

Frontseat–Backseat Control Architecture for AUVs: Enabling Mission-Specific Autonom

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Abstract—The increasing complexity of Autonomous Underwater Vehicle (AUV) missions demands specialised behaviours that are difficult to integrate into a general-purpose vehicle controller without sacrificing operational flexibility. A frontseat-backseat control paradigm addresses this challenge by allowing a secondary backseat controller to assume partial vehicle control for mission-specific tasks, while the primary frontseat controller maintains vehicle safety and essential operation. This paper presents the frontseat-backseat architecture developed at the National Oceanography Centre (NOC) for use on board its fleet of marine autonomous vehicles, built around the Onboard Control System (OCS) as the frontseat. Central to this architecture is the Backseat Gateway: a dedicated interface that manages all frontseat–backseat communication, enforces operator-configured safety constraints on backseat manoeuvre requests, and regulates the control handover process. The architecture is validated through simulated thermocline tracking missions using the NOC Gazebo Simulator, demonstrating that a backseat controller can direct intelligent, real-time mission-specific manoeuvres without requiring any modification to the independent frontseat controller.

Index Terms—autonomous underwater vehicles, intelligent mission autonomy, modular robot control architecture.

I. INTRODUCTION

Autonomous Underwater Vehicles (AUVs) are being used for an increasing variety of tasks across many fields. As variety increases, so does the complexity and specificity of the tasks AUVs are required to complete. This leads to the necessity of specialised behaviours for individual tasks. Specialising a vehicle for a specific task can, however, come at the loss of general flexibility, hampering that vehicle’s ability to perform other task sets without the need for reconfiguration, which can be complex and time-intensive. This is especially true for cases where reconfiguration of a vehicle’s software architecture is required.

In these situations, a specialised backseat controller operating in parallel to the vehicle’s standard frontseat controller can be the most suitable solution. This allows for a frontseat-backseat control paradigm, where:

- The **frontseat** is the primary vehicle controller, a stable base responsible for essential AUV functionality and safe operation.

The development of the backseat controllers detailed in this paper and the continued development of the OCS frontseat-backseat control paradigm are being funded through the *Technology based impact assessment tool foR sustainable, transparent Deep sEa miNing exploraTion and exploitation* (TRIDENT) project under grant agreement No.101091959.



Fig. 1. An ALR vehicle developed at NOC running the OCS

- The **backseat** is a secondary controller to which (limited) control can be handed to perform mission-specific, specialised tasks.

While the backseat has (partial) control of the vehicle, the frontseat should still constantly monitor vehicle behaviour to ensure AUV safety despite not necessarily having complete knowledge of internal actions taken by the backseat.

This work builds upon and extends existing frontseat-backseat control architectures, most notably the Mission Oriented Operating Suite Interval Programming (MOOS-IvP) system [1], [2]. Unlike this system, the backseat is an optional additional component. The OCS frontseat is capable of controlling a vehicle on its own; a backseat is only required for mission-specific tasks not implemented in the general controller. Furthermore, an additional interface between the controllers, the Backseat Gateway, is introduced. This interface is used to manage communication between both controllers, grant and revoke temporary partial control during a predefined handover window and reject unsafe requests based on operator-set safety limits. This also allows for language- and hardware-agnostic backseat controllers; the only hard requirement for a backseat controller is the ability to communicate with the gateway interface. The frontseat-backseat paradigm has been implemented beyond the MOOS-IvP ecosystem on

platforms such as the Slocum Glider [3]; however, safety enforcement is typically left as the responsibility of the individual controllers instead of a dedicated intermediary. The predefined Backseat Gateway interface allows for the independent development and simple integration of modular backseat controllers without sacrificing the safety standards built into the primary vehicle controller.

This paper presents the frontseat-backseat architecture developed at the National Oceanography Centre (NOC) and integrated into the Onboard Control System (OCS) [4] used on board the NOC fleet of in-house-developed AUVs, such as the Autosub Long-Range (ALR) [5] shown in Fig. 1. First, the design principles will be discussed in section II, followed by the components of the complete frontseat-backseat system in section III. The interfaces between the different system components will be detailed in section IV. The case study of a simulated autonomous mission where a backseat controller was used to facilitate mission-specific thermocline tracking will be presented in section V. Finally, the conclusions and areas for future work will be discussed in section VI.

