7.85         \$7.85           Brushed DC Motor: 130 Size, 6V, 11.5kRM, 800mA Stall         2         Pololu         117         \$1.31         \$2.39           Tools and Utilities         1         Pololu         951         \$2.39         \$2.39           Tools and Utilities         1         Jameco         179902         \$3.59         \$3.59           Vire 22AWG solid wire (100ft spool)         1         Jameco         1638 </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>						
120 ohm resistor         1         Digikey         CF14JT220RCT-ND         \$0.08         \$0.08           330 kOhm resistor         1         Digikey         CF14JT30KCT-ND         \$0.08         \$0.08           300 kOhm resistor         1         Digikey         CF14JT10KCT-ND         \$0.09         \$0.03           4-pin male header         1         Digikey         SAM1031-50-ND         0.19         0.19           0mron Snap Action Switch         1         Sparkfun         COM-00098         \$2.195         \$1.95           5G90 Servo         1         HobbyPartz         Servo_TPro-SG90         \$2.77         \$2.77           Drive Train         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 8918 Double Gearbox Kit - Clear         1         Pololu         63         \$6.75         \$6.75           Folou Ball Caster with 3/8" Metal Ball         1         Pololu         351         \$5.38         \$3.38           Diagand Lutter         1         Jameco         179902         \$3.59         \$3.59           Colous and Utilites         1         Jameco						
330 kOhm resistor       1       Digikey       CF14IT330KCT-ND       \$0.08       \$0.08         10 kOhm resistor       1       Digikey       CF14IT30KCT-ND       \$0.029       \$0.03         4pin make header       1       Digikey       SAM103150-ND       0.19       0.19         Omron Snap Action Switch       1       SparkFun       COM-00098       \$1.95       \$1.95         SG90 Servo       1       HobbyPartz       Servo_TPro-SG90       \$2.77       \$2.77         Drive Train       1       Pololu       1677       \$7.85       \$7.85         Brushed DC Motor: 30-5ize, 6V, 11.5kPM, 800mA Stall       2       Pololu       117       \$1.31       \$2.62         Tamiya 2043 Narrow Tire Set (2 trics)       1       Pololu       63       \$5.75       \$5.75         Pololu       351       \$2.39       \$2.						
10 kOhm resistor         1         Digikey         CF14JT10WCT-ND         \$0.029         \$0.039           4-pin mak header         1         Digikey         SAM1031-50-ND         0.19         0.19           0mron Snap Action Switch         1         SparkFun         COM-00098         \$1.95         \$1.95           SG90 Servo         1         HobbyPartz         Servo_TPro-SG90         \$2.77         \$2.77           Drive Train           HobbyPartz         Servo_TPro-SG90         \$2.77         \$5.75           Brushed OC Motor: 130-Size, 6V, 11.5kRPM, 800mA Stall         2         Pololu         117         \$1.31         \$2.62           Tamiya 89918 Double Gearbox Kit - Clear         1         Pololu         63         \$6.75         \$5.75           Tamiya 70145 Narrow Tire Set (2 tires)         1         Pololu         63         \$5.75         \$5.75           Pololu Bil Caster with 3/8" Metal Ball         1         Pololu         351         \$3.38         \$3.38           Mire cutter/Striper, 10-30 AWG         1         Jameco         179902         \$3.49         \$3.49           Vire cutter/Striper, 10-30 AWG         1         Jameco         16838         \$1.49         \$4.99           Precision screwdri		1				
4-pin male header         1         Digikey         SAM103150-ND         0.19         0.19           Omron Snap Action Switch         1         SparkFun         COM-00098         \$1.95         \$51.95           SG00 Servo         1         HobbyPartz         Servo Thro-Sc90         \$2.77         \$2.77           Drive Train         -						
Ommo Snap Action Switch         1         SparkFun         COM-0098         \$1.95         \$5.95           SG90 Servo         1         HobbyPartz         Servo_TPro-S690         \$2.77         \$2.77           Drive Train         -         -         -         -         -         -           Drive Train         1         Pololu         1677         \$7.85         \$5.85         S7.85         \$7.85		1				
