Xtra Tropical Robotics

Grove Academy
Dundee, Scotland

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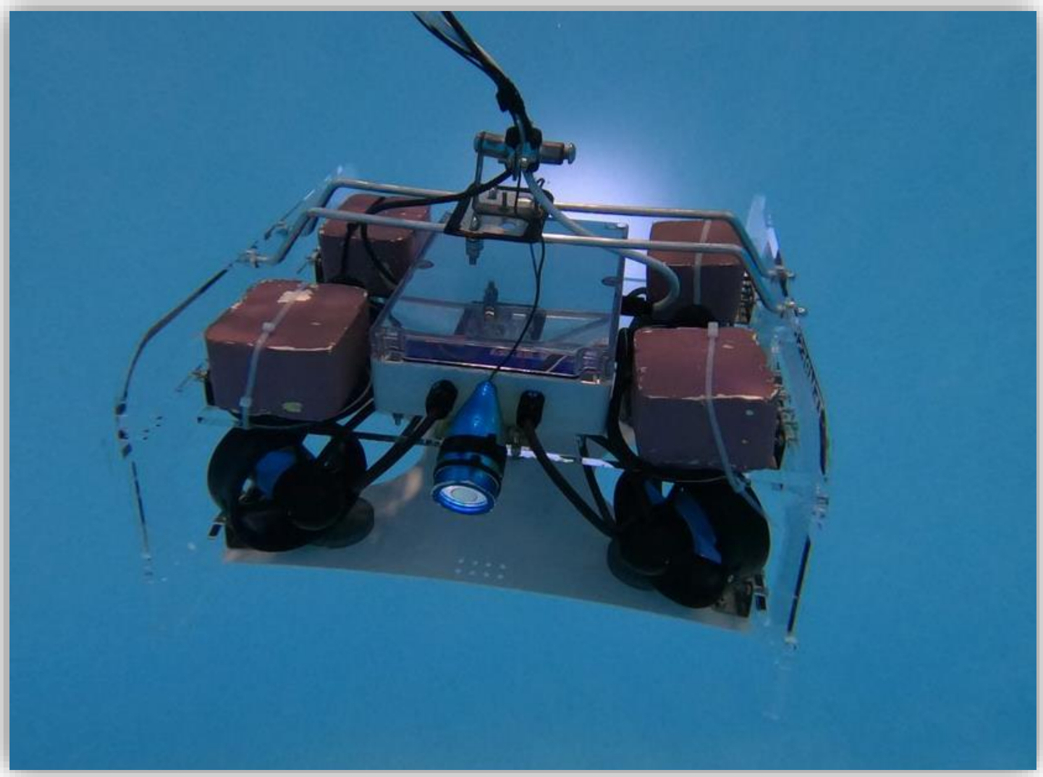
ABSTRACT

Xtra Tropical Robotics' newest product 'Tempest VI' is a remotely operated vehicle which has been designed to complete a series of tasks. Focused on solving the issues with our ocean and creating a more sustainable future, the ROV has been designed with a strong focus on its ability to operate and carry out tasks under the ocean surface. Our company has a strong interest in preserving our planet, especially the ocean and all the life contained within, and Tempest VI represents our effort to stop its deterioration. Many of the issues within the ocean are pollution issues, and Tempest VI is designed to help clean up infected areas of coral, help protect endangered species and to help aid research into renewable energy sources. Our company, despite encountering many setbacks, has employed methods and strategies that relate to key areas such as fault finding, problem solving and collation of ideas and operations. Through key leadership focused on the inclusion of ideas and approaches, the company has operated well in finding problems, brainstorming solutions and then putting the solutions into action. This has led to an ROV which is a product of many individuals' hard work and creative problem solving, turning it into a representation of our company's passion for developing ROVs.



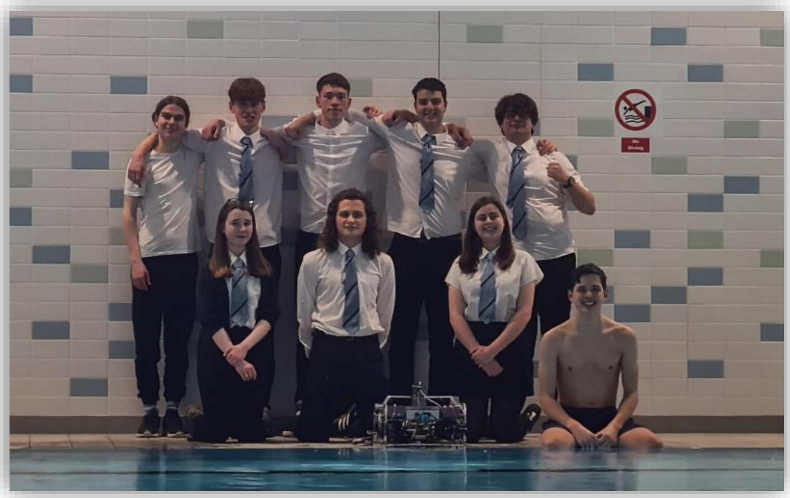
Early version of Tempest VI in the water - Photo by Thomas Kobine

Project Management

COMPANY CONTRIBUTIONS AND PROJECT MANAGEMENT

Our ROV is the result of teamwork and organisation from every member of our team. Each member has worked on at least an area of the ROV that was best suited to their skill set. Some of these included Frame Design and Construction, Programming, Tool Design and Manufacture, and Tether Management.

Since we had a limited time to build our ROV, we had to set deadlines for specific tasks. We split the tasks up and every group member was responsible for at least one task while constructing and testing Tempest throughout its iterations.



The XTR Team - Photo by Dillon Armstrong

RESOURCES, PROTOCOL AND PROCEDURES

Many of the resources used to construct Tempest VI were re-used. This helped us to keep costs low and allowed us to compare the pros and cons of build vs buy.

Everyday protocol was used to ensure all deadlines were met and all team members always remained in a safe environment. This included scheduled time to test Tempest VI in the pool and a team meeting at the beginning of every week, this allowed us to set out a plan for the upcoming week and review tasks that had been completed the previous week.

