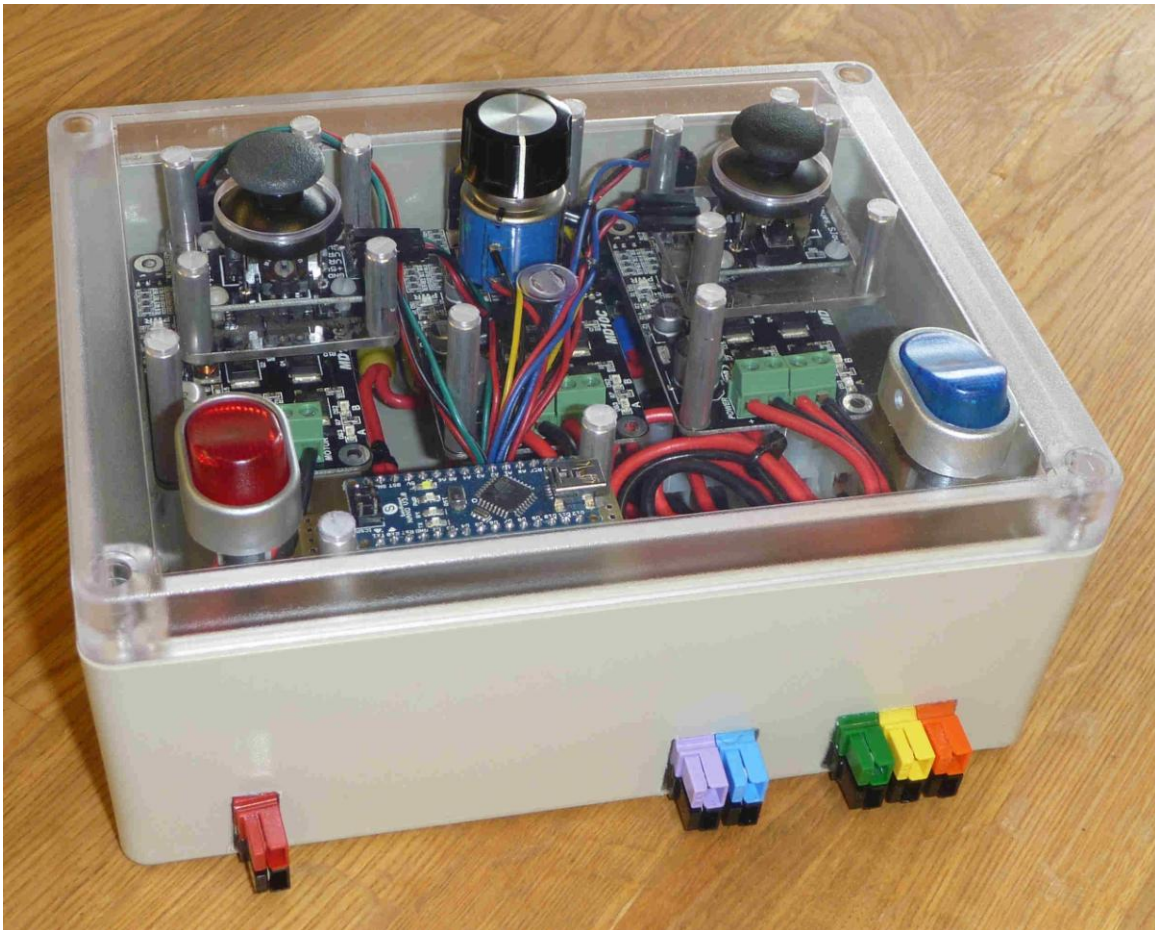


# **Variable Speed ROV Controller**

## **VSRC-1**



## Variable Speed ROV Controller VSRC-1 2014, Robert L Kershaw

One of the challenges for a novice MATE Ranger ROV team (Remote Operated Vehicle) is creating an effective thruster control system. The simplest method is a 3 position toggle switch, connected directly to a thruster. While this system is cheap, it produces herky-jerky movements and the ROV is unable to “hover”. An ROV *must* be able to maintain a desired water depth in order to perform tasks underwater. A Variable Speed ROV Controller (VSRC-1) can solve these problems.

The goal for this project was creating a low cost, 3 axis (X-Y-Z) control box. The control system described here will run approximately \$250. All of the parts can be purchased online or locally and only hand tools, a drill motor, a dremel style tool, and a soldering iron are required for assembly. With simple programming, the control box provides variable power control from 2 thumbsticks and 1 potentiometer.

The heart of the system is an Arduino Nano micro-controller. The Nano can be configured for PWM output, analog input, and digital input/output. The Nano can use 5 - 13.8 VDC power input, and it has both 5 VDC and 3.3 VDC outputs available for powering the center pin of the PWM connections. Using the Arduino IDE software, students can setup channel functions, test devices and write simple “sketches” to operate thrusters. Two thumbsticks and one potentiometer, all 5 kilohm, are connected as inputs to the Nano with female-to-female jumper wires. These input devices provide output signals through the Nano to three Cytron MD10C Motor Speed Controllers, using similar female-to-female jumpers. Finally, the motor speed controllers connect to each thruster via box connectors which attach to an ROV tether cable.

All of the components are installed in a plastic box with a clear top, allowing continuous monitoring of indicator lights on the boards (no additional LEDs to install). A lighted power switch was used to speed troubleshooting without a multimeter, i.e. switch on / light off = no 12v power or a bad fuse.

The control box complies with MATE Ranger ROV Competition requirements. It contains a single power input connection, multiple thruster power connectors downstream of the primary power fuse, and a camera power connector. An auxiliary switch and associated connector were added to allow one additional electrical function. A fuse for each motor speed controller (5-15 amp), a fuse for the micro-controller (1 amp), and a camera fuse (3-5 amp) has been added to protect the devices. A primary power fuse (25 amp) was also included. Anderson power connectors were used to facilitate fast connections.

**Note: (1) The MATE required inline 25 amp fuse (within 30cm of power connection) and banana plug power connectors are NOT included. (2) Banana plugs provide weak electrical connections.**

Design and building instructions are mostly generic, but specific when a mistake on crucial tasks would cause component failure or extend build time. Teams can determine their own component layout. Electrical drawing are not included (teams will need to generate their own).

### CHALLENGES

The project started with a review of Ranger thruster requirements. A typical ROV thruster is created from a 500-800 gph bilge pump, which requires 12 VDC at 3 amps. Long tethers produce a voltage drop that increases this circuit current. So, a motor speed controller needed a capacity of more than 7 amps. Most of the motor speed controllers on the market were either not able to handle 10 amps or they cost \$50 or more for 30 amp versions. Cytron MD10C Motor Speed Controllers can carry 13 amps continuous and cost \$16.50. This controller will run cooler and handle motor startup current.

The first micro-processor tested was a Pololu Micro Maestro 6 USB Servo Controller. The Maestro is very small, simple to program and outputs RC PWM signals. When the Maestro was connected to the Cytron motor controllers nothing happened. After several days of research, it was determined the Cytron controllers require a “true” PWM, not an RC PWM. An RC PWM signal is a 20ms pulse (50 Hz). The on or positive part is 1 to 2ms, and the off part is 18 to 19ms. RC PWM motor controllers only use the 1 - 2ms portion of the pulse. Motors will be off at 1.5ms, full forward at 2ms and full reverse at 1ms. True PWM operates at a selected frequency in the range of 10 Hz – 30 KHz. At a 50% duty cycle the positive part of the pulse is one half of the full cycle, and the negative part fills out the remaining half. In this condition the output voltage is 0. When the positive pulse moves above 50% the voltage output is positive from 0 to 12 volts. The opposite is true when the positive pulse moves below 50% (negative 0 to 12 volts). Arduino boards produce true PWM. The standard PWM output is approximately 1000 Hz on pins 5 and 6 (timer 0); and 500 Hz on pins 3, 9 and 10 (timer 1), and pin 11 (timer 2). This works out to a 2ms pulse cycle.

The Ztrades thumbsticks did not initially perform as expected. The thumbsticks' resistance should be 0 to 5000 ohms, with 2500 ohms at the center. The thumbstick's X-axis was off by 200-300 ohms, especially at the center position. The Y axis produced better center-point values, so the thumbsticks were turned 90 degrees before mounting.

A three turn potentiometer was selected over the standard one turn version. Three turns provides a wider range of control, however, a single turn potentiometer will suffice. This is one of the more expensive items at \$25.