SG90 Servo         1         HobbyPartz         Servo_TPro-SG90         \$2.77         \$2.77           Drive Train         1         Pololu         1677         \$7.85         \$7.85           Brushed DC Motor: 130-Size, Kit - Clear         1         Pololu         1117         \$1.31         \$22.62           Tamiya 20145 Narrow Tire Set (2 tires)         1         Pololu         1117         \$1.31         \$26.62           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           Toots and Utilities         1         Pololu         351         \$3.38         \$3.48           M00-point breadboard         1         Jameco         179902         \$3.59         \$3.59           Mire cutter/stripper, 10-30 AWG         1         Jameco         16838         \$1.49         \$3.49           Precision screwdriver set         1         Jameco         16838         \$1.49         \$3.49           Precision screwdriver set         1         Jameco         36881         \$5.59         \$5.59           Tamiya 8 attery Charger         1         BatterySpace.com		1				
Tamiya 89918 Double Gearbox Kit - Clear       1       Pololu       1677       \$7.85       \$7.85         Brushed DC Motor: 130-Sitze, 6V, 11.SkRPM, 800mA Stall       2       Pololu       63       \$6.75       \$5.675         Pololu Ball Caster with 3/8" Metal Ball       1       Pololu       63       \$5.75       \$5.75         Pololu Ball Caster with 3/8" Metal Ball       1       Pololu       951       \$2.39       \$2.39         Tools and Utilities       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         Precision screwdriver set       1       Jameco       16838       \$1.49       \$5.19         Toolbox       1       Jameco       3681       \$5.59       \$5.59         Power System       1       Jameco       3681       \$5.59       \$5.59         2.1 mm power cable       1       Digkey       CP-2213-ND       \$3.33       \$3.33         Chasis       1       Digkey       CP-2213-ND       \$3.33       \$3.33         Chasis       1       Micraster       9108		1		Servo TPro-SG90		
Tamiya 89918 Double Gearbox Kit - Clear       1       Pololu       1677       \$7.85       \$7.85         Brushed DC Motor: 130-Sitze, 6V, 11.SkRPM, 800mA Stall       2       Pololu       63       \$6.75       \$5.675         Pololu Ball Caster with 3/8" Metal Ball       1       Pololu       63       \$5.75       \$5.75         Pololu Ball Caster with 3/8" Metal Ball       1       Pololu       951       \$2.39       \$2.39         Tools and Utilities       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         Precision screwdriver set       1       Jameco       16838       \$1.49       \$5.19         Toolbox       1       Jameco       3681       \$5.59       \$5.59         Power System       1       Jameco       3681       \$5.59       \$5.59         2.1 mm power cable       1       Digkey       CP-2213-ND       \$3.33       \$3.33         Chasis       1       Digkey       CP-2213-ND       \$3.33       \$3.33         Chasis       1       Micraster       9108				_		
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         1         Pololu         351         \$3.38         \$3.38           Diagonal cutter         1         Jameco         179902         \$3.59         \$3.49           Othp puller (yellow)         1         Jameco         18992         \$3.49         \$3.49           Precision screwdriver set         1         Jameco         26094         \$2.95         \$2.95           Tools and Utilities         1         Jameco         36881         \$4.99         \$5.59           Wire 22AWG solid wire (100ft spool)         1         Jameco         36681         \$5.59         \$5.59           Tomiya Battery Charger         1         BatterySpace.com         RC-HAAGRIWR22         \$1.95         \$1.95           Tamiya Battery Charger         1         BatterySpace.com         CH-UN123         \$18.95         \$18.95           2.1 mm power cable         1	Drive Train					
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       -<	Tamiya 89918 Double Gearbox Kit - Clear	1	Pololu	1677	\$7.85	\$7.85
Pololu Ball Caster with 3/8" Metal Ball         1         Pololu         951         \$2.39         \$2.39           Tools and Utilities         -	Brushed DC Motor: 130-Size, 6V, 11.5kRPM, 800mA Stall	2	Pololu	1117		
Tools and Utilities         Image: Constraint of the search of the s						
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         -         -         -         -           Wire 22AWG solid wire (100ft spool)         1         Jameco         36881         \$5.59         \$5.59           NiMH 7.2 V Battery         1         BatterySpace.com         CH-HAA6R1WR22         \$15.95         \$18.95           2.1 mm power cable         1         Digikey         CP-2213-ND         \$3.33         \$3.33           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	Pololu Ball Caster with 3/8" Metal Ball	1	Pololu	951	\$2.39	\$2.39
