



Introduction to Remotely Operated Vehicles (ROVs)

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Overview

Today you will learn about Remotely Operated Vehicles (ROVs). ROVs are unmanned vehicles, which are operated by a person aboard a vessel or on land. They are connected to the controls by a cable that carries electrical power. You will build your ROV using a ROV-in-a-Bag kit. The kit consists of easy-to-assemble parts that make up the electrical and structural parts of a ROV.

Ocean and marine engineers have been building ROVs since the 1950s for a variety of science, military, and salvage missions. These missions include photographing deep-sea animals, recovering torpedoes from the ocean floor, servicing underwater oil & gas structures, and locating historic ship-wrecks. With connections to many areas of science, technology, and engineering, ROVs are used in a variety of exciting career options.

These Learning Cards were designed as a step-by-step guide to building your ROV. The steps in green font have been completed before this workshop to shorten the time it will take you to complete the build. As you work your way through the Learning Cards, you should still read through these steps to understand the overall electrical, mechanical, and structural components of the ROV. With the ROV partially built to this point, we estimate it will take you 4 hours to build an ROV, test it, make adjustments, and accomplish your mission.

We encourage you to host a similar *Introduction to ROVs* workshop in your region, to train local informal science educators. In turn, these educators can deliver afterschool ROV programs to middle school girls as a step toward understanding the exciting and diverse world of underwater robotics. Educators and girls can also get involved in regional and national ROV competitions (contact information on pg. 27).

By building their own ROVs, girls will gain valuable engineering design skills, while learning basic physics concepts, problem solving, teamwork, and technical procedures. Who knows? Maybe one of these girls will become excited about becoming an engineer one day!

Happy ROV-ing!

Mission

Your mission, should you choose to accept it, is twofold:

1. Navigate your ROV through a shipwreck.
2. Retrieve some of the ship's treasures.

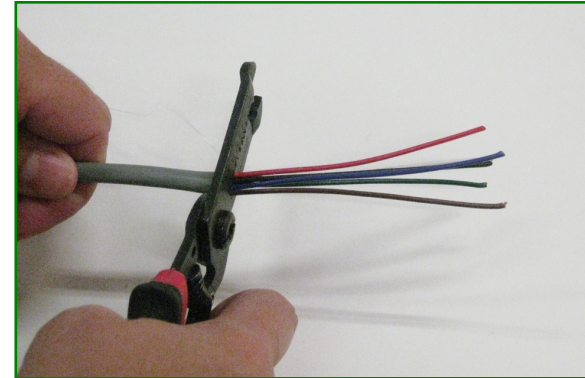
Switches

The three switches in the control box allow the operator to control the three motors in the ROV. Two switches control horizontal (right/left) motions and one switch controls vertical (up/down) motions. We will start by making wires to connect the switches. You may refer to the wiring diagram on page 11.

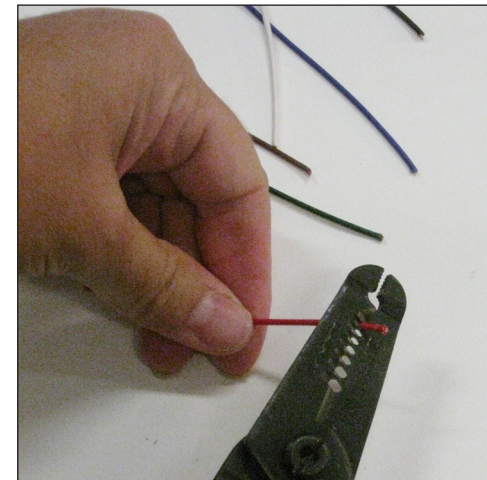
1. Take the wire stripper and strip 7 cm (3 inches) of grey covering off of the grey cable. (Tip: Nick the grey sheath with a blade, then twist the grey sheath off).



2. Use the wire stripper to strip 1 cm (less than ½ inch) off the ends of ALL SIX colored wires (green, red, blue, brown, white, black).



3. Use the wire cutter to cut off the exposed colored wires. (You may discard the silver aluminum covering and the silver wire.) Strip off the other ends of the six colored wires.

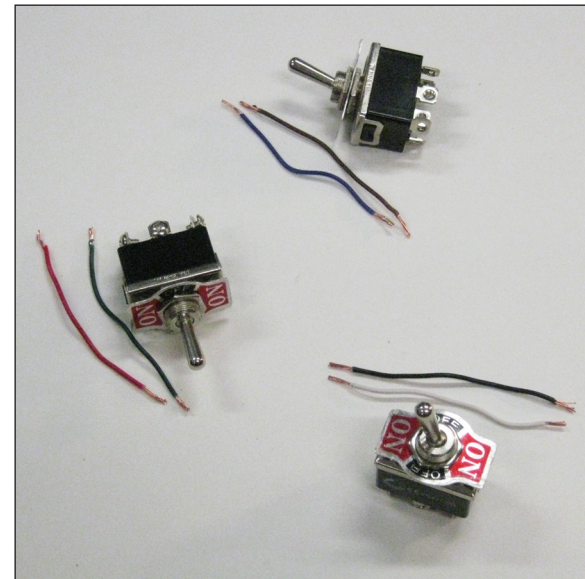


4. Use the screwdriver to remove the six little screws from the back of the three switches. Keep the screws in a plastic baggy; you never know where they might come in handy!

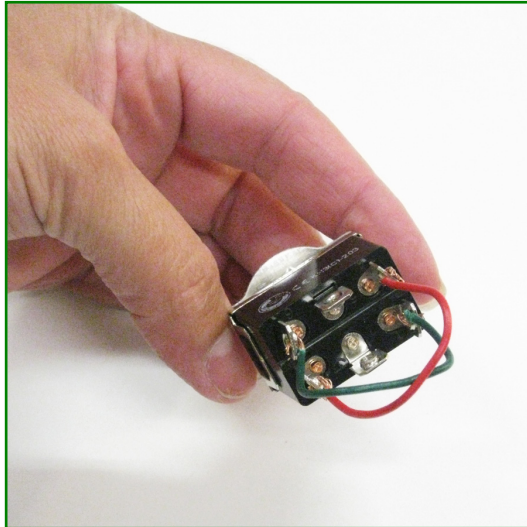


5. Gather the three switches. Pair two of the wires with each switch. It is important to pair the wires in a designated way, so that if help is needed later on, workshop staff can help you troubleshoot. Here's how to remember the color pairings:

- Red/Green: Red is for the “right” handed motor
- Blue/Brown: Brown rhymes with “down” for the up/down motor
- White/Black: It is what is “left” over for the left handed motor



6. Take the 3-inch red wire and push one of the stripped ends of the wire through one of the corner holes where you just removed the screw from (always push from the inside out); push the other end of the red wire through the opposite (diagonally) hole; wrap the exposed ends of the wires over the outside of the hole to secure the wire to the switch. Later we will be soldering these connections to permanently secure the connection.



7. Take the 3-inch green wire and repeat on the same switch, so the green wire crosses the red wire in an “X” pattern.

8. Repeat steps 6 and 7 with the second switch, using the blue and brown wires.
9. Repeat steps 6 and 7 with the third switch, using the white and black wires.