During one of the programming sessions the Arduino Nano failed to upload a change. The Nano was connected to the USB port of a computer (5 volts), and also connected to all of the field devices. Twelve volt power was not connected to the box. The Nano power light came on, the LED flashed, the Cytron power lights came on, and the Cytron A/B LEDs came on dimly. The Nano 1 amp fuse failed. Without 12 volt power on the Cytron boards, the USB 5 volts was running through the Nano trying to power up the Cytron circuitry. The higher current through the Nano caused a fatal injury. So, \$14 went into the trash bin.

The first test after construction contained a surprise. Motor speed controllers using PWM signals output 0 VDC at 50% of input signal. This condition can generate a squeal or tone from a DC motor due to the rapidly reversing electro-magnetic fields inside the motor. Nano output pins D9 through D11 operate at 500 Hz which produces a very audible tone. Fortunately, a little research explained how to change the frequency through programming.

```
// set PWM timer divisors to 8 for PWM frequency of 3921.16 Hz; reduces motor 'off' squeal
// TCCR2B = Pin 11 timer
// TCCR1B = Pins 9 & 10 timer
TCCR2B = TCCR2B & B11111000 | 0x02;
TCCR1B = TCCR1B & B11111000 | 0x02;
```

The motor squeal is still there, but not as noticeable.

## Instructions:

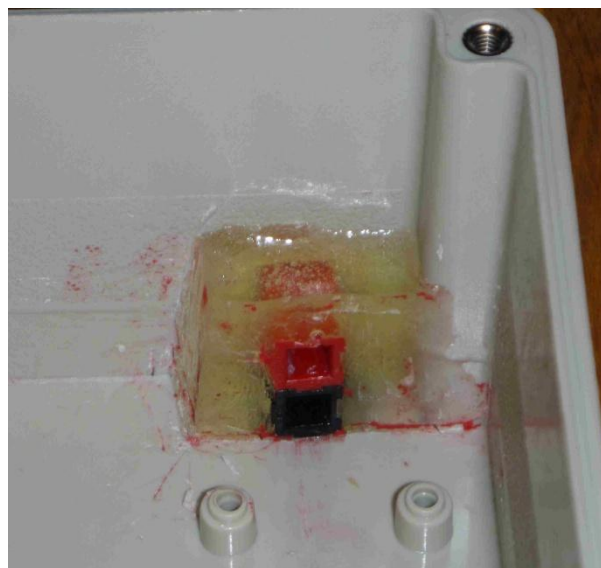
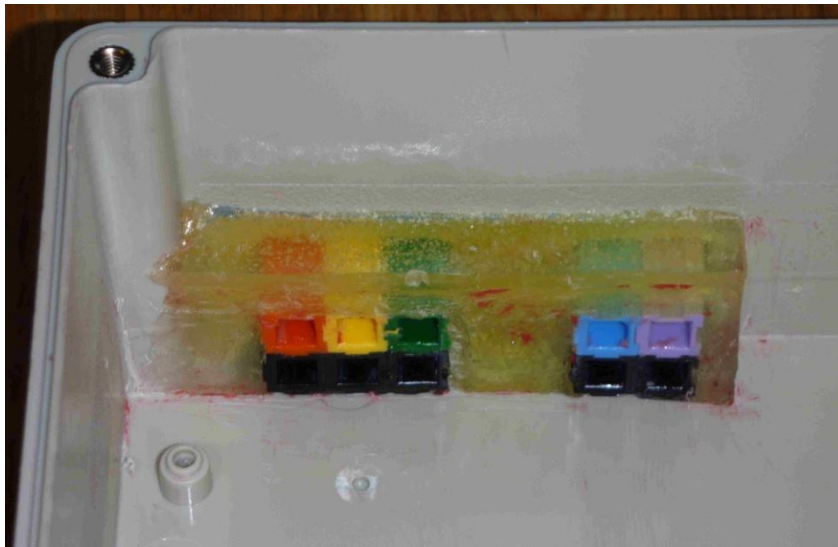
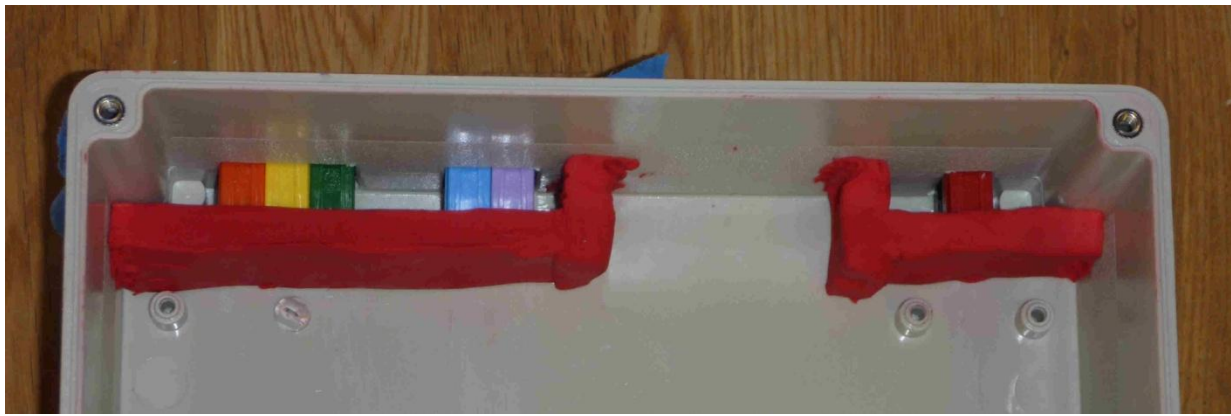
Building this control box requires precision work. The box is not large, so parts must be laid out to fit in close proximity to other parts. To start this project, materials and parts need to be ordered well in advance. Items from Amazon.com may arrive in a few days. The remaining parts could take two weeks. Estimated time for completing the box is 30-40 student hours.

**Anderson connectors-** *Note: Exterior screw terminal strips or direct connection to internal devices can also be used.*

Assemble the Anderson shells into three blocks. One pair of shells will be power input. Three pairs are the motor connections. Two pairs are camera power and auxiliary power. Mark the front of the project box and drill out most of the material, then use a medium file to shape the rectangular holes to fit the plastic shells. Fill the holes in the shells, on the side that will be epoxied, with a small amount of grease. This will prevent the epoxy from leaking into the holes. Fit the Anderson shells into the box holes and tape in place from the outside of the box. On the inside of the box, form modeling clay around the plastic shells. The clay should be lightly pressed against the shell holes; leave a 9 - 10mm gap on the sides and top of the plastic shells. Fill the area with epoxy.

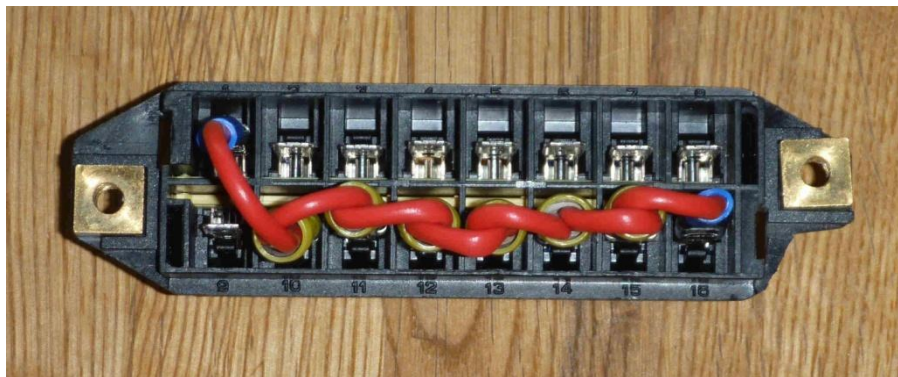






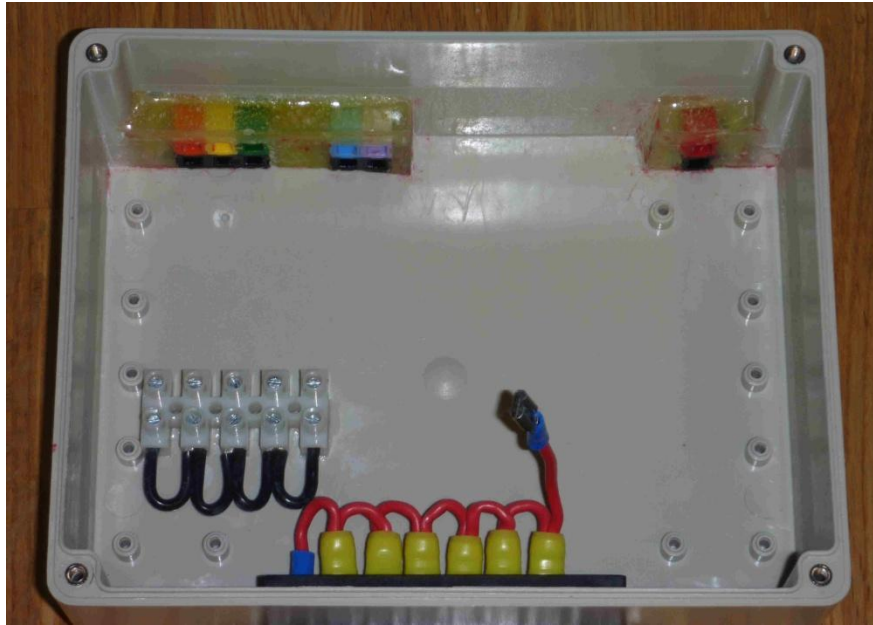
**Fuse block-** Mark a rectangular hole in the back of the box for the fuse block. Keep the hole low, at the bottom edge of the box. This design is for an 8 circuit fuse block. Use a dremel style tool to remove the plastic material. Shape the hole with a medium file and install the fuse block.

