Norway *to* Newfoundland

Testing Remote Operations *Across the Atlantic*

by Bethany Randell

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Project Overview

In November 2022, a delegation from the Marine Institute (MI) visited the Norwegian University of Science and Technology (NTNU) to grow the partnership between two similar institutions. The delegation came back with an ambitious plan: in May 2023, an MI representative in Newfoundland, Canada, would fly a remotely operated vehicle (ROV) in Norway.

Remote operations can provide many benefits to the ocean sector and are already being explored by several industry players. From a safety perspective, remote operations mean fewer people on board ships. Fewer people on board could lead to smaller ships, which in turn could mean a smaller environmental impact and fuel savings. Onshore remote operations also open the door of opportunity for those who would otherwise not be able to take part in the ocean sector. That could mean people with a physical limitation who would be prevented from safely working on a ship, or those who have commitments making weeks-long offshore deployments impossible, as examples. This joint project allowed team members to explore the challenges that must be overcome to make remote operations more feasible.

It took six months of hard work on both sides of the Atlantic, with resources from MI's Centre for Applied Ocean Technology (CTec) and NTNU's Applied Underwater Robotics Laboratory (AURLab) working closely together to make the remote operation happen.

AURLab has a fleet of ocean vehicles, both autonomous and remote controlled. Its autonomous vehicles include several OceanScan Light Autonomous Underwater Vehicles (LAUVs), and a 7 m long autonomous surface vehicle (ASV) called Grethe, made by Maritime Robotics. It also has a number of Blueye ROVs, a Sperre SUB-fighter 30K work class ROV, and an Eelume hybrid ROV/AUV (autonomous underwater vehicle). While the teams wanted to try operating as many vehicles as possible from Canada, the final demonstration would have a pilot at The Launch (MI's facility in Holyrood, Newfoundland, Canada) fly the Eelume on an inspection mission in Trondheim, Norway.

A virtual private network (VPN) is used to connect all of AURLab's devices and vehicles. Most vehicles have their own subnet that includes the vehicle control computer and various onboard sensors. Each vehicle has a companion single board computer with a network bridge configured and VPN client installed to connect each vehicle network to the AURLab VPN. This allows anyone with a VPN connection to access all the devices on the vehicle's subnet. The first step towards remote operation was to add CTec devices to AURLab's VPN so that CTec operators could communicate with AURLab vehicles.

Remote Operation of a Small, Inspection Class ROV

Since Blueye ROVs (small, inspection class) are meant to be controlled by a mobile device, the project team decided this would be a good place to start. The VPN client and the Blueye control app were installed on a CTec mobile device and a connection to the ROV through the VPN was established. While control of the thrusters was reliable and experienced negligible delay, establishing a reliable, low-latency video connection proved challenging. While there were periods where the video was clear and smooth, this was interspersed with periods of several seconds where the video was choppy, laggy, and stuttering (Figure 1). Akin to flying in very turbid conditions, the pilot would have to hold station and wait for the video to clear. There was no predictability in when such periods would occur, or how long they would last. Even during smooth periods, latency varied between one to three seconds, depending on if the video was viewed in the native app on the mobile device, or streamed to a computer via the Real-Time Streaming Protocol (RTSP) and viewed through VLC media player or GStreamer. Interestingly, this seemed to be the case for both the remote system in Canada and a

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Figure 1: Real-Time Streaming Protocol (RTSP) video stream from Blueye ROV showing camera stutter.

computer connected in an identical fashion in Norway. This led the team to understand the distance between the remote operator and ROV was less of a problem than the many links and bottlenecks in the network. Video from the ROV's camera runs through the copper tether to the Blueye topside unit, where it can be routed by either hardwire or Wi-Fi to a single board computer with a network bridge configured. This network bridge connects the Blueye network to the AURLab VPN. A remote controller, either in Norway or in Canada, needs to connect to the AURLab VPN through the internet. The nature of VPNs can lead to the introduction of latency and increased traffic to a network connection. Due to the complexity of the network, it was unsurprising to the project team that the video quality was poor.

Flying the Blueye around a former aquaculture tank was the first milestone for the joint NTNU/MI remote operations centre (ROC) project. A pilot in Holyrood, Canada, controlled an ROV in Trondheim, Norway, more than 4,000 km away, proving remote operations are possible. However, this first experiment showed the types of challenges the teams could expect moving forward.