II. DESIGN PRINCIPLES

The OCS frontseat-backseat system was developed according to the following principles:

- The frontseat should allow for as much flexibility as possible in terms of backseat capabilities. The additional features required for future backseat tasks are not known *a priori*, and as such, backseat developers should be given sufficient space to implement novel vehicle capabilities.
- The frontseat must maintain operational safety at all times. For this, it will require periodic information about the status of a backseat controller in addition to the typical data it acquires during operation (e.g. vehicle pose, device health information, etc.).
- The interface between the frontseat and backseat should allow for easy development of new backseat controllers. This means that the interface should use simple standard protocols for communication between the two controllers.
- Separation should be maintained between the frontseat and backseat. Apart from the communication necessary for safe operation, they should be treated as two isolated systems. Limiting communication simplifies the development of both the frontseat and backseat controllers and improves the security of both systems, an essential requirement for security-critical use-cases.

III. SYSTEM COMPONENTS

The complete frontseat-backseat system described in this paper consists of three distinct components: the frontseat, the backseat and the Backseat Gateway.

A. Frontseat

The frontseat is the main vehicle controller, and for the AUVs developed by the NOC, this is the OCS. The OCS, developed using the Robot Operating System (ROS), operates independently of the backseat and can control a vehicle to

perform standard manoeuvres safely without any backseat controller present. The OCS is responsible for essential AUV functionality such as vehicle guidance, navigation and control (GNC) [6]; mission executive decision making and health monitoring [4]; and providing the vehicle-side interface with the piloting command and control (C2) platform [7]. The software integration of vehicle devices such as control surface actuators, critical navigation devices and permanent payload sensors is also incorporated into the OCS. The OCS is a versatile general vehicle controller and has been used on board autonomous vehicles of various classes (surface vehicles, flight-style AUVs and hover-style AUVs).

B. Backseat

Reflecting the flexibility design principle, backseat controllers should not have to be unnecessarily constrained in their design. They can be designed for an individual vehicle or even a specific mission; operating alongside the frontseat to complete tasks outside of the usual operational domain of the primary controller, while relying on this primary controller to ensure safety and handle low-level vehicle operation. A backseat controller can be run in parallel to the frontseat on board the main vehicle computer, or can be run on its own separate computer. If required for a specific task, additional hardware can also be added to an AUV to be managed by the backseat, completely separate from the frontseat. As highlighted in section II, allowing flexibility of backseat formats is a key design requirement, and as such, backseat controllers can be built using the programming language or framework most appropriate as long as they can communicate with the Backseat Gateway via the ROS master running the OCS.

C. Backseat Gateway

A key component of the OCS frontseat-backseat architecture, which allows it to enable backseats and monitor their activity, is represented by the Backseat Gateway. The gateway not only serves as the interface between the frontseat and the backseat, but also adds another layer of protection against unsafe backseat behaviour, upholding the safety design principle. While the frontseat already implements its own health and safety monitoring system, backseat controllers cannot be assumed to uphold the same level of concern for vehicle safety. The Backseat Gateway therefore provides an additional layer of enforcement, independent of either controller. The Backseat Gateway supports multiple registered backseat controllers simultaneously, though vehicle control is only granted to one at a time.

Fig. 2 shows the OCS implementation of the frontseat-backseat paradigm, highlighting the role of the Backseat Gateway; as mentioned above, this component constitutes the only interface between the frontseat and the backseat (consistent with the separation principle): all communication between the two systems is handled by the gateway, and the control handover process is strictly regulated to guarantee the safety of the vehicle at all times. In addition, should the frontseat deem the actions of the backseat unsafe, control can be removed