One fuse slot will be for the main power (this is an additional protection for the box). The Anderson power connector goes directly to the input of the power fuse. The output of this fuse should go to the main power switch. The output of the main power switch returns to the remaining fuse slots. Use short jumpers (14 AWG, red) between each fuse slot.



**Note:** The jumper marked by the arrow is an error. It does not connect to the primary fuse. It should be long enough to connect to the main power switch output.

**Terminal strips-** Install 5 jumpers (14 AWG, black) on a 6 position screw terminal strip (this picture only has 5). Glue the terminal strips to the bottom of the box with gel superglue.





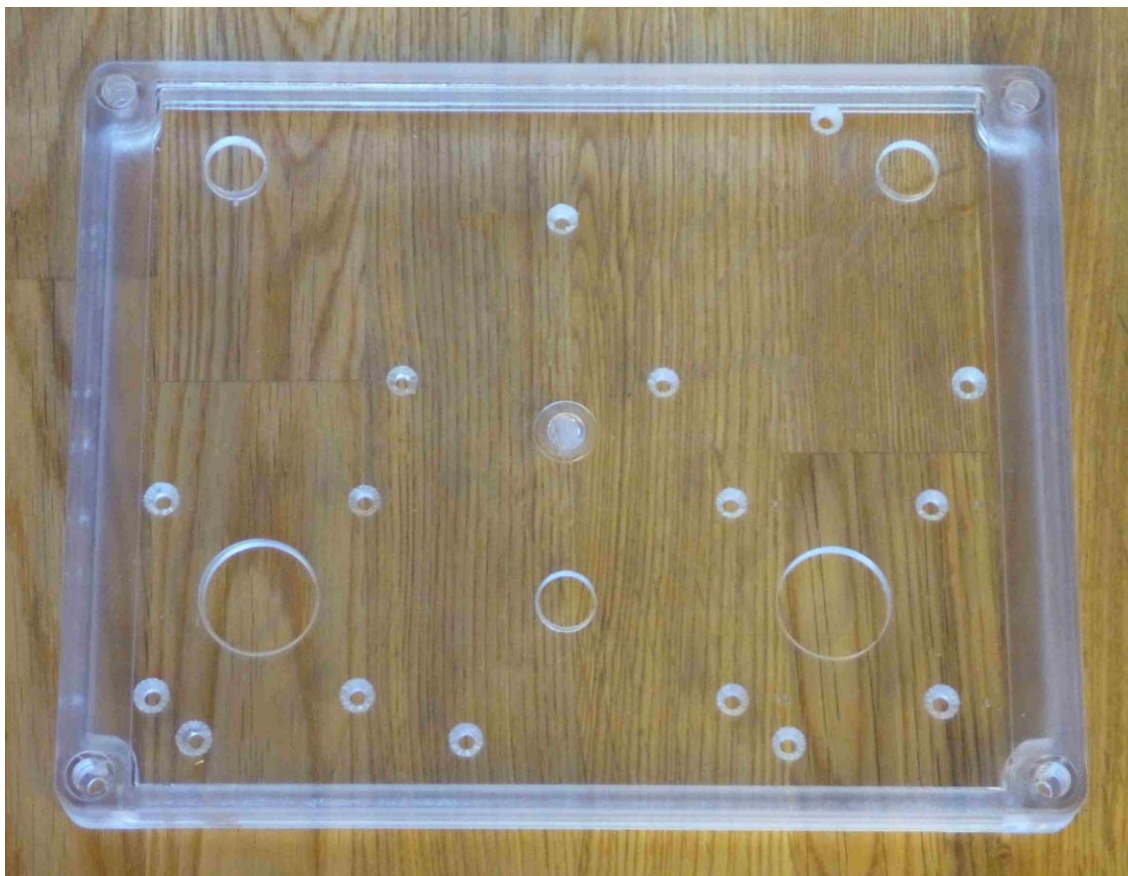
**Construction tip:**

**Mark and drill all holes in the project box clear top prior to installing devices.**

1. Start with a horizontal line for the rear motor controller mounting screws. Next, mark a line for the rear thumbstick mounting screws. The thumbsticks must clear the signal connector on the motor controllers. Next, add horizontal lines for the remaining mounting holes (only thumbsticks and motor controllers).
2. The potentiometer should be in the vertical center of the top (from left to right), and aligned horizontally with the thumbsticks.
3. Thumbstick modules should be near the left and right edge. Thumbsticks are attached to the top with four 4-40 countersunk screws. The left thumbstick mounting holes must be marked **before** determining the horizontal position of the associated motor controller. The right motor controller horizontal holes are marked **before** determining the right thumbstick's horizontal position. **Read Thumbsticks.**

*Note: The motor controllers should be offset from the thumbsticks to permit viewing of the power LEDs and A and B LEDs.*

4. Motor controller boards are positioned below the thumbstick modules with 2, 4-40 countersunk screws. **Read Cytron motor controllers.**
5. The power switch should be placed at the front of the clear top, near the Anderson power connectors. **Read Power switch.**
6. Four auxiliary switches can be added for other functions. One switch is included in this project. The wiring will depend on the function and type of switches used.
7. The micro-controller should be near the power switch. Orienting the USB connector opposite of the power switch allows attachment of the programming cable. The micro-controller is attached with two 4-40 countersunk screws. **Read Arduino Nano.**





**Potentiometer-** *Note: Both a 3 turn and a 1 turn potentiometer are shown in the Materials section.*

Select three, 150mm, female-female jumper wires: a red, a black and another color. Cut off the female connector from one end of each wire, then solder the wires to the potentiometer:

red = pot 1, black = pot 3, color = pot 2.

The output signal is always connected to the “wiper” or moving part of a variable resistor. The ground and 5 volt wires determine the polarity of the output signal. Connected above, clockwise motion above 50% results in a positive output at a motor controller. Swapping red and black will produce a negative motor controller output when the pot is turned clockwise above 50%.

Install the potentiometer in the clear top. Attach the pot knob (the indicator line is usually toward the front of the top).



**Thumbsticks-** Attach each thumbstick to a piece of polycarbonate, 45mm square. The center of the thumbstick should be centered on the plate.

***Note: The thumbstick is NOT in the center of the circuit board. The Y axis provides a better signal. Install the thumbsticks with the wiring pins toward the center of the box.***

Select three, 150mm, female-female jumper wires: a red, a black and another color. Plug one end of each wire into the thumbsticks:

VRX = color

Left +5 = black, left GND = red

Right +5 = red, right GND = black.

Mark two thumbstick holes and 8 mounting holes in the project box's clear top, and install the thumbsticks in the clear top. Use flathead, 4-40 screws.