Remote Operation of an ASV

The project team decided to try the next vehicle: the ASV Grethe. Grethe is outfitted with a 4G modem for wireless communication and a forward-looking camera, the output of which is streamed via RTSP. AURLab uses an open-source software tool chain developed by Underwater Systems and Technology Laboratory of Porto University on many of its autonomous systems. The vehicle runs DUNE: Unified Navigation Environment to handle low-level control of the vehicle's systems such as navigation, communication, and movement. DUNE takes information from Neptus, the command, control, communications, computer, and intelligence software. Neptus allows a user to create mission plans involving different vehicle behaviours, such as transiting to waypoints, holding station, and loitering. Once a mission is running, a user can communicate with the vehicle through Neptus, to view data, pause or abort a mission, or change a mission on the fly. Post mission, Neptus provides mission review and analysis tools.

As with the Blueye, Grethe's subnet is connected to the AURLab VPN through a network bridge, enabling remote access. A CTec team member installed an instance of

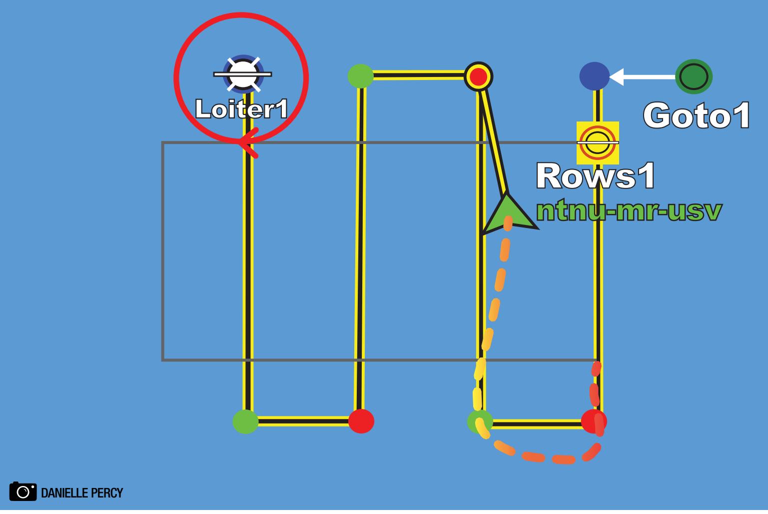

Figure 2: A zoomed in view of the Neptus operator console, showing the mission plan (straight lines with red and green dots), the USV Grethe (green arrow), and the actual path of the USV as it tries to complete the plan (yellow-orange dotted line). This mission was created in Holyrood, NL, Canada, and executed in Trondheim, Norway.

Neptus and connection configuration files for AURLab's autonomous systems on a computer with a VPN connection. The operator was able to observe the ASV and an LAUV performing manoeuvres live during a mission, and reliably watch the video stream from Grethe as it ran survey lines in Trondheim's harbour. However, this experience revealed one of the human factor challenges of remote operations: motion sickness. This experience offers an important avenue of research as remote operations become more commonplace.

The next step for the CTec team was to create and remotely upload its own missions to Grethe. This started with simple missions while the ASV was out of the water so the AURLab team could observe the vehicle's behaviour. Once the teams were satisfied the vehicle was operating as expected, it was launched to perform missions in the harbour. The CTec team uploaded a lawnmower-pattern mission plan, typical of surveys, and the vehicle immediately began executing the manoeuvre (Figure 2). At one point during the operation, an AURLab team member told the CTec operator that a ship was approaching and Grethe would need to hold station to wait for the ship to pass. The teams decided to attempt to pause the mission remotely, knowing that if there was a problem, AURLab could intervene before the ship arrived. The remote command succeeded, instantly causing Grethe to hold station as the ship passed (Figure 3). Once the ship was safely out of the operational zone, the mission resumed.

While there was a desire to include the LAUVs in the remote operation project, these were eliminated from the project goals in the interest of time. Remote operation of an LAUV is expected to be the same as Grethe since they both use the DUNE/Neptus software tool chain. The teams decided to move forward and test the Sperre 30K work class ROV.

Remote Operation of a Work Class ROV

The 30K ROV was installed on the R/V *Gunnerus*, NTNU's research vessel, which provides an internet connection through a 4G modem. The AURLab team had already developed a robot operating system (ROS) control node for the 30K. To accomplish control from Canada, a ROS node was built on a CTec computer connected to the VPN that relayed commands to the 30K ROS control node. The ROV's sonar, a network device, was made available via the VPN connection. Video from the ROV was passed through an IP video encoder on the same network, which added an overlay, and was viewable in Canada via RTSP. While taking control of the 30K from Canada experienced some initial technical challenges, once the connection was established the video and control was stable. So much so that the MI ROV pilot expressed surprise at the smoothness and stated it would be easily possible to perform real remote operations (Figure 4). Although there was some video stutter, this was deemed to have minimal impact since it was similar to the ROV disturbing the seafloor and having to wait for the debris to settle (Figure 5).