Frontseat/Backseat Interfaces

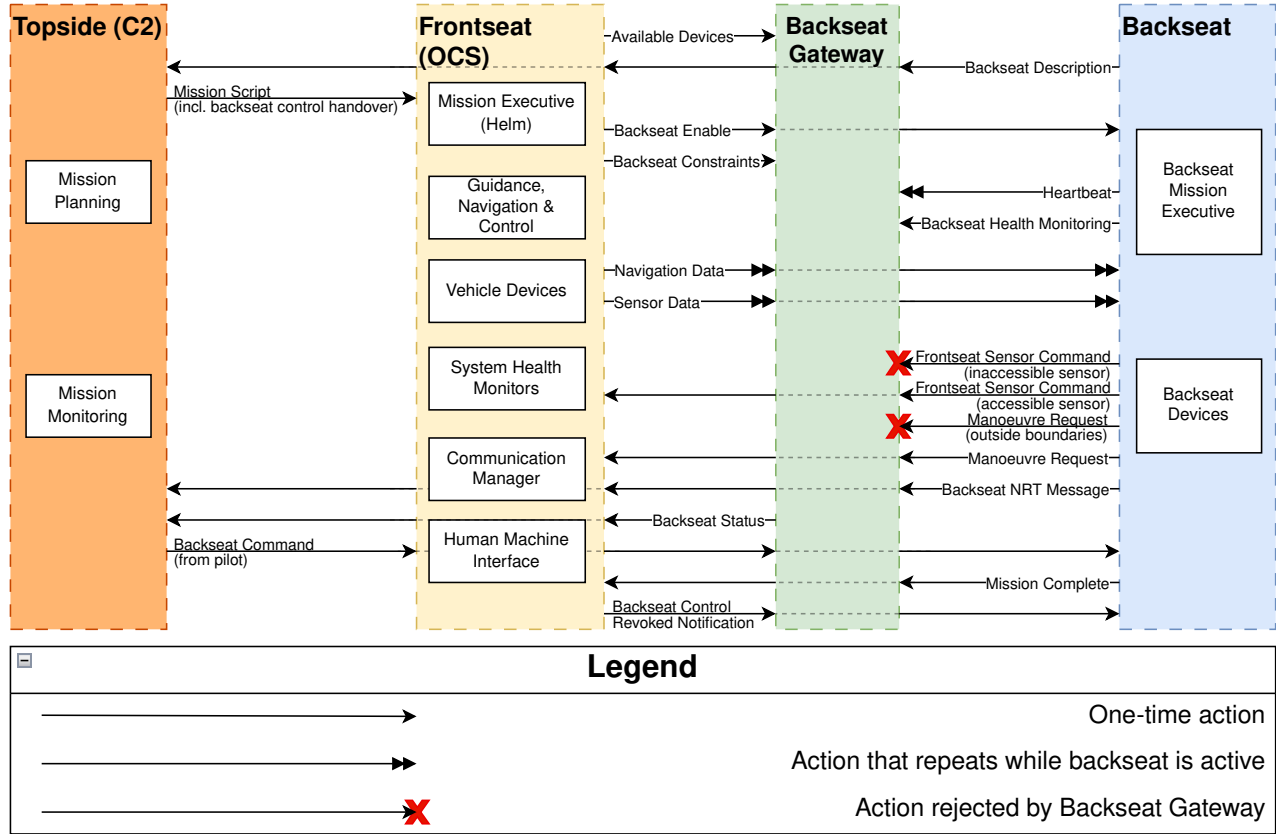


Fig. 2. Overview of interfaces between the frontseat and backseat, all passing through the Backseat Gateway

from the backseat at any time. The interfaces shown in Fig. 2 will be discussed in the upcoming section.

IV. SYSTEM INTERFACES

Communication to and from the Backseat Gateway is achieved through ROS messages, a simple and standard protocol facilitating ease of development. Communication between the frontseat and topside systems is achieved through near-real-time (NRT) messages using the communication devices available on board the vehicle and the topside system. In practice, for the ALRs, this usually means either WiFi, Iridium satellite communication or acoustic communication.

To detail the interactions between system components, the stages of a typical mission where control is handed over to a backseat controller will be broken down and described within the three subsequent subsections.

A. Handing over Control to Backseat Controller

For missions where the OCS serves as a vehicle's primary controller, pilots must create a mission script beforehand. This is a file (can be formatted as a JSON file) in which all the manoeuvres that the frontseat controller of a vehicle is

expected to execute over the mission are listed. For a mission where control will be handed over to a backseat controller, a Backseat Control Handover manoeuvre needs to be added to this mission script. Inside this manoeuvre, the pilot can indicate which of the registered backseat controllers to grant partial vehicle control to, as well as a maximum duration to allow backseat control for. Pilots can also set safety constraints to limit the acceptable range of manoeuvres that a backseat controller can request. This can be used to limit manoeuvre parameters such as requested vehicle speed or pitch, or even to restrict requested manoeuvres to a specific geographic area. Finally, the pilot can also set parameters for the Backseat Waiting manoeuvre. This is a loiter-in-place that a vehicle will perform once a backseat controller has been given control, but has not yet requested any manoeuvres. A pilot may want to modify parameters such as the speed or minimum altitude of this waiting manoeuvre for different vehicles or operating conditions.