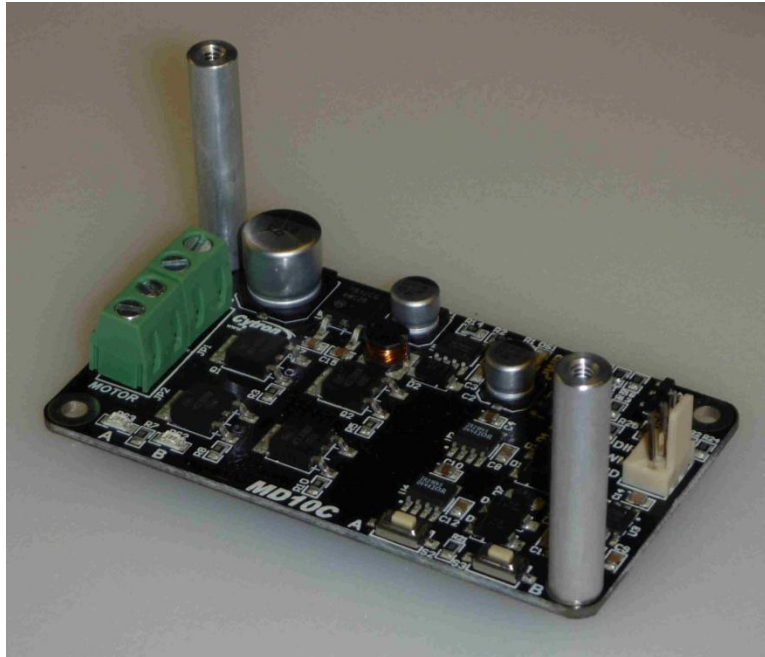
*(Construction tip: The aluminum standoffs restrict movement of the thumbstick. One solution is to sand down the lower plastic shroud. A better solution is to attach the thumbstick to a larger plastic plate, then mount the plate to the clear cover. )*



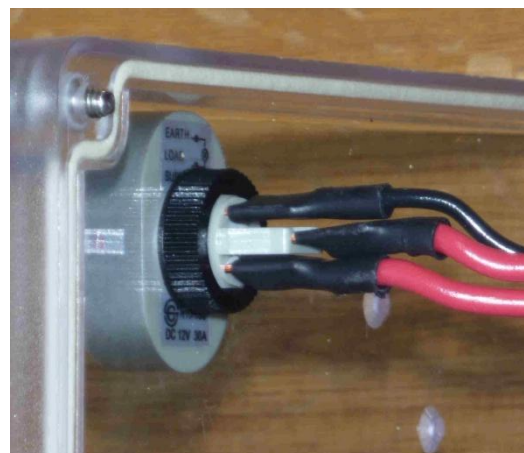
**Cytron motor controllers-** Attach 2, 4-40 aluminum spacers to each Cytron board. Attach four 14 AWG wires, 300mm long, to the power and motor connections. Plus should be red and minus will be black. Select three female-female jumper wires (a red, a black and another color) for each motor controller. The left controller and the vertical controller require 150mm wires. The right controller needs 200mm wires. Plug one end of each wire into the signal connector:

black = GND, red = PWM, color = DIR.

Mark 2 holes for each Cytron board in the project box's clear top. The boards should be mounted below the thumbsticks and potentiometer, and forward of the center. The Cytron output LEDs should be visible in the clear top. The A LED means plus voltage is applied to the plus connection. The B LED indicates plus voltage is applied to the negative connection.



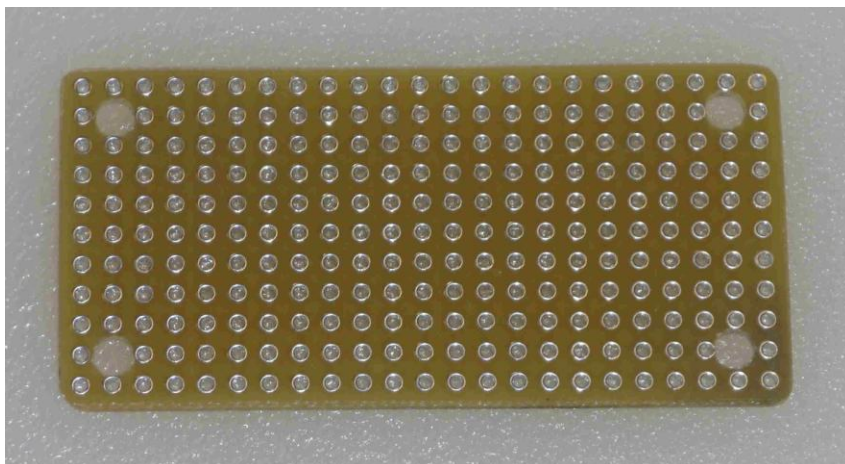
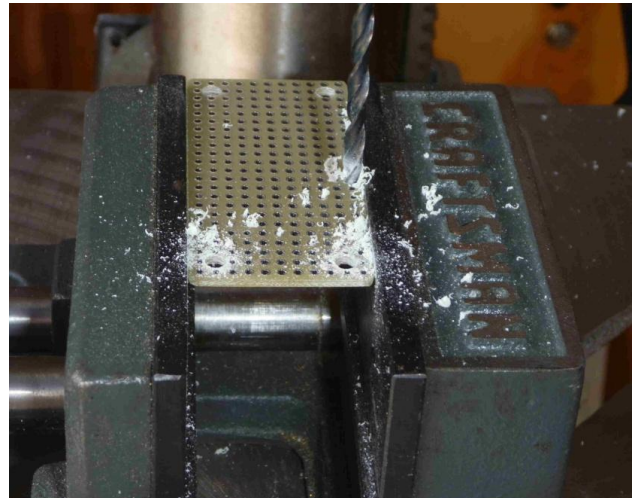
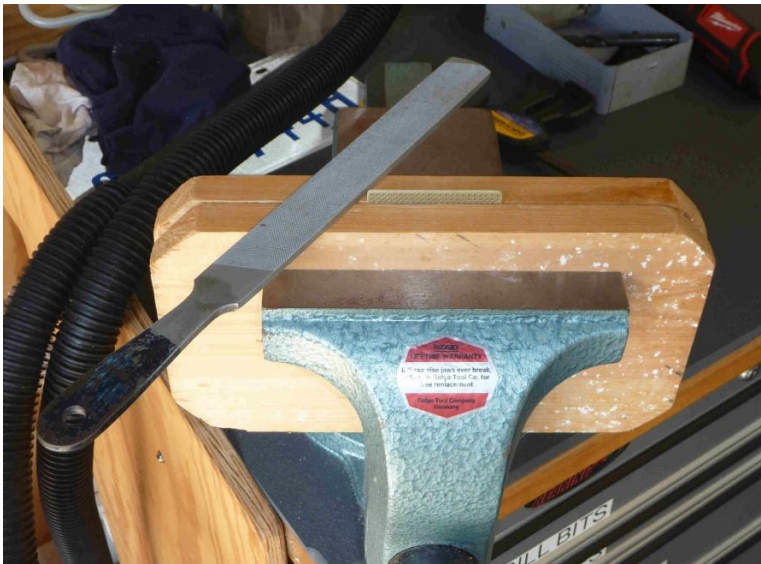
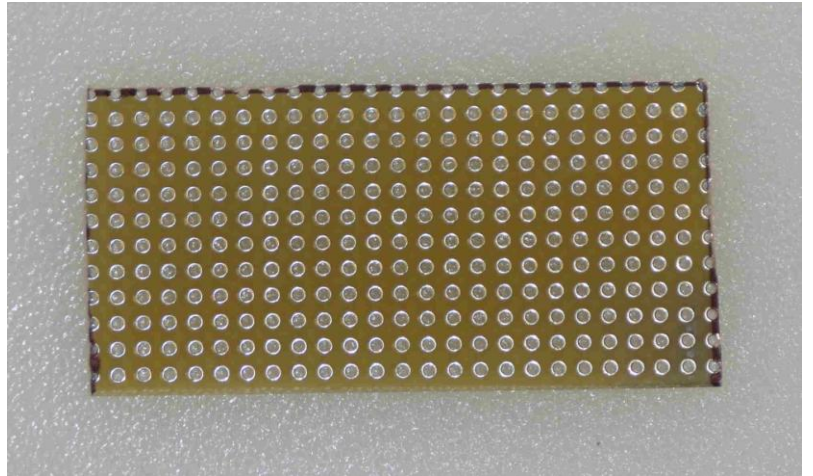
**Power switch-** Solder two, red 14 AWG wires (300mm) to the power switch. Solder a black, 18 AWG wire to the ground or earth tab of the power switch. Mark a hole in the project box's clear top for the power switch. The switch should be near the front corner of the box. Install the power switch with the black wire toward the front edge. Repeat this process for other switches used. Install other switches on the side opposite of the power switch.





**Arduino Nano-** *Note: Building the Arduino Nano mounting board is a complex, precision task. Arduino female headers have long pins which simplifies construction.*

Cut a double sided prototyping board 32mm by 64mm. Cut in the center of the holes and sand the edges smooth. Drill a 3mm hole in each corner; use the second hole from each corner as the center.