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         -         -         -         -           Wire 22AWG solid wire (100ft spool)         1         Jameco         36881         \$5.59         \$5.59           NiMH 7.2 V Battery         1         BatterySpace.com         CH-HAA6R1WR22         \$15.95         \$18.95           2.1 mm power cable         1         Digikey         CP-2213-ND         \$3.33         \$3.33           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						
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         1         Stockroom         \$5.59         \$5.59           Power System         1         Jameco         36881         \$5.59         \$5.59           Tamiya Battery Charger         1         BatterySpace.com         RC-HAA6R1WR22         \$18.95         \$18.95           2.1 mm power cable         1         Digikey         CP-2213-ND         \$3.33         \$3.33           2.1 mm power cable         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), 0.12" Surgare, 6' Length         1         Mcmaster         9008K23         \$15.08         \$0.30           21nc-ptld Stl P						
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               Wire 22AWG solid wire (100ft spool)         1         Jameco         36881         \$5.59         \$5.59           Power System         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         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-pibtd Stl						
Chip puller (yellow)         1         Jameco         16838         \$1.49         \$1.49           Precision screwdriver set         1         Jameco         226094         \$2.95         \$2.95           Toolbox         1         Stockroom         -         -         -           Wire 22AWG solid wire (100ft spool)         1         Jameco         36881         \$5.59         \$5.59           Power System         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           2.1 mm power cable         1         Digikey         CP-2213-ND         \$3.33         \$3.33           2.1 mm power cable         1         Micmaster         91780A202         \$0.71         \$2.84           Multipurpose Aluminum (alloy 6061), 1/2" Square, 6' Length         1         Micmaster         900823         \$15.98         \$0.30           Zinc-pitd Sit Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length         9         Mcmaster         90272A194         \$2.85         \$0.26           Multipurpose Aluminum (	0	1				
Precision screwdriver set         1         Jameco         226094         \$2.95         \$2.95           Toolbox         1         Stockroom						
Toolbox         1         Stockroom           Wire 22AWG solid wire (100ft spool)         1         Jameco         36881         \$5.59         \$5.59           Power System         Image: Comparison of the system <thimage: comparison="" of="" system<="" th="" the=""> <thimage:< td=""><td></td><td></td><td></td><td></td><td></td><td></td></thimage:<></thimage:>						
Wire 22AWG solid wire (100ft spool)         1         Jameco         36881         \$5.59         \$5.59           Power System         Image: Constraint of the system				220094	\$2.95	\$2.95
Power System         Image: Character System </td <td></td> <td>1</td> <td></td> <td>36881</td> <td>ĆE EO</td> <td>ćE EN</td>		1		36881	ĆE EO	ćE EN
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         1         Digikey         CP-2213-ND         \$3.00         \$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-ptld Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length         9         Mcmaster         900272A194         \$2.85         \$0.26           Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         90272A194         \$2.85         \$0.26           Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         90272A194         \$2.85         \$0.26           Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         90272A077         \$2.8/100         0.05           4-40 x	wire 220wg 20lin wire (100li 200l)	+	Jameco	TOOOL	\$3.59	şə.59