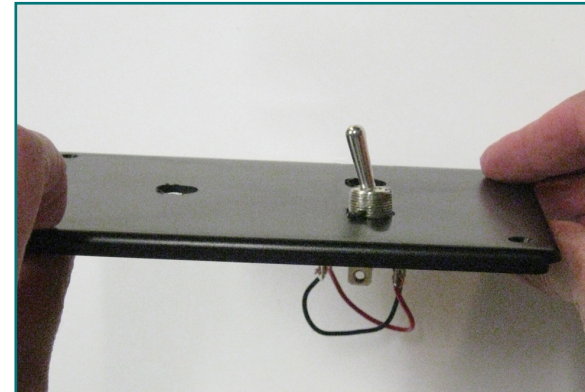
Switches to Control Box

1. Remove the two nuts on each of the three switches and set aside for a minute.

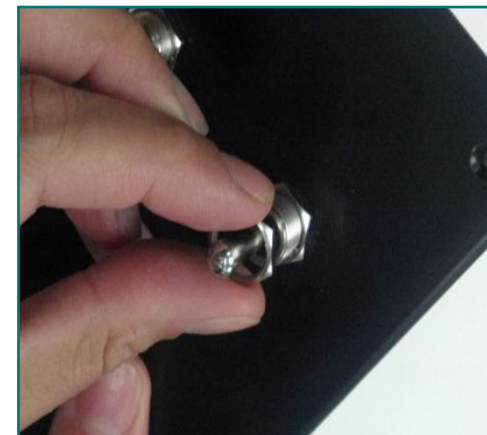


2. Push the “red/green” switch through the pre-drilled hole on the top right side of the control box lid. This way, when you are operating the ROV, the “right” switch will control the right hand movement.

Note: When you place the switches in the holes in the control box lid, ensure that they are in the right position, when looking at the control box lid from the outside.



3. Screw the nuts on to the switch to secure it to the control box lid.

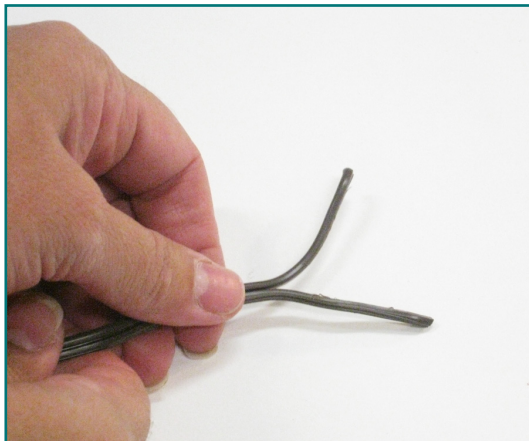


4. Repeat steps 2 and 3 for the white/black switch (left-handed movement); on the left side of the control box lid.
5. Repeat steps 2 and 3 for the blue/brown switch (up/down movement); on the bottom of the control box lid.

Power Wire at Control Box

Just like a battery has a positive and a negative side, the power wire has a positive (red) and a negative (black) lead. The power wire will be connected to each of the switches of the control box.

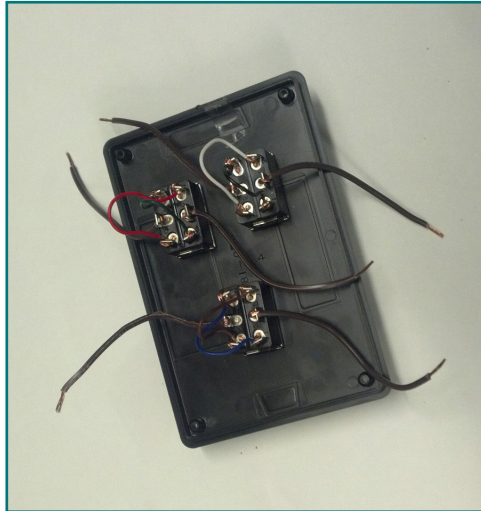
1. Cut off a 30 cm (12 inch) section of the power wire (one side smooth and one side rough). Pull apart the two parts of the wire. Cut into three equal sections (approximately 10 cm/4 inches each) so that you have six sections of wire (three smooth and three rough).



2. Strip off 1 cm (less than 1/2 inch) of both ends of the six sections of power wire.

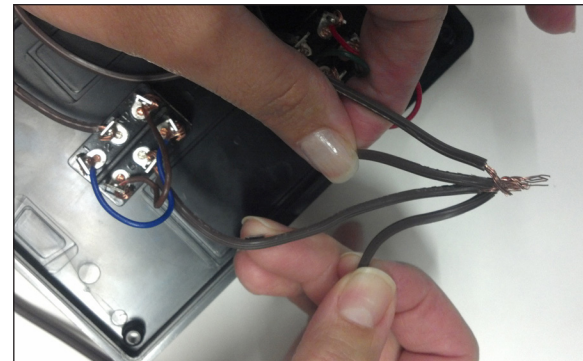
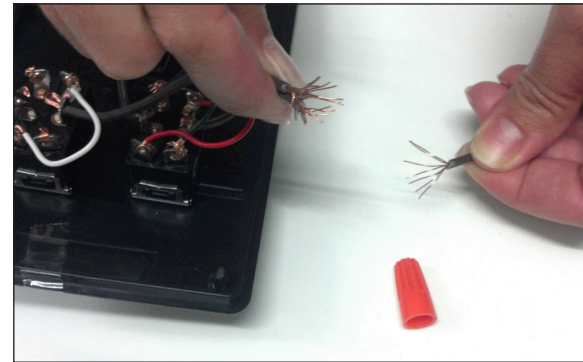


3. Take one of the rough wire sections of power wire, and push one of the stripped ends through the left-hand middle holes of one of the switches (push from the inside out). Wrap the exposed end of the wire over the outside of the hole to secure the wire to the switch. Later we will be soldering these connections to permanently secure the connection. Repeat with smooth wire on the right-hand middle hole.

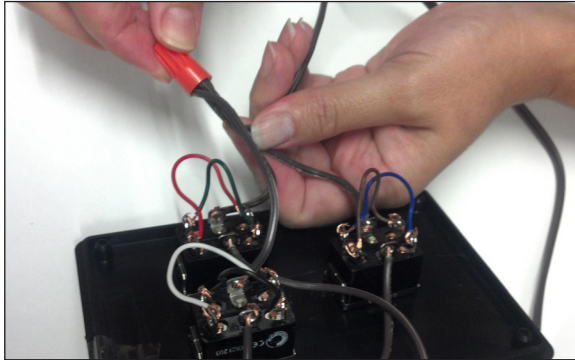


4. Repeat step 3 for the other two switches.

5. Connect all three rough ends of the power wire (that are connected to each switch), plus the rough end of the remaining power wire, by twisting the stripped copper ends of the wire together.



- Twist an orange wire cap on to the four joined wires to secure them together. Make sure that all copper wires are touching!

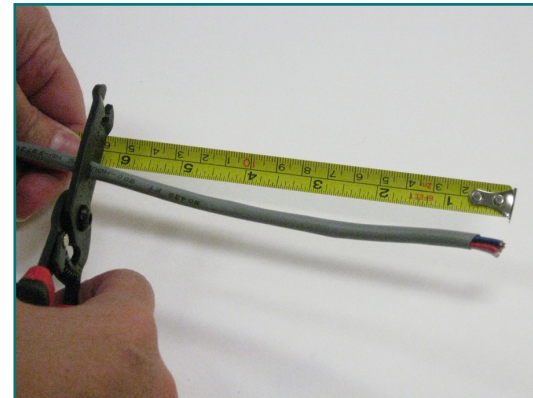


- Repeat step 5 with the four smooth ends of the power wire and secure with a wire cap.

Control Box to Tether

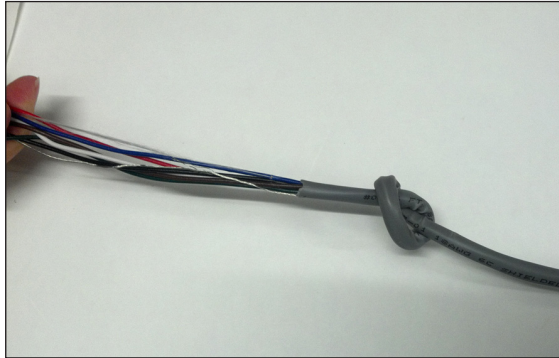
ROVs, by definition, are tethered to a control box. The tether is a cable that carries power, and sometimes audio-visual signals, to the ROV.