*Note: Arduino header sets contain 4 pieces making 2 columns of 16. These work well and the 2 excess holes should be filled to prevent misalignment of the Nano.*

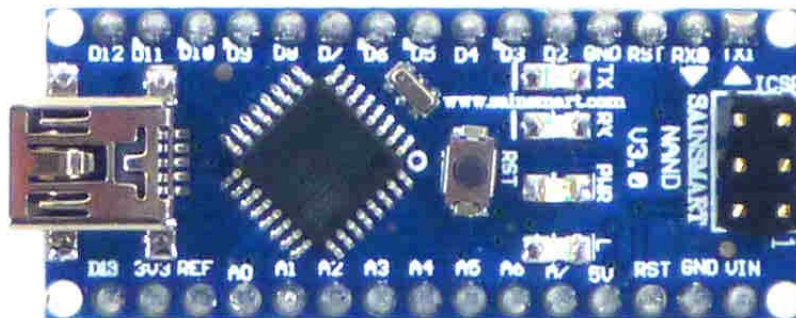
Insert the Nano board into 2 columns of 15 (or 16) female header pins. Orient the Nano on a horizontal axis, with **VIN** on the lower right corner. Then insert the header pins into the prototype board. There will be two columns of open holes on the top and bottom, and four rows of open holes on the left and right side. Mark the header that has the **VIN** pin with a bright paint. Fold the female header pins for both **RSTs**, **A5**, **A6**, **D5**, **D6**, **D12**, and **D13** toward the center, making contact with the closest column of holes and solder, then cut off the excess pin material. **Next, remove the Arduino Nano from the prototype board. Further soldering will damage the Nano from excessive heat.** Fold the remaining female header pins toward the center, making contact with the closest column of holes. Solder these pins to the open holes and cut away the excess pin material.

*Note: Male header pins for jumper connections are inserted from the bottom of the prototype board, and soldered from the top side.*

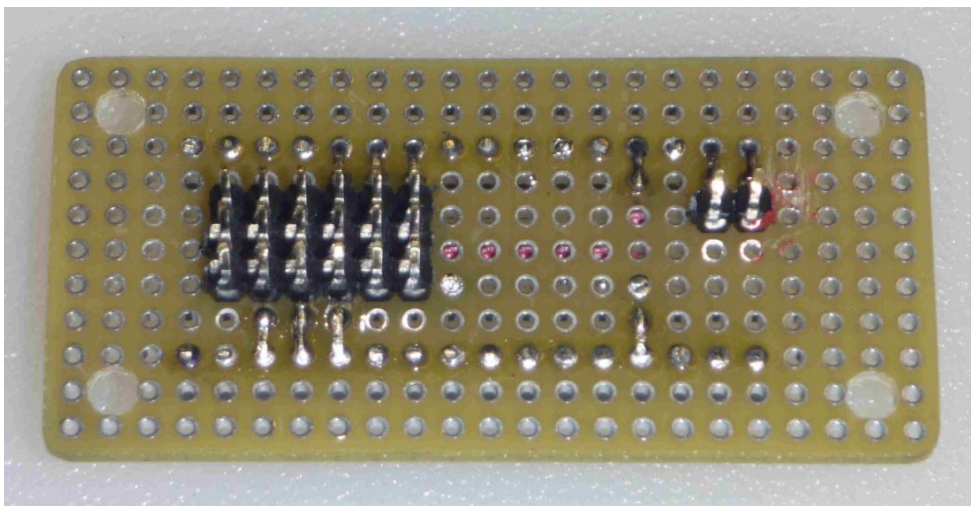
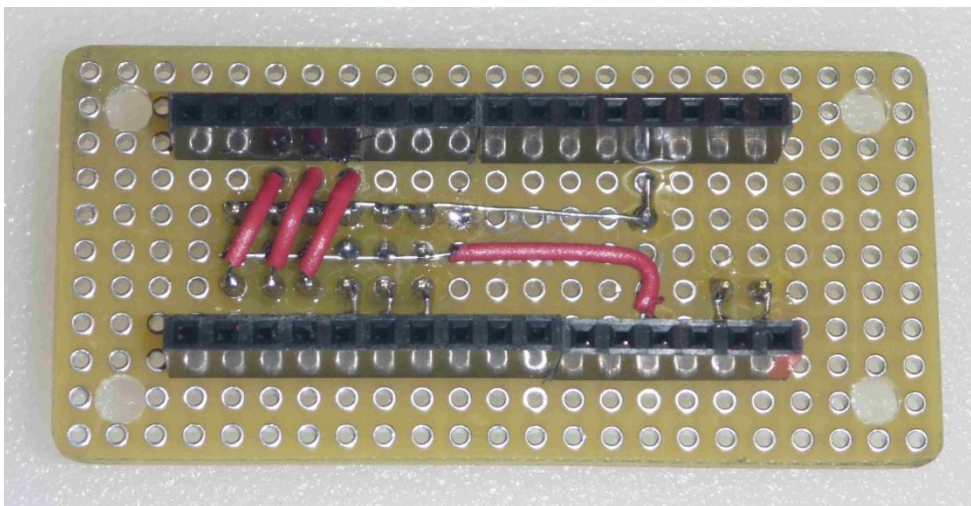
Cut one set of 2 male header pins. Put these pins into the open holes (toward the center) closest to **VIN** and **GND**. Solder these pins in place. Bridge the gap to the **VIN** and **GND** contact holes with excess pin material, or 26 AWG wire, and solder in place. Mark the new **VIN** male pin with bright paint.

Cut three columns of 6 male header pins. Insert one column of 6 male header pins into the center column of holes, from **D13** to **A2**. Solder 1 or 2 pins. The plastic on the male header pins may not allow 3 columns to be inserted together. If necessary, sand a small amount from one side of the remaining 2 columns of male header pins. Insert these on either side of the center column of pins, and solder 1 or 2 pins each.

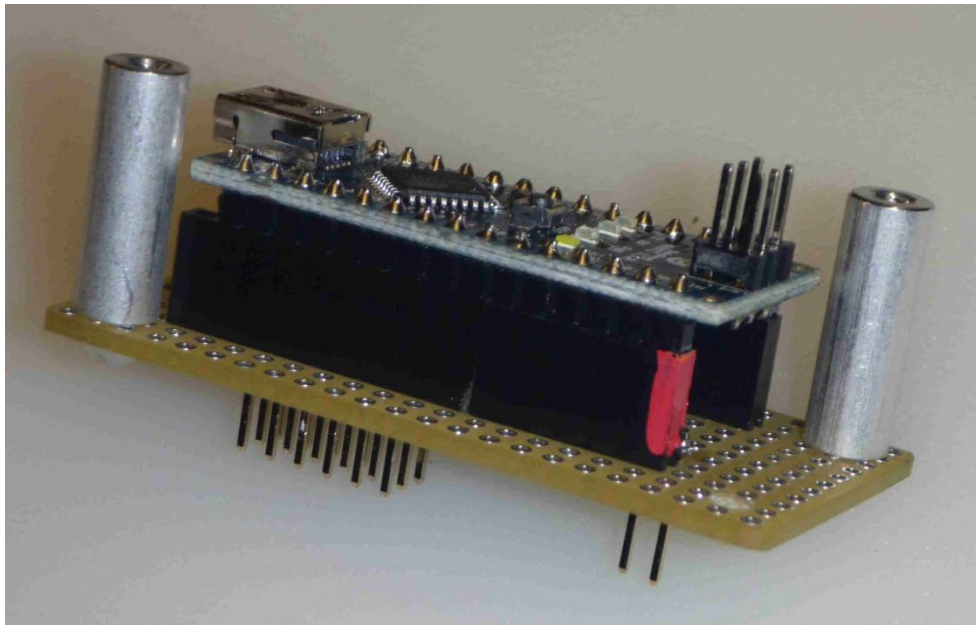
Make the top column of pins (closest to **D9**) a common ground bus. Solder one end of a bare 26 AWG wire to the **GND** pin hole near **RST** and extend the wire to the common ground pins; solder all pins. Make the center column of pins a common 5V bus. Solder one end of an insulated 26 AWG wire to the **5V** pin hole. Strip the insulation from the wire starting at the 5V bus pins and solder all pins. The bottom column of male header pins (closer to **A0**) are signal pins. Using bare 26 AWG wire or excess pin material, solder **A2**, **A1**, **A0** to the 3 pins directly opposite the contact holes. Solder three 26 AWG insulated jumpers from **D9**, **D10**, and **D11** contact holes, diagonally to the remaining 3 signal pins.







Attach two, 4-40 aluminum spacers to the top side of the prototype board. Plug the Arduino Nano into the female headers (align **VIN** with **VIN**). Attach the prototype board to the project box's clear top with flat head 4-40 screws. The prototype board should fit near the front of the box.



