PufferFish ROV Kit Assembly Instructions

1. Assembling the Frame
   Time Required: 1 to 5 hours depending upon the complexity of the frame.
   Tools Required: PVC cutter, ruler, pencil, sketch pad, or engineering notebook.
   Tools recommended: Drill and drill bits if you decide to use sheet metal screws.
   Parts Required: ½” PVC pipe (10-20 feet depending on ROV size), PVC connectors (20-30 depending on complexity) such as Tee’s, Elbows, and Crosses etc.

The frame can be fairly simple or involve a bit of experimenting. We recommend taking your time to come up with a design you are happy with. Sketch out ideas! If you want to get fancy, you can run your wires inside the PVC pipe for a nice clean look. You can even purchase colored PVC at http://www.simplifiedbuilding.com/blog/color-furniture-grade-pvc-fittings-now-available/ (this is a special order and a bit more expensive than white PVC – see Photo 1).

![Photo 1](image1)

The PufferFish comes with PVC motor mounts, which are 1 ¼ x 1 ¼ x ½ inch reducing Tee’s with the ends cut off (Photo 2). The Johnson bilge pump motor will fit nice and snug into the motor mount. You will need to remove the sticker on the motor to get a good fit. This motor mount makes it very easy to attach the motors to a PVC frame.

Here are a few guiding principles to help steer the frame design process:

I. Bigger is not necessarily better. Think about the tasks that the ROV needs to accomplish and build with that in mind. Most ROVs are built for a mission or series of missions; see the MATE ROV competition guidelines for examples. Some questions to ask – What type of tools and/or sensors might you want to add to your ROV. Will your ROV need to fit in tight or dark spaces, etc.?

II. Water will need to flow freely in and out of your frame. Using PVC Tee’s as corner pieces can make this easy (Photo 3); otherwise you might need to drill a lot of holes in your frame to accomplish the same thing.

III. Think about stability. Some designs will be very stable (not likely to roll belly up like a dead fish) and others may act like Spinner Dolphins. Look at photos of commercial ROVs and discuss their designs and how they relate to stability in the water (Photo 4).
IV. Neutral buoyancy is optimal (i.e. your ROV doesn’t float, doesn’t sink). If you are working with foam (Photo 5) or material that can compress under pressure (can you squeeze it in your hand?) and you want to fly your ROV to the bottom of a deep pool or use it in the ocean or a lake, you could end up with a mini anchor if you are not careful (i.e. your ROV may be too heavy to come up under its own power). Experimenting with foam is great and easy. Once you have a design you are happy with, think about using closed containers or PVC pipe sealed off with end caps to create rigid, non-compressible buoyancy (Photo 6).

V. Think about the placement of your buoyancy. Would you ever jump in the ocean with a life jacket around your feet? Motors are heavy in the water and foam is light. Think of how you might what to position these materials on your ROV for maximum stability.

VI. PVC joints can be secured by using PVC cement (but you will never get the PVC apart again, so make sure your frame is how you want it to be!) PVC cement also makes the joints brittle and more likely to crack. Another way to secure PVC joints is to use stainless steel sheet metal screws\(^1\), which allows you to take the frame apart and reassemble it (Photo 7). Sheet metal screws require pre-drilling at the joints before adding the screws.

\(^1\) 18-8 stainless steel, Phillips, No. 6 Size, 1/4" Length
2. Assembling the control box

Time Required: 1 hour

Tools Required: Soldering iron, solder (we recommend 60/40 Rosin Core Solder in .032” (0.08mm) diameter), wire cutters, wire strippers, utility knife, Phillips screwdriver, ruler with metric scale.

Tools recommended: Solder sucker to remove hot solder if you make a mistake

Parts Required: Pre-drilled project box, Printed Circuit Board (PCB), components, and wires (listed below).

The following PufferFish components need to be soldered to the PCB:

a. Resistors (4)
b. LEDs (4)
c. Switches (3)
d. Power wire: 2 solder joints
e. Motor wire: 6 solder joints

If you are unfamiliar with soldering, watch some videos on how to solder and how to tin your soldering iron. One of the problems that can occur with cheap soldering irons is that they may not get hot enough or they may get too hot. Soldering should be fairly straight forward if you have a good soldering iron. Read the reviews on soldering irons before you buy. MATE also sells practice mini-printed circuit boards. If you are doing this activity with a number of people who have not soldered before, we recommend soldering the practice board first. The MAKE Electronics book gives a good overview of soldering in Chapter 3 and MATE has a nice soldering PPT at 

When soldering all of the components, it is important that they do not move while you are soldering. Use electrical tape to hold the components in place if they are not secure. This is especially important for the switches. With six electrical connections you do not want to solder them in cockeyed!