SCHEDULE

Brainstorm Design- A group of 4 set off to design the rov. Mock up on paper of provisional design.

Learn Arduino- One of us set out to learn how to code from scratch.

Finalise Design-The finishing touches were placed into CAD and the frame was ready to be cut.

Begin Cutting- After the CAD design we sent it to the laser cutter to be cut in MDF.

Design NMRD and MRD- 2 of us split off to design our all-purpose tools to do the tasks.

Build ROV in MDF- our first practically built design.

First Test Code- We made a test rig to see if our code could control the propulsion units.

First Acrylic build- MDF is not waterproof, so we decided all future builds will be made from acrylic.

Wire Control Box- We had our box wired up but there was still work to be done to make it tidier and easier to work with.

Begin Water Proofing- We are using a watertight container for all the coding and wiring. This needs to be able to go at least 2m deep so we began ensuring that it could.

Tempest IV-This is the first build that really started to take the shape of our final build and got us to learn so much more about how our ROV works.

Float Design-The float project started later but we still cracked on with It.

Complete NMRD- The NMRD is our first of our all-purpose tool that can be used.

Tempest V- This is where all our major changes came together to make this very similar tour final design.

First Water test- The ROV was waterproof, but we had to see if everything had come together to make it swim.

Waterproofing Complete- After many different attempts we managed to get the ROV waterproofed.

Finalisation of Wiring- The wiring finally looked clean ad it made it more reliable and easier to work on.

Tempest VI – We got to our final revision we make small changes to strengthen our ROV and make it task ready.

Complete MRD- We had finalised the MRD after many times waterproofing the servo and trying to get things mounted properly. It finally worked and was ready for the tasks.

Begin Practice – After everything was done and our ROV was task ready we needed practice and we spent as much time as possible getting the ROV in the water to make sure we were ready.

Complete float – We made many different attempts to get all our systems to work together but we got it all working together in the end.

Engineering Design Rationale

FRAME

The initial inspiration behind the Tempest series was taken from ROVs operating in the North Sea. The unique features of these ROVs we found is that they were mostly cube/cuboid shaped with the thrusters situated 'within' the frame. With this in mind, we started by making our first of many, prototypes out of medium density fibre board (MDF). This was done because MDF is relatively cheap and would give us a good idea of what the frame would look like. It also allowed to make quick and easy modifications to prototypes.

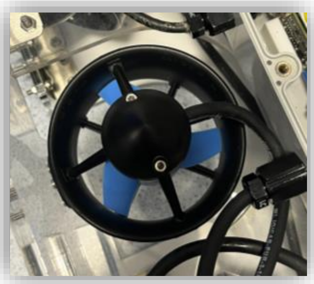
Frame of Tempest I - Photo by Lewis Smith

We have made several modifications while developing the tempest series, some of these include changing the motor mounts to ensure maximum thrust, rounding edges to minimise the risk of cracking and fractures of the frame and slots in the side plates for a more structurally sound frame.

The evolution of side plates for Tempest I to V - Photo by Eilidh Payne

THRUSTERS

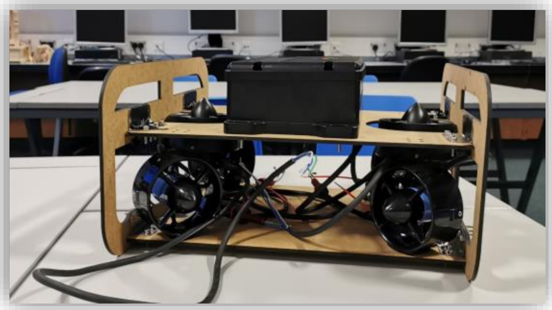
We decided to reuse propulsion units from teams prior as purchasing new motors would have been a massive expense that would not be justifiable.



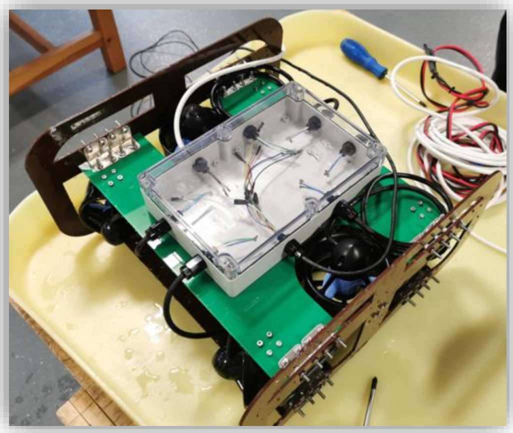
T200 Thruster - Photo by Eilidh Payne

XTR has access to four T100 thrusters and two T200 thrusters. The four T100 thrusters provide power in all directions on the horizontal plane. This allows us to crab, rotate (yaw) and glide through the water. The two T200 thrusters, being more powerful, are utilised for the vertical movement of the ROV. The higher thrust of these motors allows us to lift heavier objects and complete tasks more swiftly.

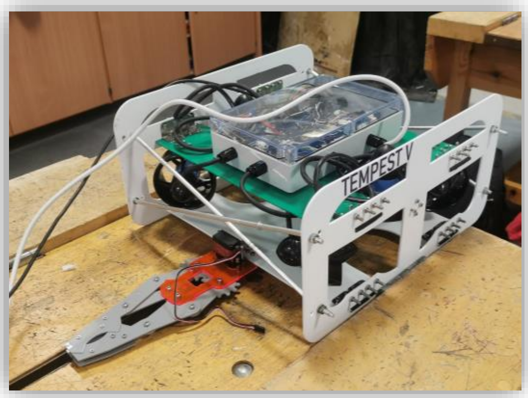
T100 Thruster - Photo by Lewis Smith



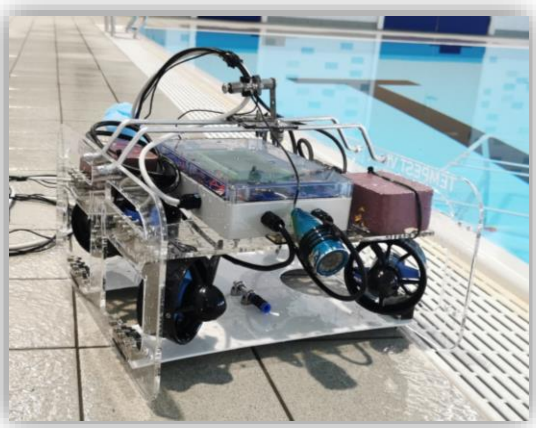
Tempest II - Photo by Lewis Smith



Tempest IV - Photo by Lewis Smith



Tempest V - Photo by Lewis Smith



Tempest VI - Photo by Lewis Smith

THE DESIGN PROCESS

Tempest I - Initial prototype of Tempest: MDF construction, all mounts were hand drilled.