**Power wiring-** *Note: Non-insulated crimp type wire terminals should be soldered after crimping. Exposed solder points should be covered with heat shrink tubing. Power wiring should be 14 AWG; red for positive, black for negative.*

Install a red power wire from the positive Anderson power input connector to the input of the main fuse slot. Connect the **Supply** wire from power switch to the main power fuse output. Connect the power switch **Load** wire to the fuse block common jumper wire. Connect the black **Earth** wire from the power switch to the negative terminal strip.

The camera connector is not switched. Connect a red power wire between the positive Anderson **Camera** connector to a separate fuse slot output. Install a black power wire from the negative Anderson **Camera** connector to the negative terminal strip.

Connect the red **Supply** wire from any auxiliary switches to independent fuse outputs. Connect the red **Load** wires to positive Anderson connectors. Tie the black **Earth** wires to the negative terminal strip.

Terminate the red **Power** wires from each motor controller to a separate fuse slot output. Connect the black power wires to the negative terminal strip. Connect the red and black **Motor** wires from each motor controller to their respective Anderson motor connector.

The Arduino Nano will use 28 AWG jumpers for power. Select a red and black, 200mm, female to female jumper wire. Cut off the connector from one end of each wire. Plug the female connectors into their respective pins on the prototype board.

**Note: Reverse polarity will fatally damage the Nano. Diodes can be added to protect the board.**

Install a female blade connector on the red wire and plug it into the Nano fuse output slot. Connect the black wire to the negative terminal strip.

**Signal wiring-** Plug the female connectors of the jumper wires into the prototype board:

1. Left thumbstick- color = A0, red = +5v (center), black = GND
2. Left motor controller- color = D9, red = +5v (center), black = GND
3. Vertical potentiometer- color = A1, red = +5v (center), black = GND
4. Vertical motor controller- color = D10, red = +5v (center), black = GND
5. Right thumbstick- color = A2, red = +5v (center), black = GND
6. Right motor controller- color = D11, red = +5v (center), black = GND

**Programming- Note: Uploading a sketch to the Arduino Nano while it is connected to other devices can cause high current through the Nano and fatally damage the board. Isolate the Nano from all field devices while programming.**

Download the Arduino IDE from- <http://arduino.cc/en/Main/Software>. Setup the IDE software and libraries. Connect the Arduino Nano to a computer USB port. Add a device to your computer, and allow the OS to find and load the device drivers from the Internet. If the computer does not auto-load the drivers, go to this site: <http://www.ftdichip.com/FTDrivers.htm>.

Open the Arduino IDE application, select the correct port, then the correct board. Copy the Arduino Sketch on page 16 to the IDE software. Verify the sketch, then upload the sketch to the Arduino Nano.

**Function test-** Install ATO or ATC fuses:

1. Main power = 25 amp
2. Micro-controller = 1 amp
3. Camera = 3-5 amp
4. Auxiliary switch = 3-5 amp
5. Motor controllers = 10-15 amp

Connect the ROV control box to a 12 VDC power source (**reverse polarity WILL damage components**). Turn on the power switch:

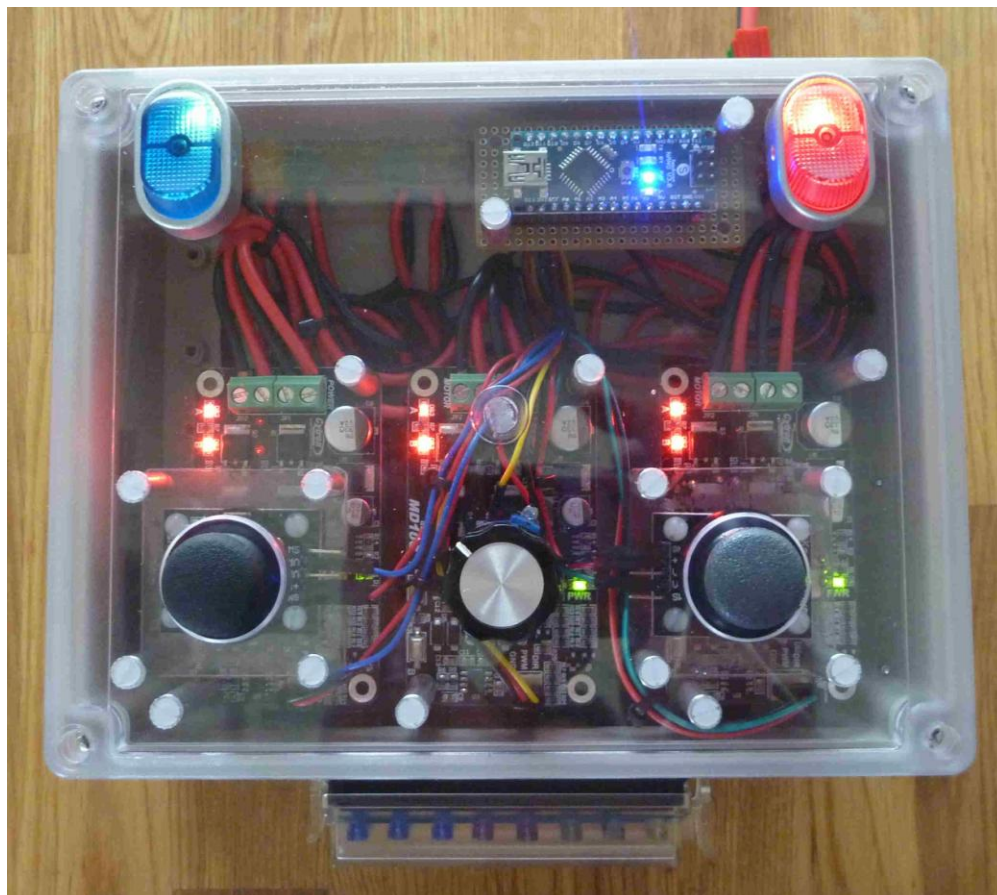
Power switch light (red) should be on,

Arduino power LED should be on,

Cytron power LEDs (green) should be on,

Cytron A and B motor LEDs (red) should be on (if thumbsticks and potentiometer are centered).

When thumbsticks are forward the Cytron A LED should be on, B LED should be off. Positive 12 VDC will be on the positive connector. Reversing the thumbsticks produces the opposite effect. When the potentiometer is turned clockwise the B LED should dim then go off near the end of the range. Again, the positive connector should be plus 12 VDC. Turning the potentiometer counter-clockwise past the center point dims then turns off the A LED.





## Arduino Sketch:

```

/*
Variable Speed ROV Thruster Controller, VSRC-1
Created by Robert L Kershaw, on 10 August 2014
This Arduino sketch was created for MATE ROV teams.
*/

// PWM outputs connected to digital pins
int RightPWMpin = 11;
int LeftPWMpin = 9;
int VerticalPWMpin = 10;

// analog inputs connected to analog pins
int RightAlpin = 2;
int LeftAlpin = 0;
int VerticalAlpin = 1;

// variable to store read values
int RightVal = 0;
int LeftVal = 0;
int VerticalVal = 0;

void setup()
{
// set digital pins as outputs
pinMode(RightPWMpin, OUTPUT);
pinMode(LeftPWMpin, OUTPUT);
pinMode(VerticalPWMpin, OUTPUT);

// set PWM timer divisors to 8 for PWM frequency of 3921.16 Hz; reduces motor 'off' squeal
// TCCR2B = Pin 11 timer
// TCCR1B = Pins 9 & 10 timer
TCCR2B = TCCR2B & B11111000 | 0x02;
TCCR1B = TCCR1B & B11111000 | 0x02;
}

void loop()
{
// read analog input pins
RightVal = analogRead(RightAlpin);
LeftVal = analogRead(LeftAlpin);
VerticalVal = analogRead(VerticalAlpin);

// analogRead values from 0 to 1023 converted to
// analogWrite values from 0 to 255
analogWrite(RightPWMpin, RightVal / 4);
analogWrite(LeftPWMpin, LeftVal / 4);
analogWrite(VerticalPWMpin, VerticalVal / 4);

// delay next loop by 10 ms
delay(10);
}