- Take the grey tether wire and the wire strippers, and strip 15 cm (6 inches) of the grey protective sheath from one end. Be careful not to nick any of the colored wires inside.

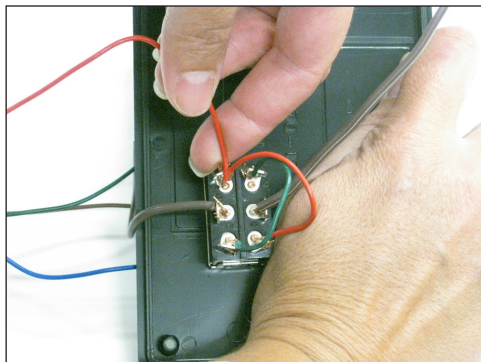


- Strip all six colored ends of the tether by $\frac{3}{4}$ inch.

3. Tie a knot in the end of the grey wire. This will help provide strain/tension relief on the connections inside the control box, if the tether is pulled too hard.



4. Push the stripped end of the red wire from the tether into one of the holes on the switch that already has the small piece of red wire, so that the red wire from the tether is connected to the red wire on the switch.

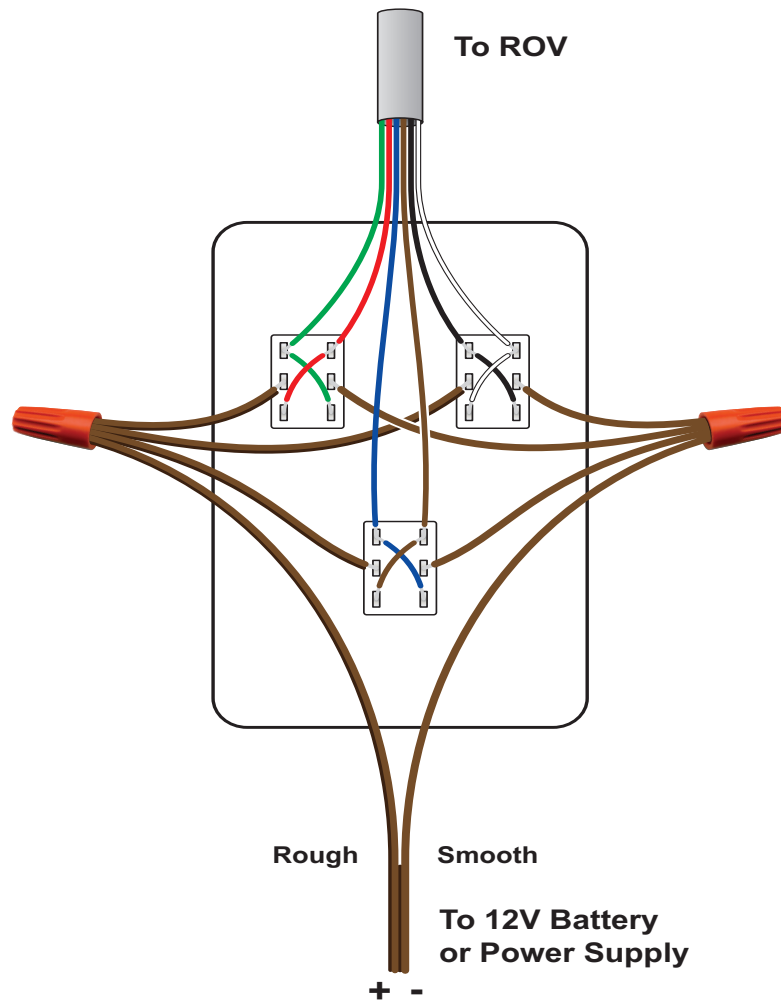


5. Repeat step 4 for the remaining five colored wires from the tether.

Note: The grey tether will come out of the control box leading towards the ROV (and away from you), so connect the colored wires from the tether to the colored wires on the switches on the side of the control box leading away from you.



ROV Control Box Wiring Diagram

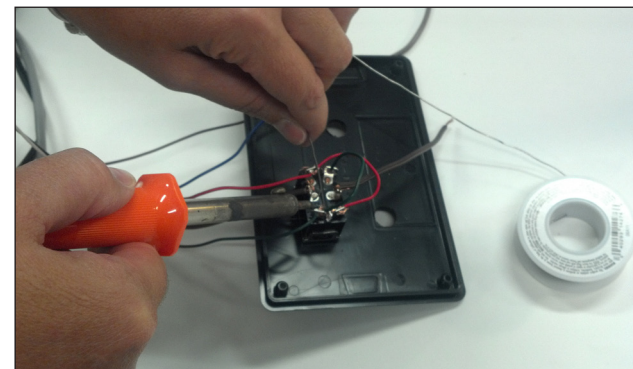


Soldering

Soldering is used to secure connections between metals such as two copper wires. Solder has a much lower melting point than copper and when it is heated, it melts and covers the wires. As it cools and hardens, it creates a strong, protective sheath over the connection.

Before you get started, make sure that you have proper ventilation in your work area and a flat piece of wood or cardboard to protect your working surface from the hot solder.

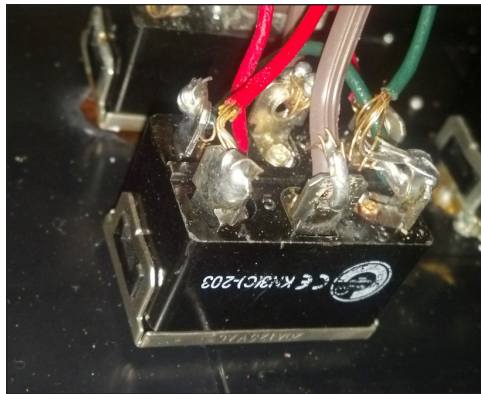
1. Plug in the soldering gun and allow time for it to heat up.
2. Hold the soldering gun in one hand and the solder in the other. Hold the end of the soldering gun to one of the joints you will be soldering, allowing it to heat up. Hold the end of the solder to the tip of the soldering gun. As it melts onto the connection, push the solder towards the end of the gun so that more of the solder melts onto the joint, securing the connection.



Note: Be careful not to touch the tip of the soldering gun to the plastic wire coverings, as they will melt.

- Solder all 18 connections in the control box. You may opt to use a drop of solder flux fluid or paste on each connection to facilitate the soldering process.

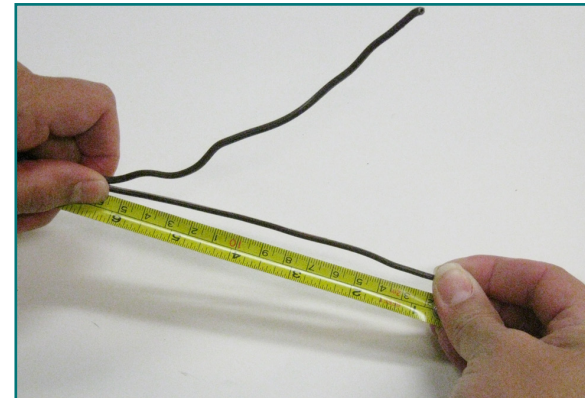
A good solder joint should be smooth and uniform with concave sides. A bad solder joint will look dull and grainy. The solder connection on the lower left terminal of the switch shown below is an example of a good solder joint.



Power Wire at Power Source

Just like a battery has a positive and a negative side, the power wire has a positive (red) and a negative (black) lead. The power wire will be connected to a 12V battery that will power the ROV.

- Take the other end of the power wire and separate the two smooth and rough sides of the wire by 15 cm (6 inches).