Once the vehicle is powered on and the OCS has started, each device node integrated into the OCS sends out a ROS message containing its OCS device ID as well as the level of access allowed for backseat controllers. The level of control is

specified by operators during OCS configuration and is broken down into two levels: can backseat controllers read device data outputs such as sensor measurements, and can backseat controllers send commands to the device such as power requests or changing a device mode. These two levels of control can be set independently. The Backseat Gateway listens for these messages and creates ROS publishers and subscribers for forwarding device data and commands accordingly.

After the OCS has been started, backseat controllers may send a backseat description message to the Backseat Gateway. This is a ROS message that contains the name of a backseat controller, a flag indicating whether the backseat can control the vehicle, a list of commands accepted by that backseat controller (such as pilot overrides) and a list of backseat health monitors. The Backseat Gateway checks the backseat name against a list of permitted backseats (set during OCS configuration) and, if the backseat is permitted, registers internally the backseat controller name, its commands and whether it can control the vehicle.

After a backseat controller has been registered, the Backseat Gateway starts expecting a state message heartbeat from the backseat controller. This and a monitor for consecutive invalid manoeuvres are the two health monitors that are set for every backseat. The limits for both of these are configured in the frontseat and are used to set general policies for revoking control from any backseat not meeting the minimum safety conditions of demonstrating a stable connection and sending safe, coherent manoeuvre requests. These are monitored alongside any additional backseat-specific health monitors listed in a backseat's description message. How the vehicle responds to any failures of these monitors is configured in the frontseat at a per-monitor level.

B. During Backseat Control

Control is handed over to a backseat only during the Backseat Control Handover manoeuvre. The mission script is sent to the vehicle from the topside system (C2) and, on reception, the vehicle will start the first listed manoeuvre. Once the vehicle reaches the Backseat Control Handover manoeuvre, it will attempt to hand partial control over to the backseat named in the manoeuvre. First, the gateway will perform a few checks. The Backseat Gateway verifies that the requested backseat has been registered and its description states that it can control the vehicle. The gateway also verifies that the backseat constraints are valid. Specifically, it checks the geographical bounding box does not wrap over the poles as this would complicate manoeuvre verification. Constraints where a minimum limit has been set higher than the maximum limit for a given parameter will be accepted by the gateway, but will result in all requested backseat manoeuvres being rejected. If all checks pass successfully, the Backseat Gateway will send the backseat controller an enable message, and start listening for backseat manoeuvre requests.

A backseat controls a vehicle by requesting manoeuvres. While the Backseat Gateway has granted control to a backseat controller, it will constantly listen for manoeuvre requests,

and if it receives well-formatted requests inside the backseat manoeuvre safety constraints, the gateway will forward these to the frontseat. Available manoeuvre types are predefined in the frontseat, but a backseat controller can fill out the parameters of a manoeuvre — such as desired trajectory, pose, and speed — based on its own decision-making algorithm.

To enable a backseat controller to intelligently plan manoeuvres, frontseat navigation and sensor data is forwarded through the gateway to backseat controllers. The navigation solution provided by the localisation package [8] is provided to the backseat at a rate of 1Hz and contains information on the vehicle's pose, velocities over ground and sea current velocity. Sensor data from backseat-accessible sensors is provided in real-time, as it is available in the frontseat. In addition to this, for devices to which sensor command access has been granted during vehicle configuration, the backseat can send requests to change the operating mode, power the device on/off, change device configuration and any other commands supported by the device node.

Finally, the Backseat Gateway facilitates NRT communication of backseat data between a backseat controller and C2, or between backseat controllers on separate vehicles. To keep message sizes low — critical for acoustic and satellite communication — data is formatted as predefined DCCL messages [9]. The gateway produces a periodic *BackseatStatus* message containing basic status information for each registered backseat controller. Backseat controllers can also send and receive *BackseatDataset* messages via frontseat communication devices, enabling intelligent decisions based on other vehicles' actions or near-real-time configuration commands from C2.

C. Revoking Backseat Control

Control will be revoked from a backseat controller under the following conditions:

- The control timeout specified by the pilot in the Backseat Control Handover has elapsed.
- The vehicle receives a command from a pilot via C2 to end backseat control.
- The active backseat informs the Backseat Gateway that it has achieved its goal.
- The primary controller determines that it is unsafe to continue providing a backseat partial vehicle control.