Note: The front of the board or PCB has printed words; the back of the board does not. You insert the components on the front of the board and solder on the back. However the wires for power to/from the battery and to/from the motors are fed through the back and soldered on the front of the board.

Solder the components and wires in the following order:

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A. **Resistors (4): Orientation DOES NOT matter.** Bend resistor leads (wires on either side of resistor) and insert the two ends into any of the R1-4 holes (Photo 8). Splay the leads as they come through the back of the board to hold the resistor in place (Photo 9). Solder the leads; the solder joints should look like mini, shiny, silver Hersey Kisses on the back of the board. Clip the ends of the leads off (Photo 10). Solder all 4 resistors into place.

B. Learning to read the resistor code is helpful. *Do you know why we need to use resistors for the LEDs? How many Ohm’s of resistance do these resistors provide?*

C. **LEDs (4): Orientation DOES matter.** Look carefully at the LED; it is almost circular, but if you look closely, one side is flat. Look at the LED symbol on the PCB; one side is flat. Insert the LED so the flat sides match (Photo 11) and solder the leads. These are special bi-polar LEDs. The color will change with polarity change.

D. **Switches (3): Orientation DOES NOT matter.** These are double-pole, double-throw (DPDT) toggle switches. DPDT switches allow the motors to run in forward and reverse by switching the direction of electricity flowing through the DC motors (and thereby reversing the rotation of the motor.) Remove the lid from the box, invert it and set it on top of the box-bottom as shown (Photo 12). Tape the lid to the box-bottom to create a stable platform. Insert the toggle of the switches through the holes on the lid so the six pins on each switch are pointing up. Place your PCB over the switch pins bottom up (Photo 13). Solder the switches in place. When you are finished, all the space between the switch pin and the board should be filled with solder (Photo 14). Remove the tape and take the board out of the lid. See https://learn.sparkfun.com/tutorials/switch-basics/poles-and-throws-open-and-closed for a nice overview of switches.
E. **Stress relief connectors:** There are two stress relief connectors; each has 3 parts. The nut will be on the inside of the box and the other two pieces will be on the outside of the box. The box-bottom is keyed so in order to avoid a cable cross-over later, put the shorter relief on the side with the indent on the screw-socket in the box bottom and longer one on the side with the tab on the side of the screw-socket (Photo 15). Connect the nut to the connector so that they are fastened to the box (Photo 16a). Feed the red/black power wire through the shorter connector and the gray 18/6 cable through the longer connector (Photo 16b). Secure the cables with ~50 cm of cable through the box bottom by turning the base of the connector; don’t make too tight at this time, the cables should feed through with slight resistance.

F. **Power cable:** Your power cable should be fed through the stress relief connector in the control box at this point (see D above). Look for the PWR_IN on the PCB. The red (positive) wire is soldered to the +12V hole and the black (negative) wire is soldered to the GND (or Ground) (Photo 17). Separate the two wires 6 mm from the end and strip 4 mm off of the end of each wire. Take one wire and bend the wire 3 mm from the wire at a right angle and feed the wire through the proper hole and solder. Do the same for the other wire. It is important that your wires and solder DO NOT exceed the footprint of the silver metal pads otherwise you will short out the system if they touch (Photo 17).

G. **Check that all LEDs and switches work:** Connect the power wire to a power source. If you have a 4 AA battery holder you can use alligator leads to attach the battery leads to the power wire. Does the power LED turn on? Is it green? If it is red something is backwards. Do your switches work? As you move the switch towards the top of the board the LED should turn green (forward); as you move the switch towards the bottom of the board the LED should turn red (reverse). Test all the switches and LEDs. If the LED is red, not green, when you move the switch towards the top of the board, something is backwards.

H. **Motor cable:** Your 18/6 gray motor cable should be fed through the stress relief connector in the control box at this point (see D above). Carefully use a utility knife to cut open part of the gray sheath, be careful not to nick or cut any of the wires inside the sheath. All of the wires are surrounded by an aluminum foil sheath; tear it away. You should see 6 stranded copper wires enveloped in 6 different colored sheathes. You should also see a metal silver wire and a feathery string. The silver wire is used to help split open the gray sheath as you pull down on it. Remove about 5 cm of gray sheath. Trim off the gray sheath, the aluminum foil, the silver wire, and string. Strip 4 mm of insulation off of each of the colored wires (Photo 18). Shorten center wire pair if needed.
It is important to make sure the control box wiring matches the motor wiring. Here is an example of how you might want to wire the controls.