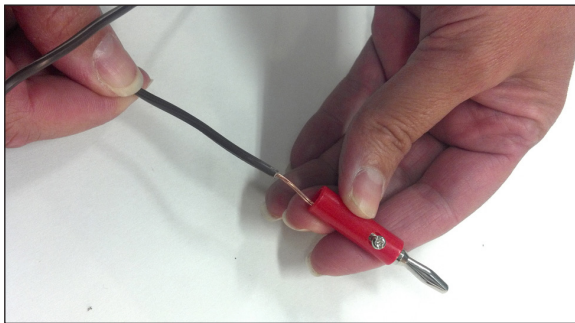


- Strip the ends of both sides of the power wire by ½ inch each.

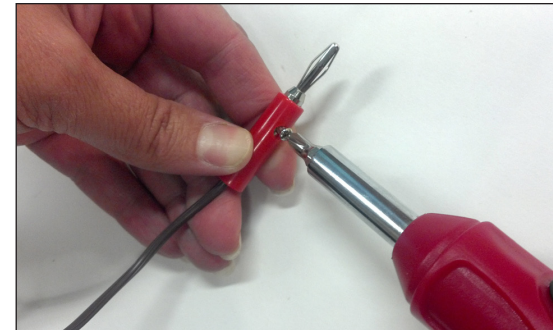
3. Take the red and black metal plugs from the baggy of supplies and partially unscrew the metal plug from the red and black plastic pieces.



4. Place the red colored plastic over the rough side of the power wire.



5. Secure the plug to the wire by tightening the small screw on the plastic piece.

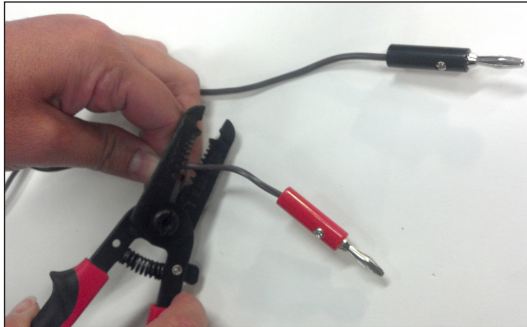


6. Repeat step 4, this time placing the black colored plastic over the smooth side of the power wire and re-secure the metal plug with the screw.

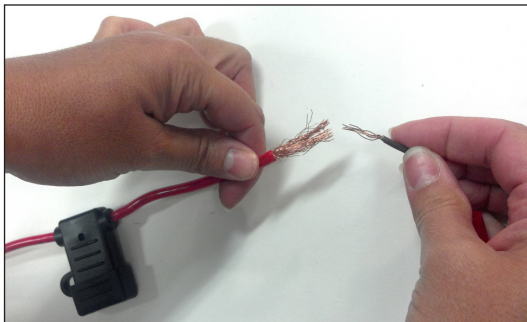
7. Take the fuse and cut the red loop of wire so that there is an equal amount of red wire on either side of the fuse box. Strip 1 inch off both ends of the fuse wire.



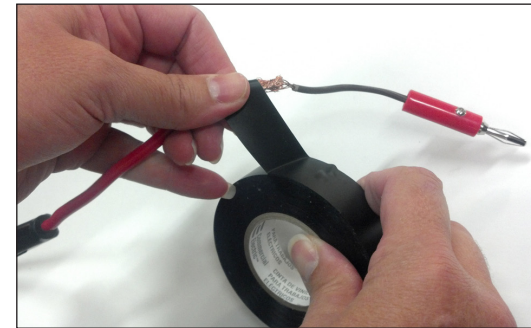
8. Cut the rough part of the power wire (between the red metal plug and the place where the power wire is separated into the two sides.)



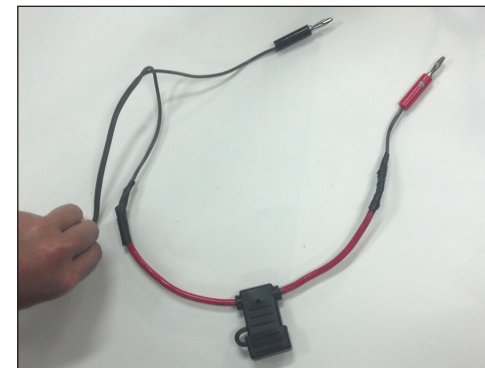
9. Strip both ends of the power cord you just cut.
10. Use the broomstick method (splay the copper wires out, connect and twist to secure) to connect one end of the fuse wire to the rough side of the power wire. Connect the other end of the fuse wire to the piece of power wire you cut off in step 8.



11. Solder both connection points and wrap with electrical tape.



12. The power wire should now have a positive (rough/red) end with the fuse connected, and the negative (ground/smooth/black) end. These will attach to the battery or to the power supply.



13. Ensure the fuse is pushed all the way inside the black fuse box.

Motors/Propellers Assembly

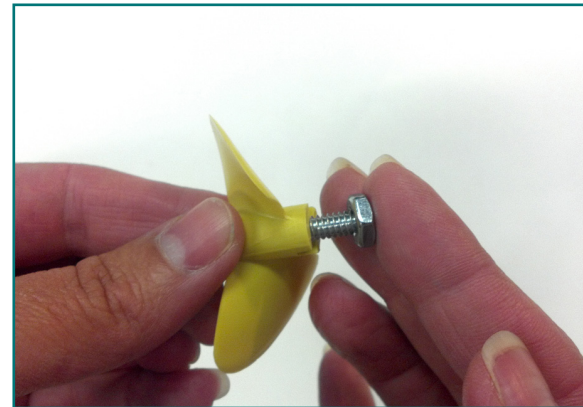
Our ROVs have three motors/propellers. Two of them are “right-handed” and one of them is “left-handed.” The left-handed propeller is marked with an “L,” but you can differentiate by noticing that one propeller has the opposite direction of twist. The “left-handed” motor and one of the “right-handed” motors will power horizontal (left/right) motions. The second “right hand” motor will power vertical (up/down) motions of the ROV.

Note: Sometimes the motors come with a plastic beige propeller adaptor. This piece should be removed before going forward.

1. Insert a 1-inch screw through a yellow propeller.



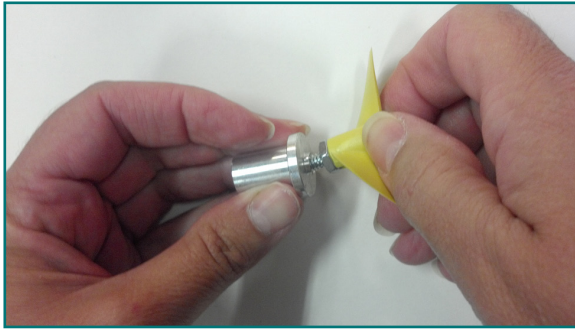
2. Twist a nut on to the screw to hold the propeller on the screw.



3. Place a drop of glue/epoxy (use Loctite® or mix equal parts of J-B Weld® steel and hardener) on the threads of the screw sticking out of the propeller.



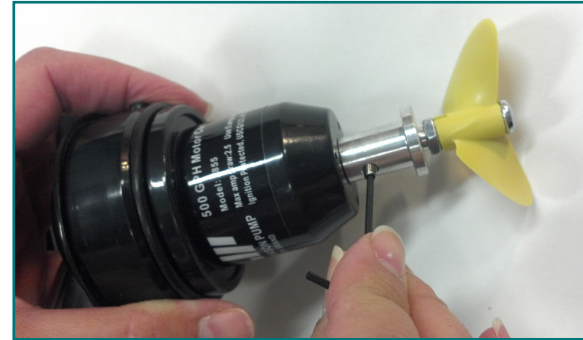
4. Attach the propeller to the motor mounts (silver cylinder) by inserting and twisting the screw into the motor mount.



5. Place the motor mount onto the motor shaft. Be sure that the hole on the mount lines up with the flat side of the motor shaft.



