Autonomous surface vehicles (ASVs) are a critical component in environmental monitoring and surveillance operations to support Canada's developing Blue Economy [1] [2]. However, autonomous docking in disturbed waters remains a significant bottleneck in deploying 'resident' systems [3]; ASVs must compensate for dynamic disturbances at various speeds and angles [4]. Existing dynamic positioning (DP) systems are designed for low, constant-speed maneuvers, and many planners run with a narrow focus to near-perfect conditions [4]. Moreover, underactuated ASVs struggle to compensate for disturbances because their limited actuation may not align with the direction of wind and currents. Multi-phase planners, which decouple transit, approach, berthing, and quay phases, have been shown to optimize docking reliability but are relatively rigid [5]. Current-aware planners can adjust the ASV's course depending on currents and winds to take advantage of them [6] [7], but are often isolated from the controller, which may cause erratic behaviour. Simultaneous Planning and Control (SPaC) approaches have demonstrated promising results in replanning based on controller error [8], but have not yet been effectively combined with multi-phase planning.

This research proposes the development of a current-aware multi-phase SPaC framework for underactuated ASVs in disturbed waters. It is hypothesized that a multi-phase framework, with control error informing live replanning, will outperform single-phase and decoupled planning and control frameworks in bounding tracking error, stability, and time efficiency. This problem is an open challenge; the optimal architecture and performance limits of a unified, disturbance-adaptive framework are not yet known. The scope of this work thus includes the development of this framework, validation in simulation, and experimental field trials.

The ASV will be thrust-controlled using a 6-degree-of-freedom hydrodynamic marine vessel model, which accounts for relevant disturbances such as current, waves, and wind [9]. Existing simulations integrate this model and can be adapted to variant ASV configurations [10]; a differential-drive ASV model will be used. Current-induced disturbances can be effectively estimated using existing non-linear extended state observer methods [11]. The ASV and disturbance model will be used to implement Model Predictive Control, which is considered promising for SPaC applications due to its ability to account for system dynamics in a defined time-horizon to determine control outputs [8]. It is assumed in this work that the target docking position is known. Deterministic current-aware path-planning algorithms are optimal for generating a trajectory for the approach phase [6], while pattern-based maneuver policies are optimal for berthing [12]. In the multi-phase system, MPC will serve as the unifying controller to track these references while rejecting disturbances.

This work will begin with the integration of a SPaC system into an existing digital hydrodynamic simulation framework to validate cross-track error, computation time, and successful docking rate (%) under varied current conditions. The highest performing SPaC framework derived from simulation results will be implemented on the lab's Maritime Robotics AS Otter. This vehicle will be deployed in experimental field trials at industry partner facilities, under varied current and disturbance conditions. The vehicle will be equipped with a Global Navigation Satellite System (GNSS) receiver and an Inertial Measurement Unit (IMU) for state estimation. The multi-phase current-aware SPaC framework will be benchmarked against each component in isolation: a current-aware planner with decoupled control, a multi-phase planner, and a single-phase SPaC framework with standard disturbance rejection.

This research will advance the state-of-the-art in planning and control for mobile robots in the presence of challenging disturbances. This is achieved by extending current-aware planning and non-linear control into a unified, disturbance adaptive, multi-phase SPaC framework with sim-to-real validation. Furthermore, the SPaC framework is scale-invariant; it can be directly applied to larger vessels, which enable 24-hour surveillance of the coastal Arctic, removing humans from hazardous Arctic conditions [1]. By enabling robust autonomous docking, this innovation allows for "resident" ASV networks that can provide continuous, temporal data without intervention [3].

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