Tempest II – Major changes: widened top and bottom plates, bomb fitted, new side plates, all mounts were laser cut.

Tempest III – Improving structural stability: tabs were added on the top and bottom plates to slot into the side plates.

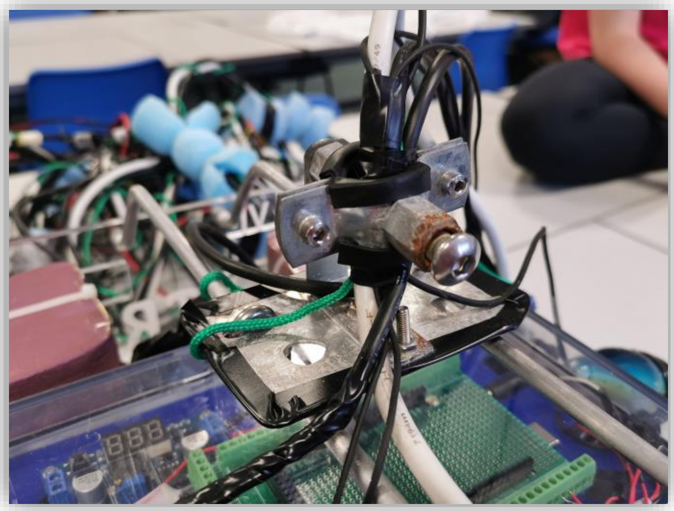
Tempest IV – First full acrylic version: thruster mounts changed to the top plate, full acrylic frame, new bomb was installed.

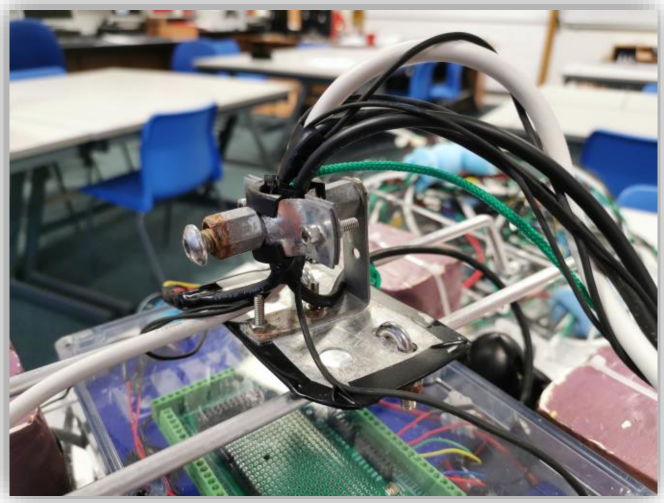
Tempest V – General upgrades: side plates were widened for instillation of crossbars, the ability to mount the gripper and other attachments were added, camera mounts were added.

Tempest VI – Final variation: almost full frame was swapped to 6mm acrylic, plate for supporting the umbilical tether was installed, crossbars were uninstalled (the frame was considerably stronger in 6mm acrylic and no longer needed them), rounded edges were added on all acrylic plates to prevent cracks and breaks, new bolts were installed, gripper handling ability was improved.

TETHER AND WIRING HARNESS

After testing, it was decided to house the control system onboard Tempest, this coming the advantage of having a much smaller umbilical decreasing the effects of drag. We also installed a rope that ties the wiring harness together to make it tighter and much neater. Furthermore, a metal plate was specifically designed to thread the wires to and through the top of the ROV. This made it easier to braid them together while simultaneously causing the wires to be more organised.





Tether Plate - Photos by Lewis Smith

CONTROLLER

The controller consists of a laser cut acrylic plate with two dual-axis joystick modules mounted to it. The dual-axis joystick modules allow us to utilise their analogue input signals that are then sent to the Arduino, this allows us to use exponential control on the thrusters onboard Tempest IV.

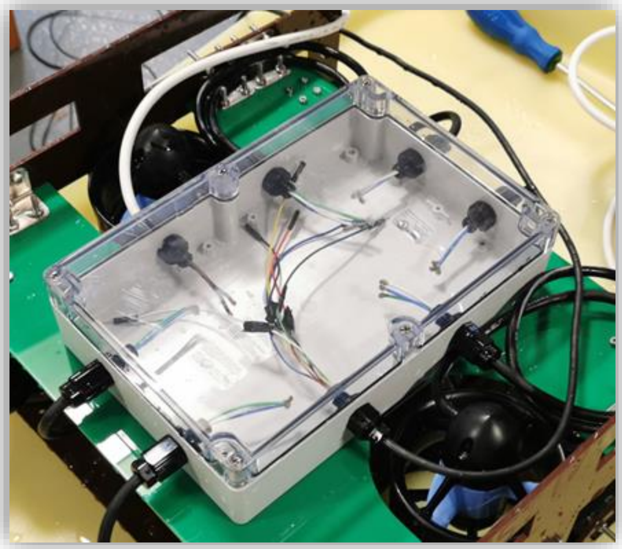
Additionally, a U-bolt is used to secure the controller cable to the controller, this is necessary to as it massively decreases the chance of inaccurate signals coming from the controller. Also, by decreasing the tension in the cable, it prevents damage to the; wires, delicate soldering points and the joysticks.

