SUBS in Schools
Re-Engineering Australia Foundation Ltd

Instructions for the Digital ROV Kit Assembly

This document is downloadable from: https://rea.org.au/subs-in-schools/resources/

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Digital ROV Systems

An ROV consists of many systems that are independently constructed and then assembled into a single ROV. The frame, power, controls, propulsion, and buoyancy are the major systems. In addition, your ROV may have a number of other systems depending on it purpose and mission. Mission tools such as grippers, hooks, temperature probes, or sampling devices may need to be constructed. A camera can be added to the vehicle. All of these systems need to be integrated together into one vehicle. All of the systems are interconnected, altering one system may affect another system. For example, adding more manipulators may mean adjusting buoyancy. You will also need to adjust your frame to hold additional tools. The design of the control box influences the number of motors and the placement of those motors on the frame. You job is to combine all the ROV systems into an integrated vehicle to complete the task at hand.

- Frame: A sturdy three-dimensional structure that holds all the systems together.
- Power: Provides the pathway for the electrical energy to get from the surface controller to the ROV.
- Control: Allows the ROV pilot to control thrusters, tools, cameras, lights, and other subsystems on the vehicle.
- Tether: Transmits data and power between the vehicle and the controller on the surface.
- Propulsion: Provides the force to move the ROV through the water.
- Buoyancy: Adjusts the tendency of the ROV to float or sink.
- Mission Tools: Grippers and sensors to achieve the mission tasks.

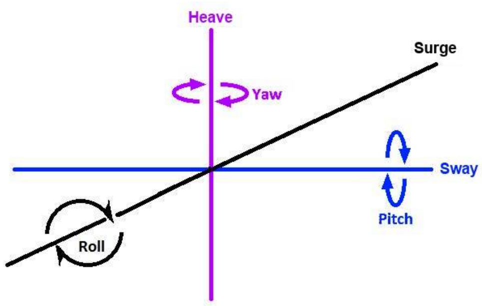
The Digital ROV kit comes with a control box with power wires (control system), motors (propulsion system), and a tether with sheath (tether system). The Digital ROV kit does not come with a frame, power supply, buoyancy, cameras or mission tools. You can find these additional components from another source of your choosing.

1. The Frame

Time required: 30 min to 2 hours
Tools needed: PVC cutters
Tools recommended: Ruler
Parts required: PVC pipe, connectors or other material.

The ROV frame is a sturdy three-dimensional structure that holds all the system components together. Unlike a simpler 3-motor configuration, the Digital ROV employs a fourth motor that adds an additional direction of movement.

- Direction of Movements:
- Surge: Forward and reverse movement.
- Sway: Side to side, crabbing or strafing movement. Moving sideways without turning.
- Heave: Up and down movement.
- Yaw: Turning left and turning right.
- Pitch: Nose up or down.
- Roll: Side up or side down.



With a simple three motor ROV, surge, heave and yaw are the typical directions of movement. By adding a fourth motor to the Digital ROV, sway is added to the allowed directions of movement. A very stable ROV, with its flotation at the top and weight below, usually prevents pitch and roll. See the buoyancy section for more information on stability and centre of mass versus centre of flotation.

The Digital ROV uses two distinct frame designs. The vectored design uses two motors to provide surge and yaw, and two motors to provide heave and sway. The orthogonal design uses two motors to provide surge and yaw, one motor to provide heave, and one motor to provide sway. The frame design used is up to you.

Information on the vectored and orthogonal frame design can be found in the presentation found here:

PRESENTATION LINK: [TWO TRIGGERFISH/DIGITAL ROV FRAME DESIGNS](https://www.google.com/url?q=https://docs.google.com/presentation/d/1gpQl4kAATr0NFFqIYVsXUG8Jj8HCRN9I3-hbIcEmFBQ/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517767000General)

https://www.google.com/url?q=https://docs.google.com/presentation/d/1gpQl4kAATr0NFFqIYVsXUG8Jj8HCRN9I3-hbIcEmFBQ/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517767000General

Frame Guidelines:

Before building a frame, we recommend taking time to sketch an initial frame design or build a model of the frame (cardboard, pipe cleaners, or computer drawing tools) to get an idea of the basic shape and where equipment will be placed. Consider where the motors will be mounted, if tools or cameras are going to be attached, and what the ROV is designed to do. Frame designs often go through four or five iterations to get it exactly right. Therefore, it helps if the frame is modular or can be easily changed to incorporate new designs.