<table>
<thead>
<tr>
<th>Motor / Switch</th>
<th>MTR1 Left Switch</th>
<th>MTR3 Center Switch</th>
<th>MTR2 Right Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire / Pad Pairing</td>
<td>Green (+) = Pad A White (-) = Pad B</td>
<td>Brown (+) = Pad A Black (-) = Pad B</td>
<td>Red (+) = Pad A Blue (-) = Pad B</td>
</tr>
</tbody>
</table>

Solder the wires to the board following the key above or make up your own. Just make sure you have one! This is what it should look like from the back of the board when you are done (Photo 18b).

I. **Close up the control box.** Mount the box-top to the switches by aligning it with the holes and securing them with washers and nuts. Put the smooth round washer over the switch first with the very small tap bent up away from the lid. Put the corrugated washer on next followed by the nut. Make the nut snug using your hand. Screw the rubber boot on last. Then push the box “screws” (large plastic ones that match the color of the box-bottom) through the top holes. They are sprung so then need a bit of pushing. Then adjust the motor and power cables by pulling on them from outside the box so you have just a little cable in the box. Carefully put the lid on the box so the switches pop through the three holes on the clear lid. Finally, tighten the box-screws *gently* with a screwdriver.

3. **Adding the Fuse holder to the power wire and adding the Banana Plugs**

*Steps 3 and 4 will require you to splice and seal wires. Please review the following PPT.*


**Time required:** 30 minutes

**Tools required:** Wire cutters, wire strippers, soldering iron, solder, hot glue gun

**Parts required:** Power wire, blade fuse holder, 15 amp fuse, heat shrink, hot glue, banana plugs

Your red and black power wires should be soldered to your control board. The wire should run through the stress relief connector and out through the bottom of the box.
A. At the far end of the power wire not attached to the board, separate the red and black wire for about 28 cm.
B. Cut the blade fuse wires so the total length is 25 cm with an equal amount of wire on each side of the fuse holder.
C. Cut the red wire power wire so it is 25 cm shorter than the black wire.
D. Strip 25 mm of insulation off of each end of the blade fuse holder and 25 mm of the end of the red wire.
E. Slip 50 mm of red heat shrink tubing over the wire then twist the wires together (Photo 19 & 20).
F. Solder the wires together and inspect.
G. Cover one side of the joint with hot melt glue, let cool, then cover the other side with hot melt glue (Photo 21). Let cool.
H. Slide the heat shrink tubing over the solder joint. (Make sure it is large enough to go over the glue as well as joint.)
I. Completely heat the joint. You will see the tubing form over the rough, hot melted glue then the tubing will melt and reform the glue around the wire. The final splice should be completely smooth (Photo 22).
J. Check to see that the red and black wires are even in length. If not, trim them to make even.
K. Strip 25 mm off the end of the black wire and the red wire with the blade fuse holder.
L. Matching the red plug with the red wire, unscrew the banana plug and insert wire through the bottom part of the banana plug and wrap any excess around the plug in the clockwise direction (same as the way the cover screws on).
M. Screw the banana plug back together. Make sure the wire is secure.
N. Repeat for the black wire.
O. Insert the 15 amp fuse into the fuse blade holder.

Remember to put heat shrink on the wire before you join the wires!
4. Adding the propeller to the motors

*Time required:* 30 minutes  
*Tools required:* Loctite or some other thread adhesive, small hex wrench (it is in the kit), Phillips head screwdriver  
*Parts required:* Motors (3), propellers (3), screws (3), propeller adapters with small hex socket screw (3)

The motors should be mounted in the motor mounts at this time (See Step 1).

A. Thread the large screw through the propeller so the indented end of the propeller faces the screw head (Photo 23).

B. Add a drop of Loctite to the end of the screw. Insert the screw into the back of the propeller adapter (the side further away from the small hex socket screw). Use a screwdriver to tighten the screw into the propeller adapter. (Photo 23).

C. Remove the impeller from the motor using a slotted screwdriver to pop it off (Photo 24).

D. Remove the small hex socket screw that is in the side of the propeller adapter with the small hex wrench. Slide the propeller adapter onto the motor shaft. Align the propeller adapter so the small hex socket screw is oriented against the flat side of the motor shaft (the small hex socket screw should tighten down against the flat side of the motor shaft). Apply a drop of Loctite near the tip of the screw and screw back into the propeller adapter.

E. Make sure the propeller assembly is snug (Photo 25). Photo 25 is showing the motor wire entering the the motor mount through a 3/8” drilled hole. The motor mount has been spray painted with paint for plastics (Home Depot).