Innovation

BENEFICIAL CHANGES MADE

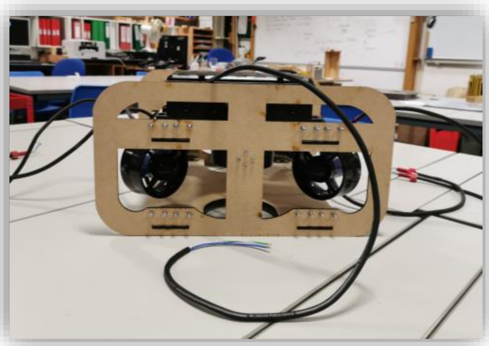
Many beneficial changes have been made to Tempest throughout its many variations. Some of these include:

Control Box - At first Tempest was not going to house its hardware onboard, with the disadvantage having a massive umbilical tether and the fear that Tempest would not perform with all the drag, so a control box was added to the next variation.



Control Box - Photo by Lewis Smith

Thruster Mounts – Originally the T100s were to be mounted to Tempest's bottom plate, this came with the benefit of a lower COG (centre of gravity) and hence a more stable ROV in the water. Although problems with the water flowing through the side plate meant that the thrusters had to be mounted to the top plate. So, the gap between top and bottom plates was shortened to lower COG and thrusters were mounted to the top plate, this allowed us to have a more stable ROV without interfering with propulsion.



Tempest III's frame with vertically mounted thrusters - Photo by Lewis Smith

Control/Electrical System

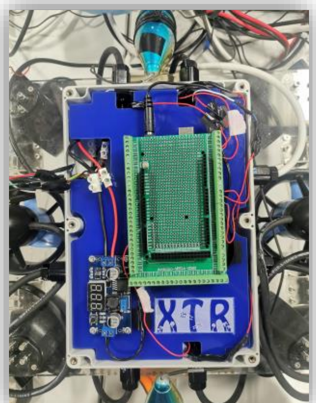
CONTROL SYSTEM

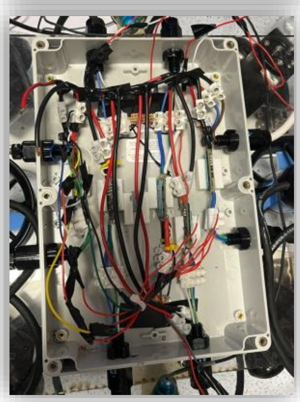
After some research, we decided to use Arduino software to program our ROV as it is an industry standard, and it is an easy code to learn and use. A few benefits of using Arduino were that we were able to program exponential control to each of the thrusters and have all six thrusters rotate at the same time, both being firsts on a ROV at Grove Academy.

```
tempestcode_V3.ino
  servo4.attach(motor4);
  servo5.attach(motor5);
  servo6.attach(motor6);

  servo1.writeMicroseconds(1500);
  servo2.writeMicroseconds(1500);
  servo3.writeMicroseconds(1500);
  servo4.writeMicroseconds(1500);
  servo5.writeMicroseconds(1500);
  servo6.writeMicroseconds(1500);

  delay(7000);
}

void loop() {

  int Y1Val = analogRead(Y1);
  int X1Val = analogRead(X1);
  int Y2Val = analogRead(Y2);
  int X2Val = analogRead(X2);


  Y1Val = map(Y1Val, 0, 1023, 1200, 1800);
  X1Val = map(X1Val, 0, 1023, 1200, 1800);
  Y2Val = map(Y2Val, 0, 1023, 1200, 1800);
  X2Val = map(X2Val, 0, 1023, 1200, 1800);


  Y1up = Y1Val - 1500;
  X1up = X1Val - 1500;
  Y2up = Y2Val - 1500;
  X2up = X2Val - 1500;
```

A section of code for Tempest - Photo by Jack Harrow

As for hardware, Tempest VI houses an Arduino Mega as opposed to an Arduino Uno. This choice was made as the Mega is more powerful and has more pins than the Uno, this was crucial as the Arduino must control six ESC units needed for the two T200 and four T100 thrusters onboard.