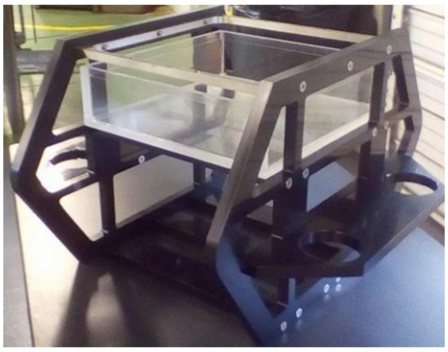
Using PVC:

PVC is often used as the material to construct a frame. PVC is cheap, easy to work with and is readily available in most hardware stores. PVC comes in many sizes, measured from the inside diameter of the pipe. 13mm pipe is the smallest, commonly available size of PVC, but 19mm, 25mm, 32mm and 50mm are also readily available at most hardware stores. 75mm, 100mm, 150mm and larger diameter pipe is much more difficult to find. The other benefit of PVC is the many different connectors that are available. Tees, 90 elbows, 45 elbows, side out corner pieces, crosses, couplings, end caps and more. Reducer bushings that connect two different sizes of pipe are also available. PVC pipe will allow almost any shape and size of frame.

Other Frame Materials:

A frame can be made out of any material. Professional ROVs use aluminium or even titanium for the frame. Aluminium and plastic sheeting are common frame materials as well. Use whatever works best for creating your frame.

Frame Design:



There is no set MATE frame design. Building a frame depends on the tools and other systems that are going to be incorporated into the frame, and the tasks that the ROV will be required to do. MATE does have some guidelines to help when building a frame.

1. Bigger is not always better. With a set amount of thrust, a bigger frame will move and turn more slowly, while a smaller frame will move and turn more quickly. Which is better? It depends on what the ROV is doing. Sometimes slow is better. Consider what your ROV is going to be doing and design accordingly.
2. Let water flow through the frame. Don't plan to use the air inside the pipe as buoyancy. It is too difficult to prevent the air inside the pipes from leaking out, and then the buoyancy is lost. The water inside the pipe is also mass, which must be pushed around by the motors. Consider using tees at the corners so water can flow through the pipes.
3. Build a symmetrical frame. If a 120mm length of pipe is cut for one side, a 120mm length of pipe will probably need to be cut for the other side. This is not always the case but is a good rule to follow. Not doing this can lead to a PVC frame that does not fit together well and breaks apart too easily.
4. Place things around the centre of the ROV. If the vertical motor is not near the centre of the vehicle, the ROV may pitch (nose up, nose down) when moving up and down. Heavier items should be kept below the centre-point. Light items (flotation) should be kept above the centre point. Ideally the tether should come out of the top middle or top rear of the ROV.
5. 25mm PVC pipe inserts approximately 15mm into a tee, elbow or other connector. Plan accordingly. Keep excess PVC to a minimum. The purpose of the frame is to hold the other systems together in a functional spatial arrangement. If a length of PVC isn't needed, don't insert it.
6. Pushing the pipe into a tee, elbow or other joint by hand should be enough to secure the connection. If the connection is still bad, look at the symmetry of the connecting pieces. If necessary, use a small screw to hold the pipe together instead of PVC glue. PVC glue makes a connection that is inflexible, brittle and prone to breaking.

Another option is to run the motor wires through the frame of the ROV. This keeps the wires out of sight and out of harm's way, and they emerge from the vehicle frame at a single strain relief point. To run the motor wires through the frame, drill a 3/16-inch hole through the 25mm portion of the motor mount. Push the wires through this hole and work them through the framework of the ROV, and out through the strain relief. Note that if you are using screws to hold the frame together, buy short, 10mm screws. Otherwise the points of the screw can damage the wires inside the PVC pipe.