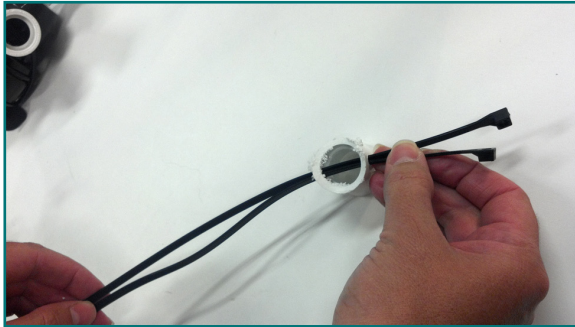
6. Using the Allen wrench (L-shaped tool), make sure the tiny screw is tight against the flat side of the motor shaft, securing the propeller to the motor.



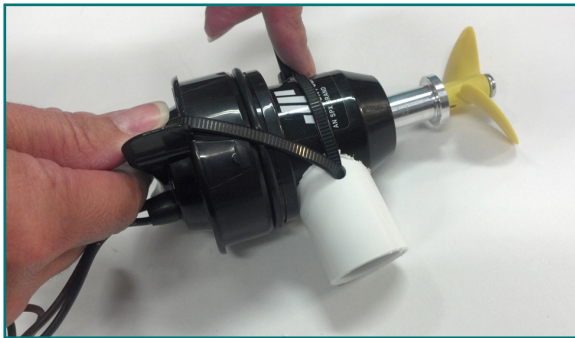
7. Repeat steps 1 – 6 with the other two motors/propellers.



8. Take the pre-cut 3 cm (1 inch) piece of PVC pipe and push two zip-ties through the pre-drilled holes (make sure that the zip-ties are facing the same way).



9. Place the motor on top of the curved part of the pipe, and tie one zip-tie around the motor to secure it to the pipe, and tie the other zip-tie around the back of the motor to stabilize it. Cut off the ends of the zip-ties.



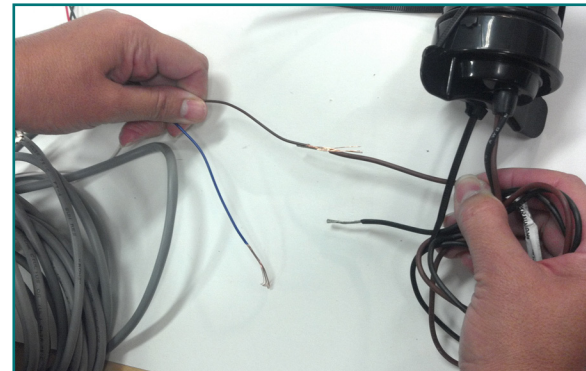
10. Repeat for the other two motors.

Motors/Propellers Wiring

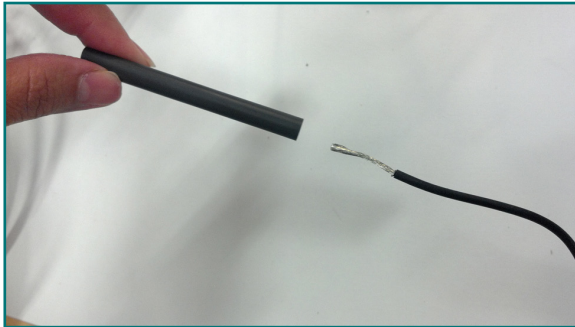
1. Cut off the tinned tips of the wires for each of the three motors and strip the ends.



2. Match each motor with a pair of colored wires in your grey tether – one motor per switch. Each motor has a brown (+) and a black (-) wire.

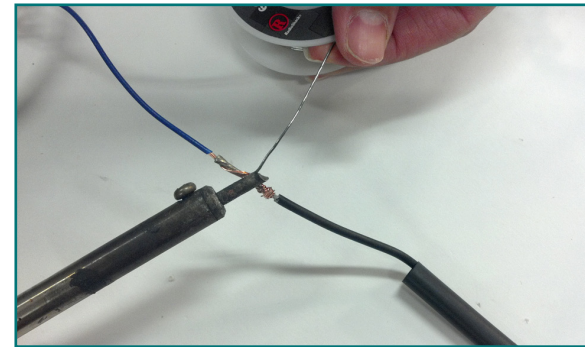


3. Because your motors/propellers will be underwater, the connections between the motor wires and the colored wires from the grey tether will need to be waterproofed. (Cut six pieces of heat shrink long enough to cover each of the connection points.)
4. Slip a piece of heat shrink onto each of the black and brown wires of the motor. Slide the pieces of heat shrink towards the motor and leave them there until you have made the connections in step 6.



5. Repeat step 4 for the other two motors.
6. Using the broomstick method, connect:
 - a. Right-handed motor #1, brown to red and black to green
 - b. Right-handed motor #2 (this will be your vertical up/down motor), brown to brown and black to blue
 - c. Left-hand motor, brown to white and black to black

7. You will need to **test the connections** to make sure the switches operate the correct motors by connecting the power wire to a battery before soldering. To do this, connect the red metal plug from the power wire to the positive (+) lead of the battery and the black plug to the negative (-) lead. Then flip each switch up and down and observe how your propellers can drive the ROV forward/back, up/down and right/left.
8. For one of the motors, solder the two connections between the motor wires and the tether wires. Let it cool down.



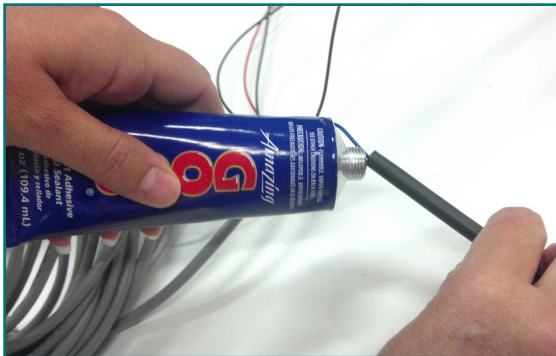
9. Repeat step 8 for the other two motors.

Waterproofing

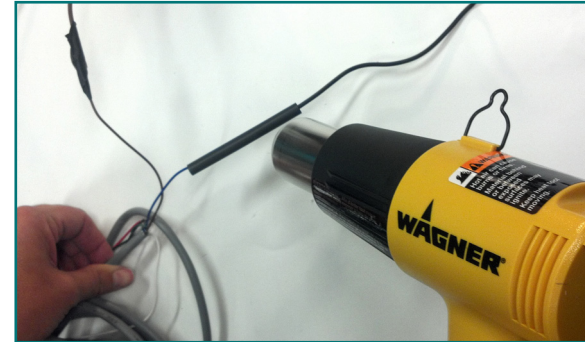
1. Now that you have connected your motors to the colored wires from the grey tether, tested them, and soldered the connections, cover the two connections for one of the motors with Plumber's Goop®.



2. Bring each piece of the heat shrink over each of the two connections. Squeeze as much Plumber's Goop® inside the shrink-wrap as you can. It may help to twist the shrink-wrap as you slide it over the goop.



3. Use a heat gun to contract the shrink-wrap over the two soldered joints. You want to see Plumber's Goop® being squeezed from both ends of the shrink-wrap.



4. Repeat steps 1-3 for the other two motors.
5. Once your motors are waterproofed, test your control box once again to verify that all three switches are operational. If everything is working, use the four screws to secure the control box lid to the control box, making sure that the tether cable is out of the top and the power cable is out of the bottom.

The Frame

The frame of your ROV is the structure that connects and supports all the parts of the ROV, including the motors/propellers, the flotation, the tethers, and end effectors (i.e. the part that will scoop or collect objects). There is no prescribed way to build a frame, but there are several design elements to consider to make your ROV as effective and seaworthy as possible.

Shape

The PVC pipes and “L” and “T” joints provided in the kit will allow you to construct all kinds of 3D square or rectangle shapes. Experiment with the dimensions (length, width, height), symmetry (balance and center of gravity is important), and placement of motors (more on motors below).

Orientation

Decide the orientation of your ROV before you position the motors, propellers, and end effectors (more on end effectors in the next section).