Inside the control box - Photos by Lewis Smith

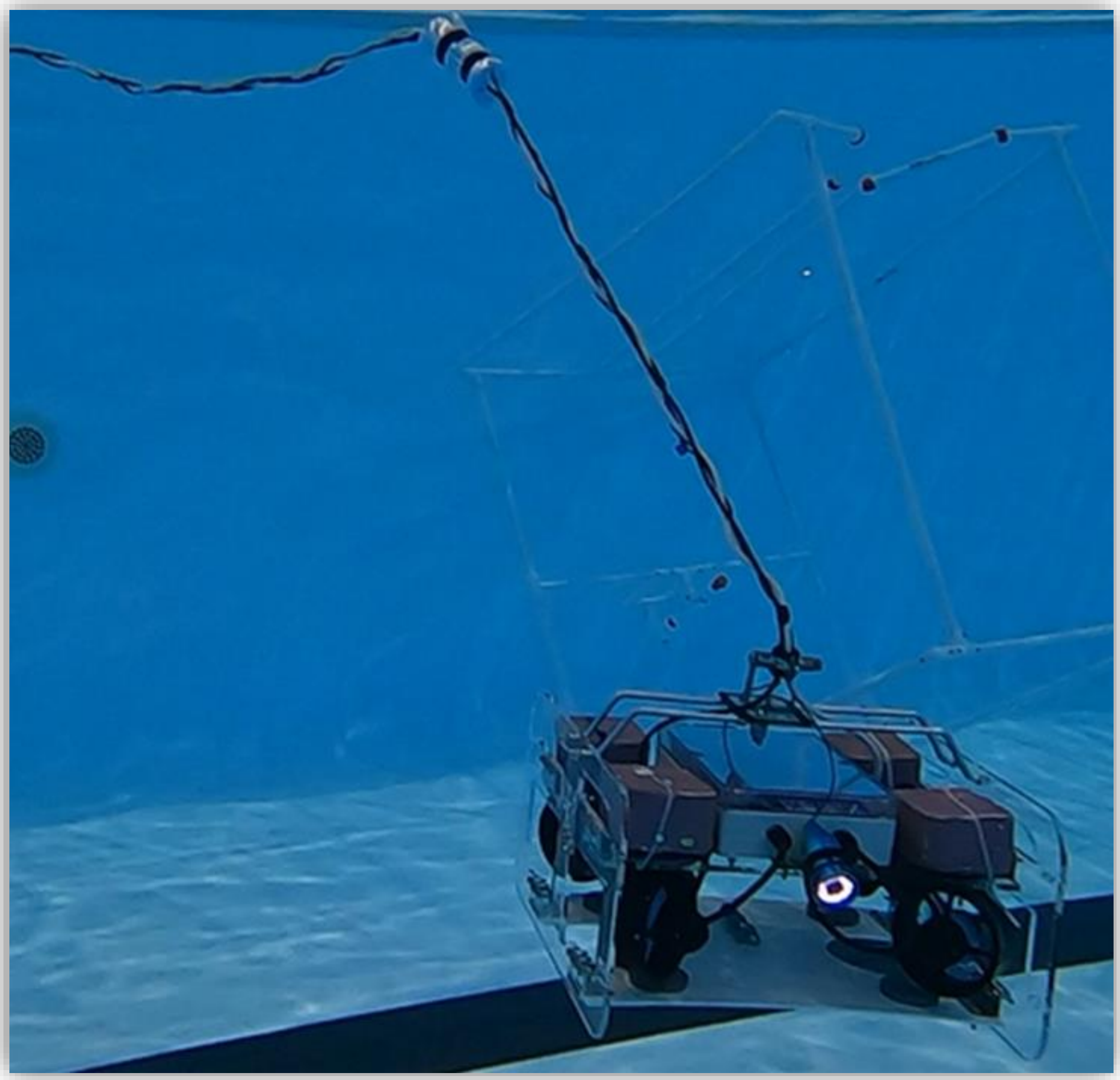
WIRING

The onboard control box houses six ESCs, a voltage regulator and the Arduino Mega. The box also has multiple cables entering it, these include: the power for the ESCs and Mega, the controller input signals and all the output signals for the six T200/T100 thrusters.

Within the control box, the six ESCs are arranged in a row and are secured in custom 3D-printed mounts along the bottom of the box. The Arduino and voltage regulator are mounted on an acrylic 'separator' plate above the ESCs. Power lines run perpendicular to the ESCs and then up and into the voltage regulator. Outputs from the Arduino run down from the separator plate and into the ESCs. All ESCs must be grounded to the Arduino, so to keep all the box tidy all ground wires go to a copper board first. This allows to only have two ground wires going to the Arduino as opposed to six.

TETHER MANAGEMENT PROTOCOL

A green cord was wrapped around the wiring harness so in the event that we must pull on the tether it doesn't put any additional strain on the wires and possibly damage them. We also braided the tether, this greatly reduced the wires tangling together, and made it much easier to manage and unpack/store by the poolside crew. When Tempest VI is in the water the tether must be fed out/retracted at the correct rate so as not to hold the ROV back due to too much (drag) or too little (tension) wire being let out.



Tempest completing a test dive - Photo by Thomas Kobine

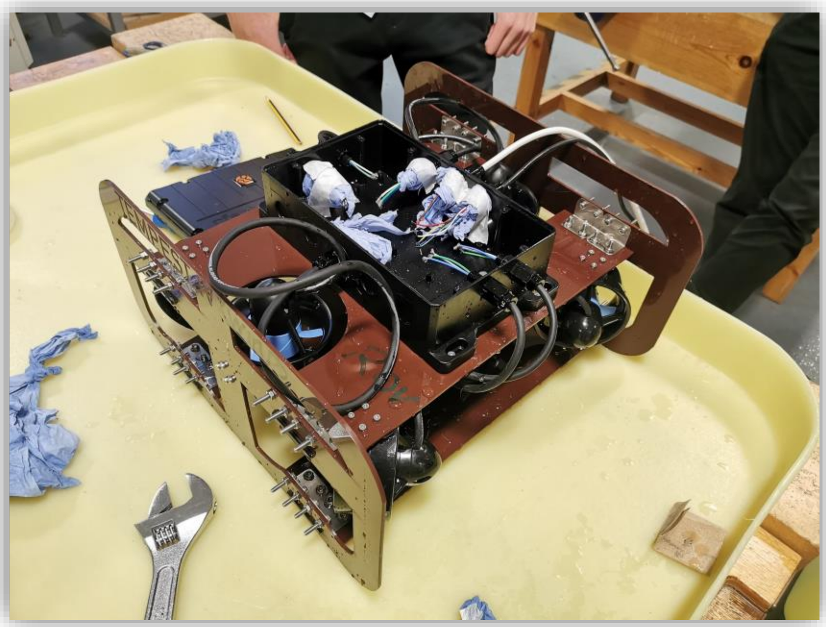
Problem Solving

BRAINSTORMING IDEAS

Our company brainstormed ideas using an open meeting type structure. This allowed ideas to be introduced and discussed and allowed every company member to have a chance to problem solve any issues, and creatively overcome setbacks. This led to a mixture of differing approaches and interpretations of the problems seen on the ROV and allowed a more thorough and accurate effort to overcome the complications.

OVERCOMING PROBLEMS

During the development of Tempest VI, and its predecessors Tempest I-V, many problems and setbacks emerged and had to be addressed. The method our company adapted to help reach a creative solution was a full company brainstorming meeting, which then led to our team's problem-solving ability improving and the ROV becoming a better version of the previous prototype. This method has resulted in an ROV which is a representation of our best combined ideas as a company and a symbol and expression of our combined characters as a group.



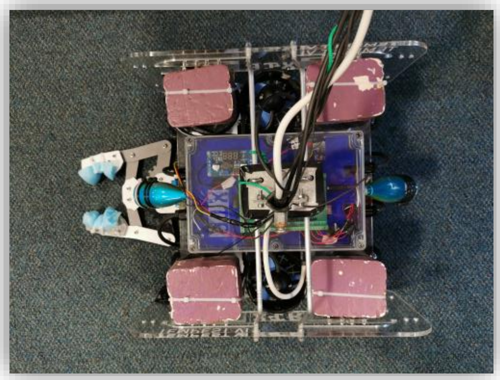
An attempt to waterproof Tempest - Photo by Lewis Smith

Buoyancy and Ballast

PLACEMENT OF THRUSTERS

The four T100 thrusters are mounted at a 45° angle, this was done to ensure equal thrust vectoring between moving in both x and y-axis.