5. Wiring the motors to the 18/6 cable.

*Time required:* 1 hour  
*Tools required:* Wire cutters, wire strippers, soldering iron, solder, hot glue gun  
*Parts required:* 18/6 gray cable, motors, heat shrink, hot glue

Your frame should be assembled with the motors mounted to the frame and the propeller attached to the motors. The control box should be wired. Now you need to match the appropriate switch wire pair to the appropriate motor. On the motors the brown wire is positive and the black wire is negative.
A. Check the thrust direction of the motors using your 4 AA batteries and alligator leads or another power source. When connected with the brown wire to positive and black wire to negative, will the motor give you a forward thrust for the right and left motor? And an upward thrust for the up/down motor? Use a little strip of paper taped to a stick to observe “wind” direction created by the motor. Make sure a positive to positive wire connection creates the direction of motion that you need for your ROV design. You can always reverse the wires if your ROV design requires it.

B. Slip the 50 mm piece of black heat shrink over the motor cable.

C. Split the motor cable for 5 cm and trim the foil, silver wire and thread.

D. Using the wiring procedures in step 3, strip 25 mm of insulation off of every wire to be spliced.

E. **Don’t forget to** slide the 50 mm of red heat shrink over each wire connection before you twist the wires together.

F. Solder the wire connections, apply hot glue to both sides of the connection, move the heat shrink into place, and apply heat to completely shrink it and create a smooth connection.

G. Test all the control boxes switches to make sure your motors are operating as they should.

H. If something is reversed, fix it now by cutting the wire joint off and starting again with the correct wiring pairing.

I. Once you have all the wires connected and TESTED hot glue the motor cable where the 6 wires start to separate at the base of where the gray sheath was removed. [It is possible for water to wick up the cable and end up in the control box. This procedure will help prevent that.]

J. Slide the black heat shrink over the hot glue joint and apply heat until the joint is smooth.

6. **Adding tools and sensors to the ROV**

   If you are not adding tools or sensors at this time proceed to step 7.

   **Time required:** 30 minutes to 2 hours depending upon the complexity

   **Tools required:** pool or testing tank

   **Parts required:** assembled ROV, tools or sensors

The tools and sensors you add will depend upon the tasks you would like your ROV to perform. Common household items can become useful underwater tools. Cameras, especially waterproof backup cameras for cars, are quite good and inexpensive. Make sure you read the notes on the MATE website about building camera filters before you add a camera since you can potentially destroy it with voltage spike as you switch your motors on and off. See [http://www.marinetech.org/triggerfish-instructions-and-curriculum-2/](http://www.marinetech.org/triggerfish-instructions-and-curriculum-2/) read #8.
Above left is a spray painted kitty litter scoop (**Photo 26**). Above right is a wide angle, waterproof backup camera that sells for about $13 on Amazon (**Photo 27**).

7. Adjusting the buoyancy on the ROV

   **Time required:** 30 minutes to 2 hours depending upon the complexity

   **Tools required:** Pool or testing tank

   **Parts required:** Assembled ROV, flotation material.

**Before you put your ROV in the water, secure the gray motor cable to the ROV frame with a zip tie so you are not tugging on your solder joints.** If you are adding tools or sensors, you should do that before you adjust your buoyancy. Again, neutral buoyancy is optimal (your ROV doesn’t float, doesn’t sink). If you are working with foam or material that can compress under pressure (i.e. you can squeeze it in your hand) and you want to fly your ROV to the bottom of a deep pool or use it in the ocean or a lake, you could end up with a mini anchor (i.e. your ROV may be too heavy to come up under its own power). Experimenting with insulation foam or water noodles is easy. Once you have a design you are happy with, think about using closed containers or PVC pipe sealed off with end caps to create rigid, non-compressible buoyancy (see step 1.)

8. Piloting your ROV

   **Time required:** Lots of time

   **Tools required:** Pool or testing tank

   **Parts required:** Assembled ROV that is neutrally buoyant, power source.

There are many different 12 volt DC power sources that you can use: a car battery, a compact rechargeable 12 volt battery, or a car power pack for jump starting a car. We like car power packs because they are inexpensive (about $50 Harbor Freight), they have a nice handle for carrying, and they are easy to recharge (plus if you and a dead car battery...) (**Photo 28**). The power packs have cigarette ports for power. Depending on the power source that you use, you may need an adapter (**Photo 29**). Radio Shack has a variety of power adapters.
If you plan to compete with your ROV, build props and practice, practice, practice! This will give you a tremendous amount of insight into how you may want to modify your ROV now or for future competitions.

To learn more about the learning objectives associate with building the PufferFish and participating in the ROV competition please see:


To order PufferFish Kits please go to http://www.marinetech.org/pufferfish/

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