SAFETY:

1. PVC cutters are very sharp. Never put fingers inside the PVC pipe when cutting it.
2. A small end of the PVC pipe can fly off when cut. Wear eye protection when cutting PVC and make sure there is a shield to block any flying PVC from impacting others.
3. Never cut PVC pipe at an angle. This can cause the metal blade on the PVC cutters to break.
4. Old PVC that has been in the sun gets brittle and has a tendency to crack and shatter.

Take all the necessary precautions when cutting PVC pipe to ensure a safe experience.

Additional information can be found in the Frame Design presentation here:

PRESENTATION LINK: FRAME DESIGNS

https://www.google.com/url?q=https://docs.google.com/presentation/d/1T5Ct3aqgtEbMoHusb0Mz5fOLPzp-renR8t5GIDRrMNg/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517776000

2. The Power System

Time required:	20 min
Tools needed:	Wire strippers, soldering iron, solder, hot glue gun and heat gun
Tools recommended:	Multimeter
Parts required:	Digital ROV Power Kit (Red/black power wire, in line blade fuse holder, power-pole connectors), hot glue and heat shrink

The power system delivers electricity to the control box, which is then delivered down the tether to the ROV. The 10 or 15 amp blade fuse protects the electronic systems. The power pole connectors connect to a power source and help to prevent polarity mistakes (connecting red/positive wires to black/ground wires). The Digital ROV Power Kit comes mostly assembled. One set of power poles is already connected to the ground wire and the fuse wire. Another set of power poles must be crimped to the control box end of the power wire. USE AN ANDERSON PLUG CRIMPER TO MAKE THESE CONNECTIONS. A standard crimper is not sufficient. The fuse wire must be connected to the red power wire. Although this connection should never be underwater, it is a good idea to waterproof any solder joint you make on an ROV. To create your power system wires follow the instructions found here:

PRESENTATION LINK: POWER SYSTEM: CREATING YOUR POWER WIRES

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vRB_owLvyuNd8iDSV75_4woGGFtWirwWUzcAqRzxTVrHXuVxsgL9y21wm49XklXBWbFYfJHqMubGQvk/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517782000

Important note: Attaching Anderson Plug connectors to the wires REQUIRES a special crimping tool. If you are attaching your own Plug connectors to the wires, do not use a standard crimper to make these connections. Standard crimping tools are not sufficient to make a proper connection on the Anderson Plug. Anderson Plug will be required for all teams competing in the MATE ROV competitions.

POWER NOTE:

The MATE Digital ROV kit does not come with a power source. You will need to provide a power source to power your vehicle. The SeaMATE store offers three different solutions, depending on your budget and how you intend to use the ROV.

Power pack with Plug adapter:

Powerpacks are battery packs that will provide the power you need. They are often kept in vehicles to jumpstart a car battery if there is a problem. They will run down over time but can be recharged easily by plugging them into a wall socket. A standard power pack should be able to run a Digital ROV for 1 hour.

http://www.harborfreight.com/3-in-1-portable-power-pack-with-jump-starter-62306.html

The power packs will need an adapter for the Plug connector to plug into. This adapter plugs into the cigarette lighter outlet found on the powerpacks, and the Plug plug into the adapter. The cigarette lighter adapter can be purchased

12 volt Deep-Cycle Marine/RV car battery:

Large lead acid batteries are another way to power the ROV. MATE recommends the Deep-Cycle Marine / RV battery, as they are designed to be run down and recharged many times (a standard 12 volt car battery is not designed for this). The battery should be able to run a Digital ROV for 4 hours or you can run 3 ROVs at a time for an hour or more. The battery will need to be recharged after that. To recharge a car type battery, you will need to purchase a charger.

The battery will also need an adapter for the Plug connector to plug into. This adapter has Alligator clips that connect to the battery posts on one end and has Plug connectors at the other end.