Motors

Mount the right and left-handed motors to your ROV frame, with the propellers facing the rear of the vehicle, so that they will “propel” the ROV forward, right/left, or backward.

- Consider whether you want the propellers to protrude out, or be contained within, the frame structure, and the advantages/disadvantages of each.
- Consider whether the propellers should be near the top or the bottom of the ROV, and the advantages/disadvantages of each.

Mount the third motor, which will control up/down movement. The motor should be placed in a vertical position so your ROV can move up and down.

- Consider whether the propeller should be facing up or down. If it is facing up, what will happen if the ROV is near the surface? If it is facing down, what will happen if the ROV is exploring a sandy ocean floor?

Propellers

All propellers need to be positioned such that they can make a clear path/wake (i.e. with no obstructions and no wires/tethers in which to tangle).

- To minimize tangling, use zip-ties or electrical tape to secure the motor wires to part of the ROV frame. (Remember that the grey tether should naturally go from the back of the ROV to the control box to help make navigating easier.)

Flotation

Flotation devices, such as foam tubes (included in the kit), empty plastic pipe with end caps, or bubble wrap, should be placed at the top of the frame, in order to stabilize the weight (mainly the motors) at the middle/lower part of the frame. There should be some vertical distance between the floats and weights to provide stability/balance.

Attach flotation devices (use electrical tape so you can easily remove as needed). Every design varies in how much is needed. Remember that you want your ROV to be almost neutrally buoyant (i.e. you want it to glide through the water without sinking or returning to the surface, and only use the up/down motor as needed). Having slightly positive buoyancy is advantageous, so that if the ROV ever failed in any way, it would gradually return to the surface on its own.

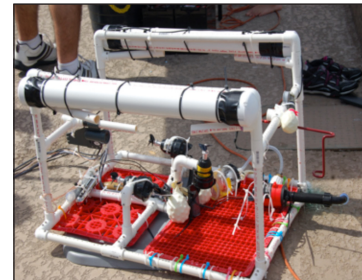
Optional

You can make the ROV frame more rigid by putting screws in the PVC pipes and joints. Drill an appropriately sized hole in each connector and tighten the screw against the PVC pipe. This will prevent the frame from tilting when it is handled.

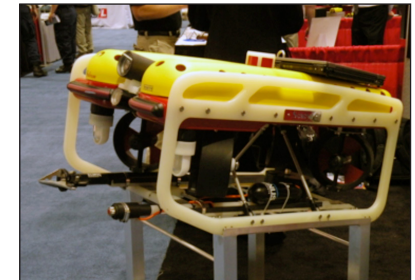
Make It Your Own

Name your ROV, give it a mascot, or decorate it (i.e. colored electrical tape, a keychain, spray paint). Be creative!

What are some design elements that these two ROVs have in common?



Student-made ROV



Professional-grade ROV used for commercial and scientific purposes

- The flotation (“empty” pipes filled with air: white on the left, yellow on the right) is above the weights (the motors and other instrumentation).
- The motors/propellers are inside of the frame structure to minimize damage or bumping into things.
- The motors are rather close together, which will provide a tight turning radius, but the smaller, quicker movements will also require more attention to detail from the ROV navigator.
- Both are symmetrical designs.
- Do you notice anything else?

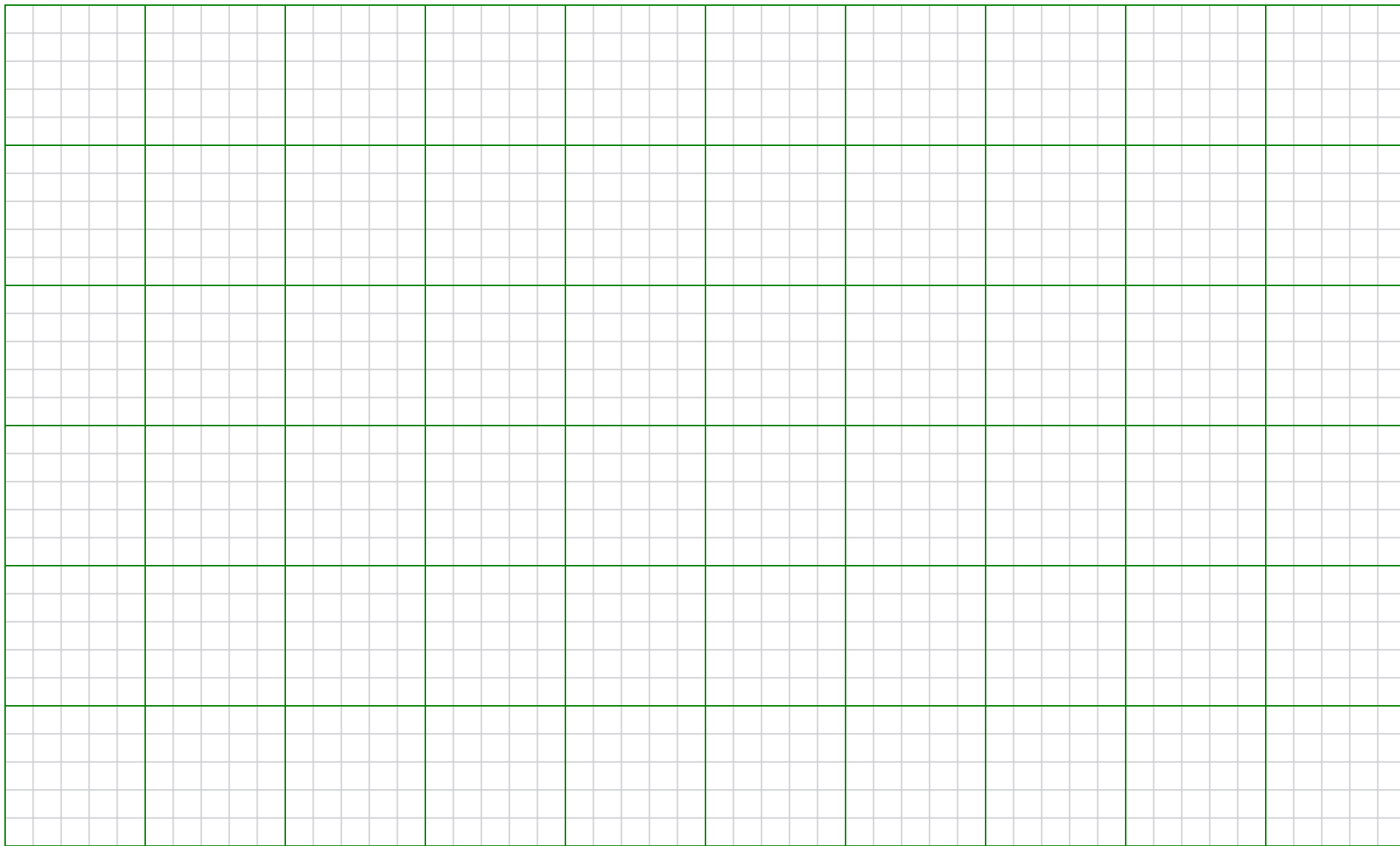
End Effectors

The end-effectors are your underwater hands – they can grab, scoop, or collect. Consider your mission when building this part of your ROV. Are you gathering a specimen? Retrieving pieces of a shipwreck? Dropping off a piece of observation equipment? Now think about everyday objects in your kitchen, garage, or work closet, and how you could adapt and attach them to your ROV. Anything can be used in ROV design, so get creative and test your options! For example, how could you use the following objects to achieve your mission?