The two T200 thrusters are mounted at 90° and on the centre line of the ROV, both of these factors ensure that Tempest does not tilt when manoeuvring in the vertical plane.



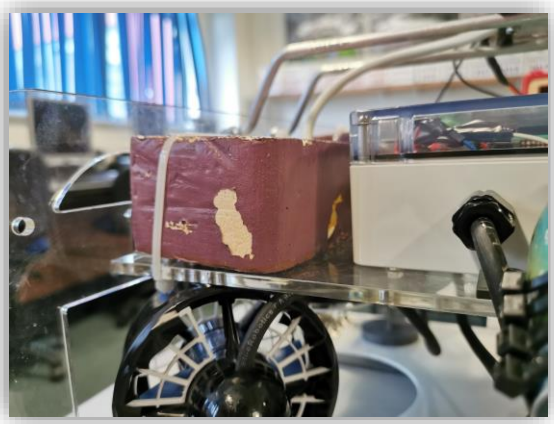
Top-down view of Tempest VI - Photo by Lewis Smith

BUOYANCY SYSTEM

Tempest VI has floatation blocks in all four corners of the ROV, these are mounted as high as possible to increase stability in the water.

To equalise our buoyancy, Tempest also has a modular ballast system installed this can allow it to be neutrally buoyant. Although to tailor our pilots' preferences we have optimised Tempest to be slightly negatively buoyant.

Ballast mass - Photo by Lewis Smith



Buoyancy block - Photo by Lewis Smith

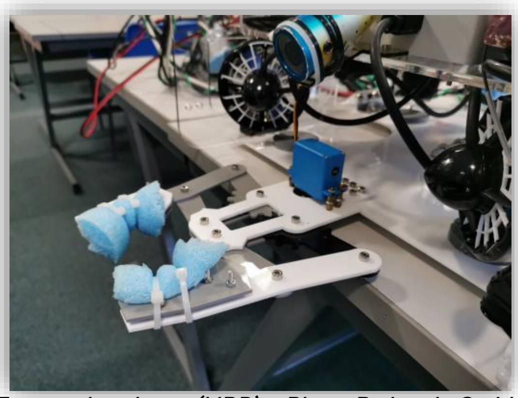
Payload and Tools

TOOLING

The ROV features a mechanised retrieval device and a non-mechanised retrieval device for retrieving items from the pool, either as part of the tasks for the competition or for cleaning the pool of any props used. The non-mechanised retrieval device (NMRD) takes the shape of a saw tooth probe. This design was chosen over a smooth probe as this design allows object to easily slide onto the probe, but doesn't allow objects to slide off the probe, allowing objects to be reliably retrieved from the pool surface. The material chosen for the NMRD was 5.5-millimeter-thick acrylic, as it has the right combination of strength, but is also lightweight, contributing minimally to the ROV's total weight. The connecting beams between the plates of the NMRD are made from aluminium rod of diameter 6 millimetre, which is also strong and lightweight, and isn't susceptible to rusting. The NMRD is connected to the ROV by a single point of contact, in this case an aluminium rod, which attaches to a 6-millimetre pneumatic push connector, attached to the ROV by U bolts, allowing the NMRD to be quickly but securely attached to the ROV. This also allows the NMRD to be removed. The NMRD is two different colours. This is to represent our Scottish heritage, and our pride in our nation. It is also to symbolise the connection between the water and the land, and how the concept of an ROV helps connect our way of life on the land to possible future ways of life in our great seas and oceans.

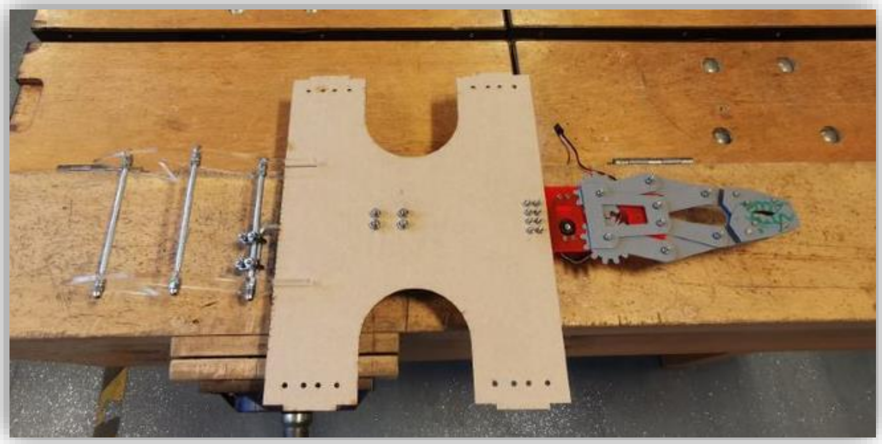
Throughout our development of Tempest, it was decided that the NMRD was no longer necessary for us to complete the tasks. The NMRD was subsequently dismantled, and parts repurposed for other tools.

The NMRD - Photo by Eilidh Payne



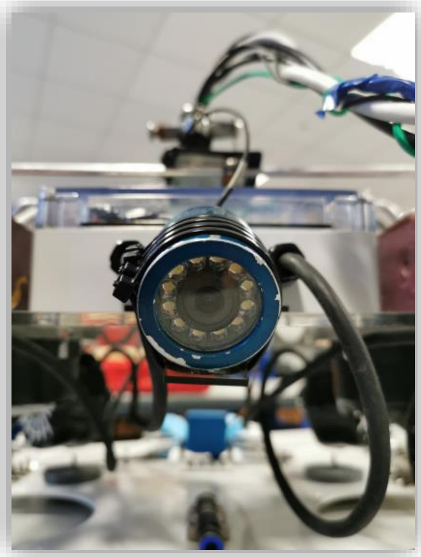
Tempest's gripper (MRD) - Photo By Lewis Smith

The Mechanised Retrieval Device was designed to use two arms that always stay parallel, rather than opening in a 'v' shape. This was done to make grabbing round objects easy as they are not pushed out of its grasp, the teeth also help to reduce this. The gripping part has multiple layers to make objects its holding wobble around less. During testing it was found that there was a lot of friction, so we added washers to reduce the load on the servo. The most challenging part was getting a servo to work underwater, we attempted to waterproof one but after several failures we resolved to buy a more expensive but waterproof servo. There was a great difficulty in coding the servo but after many weeks we finally got it.