```

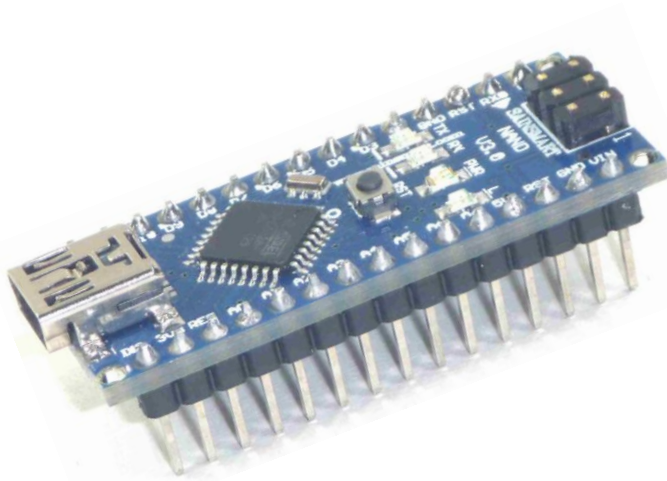


## Suppliers:

[www.amazon.com](http://www.amazon.com)  
[www.andymark.com](http://www.andymark.com)  
<http://arduino.cc/en/Main/HomePage>  
[www.cytron.com.my](http://www.cytron.com.my)  
[www.frys.com](http://www.frys.com)  
[www.mcmaster.com](http://www.mcmaster.com)  
[www.oreillyauto.com](http://www.oreillyauto.com)  
[www.powerwerx.com](http://www.powerwerx.com)  
[www.robotshop.com](http://www.robotshop.com)

## Materials:

- 1.....SainSmart Nano ATmega328 (Arduino Clone), 5v, .....\$14.00 ea  
6 PWM, 8 AI, 8 DIO, 7-12 VDC, USB A to USB mini-B cable  
[http://www.amazon.com/gp/product/B00761NDHI/ref=oh\\_aui\\_detailpage\\_o03\\_s00?ie=UTF8&psc=1](http://www.amazon.com/gp/product/B00761NDHI/ref=oh_aui_detailpage_o03_s00?ie=UTF8&psc=1)  
Guide:  
<http://arduino.cc/en/Main/ArduinoBoardNano>



- 3.....Cytron MD10C Motor Speed Controller,#RB-Cyt-132.....\$16.50 ea  
5-25 VDC, 13 A, PWM input

[www.robotshop.com/en/cytron-13a-single-dc-motor-controller.html](http://www.robotshop.com/en/cytron-13a-single-dc-motor-controller.html)

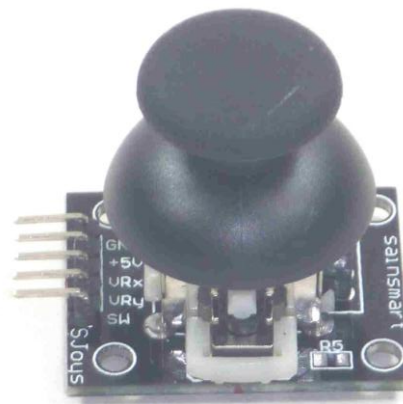
Manual:

<https://docs.google.com/document/d/1rgQzn-nWn-qcWNnHjDZvIYqUrdCeBQQxXA-TU3BF0AQ/edit?pli=1>



- 2.....Thumbsticks, 2 axis, 5K ohm, N.O. switch.....\$ 8.25 ea

[www.amazon.com/Zitrades-Joystick-Sensor-Arduino-arduino/dp/B00GWG7BIK/ref=pd\\_sim\\_sbs\\_pc\\_1?ie=UTF8&refRID=1KYP8KJPFZ91C8SAY271](http://www.amazon.com/Zitrades-Joystick-Sensor-Arduino-arduino/dp/B00GWG7BIK/ref=pd_sim_sbs_pc_1?ie=UTF8&refRID=1KYP8KJPFZ91C8SAY271)



1.....Potentiometer, 5K ohm, 3 turn, Bourns #3543S-1-502L .....\$25.00 ea  
[www.amazon.com/gp/product/B00E4WGB58/ref=gno\\_cart\\_title\\_0?ie=UTF8&psc=1&smid=A3O3SSGGJLKX15](http://www.amazon.com/gp/product/B00E4WGB58/ref=gno_cart_title_0?ie=UTF8&psc=1&smid=A3O3SSGGJLKX15)



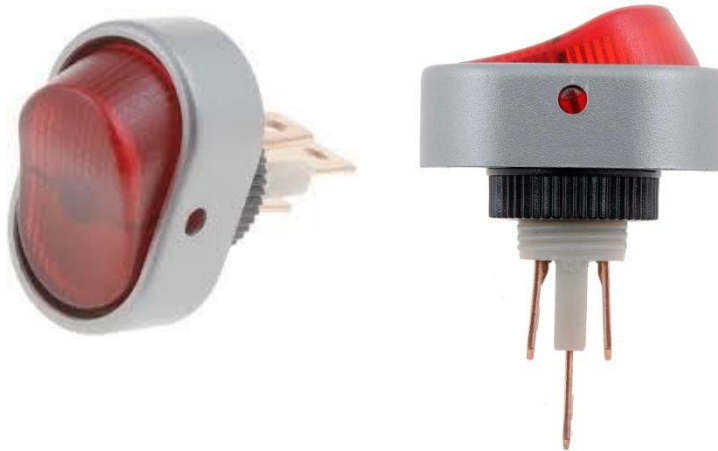
1.....Potentiometer, 5K ohm, 1 turn, Bourns #3852A-282-502AL.....\$11.56 ea  
[http://www.amazon.com/BOURNS-3852A-282-502AL-POTENTIOMETER-CERMET-5KOHM/dp/B00DECPTTS/ref=sr\\_1\\_1?ie=UTF8&qid=1409601656&sr=8-1&keywords=bourns+3852a282502al](http://www.amazon.com/BOURNS-3852A-282-502AL-POTENTIOMETER-CERMET-5KOHM/dp/B00DECPTTS/ref=sr_1_1?ie=UTF8&qid=1409601656&sr=8-1&keywords=bourns+3852a282502al)



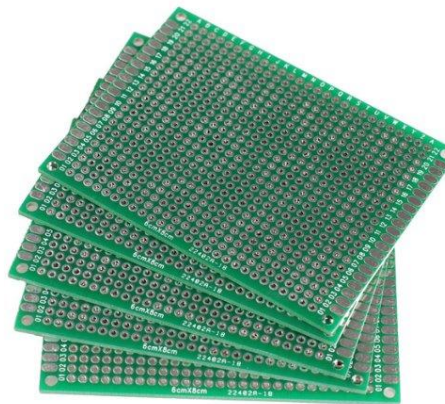
1.....Potentiometer Knob, 6 mm x 24 mm.....\$ 2.25 ea  
[www.amazon.com/Black-Silver-Potentiometer-Rotary-Knobs/dp/B008LT47C4/ref=sr\\_1\\_8?ie=UTF8&qid=1403935535&sr=8-8&keywords=6mm+potentiometer+knob](http://www.amazon.com/Black-Silver-Potentiometer-Rotary-Knobs/dp/B008LT47C4/ref=sr_1_8?ie=UTF8&qid=1403935535&sr=8-8&keywords=6mm+potentiometer+knob)



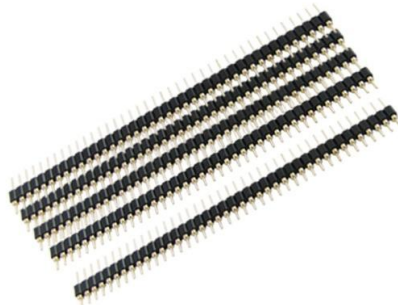
- 1.....Power Switch, 30A, lighted.....\$ 7.99 ea  
[http://www.oreillyauto.com/site/c/detail/CTI0/84870/N0945.oap?ck=Search\\_switches+-+universal+-+rocker\\_-1\\_509&keyword=switches+-+universal+-+rocker](http://www.oreillyauto.com/site/c/detail/CTI0/84870/N0945.oap?ck=Search_switches+-+universal+-+rocker_-1_509&keyword=switches+-+universal+-+rocker)



- 1.....Vktech Prototype Board, 0.1 inch grid, 6 x 8 cm.....\$ 5.00 /5  
[http://www.amazon.com/Vktech-Double-Side-Prototype-Universal-Printed/dp/B00COGNWXA/ref=sr\\_1\\_2?s=electronics&ie=UTF8&qid=1408079034&sr=1-2&keywords=perf+board](http://www.amazon.com/Vktech-Double-Side-Prototype-Universal-Printed/dp/B00COGNWXA/ref=sr_1_2?s=electronics&ie=UTF8&qid=1408079034&sr=1-2&keywords=perf+board)



- 1.....Straight Header Connector, 40 Male, 0.1 inch, #2068954.....\$ 2.29 /5  
[http://www.frys.com/product/2068954?site=sr:SEARCH:MAIN\\_RSLT\\_PG](http://www.frys.com/product/2068954?site=sr:SEARCH:MAIN_RSLT_PG)