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         1         Digikey         CP-2213-ND         \$3.00         \$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-ptld Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length         9         Mcmaster         900272A194         \$2.85         \$0.26           Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         90272A194         \$2.85         \$0.26           Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         90272A194         \$2.85         \$0.26           Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         90272A077         \$2.8/100         0.05           4-40 x						
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         1         Digikey         CP-2213-ND         \$3.33         \$3.33           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         \$0.26           Zinc-ptld Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length         9         Mcmaster         900272A194         \$2.85         \$0.26           Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         90272A194         \$2.85         \$0.26           Multipus pan head machine screw         2         Mcmaster         90272A077         \$2.8/100         0.05           4-40 x W" Phillips pan head machine screw         2         Mcmaster         90272A077         \$2.8/100         0.05           2-55 n ut         4         Mcmaster         90272A0	Power System		BatterySpace.com	RC-HAA6R1\W/R22	¢15 Q5	\$15 Q5
2.1 mm power cable         1         Digikey         CP-2213-ND         \$3.33         \$3.33           Chassis         Image: Chassis <thim< td=""><td></td><td>1</td><td></td><td></td><td>410.00</td><td></td></thim<>		1			410.00	
Chassis         Image: Chassis	NIMH 7.2 V Battery	1			\$18.95	\$18.95
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-pitd 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 X" Phillips pan head machine screw         2         Mcmaster         90272A077         2.28/100         0.05           4-40 x X" Phillips pan head machine screw         2         Mcmaster         90272A076         1.30/100         0.03           2-56 nut         4         Mcmaster         91841A003         2.77/100         0.01           4-40 nut         2         Mcmaster         91841A005         2.75/100         0.05	NIMH 7.2 V Battery Tamiya Battery Charger	1	BatterySpace.com	CH-UN123		
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-pitd 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 X" Phillips pan head machine screw         2         Mcmaster         90272A077         2.28/100         0.05           4-40 x X" Phillips pan head machine screw         2         Mcmaster         90272A076         1.30/100         0.03           2-56 nut         4         Mcmaster         91841A003         2.77/100         0.01           4-40 nut         2         Mcmaster         91841A005         2.75/100         0.05	NIMH 7.2 V Battery Tamiya Battery Charger	1	BatterySpace.com	CH-UN123		
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         90272A077         \$2.8100         0.05           2-56 x X" Phillips pan head machine screw         2         Mcmaster         90272A106         1.30/100         0.03           2-56 nut         4         Mcmaster         91272A106         1.30/100         0.03           2-56 nut         2         Mcmaster         91272A106         1.30/100         0.03           2-56 nut         2         Mcmaster         91841A003         2.77/100         0.11           4-40 nut         2         Mcmaster         91841A005         2.75/100         0.05	NIMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable	1	BatterySpace.com	CH-UN123		
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 X" Phillips pan head machine screw         2         Mcmaster         90272A077         2.28/100         0.05           4-40 x X" Phillips pan head machine screw         2         Mcmaster         90272A106         1.30/100         0.03           2-56 nut         4         Mcmaster         91841A003         2.77/100         0.11           4-40 nut         2         Mcmaster         91841A005         2.75/100         0.05	NIMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis	1 1	BatterySpace.com Digikey	CH-UN123 CP-2213-ND	\$3.33	\$3.33
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 X" Phillips pan head machine screw         2         Mcmaster         90272A106         1.30/100         0.03           4-40 x X" Phillips pan head machine screw         2         Mcmaster         91841A003         2.77/100         0.01           4-56 nut         4         Mcmaster         91841A005         2.75/100         0.05	NiMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis 3D printed chassis	1 1 1	BatterySpace.com Digikey HMC	CH-UN123 CP-2213-ND N/A	\$3.33 \$20.00	\$3.33 \$20.00
Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12"         1         Mcmaster         89015K37         \$15.77         \$0.47           2-56 x X" Phillips pan head machine screw         2         Mcmaster         90272A077         2.28/100         0.05           4-40 x X" Phillips pan head machine screw         2         Mcmaster         90272A106         1.30/100         0.03           2-56 nut         4         Mcmaster         91841A003         2.77/100         0.11           4-40 nut         2         Mcmaster         91841A005         2.75/100         0.05	NiMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis 3D printed chassis Aluminum Female Threaded Hex Standoff, 1/4" Hex, 1-1/2" Length, 8-32 Screw Size	1 1 1 1 4	BatterySpace.com Digikey HMC Mcmaster	CH-UN123 CP-2213-ND N/A 91780A202	\$3.33 \$20.00 \$0.71	\$3.33 \$20.00 \$2.84
4-40 x %" Phillips pan head machine screw         2         Mcmaster         90272A106         1.30/100         0.03           2-56 nut         4         Mcmaster         91841A003         2.77/100         0.11           4-40 nut         2         Mcmaster         91841A005         2.75/100         0.05	NiMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis 3D printed chassis Aluminum Female Threaded Hex Standoff, 1/4" Hex, 1-1/2" Length, 8-32 Screw Size Multipurpose Aluminum (alloy 6061), 1/2" Square, 6' Length	1 1 1 4 1	BatterySpace.com Digikey HMC Mcmaster Mcmaster	CH-UN123 CP-2213-ND N/A 91780A202 9008K23	\$3.33 \$20.00 \$0.71 \$15.08	\$3.33 \$20.00 \$2.84 \$0.30
2-56 nut         4         Mcmaster         91841A003         2.77/100         0.11           4-40 nut         2         Mcmaster         91841A005         2.75/100         0.05	NiMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis 3D printed chassis Aluminum Female Threaded Hex Standoff, 1/4" Hex, 1-1/2" Length, 8-32 Screw Size Multipurpose Aluminum (alloy 6061), 1/2" Square, 6' Length Zinc-pltd Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length	1 1 1 4 1 9	BatterySpace.com Digikey HMC Mcmaster Mcmaster Mcmaster	CH-UN123 CP-2213-ND N/A 91780A202 9008K23 90272A194	\$3.33 \$20.00 \$0.71 \$15.08 \$2.85	\$3.33 \$20.00 \$2.84 \$0.30 \$0.26
4-40 nut 2 Mcmaster 91841A005 2.75/100 0.05	NIMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis 3D printed chassis Aluminum Female Threaded Hex Standoff, 1/4" Hex, 1-1/2" Length, 8-32 Screw Size Multipurpose Aluminum (alloy 6061), 1/2" Square, 6' Length Zinc-pltd Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length Multipurpose Aluminum (Alloy 6061). 063" Thick, 12" X 12" 2-56 x %" Phillips pan head machine screw	1 1 1 4 1 9 1 2	BatterySpace.com Digikey HMC Mcmaster Mcmaster Mcmaster Mcmaster	CH-UN123 CP-2213-ND N/A 91780A202 9008K23 90272A194 89015K37	\$3.33 \$20.00 \$0.71 \$15.08 \$2.85 \$15.77	\$3.33 \$20.00 \$2.84 \$0.30 \$0.26 \$0.47
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2-56 x 1/4" pan-head straight slot black nylon machine screw         2         Mcmaster         94735A177         4.96         0.10	NiMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis 3D printed chassis Aluminum Female Threaded Hex Standoff, 1/4" Hex, 1-1/2" Length, 8-32 Screw Size Multipurpose Aluminum (alloy 6061), 1/2" Square, 6' Length Zinc-pltd Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12" 2-56 x %" Phillips pan head machine screw 2-56 nut	1 1 1 4 1 9 1 2 2 2 4	BatterySpace.com Digikey HMC Mcmaster Mcmaster Mcmaster Mcmaster Mcmaster Mcmaster	CH-UN123 CP-2213-ND N/A 91780A202 9008K23 90272A194 89015K37 90272A077 90272A106	\$3.33 \$20.00 \$0.71 \$15.08 \$2.85 \$15.77 2.28/100 1.30/100	\$3.33 \$20.00 \$2.84 \$0.30 \$0.26 \$0.47 0.05 0.03
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	NiMH 7.2 V Battery Tamiya Battery Charger 2.1 mm power cable Chassis 3D printed chassis Aluminum Female Threaded Hex Standoff, 1/4" Hex, 1-1/2" Length, 8-32 Screw Size Multipurpose Aluminum (alloy 6061), 1/2" Square, 6' Length Zinc-pltd Stl Pan Head Phillips Machine Screw, 8-32 Thread, 1/2" Length Multipurpose Aluminum (Alloy 6061).063" Thick, 12" X 12" 2-56 x %" Phillips pan head machine screw 4-40 x %" Phillips pan head machine screw 4-40 nut	1 1 4 1 9 1 2 2 4 2 2	BatterySpace.com Digikey HMC Mcmaster Mcmaster Mcmaster Mcmaster Mcmaster Mcmaster Mcmaster Mcmaster Mcmaster	CH-UN123 CP-2213-ND N/A 91780A202 9008K23 90272A194 89015K37 90272A077 90272A077 90272A106 91841A003 91841A005	\$3.33 \$20.00 \$0.71 \$15.08 \$2.85 \$15.77 2.28/100 2.77/100 2.75/100	\$3.33 \$20.00 \$2.84 \$0.30 \$0.26 \$0.47 0.05 0.03 0.11 0.05