AC to DC Power Supply:

For a solution that never needs recharging, the MATE Centre recommends an AC to DC, 30 amp power supply that plugs into an AC outlet, and provides a constant source of 12 volt DC power that the ROV needs. This power supply should be able to operate two Digital ROV vehicles at once, but MATE recommends only running one Digital ROV vehicle off the AC to DC power supply to be safe.

SAFETY NOTE: Since this converter is being used near water, you MUST plug this converter into a Ground Fault Circuit Interrupter (GFCI) protected outlet or have a GFCI plug on the end of the converter. DO NOT PLUG THIS INTO A STANDARD WALL SOCKET WITHOUT GFCI PROTECTION.

MATE also recommends keeping the AC to DC converter in a splash proof container or case. A small plastic tub turned upside down will work to keep splashes off the power supply.

3. Control System

Time required:	4 to 6 hours
Tools needed:	Soldering iron, solder (MATE recommends 60/40 rosin core solder in 0.32" [0.08mm] diameter), wire snips/flush cutters, wire cutters, wire strippers, utility knife, Phillips head screwdriver, ⅛ inch flat head screwdrivers, slotted jeweller screwdriver, ruler with metric scale.
Tools recommended:	Multimeter
Parts required:	Digital ROV kit

The Digital ROV controller works by potentiometers on the joysticks providing a variable voltage to the integrated circuit on the Sabertooth motor controller. The integrated circuit interprets these signals and sends commands out to the H-bridges that are also located on the Sabertooth motor controller. The H-bridges provide motor speed and direction to each of the four motors on the Digital ROV. The Digital ROV also includes a motor simulator board. This board has four bi-directional LEDs that simulate with brightness and colour, the movement of the four motors on the Digital ROV. The brighter the LED, the faster the motor will be turning. If the LED shines green, the motor will be running forwards. If the LED shines red, the motor will be running in reverse.

The control system consists of two joysticks, two Sabertooth motor controllers and four motors. The first joystick will provide input to one Sabertooth motor controller and will send signals to the forward, backward and turning motors. The second joystick will provide input to the other Sabertooth motor controller and will send signals to the up and down vertical motor(s) as well as the side to side crabbing motor(s).

To learn more about how the joysticks provide variable voltage to the IC, and how the H-bridges provide pulse-width modulation signals for each motor, see the Digital ROV Controller Simplified presentation found here:

PRESENTATION LINK: TRIGGERFISH/DIGITAL ROV CONTROLLER SIMPLIFIED

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vT1BeV4kWSiCZsWvUzn0rAbHVC2OEitjvzN2nBbslevrms0vEhkKxYjLinpaHsrxR3_wf1_h8VqzRbq/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517797000

The Digital ROV controller consists of an on/off safety switch, a Watt meter, two joysticks, two sabertooth motor controllers, and a motor simulation board. The Digital ROV also has relays to control other devices, Bluetooth, Arduino and other advanced systems to allow more operations. The Digital ROV kit also includes the wires and cables necessary to connect the various components together and a box to house the control system. A camera filter board and connections for video cameras and video monitors is also incorporated into the control boards.

To construct the Digital ROV control box, see the Constructing the Digital ROV Control Box presentation found here:

PRESENTATION LINK: CONSTRUCTING THE DIGITAL ROV

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vSf4ZRWpTd6xIQmQ6yNhQSyRqIgJqcP6R0jxb0E0qo235Ff5MSj_YIII9tGkbrhliwxeT4ADUCFa0WI/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517798000

The Digital ROV 1.0 (BETA test version) has a new backplane board and a new tether connector with strain relief. To construct the Digital ROV 1.0 controller, which comes with a new (green) backplane board and orange box, see Constructing the Digital ROV 1.0 Control Box presentation found here:

PRESENTATION LINK: CONSTRUCTING THE DIGITAL ROV 1.0 CONTROL BOX - BETA Version

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vRfjPodFdVzuhyziEAED-9Djwnqy_gBbuAQb3et9dTKrr5IUv2xJ8JxLXYlq1NHYyTUo1oabdd2Lw5b/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517799000

PRESENTATION LINK: ADDING A MONITOR TO THE CONTROL BOX

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vTmu0euW_30a00Lh_nIQB76PQXfercopNuY9k0lccdEcvzEX0f8r3ovLb6bXARjuoQn3Zj5adFeFCSJ/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517799000