Figure 3: ASV Grethe holding station while a ship passes.

Figure 4: Milestone achieved! ROV instructor and pilot, Corey Roche (right), flying a work class ROV in Trondheim, Norway, from Newfoundland, Canada. Topmost screen is a live sonar image from the ROV while the lower screen is the video feed.

Figure 5: ROV video stream with troubled connection. This view would last for a few seconds before becoming clear, during which time the pilot would hold station and wait.

The pilot was able to fly an inspection mission around the newly installed subsea observatory, part of NTNU's OceanLab.

Remote Operation of a Hybrid ROV/AUV

With this significant milestone accomplished, the teams moved on to the final part of the project, remotely operating the Eelume. An Eelume is a segmented, articulated robot that can operate either as an ROV or an AUV, tethered or untethered. It has forward and downward looking networked cameras and sonars, and is controlled through a propriety software, the Eelume suite, which combines a mission planner, sensor dashboard, and controller. Multiple instances of the Eelume suite can be connected to a single Eelume simultaneously, provided only one instance is sending control commands. This built-in feature allowed remote control by having the

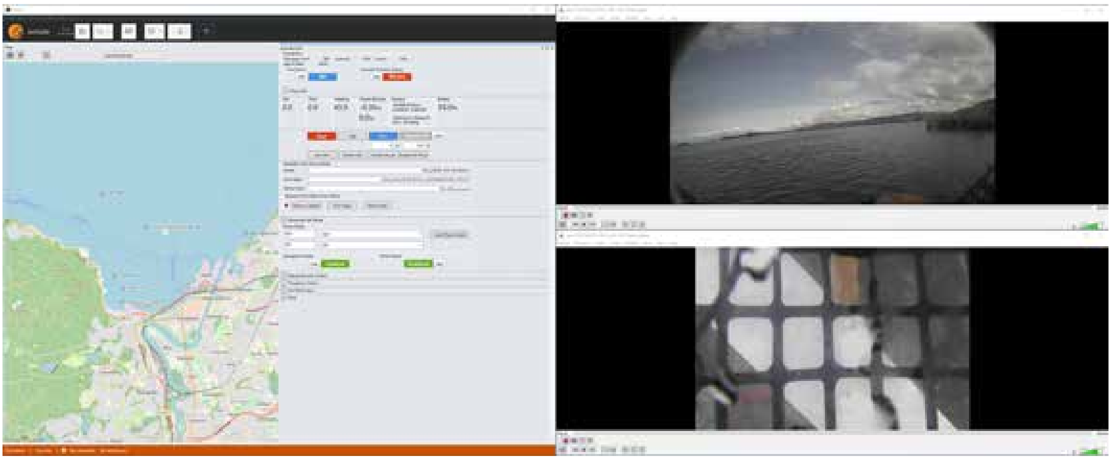

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Figure 6: Remote pilot's view from Eely, including cameras and mission control software.