Testing tool mounts - Photo by Lewis Smith

SENSORS AND CAMERA PLACEMENT



Rear-view camera - Photo by Lewis Smith

Our camera system consists of three cameras and three monitors. All cameras on Tempest VI can be adjusted to different angles with the use of custom-made camera mounts which can be swapped out within a matter of minutes.

The camera placements on Tempest VI have been custom tailored to our pilots' needs. Tempest VI features a front facing camera overlooking the gripper, a rear facing camera overlooking other attachments and a final camera with a downwards view. It is to be noted that the rear facing camera is at a more aggressive angle than that of the front facing camera.

Build vs. Buy, New vs. Used

BUILD VS. BUY VS. USED

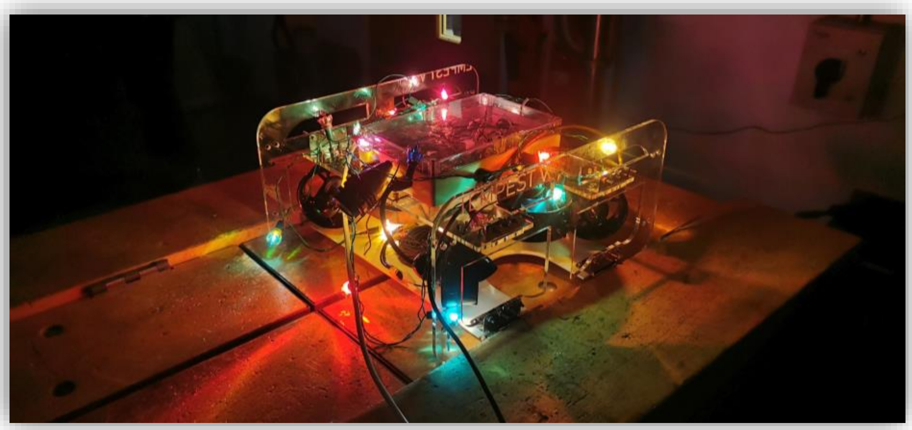
During the making of Tempest VI, the members of Xtra Tropical Robotics have thought every decision through when it came to build vs buy vs used. As a team, we decided the best way forward that was both cost – effective and resulted in a higher functioning ROV.

We reused all our thrusters, 3 cameras and 7 ESCs from previous team that had competed. These components were tested before the decision was made to reuse instead of buying new. This resulted in a reduced cost but still allowed Tempest VI to operate effectively and complete the set tasks with success.

The decision was made to buy new glands and a new control box. This was decided as buying new was more cost-effective and time-effective than reusing a control box and cleaning and re-sealing glands. This also allowed Tempest VI to have a completely watertight control box and ensured the safety of everybody on the team while working on Tempest VI.

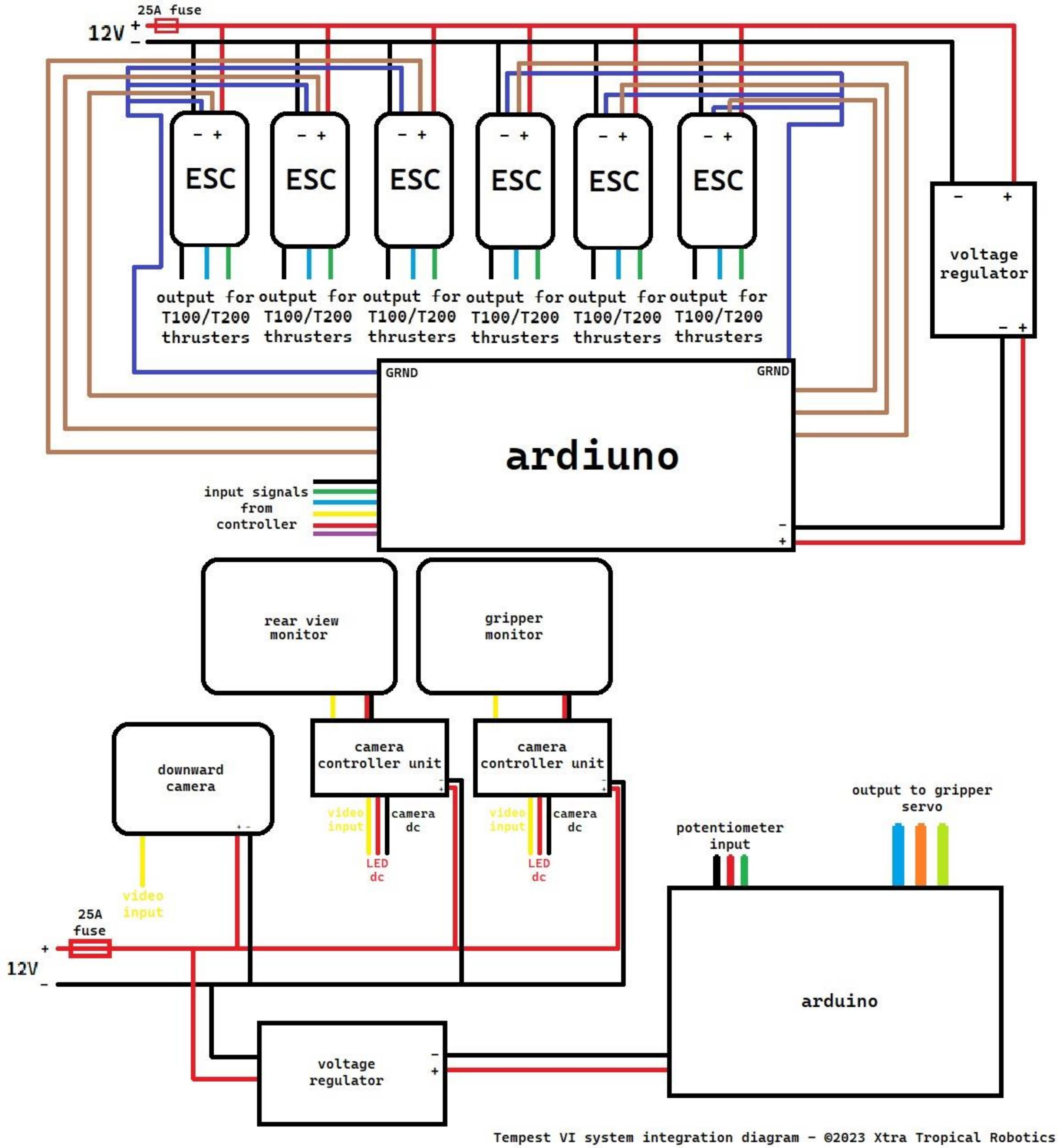
We also bought an Arduino Bluetooth Control Module and an Arduino Real-time clock to ensure that we can complete the task with our float.