PRESENTATION LINK: ADDING A MONITOR TO THE DIGITAL ROV 1.0 CONTROL BOX

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vRunx_Fd7_S-mPPik_HEGW95d3t1tE5IQ-DuP-ZK4QK8KRKEIlbKyCQ-Y6JRwUcylLpB0OTXH7gBlmL/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517800000

More information on joysticks and Sabertooth motor controller settings can be found in the presentations found here:

PRESENTATION LINK: JOYSTICKS

https://www.google.com/url?q=https://docs.google.com/presentation/d/1M8w0TxYfj0aAud6wuFcrZfR_0Ket12VuZUMgG-LGviM/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517800000

PRESENTATION LINK: SABERTOOTH OVERVIEW

https://www.google.com/url?q=https://docs.google.com/presentation/d/1N6Hj7ZIrvk8HlAahL2zbBibwVP4fgricbXPEPsAfesE/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517800000

MATE highly recommends reviewing the following presentations on soldering before you create your control box. If you need practice with soldering skills, practice soldering with wires and MATE practice boards. Soldering mistakes on the Digital ROV control board can create major issues.

PRESENTATION LINK: SOLDERING WIRES AND WATERPROOFING CONNECTIONS

https://www.google.com/url?q=https://docs.google.com/presentation/d/1hePhGYe-9f2ttyLiXMY9oTBqT7Fe8WU3_Oty-JoZHXE/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517801000

PRESENTATION LINK: MATE SOLDERING WORKSHEET

https://www.google.com/url?q=https://docs.google.com/document/d/1PC_tc0LQZgcU5t9WQ27LaUTt-DMl0uqcdbmzGWHlfHk/pub&sa=D&ust=1559780517801000

PRESENTATION LINK: HOW TO SOLDER COMPONENTS TO A PRINTED CIRCUIT BOARD (PCB)

https://www.google.com/url?q=https://docs.google.com/presentation/d/1Y8sBaYPf262359DTtrjFEGK--_qSrladpzRmFAueNKs/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517802000

4. The Tether System

Time required:	30 min
Tools needed:	Wire strippers, soldering iron, solder, hot glue gun and heat gun
Tools recommended:	Multimeter
Parts required:	Tether wire with eight 18-gauge wires (black, white, green, red, blue, brown, orange and yellow) (included in Digital ROV Kit)

The tether system connects the control box, which is on the surface, to the ROV, which will venture underwater. The tether should have two wires for each motor; one carrying power to the motor and one carrying it back to complete the circuit. Since the Digital ROV has two joysticks, each controlling two motors, that is four motors and eight wires total. The tether providing power to the motors will have eight wires. Your tether may include other wires, cords and cables as well. If a camera is used on your ROV, there will be an additional camera cable, as well as the motor power cables, that needs to be included in the tether. The camera cable will have two wires to provide power to the camera, and additional wires for the data (video signal) coming from the camera. The camera wires are usually all wrapped into one cable. If you are building a hydraulic or pneumatic manipulator, the airline tubing will be part of the tether. Other systems, lights and sensors, may require additional cables as well. Remember, although it may be nice to have lots of systems on the ROV, each system needs wires or lines, and each wire adds thickness and mass to your tether. If there are too many systems on a small ROV, the motors may not be able to push the big thick tether through the water.

If you do have two or more lines running through the tether, it may be ideal to wrap your tether in a sheathing. The Tether presentation shows how to wrap your tether in sheathing. Remember! Wrap your tether BEFORE making the soldering connections on either end. It is very difficult to impossible to do afterwards. Also make sure you have all your cables assembled before pushing them through your tether. If you add another system later, it may be difficult to push it through an occupied tether sheath.

PRESENTATION LINK: INSTALLING A SHEATH OVER YOUR MULTIPLE TETHER WIRES

https://www.google.com/url?q=https://docs.google.com/presentation/d/1XzpWaI2vV997DcX0BmMaZ9KsMR-7Y8IEUt4bQKfl6Mo/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517809000

Length of tether: Why don't we build our small, 12 volt ROVs with 32 meters (100+ feet) of tether so we can explore in a greater area? Why not 150 meters (500 feet) of tether?