Control may be cut short before the timeout for several reasons: an explicit pilot command via C2, early mission completion signalled by the backseat, or failure of a health monitor. Health monitor failures occur when a backseat sends too many consecutive invalid manoeuvres or loses contact with the gateway for too long; the vehicle response to each failure is configured at a per-monitor level in the frontseat. Other backseat-specific health monitors can also be configured as previously stated. In all cases, the Backseat Gateway notifies the active backseat that vehicle control has been revoked.

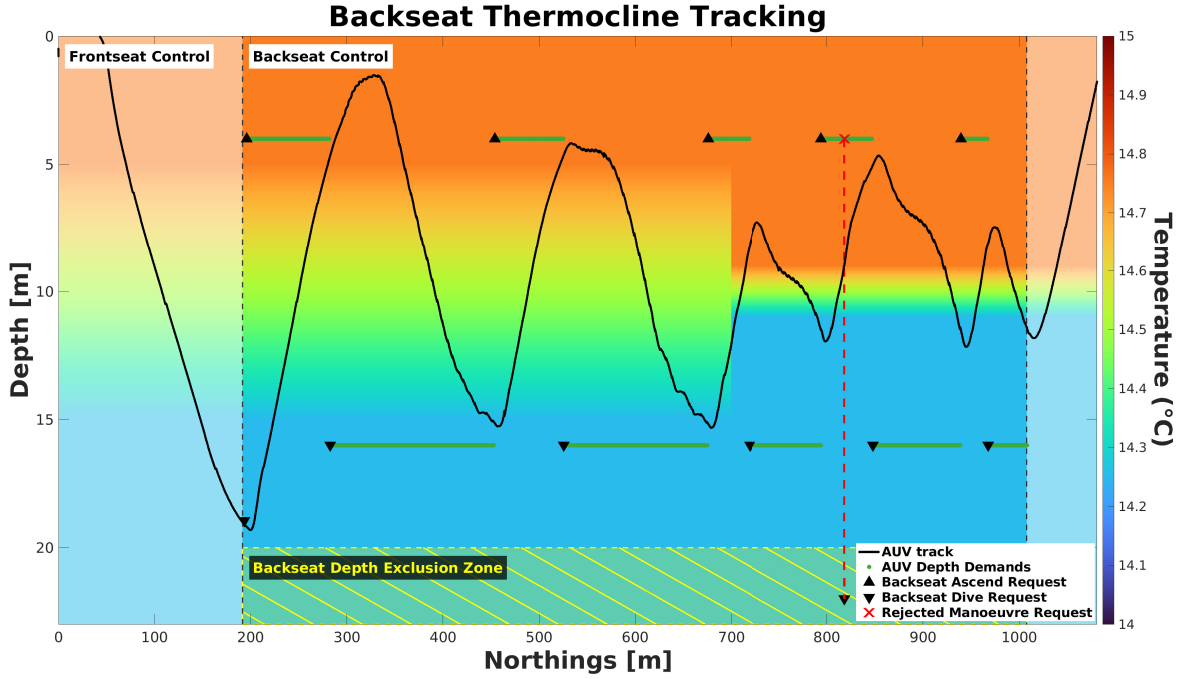


Fig. 3. Simulated thermocline tracking mission where intelligent manoeuvre planning is performed by a backseat controller

V. CASE STUDY

Prior to deployment of the frontseat-backseat architecture on real operational hardware, simulations were conducted to validate the system described in this paper. These simulations were designed to confirm that a backseat controller could direct intelligent, mission-specific manoeuvres with the Backseat Gateway providing the interface and maintaining operational safety. The results of these simulations are presented in this section using Fig. 3 as a representative simulation. The mission scenario of thermocline tracking was chosen for these tests as this will be the next real-world mission for an ALR operating with a backseat controller.

The simulations were performed using the NOC Gazebo Simulator [10] which uses the exact same OCS codebase as the ALR vehicle hardware. For the simulation shown in Fig. 3, a simple thermocline model and backseat thermocline tracking algorithm were used. The thermocline used is described in (1) where T is the temperature in $^{\circ}\text{C}$, x is the vehicle's Northing in meters and y is the vehicle's depth in meters. The thermocline is compressed into a narrower depth band at a Northing of 700m, a choice made to validate the backseat's ability to react to changing environmental conditions in real-time.