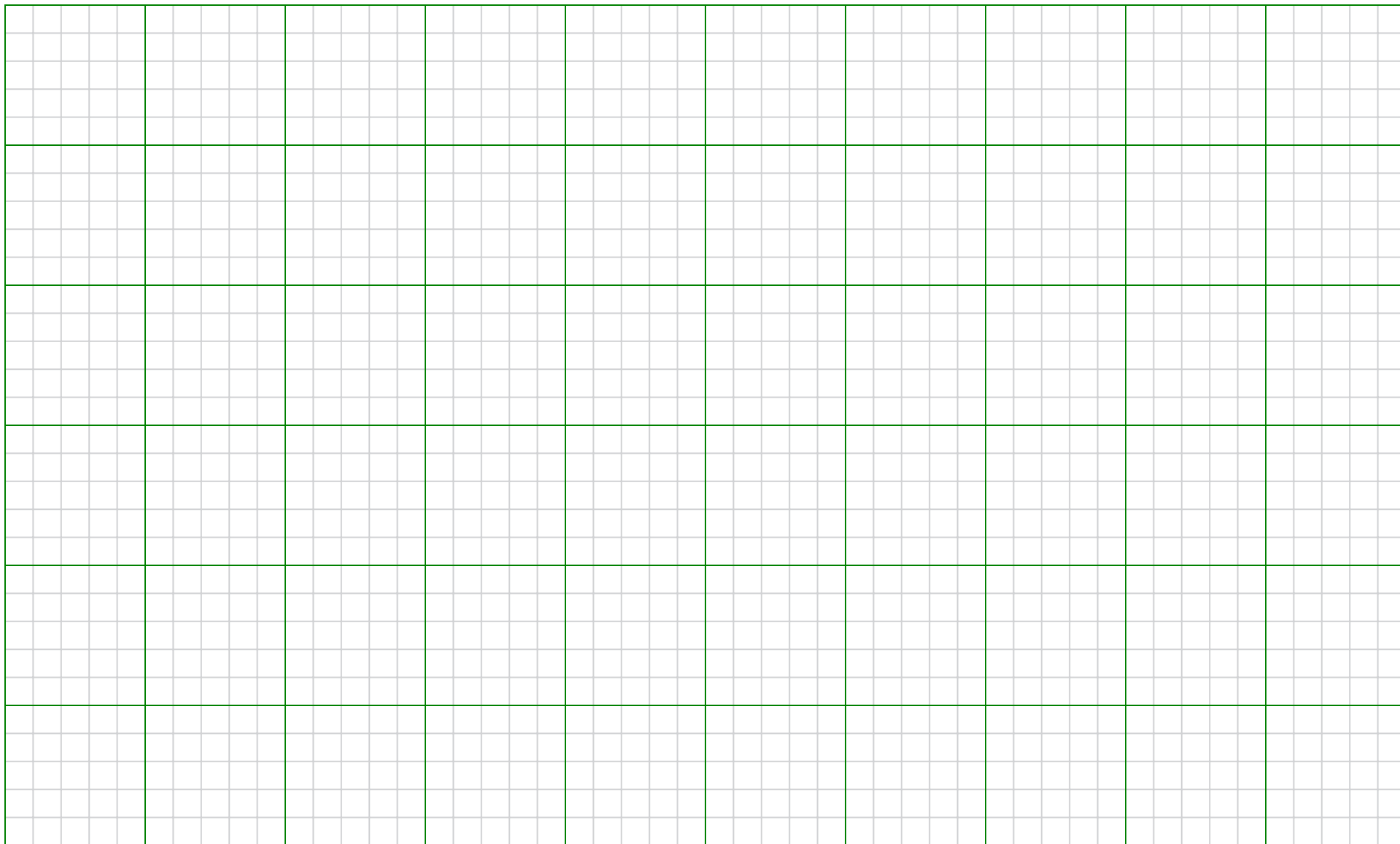
- toilet bowl scrubber
- Velcro®
- mesh
- bubble wrap
- empty tubing
- ladle
- spatula
- panty hose
- tongs
- Lego® bricks

Note: When your ROV collects a specimen or a piece of equipment, it will change the balance and buoyancy of your ROV. Consider how you may minimize this effect through the placement of your end effectors on your ROV frame.

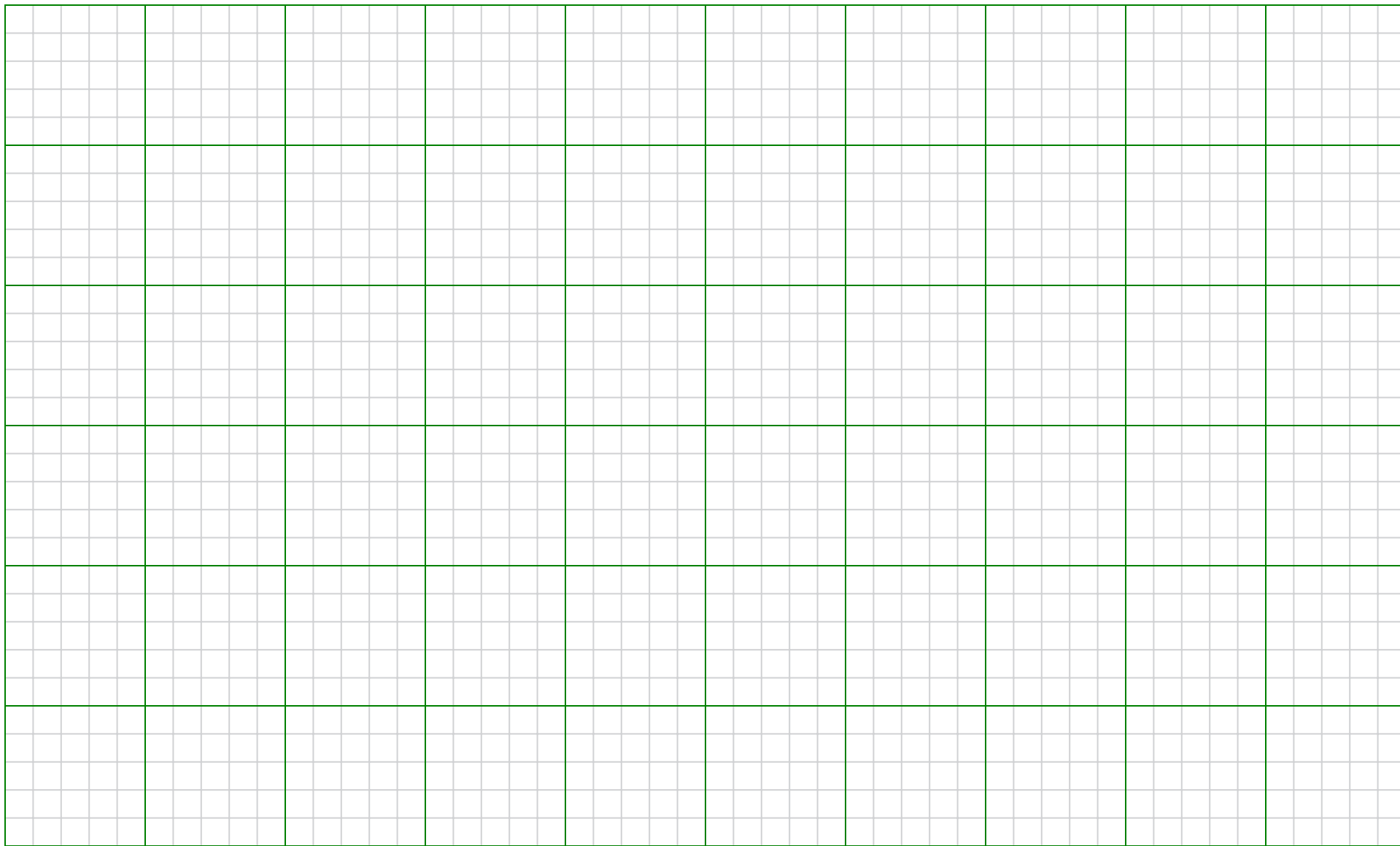
Design Ideas:



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ROVs can be related to many areas of STEM. The design and functionality is closely tied to engineering principles, the control box and propellers relate to scientific fields such as energy and electronics, and the navigation and motion of the ROV in the water connects to other scientific principles, including propulsion, buoyancy, center of gravity, and Newton's Laws of Motion. As you build your ROV and consider how you may use this resource with your own audiences, we encourage you to consider the many ways that you can incorporate ROVs into all kinds of science lessons.