Longer tethers have issues. It takes a little bit of voltage to push electricity through every bit of wire you have. As you increase the length of wire, you decrease the amount of voltage that you are getting at your motor. This is called voltage drop. Since electricity must run through a circuit (from the battery to the motor and back to the battery) every 300mm you increase your tether length, the electricity now has to travel 620mm more in distance through the circuit. All that distance can add up. As your motor sees less voltage, it won't turn as fast. That means you have a lot less thrust. At 8 meters of tether, the motors work well and provide plenty of thrust. At 10 meters they still work well, but don't provide quite as much thrust. At 13 meters to 16 meters you will really notice the drop in motor thrust. At 33 meters of tether, your motors will likely not provide enough thrust to move your vehicle through the water. There are many online tools to calculate voltage drop.

Check out the following online calculator.

http://www.calculator.net/voltage-drop-calculator.html

- Wire is copper or aluminium wire.
- Wire size is 18-gauge (AWG).
- MATE ROVs use 12 volts DC.
- MATE ROVs use single sets of conductors.
- In water, our load current is approximately 2.5 amps.

Think about some of the things that could be done to increase the voltage at the bottom end of the tether.

Attaching your tether to the control box:

This section deals with attaching the top end of your tether into the control box. The next section, Propulsion, deals with attaching motors to the bottom end of your tether. To connect the top end of the tether, follow the instructions found here:

PRESENTATION LINK: CONNECTING THE TETHER TO THE TF 3.0 / DIGITAL ROV CONTROL BOX

https://www.google.com/url?q=https://docs.google.com/presentation/d/1bm-w1Ik76GSTgWzva-LARhzLK1IFqTR55-nmJoJu2rc/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517814000

PRESENTATION LINK: CONNECTING THE TETHER TO THE CONTROL BOX FOR THE DIGITAL ROV 1.0

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vRmrSRmjQVziOMXkgDid8x8DRKmTxXSncry5jPP_hHe7w-SiogroOXmtn4SQ5PWtV8lacbkS3eCdnta/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517815000

PRESENTATION LINK: ADDING CAMERAS TO THE TF 3.0 / DIGITAL ROV TETHER CONNECTIONS

https://www.google.com/url?q=https://docs.google.com/presentation/d/1JfPODBBhzxvrcc3sQmQA0wyhS20ux54HB8Cb0ZUkEOU/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517815000

5. The Propulsion System

Time required: 1 hour

Tools needed: Phillips screwdriver

Parts required: Digital ROV Motor and Propeller Kit

The propulsion system consists of the motors, propellers, motor couplings and the tether management cross. The wires from the four motors connect to the bottom end of the tether. There are three sections to creating the propulsion system, each with its own instructions. Creating the tether management cross MUST be completed before connecting the motor wires to the tether.

Attaching propellers to the motor

Your Digital ROV Motor and Propeller Kit comes with four bilge pump motors, four PVC motor mounts and four propellers with attachments for each. The propellers need to be secured to the motors after the motor mounts have been attached. Loctite (metal adhesive) will help to secure the propellers onto the motor and keep them from falling off when moving through the water. To attach your propellers to your motors, follow the instructions found here:

PRESENTATION LINK: PROPULSION SYSTEM: MOTORS AND PROPELLERS

https://www.google.com/url?q=https://docs.google.com/presentation/d/1mcP4J4Q2bmahoElpsOrDUR52icu5sXS-rw9jk4Rwi88/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517820000

Creating the tether management cross

Not having any strain relief on the bottom side tether can cause problems. Any tug on the tether will pull directly on solder joints and could cause issues. Having loose wires on the vehicle side near the propellers might cause issues too. Loose wires can get pulled into propellers and be damaged or damage the propellers. The MATE PVC strain relief allows the wires to be tightened and secured against strain damage. Using 12mm PVC allows the strain relief to be incorporated into an ROV frame made from 12mm PVC pipe.