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 colored bands. The first three indicate the value, in ohms ( $\Omega$ ). 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 "Bad beer rots our young guts but vodka goes well".

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 x  $10^1 = 200 \Omega$ , with a 5% tolerance. Brown – black – orange – gold indicates 103, meaning 10 x  $10^3 = 10,000 \Omega$  (written 10 k  $\Omega$ ).



### 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 x  $10^4$  pF =  $10^{-7}$  F = 0.1 µF. A 2-digit code just indicates the value in picofarads. For example, 22 means 22 pF.



Ceramic - 22 pF



Ceramic  $-0.1 \ \mu F$ 



 $Electrolytic-10\ \mu F$ 

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*. It is important to solder LEDs in the correct orientation otherwise they will not work.











Slide Switch

2.1mm Power Jack

Atmega 328

L293D H-bridge









### **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 on page 6.

#### 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. *Make sure you turn off the soldering iron when you are not actively using it.* 

Place only a couple components in the board at a time. Bend the legs so that the component stays in place without having to be held; they should make a good mechanical connection 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 cut 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 place 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, not the iron itself. 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 as tapered water drop shape not as a sphere for a good solder joint. A sphere means the solder has not wet both sides of the join.

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 is 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. Be sure to pull the leads all the way through the board so the resistor lies flat against the board. Note, the labeling on the board goes down, R5 to R1.



R1 and R2 are 10 k $\Omega$  resistors (Brown Black Orange) R3 is a 160  $\Omega$  resistor (Brown Blue Brown) R4 and R5 are 200  $\Omega$  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

 $\mu$ F capacitors are bypass capacitors that stabilize the power supply on the board. The 22 pF capacitors are used to load the clock crystal to allow it to oscillate.



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 so the capacitors are as close to the board as possible.

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 (color and size may vary) C3 and C4 are the small yellow ceramic 0.1  $\mu$ F capacitors.

The 22 pF should have 2s written on the side while the 0.1 uF will not.

#### 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  $\mu$ F 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. Insert all LEDs in the board <u>before</u> 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 pins for the FTDI and servo

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. Both are located to the bottom, right of the board.

#### 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 along the outer left and right edges 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. Note each switch has two thicker legs. You should still solder these as they are for structural support. It will be easier to solder one switch at a time.



#### 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 top 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 <sup>1</sup>/<sub>4</sub>" 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 L293D 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!

## 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 a shield board with header pins to plug into your Mudduino. The shield will allow us to quickly test continuity on the board. Once the board is programmed with lab1\_tester17 code, the instructor will attach the testing shields to your board and open a serial monitor on the computer.

You will open a serial terminal and the test program will attempt to self-check the function of the board, giving you suggestions where there might be issues if it finds anything unusual.

## Clean Up

Clean up your lab station. Discard the refuse you accumulated while soldering. <u>Tin the iron and</u> <u>turn it off</u>. Please clear the benches and keep the lab clean. Wash your hands with soap and water because solder contains lead.