The backseat controller used frontseat temperature readings to send manoeuvre requests with the goal of keeping the vehicle inside the thermocline. When temperature fell below a lower bound (14.25°C), the backseat would request that the ALR ascend to a depth of 4m and, conversely, when the temperature increased beyond an upper bound (14.75°C), the backseat would request that the ALR dive to a depth

of 16m. It did so while maintaining a vehicle path along 0° longitude towards the North Pole, effectively constraining the vehicle path to a 2D plane. In the Backseat Control Handover manoeuvre inside the mission script, a depth of 20m was specified as a safety constraint beyond which backseat manoeuvre requests should be rejected. To test this, it was preprogrammed that the backseat controller would request a dive below this limit, to 23m, as its eighth manoeuvre and then wait 30s before returning to the thermocline tracking behaviour.

For $0 \text{ m} \leq x \leq 700 \text{ m}$:

$$T(x, y) = \begin{cases} 14.75 & \text{if } y \leq 5 \\ -0.05y + 15 & \text{if } 5 < y \leq 15 \\ 14.25 & \text{if } y > 15 \end{cases} \quad (1)$$

For $x > 700 \text{ m}$:

$$T(x, y) = \begin{cases} 14.75 & \text{if } y \leq 9 \\ -0.25y + 17 & \text{if } 9 < y \leq 11 \\ 14.25 & \text{if } y > 11 \end{cases}$$

After the initial dive was complete, the Backseat Control Handover phase of the mission started. This is indicated by the first vertical dotted line in the plot. In the first two seconds of backseat control before the first manoeuvre request was sent by the backseat controller, the vehicle entered the Backseat Waiting loiter-in-place state. This can be seen in the plot in the first dive request to hold the vehicle's depth at handover. After this, the first manoeuvre requested by the backseat controller

was for the vehicle to ascend as the measured temperature had fallen below 14.25°C. As reflected in the plotted AUV path, this request was forwarded to the frontseat controller and the depth demand (set by the frontseat) was updated causing the vehicle to begin to ascend. As soon as the temperature crossed the higher limit of 14.75°C, a dive request was again sent from the backseat to the frontseat and the depth demand was accordingly updated. The vehicle's plotted path does not immediately reflect this change in depth demand as it continued to ascend for a period of time. This is due to the vehicle's inertia and is how ALR vehicles perform in the real world. For the remainder of the simulation, it can be seen that the backseat controller was able to direct the vehicle to continue to track the thermocline, even as the thermocline changed at 700m. After this point, the distance the AUV dived and ascended was greatly decreased as the temperature limits were reached much earlier. This was also reflected in the shorter durations of each depth demand.

One point of interest is at 818m Northing where the preprogrammed invalid manoeuvre was sent to validate that the safety constraints were being respected. As expected, this was rejected by the Backseat Gateway and no change is seen in the depth demand. The 30s waiting period before the backseat requested its next manoeuvre did cause the vehicle to ascend much further than the previous ascent in the compressed thermocline. This also resulted in longer depth demand durations here and as the vehicle recovered. Subsequent valid manoeuvres were again accepted by the frontseat and the thermocline tracking task continued to 1008m Northing where the backseat informed the Backseat Gateway that it had achieved its goal. This is indicated by the final dotted vertical line in the plot where control was handed back to the frontseat.

VI. CONCLUSIONS

This paper presented the frontseat-backseat control paradigm used on board the fleet of marine autonomous vehicles developed at NOC. This extends previous similar architectures by demonstrating that mission-specific autonomy can be added to a preexisting controller without modifying it, lowering the barrier to deploying novel algorithms on operational vehicles. Through the Backseat Gateway interface, safety can be operator-configured and enforced without relying on the developers of a backseat controller.

The control architecture and interface were validated through simulation in a thermocline tracking mission. This demonstrated how a backseat algorithm communicating through the Backseat Gateway was able to safely achieve the goal of allowing a vehicle to complete intelligent mission-specific manoeuvres in real-time without requiring any changes to the primary controller. This work is to be continued in November 2026 using real ALR hardware in Loch Ness to track a thermocline and for multi-vehicle tracking of an emulated sediment plume. This will lead into a multi-vehicle plume tracking mission in the Atlantic Ocean in May 2027 as part of the TRIDENT project [11], [12]. Both missions

will rely on the same interfaces described in this paper and will allow for further validation of the interfaces that could not be fully tested in simulation. This includes NRT acoustic and Iridium communications and how backseat controllers on separate vehicles can be utilised to achieve safe multi-vehicle operation.

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