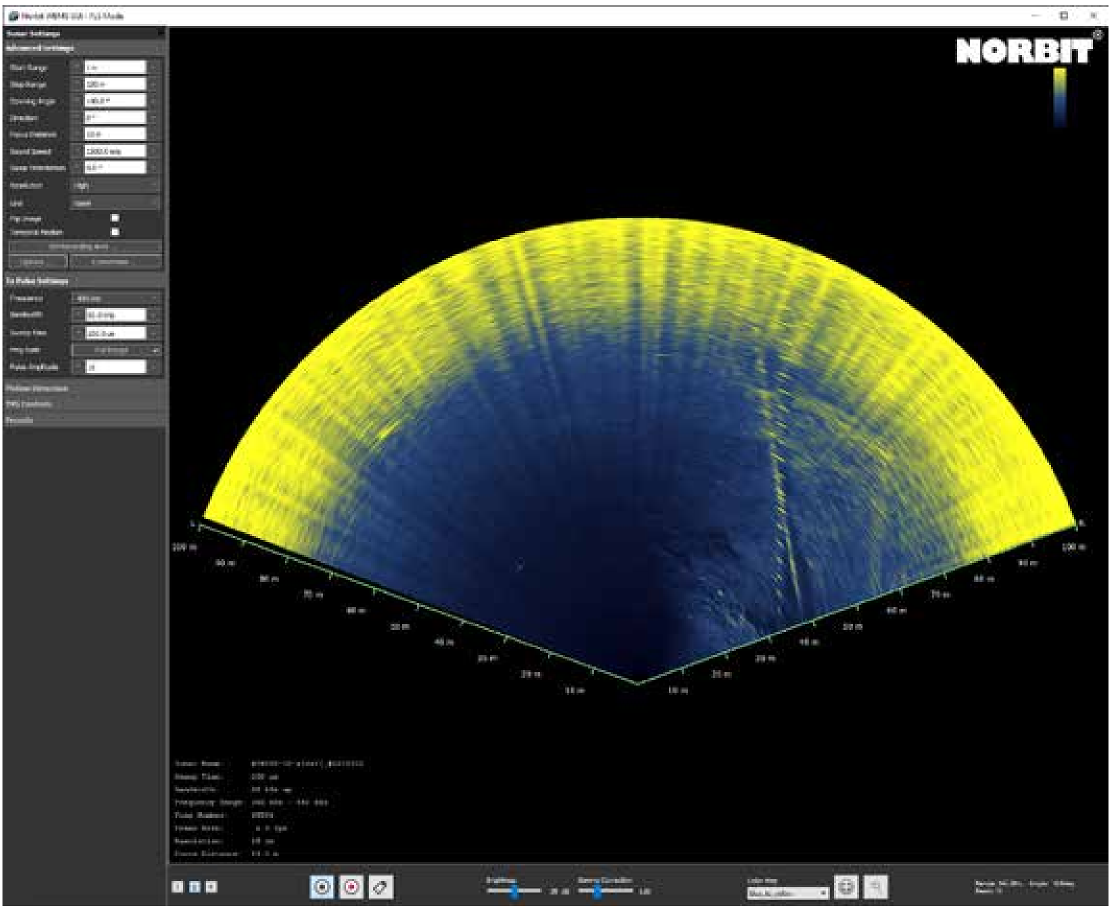

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Figure 7: Sonar image from Eely as the remote operator in Canada followed a pipeline in Trondheim harbour, Norway.

CTec computer connected to the AURLab VPN. A CTec team member was able to operate AURLab's Eelume, Eely, on two occasions (Figure 6), both times tethered. The operator used a joystick to fly Eely manually, following one of several pipelines (Figure 7) leading away from the AURLab building. In a second mission, the remote pilot sent a series of waypoints to Eely that it followed in AUV mode.

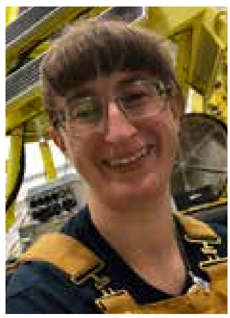
Over the six months of this project, the teams experienced good success, but unexpected problems caused the final demonstration to be less than expected. A brief flight of Eely showed that remote operations between Canada and Norway are feasible, albeit with some room for improvement.

Conclusion

Most of the technical challenges experienced were related to networking, either increased latency or lack of bandwidth caused by the complexity of the data route. This usually manifested as significant degradation of video quality or momentary losses of connectivity, both of which led to mission interruptions. Both the CTec and AURLab teams agreed that having a more direct link between the remote operator and the vehicle would be highly beneficial. This could take the form of dedicated hardware that is specific to the task of handling data flow between networks instead of consumer grade single board computers. Other options include reducing traffic through the system by establishing more robust data routing rules, or isolating vehicle networks on their own VPNs instead of one VPN bridged to many networks.

Other challenges were related to personnel in significantly different time zones trying to do a new, technically challenging project together. The overlapping work hours between AURLab and CTec were typically only four hours per day, requiring team members to occasionally alter their work schedules to make more time for collaboration. This was complicated by the fact that doing something so novel and complex required more sources of expertise to solve problems. It is likely that as remote operations become more commonplace and the technical issues are resolved, the number of experts required and time for troubleshooting will decrease. Finally, field days are difficult regardless of geographical location. Issues such as weather delays, equipment taking longer than expected to mobilize, and things breaking unexpectedly are compounded by short days.

Despite the challenges, this project proved to be a valuable experience for all parties and an excellent demonstration of the feasibility of remote operations. The Marine Institute is building on the success of this initial remote operations project by further developing its remote operations centre, located at The Launch.



Bethany Randell, P.Eng., is currently living her dream job as a project engineer with the Centre for Applied Ocean Technology at the Fisheries and Marine Institute of Memorial University. Always fascinated with the ocean and eager to solve problems, she turned her hobby of building ROVs for competitions into a career when she graduated from Memorial as an electrical engineer and went to work for Kraken Robotics. During her eight years with Kraken, she worked on all of Kraken's products, including the KATFISH, and was made lead electrical engineer of its AUV program. Since joining the Marine Institute (MI) and being stationed at The Launch in Holyrood, she has completed the first phase of MI's Remote Operations Centre through which, in partnership with the Norwegian University of Science and Technology, she was able to operate ROVs and an ASV located in Norway.