Here are just a few topics that are strongly connected to ROVs:

- Center of Gravity
- Newton's 3rd Law of Motion: Action-Reaction (propellers face back, drive ROV forward)
- Conservation of Angular Momentum (how motor placement affects movement)
- "Floats Above Weights" (think about a balloon attached to a weight in a tank)
- Buoyancy: Neutral, Positive, Negative (for ease of ROV navigation in the water)
- Propulsion (motors and propellers)
- Energy Conservation (transforming electrical energy into kinetic energy)
- Circuits (follow the wires from the control box to the tether to the motors)

Mission: Possible!

ROVs are designed for specific purposes. They must be easily maneuverable, sturdy, and also have a flexible design, in order to perform a variety of missions. In the real world, professional-grade ROVs are used to collect biological specimens, investigate shipwrecks, and retrieve objects lost on the ocean floor. Our mission for you was designed to be analogous to a real-life mission. When you run your own workshops, you can use any of these missions or be creative and design your own.

Mission #1

You are studying the effects of climate change on colonies of tubeworms. Your task is to collect at least three tubeworms and bring them to the surface. Our “tubeworms” in this mission were made from PVC pipes and connector pieces wrapped in Velcro®.



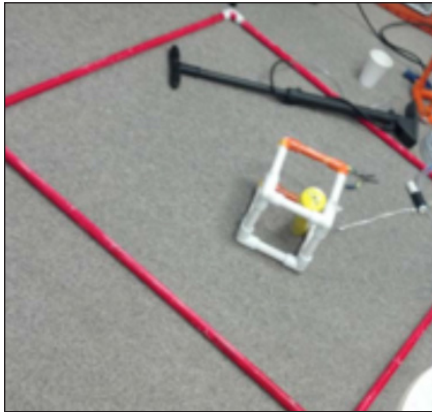
Mission #2

You are researching ocean currents and temperatures around coral reefs. Your job is to place the piece of scientific equipment (cube made of PVC pipes) inside of the designated target area (the black crate). Coral is fragile, so be gentle!



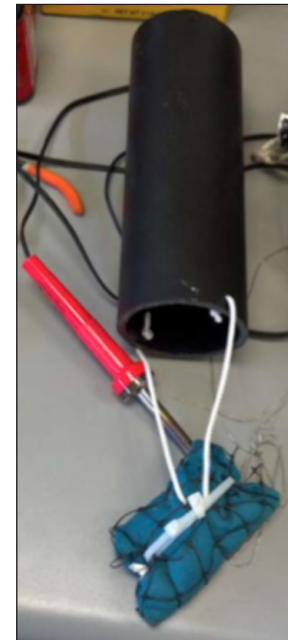
Mission #3

You are studying a shipwreck from World War II. It sank with full fuel tanks, and over time, the ship's hull has begun to degrade. You need to place the piece of camera equipment in a designated target area of the shipwreck, to determine the chance of an oil leak, so that others may find a way to prevent it.



Mission #4

A piece of equipment from a previously used ROV was accidentally dropped on the ocean floor, and your mission is to retrieve the object. Since the object is hollow, you can pump air into the black tube to ballast the object; in other words, you will change the buoyancy of the object so that it will rise to the surface.



Underwater Site

Set up your underwater mission site – it can be a plastic tank as small as 64 cubic feet or as large as your local swimming pool. If however, your pool/tank is too large to reach in and grab your mission's objects, make sure to attach a rope to them to pull them out.

Ready, Set, Go for a Dive!

Place your ROV in the water and familiarize yourself with its navigation. Observe its buoyancy and modify your ROV if necessary. You can add/remove flotation, change the height of your PVC pipes (to increase/decrease the distance between floats and weights), change the placement of your motors, and so on. Remember that this ROV kit is made to be adjustable and reusable. Anything that is not soldered together can be changed.

Now you are ready to go underwater to accomplish your mission. Good luck!

Supplies in the ROV-in-a-Bag Kit:

- 30 feet of grey wire with 6 colored strands inside it
- 10 feet of 2 conductor power wire
- Black control box and 4 screws
- 3 switches
- 3 motors
- 3 propellers (one “L” and two “R”)
- 3 screws and three nuts
- 3 motor mounts (silver cylinders) with tiny hollow set screws and Allen wrench (L-shaped tool)
- 3 pre-cut/pre-drilled 1 inch pieces of PVC pipe
- 6 zip-ties
- 20 feet of ½”-thick PVC pipe
- 20 “L” and “T” PVC joints
- Flotation (foam)
- Fuse in fuse case
- 1 red and 1 black metal plugs
- 2 orange wire caps

Materials in the ROV-in-a-Bag kits may be individually purchased at hardware, electronic, and boat supply stores. However, the MATE Center assembles the ROV-in-a-Bag kits and purchases the materials in bulk, and offers the kits for a flat rate of \$140 (including shipping). MATE is also looking into alternative supplies that will lower the cost of the kits. Contact MATE for up-to-date information on supplies and pricing.



The MATE Center

The Marine Advanced Technology Education (MATE) Center is a national partnership of educational organizations working to improve marine technical education in the U.S. and to meet the workplace needs of America’s marine-related workforce. Headquartered at Monterey Peninsula College, the MATE Center is one of eleven Advanced Technological Education (ATE) Centers established with funding from the National Science Foundation’s ATE Program. For more information about MATE, go to <http://www.marinetech.org> or contact MATE staff at info@marinetech.org or 831-645-1393. To find out more about regional national, and international ROV competitions, go to <http://www.materover.org>. For information about the ROV-in-a-Bag Program, to purchase kits, or for technical or supply needs, contact Erica Moulton at emoulton@marinetech.org.

Additional supplies you will need to conduct your own workshop. Most of these supplies can be shared in a workshop for 20 girls building 4 ROVs, exceptions noted. All items can be purchased at a local hardware/electronics store and many items can be found in your garage, basement or supply closet!

- 4 rulers
 - 4 small Ziploc® bags
 - 1 Heat gun
Home Depot SKU #809136 \$22.96
 - Heat-shrink tubing – each ROV will need 6 pieces about 1.5 inches long
Home Depot SKU #950660 \$1.97
 - Soldering irons – at least two are recommended
Home Depot SKU #800011 \$14.97
 - 2 rolls of solder (lead-free)
Home Depot SKU #872288 \$5.36
 - 1 Solder flux (optional)
Home Depot SKU #125490 \$4.86
 - PVC cutters – at least two are recommended
Home Depot SKU #639179 \$12.98
 - 4 wire strippers/cutters
Home Depot SKU #576037 \$10.48
 - 1 tube of Plumber's Goop®, all-purpose contact adhesive and sealant
Home Depot SKU #719315 \$4.57
 - 1 Glue or two-part epoxy, such as JB Weld®
Home Depot SKU #112220 \$5.67
- 2 rolls of electrical tape
Home Depot SKU #442097 \$3.88
 - 2-4 Screwdrivers with multiple heads
Home Depot Model #011-070-HKY \$4.88
 - 12 Volt battery or power supply – one battery can operate 3 ROVs at a time
Home Depot Model # 0063574 \$49.97 or Auto Zone Part #BP-DL600 \$49.99
 - Velcro
Home Depot SKU #560223 \$7.47 (optional)
 - Miscellaneous: Items for end effectors (whatever you can find), extension cord, power surge protector strip, rope (to retrieve missions' materials from the bottom of the pool), piece of wood or cardboard to protect working surface from hot solder. Up to \$30.00