Note: If you are using 12mm PVC pipe for your frame, take into account the cross in the tether management system. If you are not using 12mm PVC pipe, you will still need to take strain relief into account when building your ROV. To build your strain relief, follow the instructions found here:

PRESENTATION LINK: PROPULSION SYSTEM: CREATING THE TETHER MANAGEMENT CROSS

https://www.google.com/url?q=https://docs.google.com/presentation/d/1OqQ49ZD1G6fhgH34ldpA0NPWfAKPs6cIWxlLNhh0xcE/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517821000

Connecting the tether to the motors

The final step in adding your propulsion system to the ROV is to attach your motors to the bottom end of the tether. Make sure the colour combinations you used on the topside of the tether (tether wires going into the control box) match up with your bottom side tether (which colour wires go to which motor). If you use the MATE colour scheme (highly recommended), the red and green wires should go to MTR 1 in the control box and the left horizontal motor on the ROV. The black and white wires should go to MTR 2 in the control box and the right horizontal motor on the ROV. The blue and brown wires should go to MTR 3 in the control box and the vertical motor on an orthogonal ROV or left vertical motor on a vectored ROV. The yellow and orange wires should go to MTR 4 in the control box and the crab/strafe motor on an orthogonal ROV or the right vertical motor on a vectored ROV. If you are using a different colour combination, keep track of your colours.

Since these wire connections are going underwater, make sure to use hot glue and shrink wrap on every joint to ensure a waterproof seal. Review the waterproofing section of the SOLDERING WIRES AND WATERPROOFING CONNECTIONS if needed. To connect your motors to your tether, follow the instructions found here:

PRESENTATION LINK: PROPULSION SYSTEM: CONNECTING THE TETHER TO THE MOTORS

https://www.google.com/url?q=https://docs.google.com/presentation/d/1_93HPWE-aPsy9pZsqfuzoopn1yeF3Gt1c8lFXxB4B6g/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517822000

When you have control system is connected to the motors through the tether, close up your control box and attach your motors to your frame.

Congratulations, you have a Digital ROV control box!

6. Buoyancy

Time required: 30 min to 2 hours
Tools needed: Hacksaw or scissors
Tools recommended: Ruler
Parts required: Foam flotation or larger diameter PVC pipe.

In most cases, you want your vehicle to be as close to neutrally buoyant as possible. A neutrally buoyant vehicle will neither rise nor sink in the water. If motors are not running, it will stay where it is in the water column. Large work class ROVs and other vehicles that go into the ocean or other environment are usually slightly positively buoyant. That means they slowly rise if motors are not driving them down. A slightly positive ROV in the real-world environment has a few advantages. If the tether gets completely cut, a slightly positive ROV will come back to the surface where it can be recovered. Also, ROVs operating near a muddy bottom don't want their thrusters pushing water down (thrusting the vehicle upward to compensate for negative buoyancy). That thrust will stir up the bottom mud and can make it impossible to see. We recommend making a vehicle that is slightly positively buoyant if you plan to use it in the ocean or in a lake and neutrally buoyant if you are using it in a pool. A neutrally buoyant ROV is easier to operate.

Buoyancy and Ballast

Buoyancy is considered to be all the components that are less dense than water and will cause a vehicle to rise towards the surface when in the water. Ballast is considered to be all the components that are denser than water and will cause a vehicle to sink towards the bottom when in water. In most cases all the components of your ROV will be ballast. PVC in the frame and motors are the main sources of ballast in an ROV. Most often, flotation will be needed to offset the weight of the other components of your ROV.

The tether can be a source of ballast as well. ROV teams may want to consider adding buoyancy every meter or so along their tether to offset its weight.