1.....Arduino Header Connector, 32 Female, 0.1 inch, #7726828.....\$ 1.79 ea

[http://www.frys.com/product/7726828?source=google&gclid=Cj0KEQjw7IWgBRCjv8Cv4vfC3ckBEiQAE7nvRxMII\\_Nzqm1uGbTlv\\_pJDsCClujBlvwWFjbojaLGBuqcaAhkx8P8HAQ](http://www.frys.com/product/7726828?source=google&gclid=Cj0KEQjw7IWgBRCjv8Cv4vfC3ckBEiQAE7nvRxMII_Nzqm1uGbTlv_pJDsCClujBlvwWFjbojaLGBuqcaAhkx8P8HAQ)



<http://www.mcmaster.com/#standard-threaded-standoffs/=tluddc>



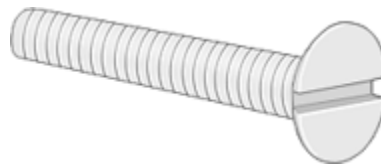
10.....Round Aluminum Standoff, 4-40 x 0.75 inch, #93330A390.....\$ .44 ea

10.....Round Aluminum Standoff, 4-40 x 1.0 inch, #93330A420.....\$ .50 ea

10.....Round Aluminum Standoff, 4-40 x 1.25 inch, #93330A430.....\$ 1.04 ea

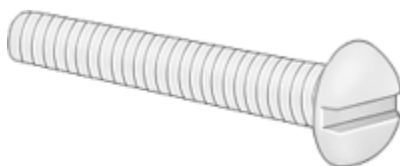
20.....Nylon Machine Screw, flathead, 4-40 x 0.5 inch, #94605A110.....\$ 5.25 /100

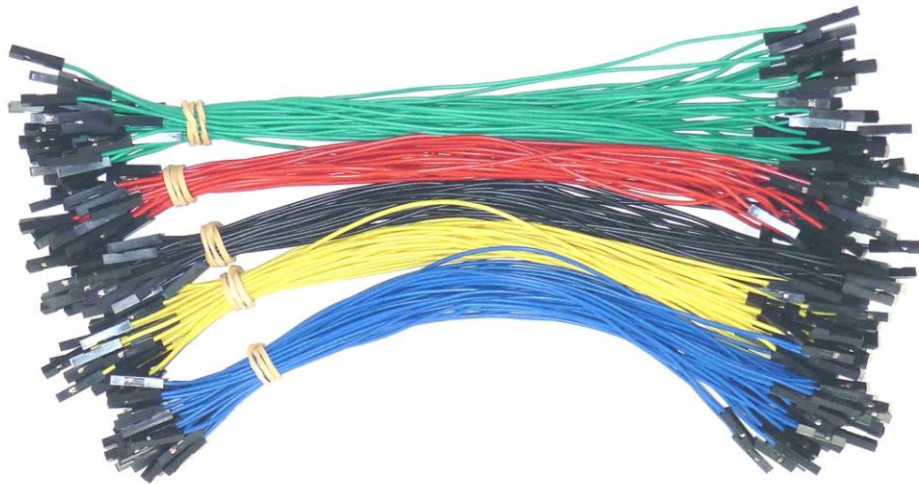
<http://www.mcmaster.com/#machine-screws/=tluejf>



20.....Nylon Machine Screw, roundhead, 4-40 x 0.5 inch, #94609A110.....\$ 5.25 /100

<http://www.mcmaster.com/#machine-screws/=tlufte>





- 1.....Jumper Assortment, 12" (300mm), 40 pin, Female – Female.....\$ 3.89 ea  
[http://www.amazon.com/Water-Wood-Female-Breadboard-Arduino/dp/B00KR9VO9K/ref=sr\\_1\\_12?ie=UTF8&qid=1409421861&sr=8-12&keywords=female+female+jumper+wires+300%2C%2C](http://www.amazon.com/Water-Wood-Female-Breadboard-Arduino/dp/B00KR9VO9K/ref=sr_1_12?ie=UTF8&qid=1409421861&sr=8-12&keywords=female+female+jumper+wires+300%2C%2C)
- 100.....Jumper Assortment, 8" (200mm), Female – Female.....\$ 8.96 /100  
[http://www.amazon.com/sunkee-100pcs-female-jumper-Arduino/dp/B00AYCON8Y/ref=sr\\_1\\_4?ie=UTF8&qid=1409420489&sr=8-4&keywords=female-female+jumper+wires](http://www.amazon.com/sunkee-100pcs-female-jumper-Arduino/dp/B00AYCON8Y/ref=sr_1_4?ie=UTF8&qid=1409420489&sr=8-4&keywords=female-female+jumper+wires)
- 100.....Jumper Assortment, 6" (150mm), Female – Female.....\$19.95 /100  
[http://www.amazon.com/Jumper-wires-premium-15cm-pack/dp/B00A6YFMTE/ref=sr\\_1\\_13?ie=UTF8&qid=1409421442&sr=8-13&keywords=female+female+jumper+wires](http://www.amazon.com/Jumper-wires-premium-15cm-pack/dp/B00A6YFMTE/ref=sr_1_13?ie=UTF8&qid=1409421442&sr=8-13&keywords=female+female+jumper+wires)
- 1.....Hookup Wire, 25', 14 AWG, Red, #ST14-25RD.....\$12.85 ea  
[http://www.amazon.com/Shaxon-ST14-25RD-Stranded-Copper-25-Feet/dp/B00IN83AAS/ref=sr\\_1\\_21?ie=UTF8&qid=1406931976&sr=8-21&keywords=hookup+wire+14+awg+25+feet](http://www.amazon.com/Shaxon-ST14-25RD-Stranded-Copper-25-Feet/dp/B00IN83AAS/ref=sr_1_21?ie=UTF8&qid=1406931976&sr=8-21&keywords=hookup+wire+14+awg+25+feet)
- 1.....Hookup Wire, 25', 14 AWG, Black, #ST14-25BK.....\$12.60 ea  
[http://www.amazon.com/Shaxon-ST14-25BK-25-Feet-Stranded-Copper/dp/B00IN837RO/ref=sr\\_1\\_29?ie=UTF8&qid=1406932152&sr=8-29&keywords=hookup+wire+14+awg+25+feet](http://www.amazon.com/Shaxon-ST14-25BK-25-Feet-Stranded-Copper/dp/B00IN837RO/ref=sr_1_29?ie=UTF8&qid=1406932152&sr=8-29&keywords=hookup+wire+14+awg+25+feet)

- 1.....Dual Row 12 Position Screw Terminal Barrier Block, #B00A8VIDNW.....\$5.91 ea

[http://www.amazon.com/Postions-Screw-Terminal-Barrier-Strip/dp/B00A8VIDNW/ref=sr\\_1\\_14?ie=UTF8&qid=1417392433&sr=8-14&keywords=plastic+wire+terminal+strip](http://www.amazon.com/Postions-Screw-Terminal-Barrier-Strip/dp/B00A8VIDNW/ref=sr_1_14?ie=UTF8&qid=1417392433&sr=8-14&keywords=plastic+wire+terminal+strip)



- 1.....Project Box, Jameco 203-112F-1-R, 7" x 5.8" x 3.0", #141859.....\$14.95 ea

[www.amazon.com/gp/product/B00B886DCW/ref=ox\\_sc\\_act\\_title\\_1?ie=UTF8&psc=1&smid=A3O3SSGGJLKX15](http://www.amazon.com/gp/product/B00B886DCW/ref=ox_sc_act_title_1?ie=UTF8&psc=1&smid=A3O3SSGGJLKX15)



- 1.....Panel Mount Fuse Block, 8 position.....\$ 9.77 ea

[http://www.amazon.com/HELLA-H84960101-8-Way-Axial-Single/dp/B000VU9D1Q/ref=sr\\_1\\_2?s=automotive&ie=UTF8&qid=1409416124&sr=1-2&keywords=8+way+single+fuse+block](http://www.amazon.com/HELLA-H84960101-8-Way-Axial-Single/dp/B000VU9D1Q/ref=sr_1_2?s=automotive&ie=UTF8&qid=1409416124&sr=1-2&keywords=8+way+single+fuse+block)



- 12....Anderson Powerpole Set, 45 amp, #PP45-10.....\$14.99 /10

<http://www.powerwerx.com/anderson-powerpoles/powerpole-sets/45-amp-red-black-anderson-powerpole-sets.html>