The quality of the frame was improved by the purchase of new brackets to ensure that the frame was sturdy enough to complete all the tasks successfully.



Tempest frame decorated for Christmas - Photo by Lewis Smith

System Integration Diagram



Safety

SAFETY PROCEDURES

It was important during the construction of Tempest VI that all team members remained in a safe environment. To ensure this, certain procedures were put into place as we worked on developing Tempest VI.

When testing the thrusters on the ROV, we had to make sure that nobody had their fingers near the blades in order to prevent any injuries. Guards were added to the thrusters so that there was a certainty that nobody could get their fingers caught in the thrusters. We also had to ensure that all team members were safe and behaved in a sensible manner while testing the ROV in the pool. This included making sure the diver assisting the ROV in the pool was a confident swimmer and that everybody on the surface was sensible in the way they moved on the potentially wet and slippy surface.

Care was also taken when soldering. The soldering iron was not to be left unattended while on to prevent burns. Measures were also taken to ensure that the soldering iron was placed back in the holder to guarantee that no flammable material could possibly start a fire.

While operating the laser cutter and other devices extra care was also taken. We had to ensure that the extractor was on while using the laser cutter in order to prevent any fires. We were also careful to ensure all CAD drawings were precise in measurements and thoroughly thought through in order to reduce waste. The correct protective equipment was used while operating certain devices to ensure maximum safety was always achieved.

While working on the control box and wiring, it was important that no current was present in the wires to prevent possible electric shocks.

Our ROV has been designed and manufactured to have no sharp edges or any parts that could potentially damage the pool. We also added a wiring harness that wraps tightly around the tether to ensure that no damage would be caused while testing and flying the ROV.

Troubleshooting and Testing

TESTING METHODOLOGY

We try to make our testing as real world as possible. This has been done by having access to a water tank that lets us test if our bomb is watertight and ultimately water worthy. This also lets us control parameters of what the test condition can be like. We have also been given access to a pool which will give us a greater area to test in.

PROTOTYPING AND TESTING

Prototyping and testing played a key role the development of the Tempest series. Every component was tested before and during its time on the ROV. We quickly learned things don't always work as intended and we have picked up different skills on how to best identify how our device is working. We like to test everything practically and hands on even with our first prototypes so that we know how each of our designs can work in the real world.

TROUBLESHOOTING STRATEGIES AND TECHNIQUES

At XTR, we realised that rarely do things go to plan, but with every downfall we can go back and improve in aspects we had previously failed in. We have learnt that we have to take our time on engineering solutions because if not, it will take longer to fix them than if we took our time in the first place. When troubleshooting we discovered that eliminating one variable at a time is the most effective and would lead to solutions quicker than attempting all possible solutions at once.

Budget and Accounts

ACCOUNTS

Product	PURCHASED/REUSED/ DONATED	IN	OUT	BALANCE
		£500.00		
Metal Brackets	Purchased from Amazon		£5.99	£494.01
Arduino Bluetooth	Purchased from Amazon		£6.49	£487.52
Syringe	Purchased from Amazon		£2.52	£485.00
Servo	Purchased from Amazon		£16.90	£468.10
ESC	Purchased from Blue Robotics		£36.00	£432.10
Glands	Purchased from Blue Robotics		£224.00	£208.10
Stop Leak Sealer Spray	Purchased from Amazon		£13.99	£194.11
Button Head Screws	Purchased from ScrewFix		£12.90	£181.21
Watertight Enclosure	Purchased from RS Components		£13.50	£167.71
Total			£332.29	£167.71
T100 Thrusters	Reused - £128.00 per item			
T200 Thrusers	Reused -£160.00 per item			
Cameras and Monitors	Reused - £100.00 per item			
Wiring Harness	Reused - £10.00			
Foam	Donated			
Acrylic	Donated			
100g Weights	Donated			

The majority of the budget was spent on waterproofing the control box. Although the overall cost of Tempest VI is rather high, the amount of budget spend is comparatively low. This is because expensive components were reused and recycled from previous Scottish regional winning ROVs.

At the time of writing travel expenses have not been made available to the team, although from previous championships we have been given an estimate of £2400 per person for flights and accommodation. To help fund our team's journey to Colorado we have reached out to several companies and organizations for sponsorship, this is in addition to receiving donations through our GoFundMe page.

Acknowledgements

- *Grove Academy* – Free use of the pool, funding, free access to 3D-printing and laser cutting facilities.

- *Mr. Waghorn* – Mentor

- *Martin Smith (Firechill Foto)* – Designer of XTR Logo

Throughout the development of Tempest, the team already obtained previous knowledge in most aspects of engineering and business. The only outside source that was used was Paul McWhorter (https://www.youtube.com/@paulmcwhorter) on YouTube to help further develop our knowledge in Arduino coding.

- *Kris Callen (The Callen Group)* – Provided $500 (≈£400) sponsorship money for flights and accommodation.

- *The Lang Foundation* – Provided £900 sponsorship money for travel expenses.

- *Robert Gordon University* – Funded flights and accommodation for six members of the team.

- *David Lloyd Clubs (Dundee)* - Free allowance to practice and test in the outdoor pool.

The companies that decided to sponsor us have identified with the mission of the MATE ROV programme and decided to not just help the planet but help a local team have a chance to represent their country. This has made a great help to our team, and we are very grateful for all the help we got.