A lot of math and science goes along with trimming your ROV (i.e. adjusting the buoyancy, ballast, pitch and roll of the ROV.) You can learn more about buoyancy here:

PRESENTATION LINK: GENERAL BUOYANCY CONCEPTS

https://www.google.com/url?q=https://docs.google.com/presentation/d/e/2PACX-1vTE66pPwUH4714_kF4lDv9b0P_NaxPxRgEdMkNE2dMF3quCHhr4vkbZ9MP3YmturuTPtaBDZ1ncSRly/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517829000

ROV Buoyancy Choices

There are a lot of different types of flotation that can be used in an ROV. A few different types are presented here, but be creative. You may find another buoyancy solution works best for you. There are lots of different ways to add buoyancy to your vehicle.

Soft Foam (Pool noodles or pipe insulation foam): Pool noodles are soft, colourful foam that is fairly inexpensive and can be found at many local big box stores (Walmart, Target, etc.). Pipe insulation foam is soft foam that is designed to fit around PVC and other pipes. It is fairly inexpensive and can be found at Home Depot and other hardware stores. Both of these soft foam options can be cut with scissors and is very easy to work with. However, there is a drawback. Soft foam is soft. Soft foam will compress at depth as water pressure increases. It is generally okay down to 1.5 meters, but as an ROV descends deeper and deeper, the foam will compress and lose its buoyancy. At 3.5 meters (12 feet), soft foam loses about half to two thirds of its buoyant property. Vehicles with soft foam at this depth can lose so much buoyancy from pressure that the motors can no longer return the ROV to the surface.

Larger Diameter Capped PVC: 2-inch, 1 ½-inch and other larger diameter PVC, with air inside, and with end caps glued to each end can also be used for flotation. The volume of air inside these rigid pipes provides a good amount of buoyancy. These pipes will not compress at pool depths but do be careful if you plan to go beyond 20 or 30 meters. You may want to test your canisters to these greater depths before taking your ROV there. Using larger diameter pipe also allows you to use math to calculate exactly what lengths of pipe you will need. See the section below on how much flotation you will need to make your vehicle neutrally buoyant.

Rigid Buoyancy: Rigid buoyancy is harder foam that can be shaped and can go down to much greater depths than soft foam. There are various types of rigid buoyancy foam, often times defined by its depth rating. For a very high price, you can purchase syntactic foam that is rated to 4000 meters, but in general, you can find less expensive foam for the depths you may be going to. Home Depot and other hardware stores have architecture foam. It is a rigid foam that can be cut with a knife, saw or box cutter. Surfboard foam is also dense and can be coated in epoxy resin to keep the water out. You may find other sources of harder foam or rigid buoyancy that you can use to go deeper. Again, be creative and you might find a unique solution for your buoyancy.

How much flotation will you need to make your vehicle neutrally buoyant?

Without flotation added, your ROV will not be neutrally buoyant and will most likely be negatively buoyant in water. Use a fish scale or spring scale to weigh your vehicle in water. Tie ropes or string to your vehicle, dip it so the ROV is completely underwater, then measure the weight. Make sure to keep your spring scale above the water, especially if it is an electronic scale. This will tell you the weight of your ROV in water (sometimes referred to as Wet Weight). Now you can calculate the amount of flotation you will need to offset this weight.

Air essentially weighs close to nothing (for our calculations here). So one cubic centimetre of air has a weight of 0 grams. One cubic centimetre of water weighs 1 gram. In water, one cubic centimetre of air will provide 1 gram of positive buoyancy. If your vehicle has a wet weight of 600 grams in water, you will need 600 cubic centimetres of air to offset that weight. (Remember to take into account the weight of the foam or cylinder you will be using, you need something to "enclose the air" and that something will have a weight.)

If you plan to use larger diameter pipe as flotation, you can calculate how much pipe you will need to offset the weight of your vehicle in water by doing buoyancy calculations. You can find out more here:

PRESENTATION LINK: Buoyancy Calculations.

> https://www.google.com/url?q=https://docs.google.com/presentation/d/1vhZ7EnAuDmo5SEff-JQoJ7RSpRXngcZCIj-6k1W8F5k/pub?start%3Dfalse%26loop%3Dfalse%26delayms%3D3000&sa=D&ust=1559780517833000

The final slide of this presentation has the Net Buoyancy for 25mm pipe, 32mm pipe and 50mm pipe. You should verify these numbers yourself before calculating the length of pipe you will need.