KRAKEN: A Knowledge-Guided Response Architecture for Kinematically-Constrained Subsea Engagement Networks

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I. EXTENDED ABSTRACT

As low-cost uncrewed underwater vehicles (UUVs) proliferate—posing asymmetric threats to critical maritime infrastructure, ports, high value vessels, naval fleets, and offshore energy—response mechanisms are insufficient for marine security. Despite advances in underwater sensing, detection, tracking and classification, today's architectures lack robust means for interdiction and denial. In other words, contemporary maritime defense terminates at situational awareness, with limited capability to deny or neutralize threats once detected. This gap is particularly acute in contested and communication-denied environments, where human-in-the-loop responses are delayed or infeasible.

We introduce KRAKEN, a multi-agent tethered UUV architecture for real-time subsea defense and threat interdiction under communication constraints. We make three contributions. First, we present a modular, three-layer system architecture that integrates (1) distributed heterogeneous sensors, (2) centralized multi-sensor fusion, and (3) coordinated deployment of tethered UUV agents (i.e., "sensing scouts" and "interceptors"). Second, we develop an analytical and simulation-based evaluation framework for assessing interception feasibility and multi-agent coordination under uncertainty. Third, we demonstrate through Monte Carlo methods that coordinated multi-agent configurations improve localization accuracy and increase interception probability relative to solo-agent alternatives, particularly in communication-denied environments. These results indicate that tethered architectures can reduce defense coordination latency and improve engagement reliability against subsea threats. Although work has established the viability of tethered UUVs for ship hull maintenance [1], deep-water scientific exploration [2–4], ocean exploration on foreign planets [5], minesweeping [6], and military payload delivery [7], cooperative multi-UUV frameworks have received little attention.

KRAKEN deploys sensing scouts to flank inbound submersible threats and reduce engagement uncertainty via localized sensing and sonar-based triangulation, directly guiding interceptors with continuously updated target estimates. This system supports multiple interdiction modalities, including both kinetic and non-kinetic (e.g., weighted nets) mechanisms, enabling graded responses based on threat classification and confidence. Designed to be modular and compatible with various sensing inputs, interceptor payloads, and C2 programs, KRAKEN is designed to be deployed across mobile and fixed platforms in diverse maritime environments.

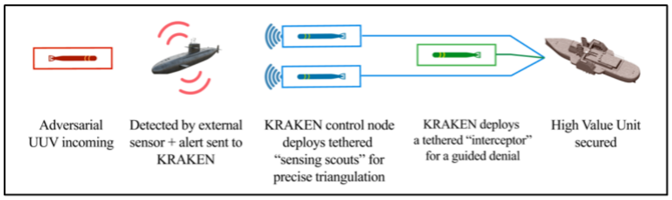

Fig. 1. KRAKEN architecture for tethered scout deployment, target localization, and guided intercept against subsea threats.

A prototype vehicle was constructed using commercial off-the-shelf components and low-cost structural materials to minimize development time and cost. The fuselage was fabricated from standard 4-inch diameter PVC pipe and fittings, yielding a torpedo-style form factor approximately two feet in length. Vehicle dynamics are controlled via three servo-actuated control surfaces, with waterproofing achieved through epoxy sealing at the aft endcap, servo mounts, and tether cable penetration, and a gripper plug securing the forward end. Power is supplied by a 6S LiPo battery through an electronic speed controller (ESC) driving an ApisQueen U2 thruster, with a Pixhawk flight controller running open-source ArduPilot firmware providing navigation and fly-by-wire (FBW) control. A Raspberry Pi companion computer bridges tethered Ethernet communications to the Pixhawk via UART, providing a flexible computing platform extensible to advanced perception and autonomy payloads.

To evaluate feasibility, we adopted a multi-layered methodology combining analytical modeling and Monte Carlo simulation. The simulation framework models the full sensing-

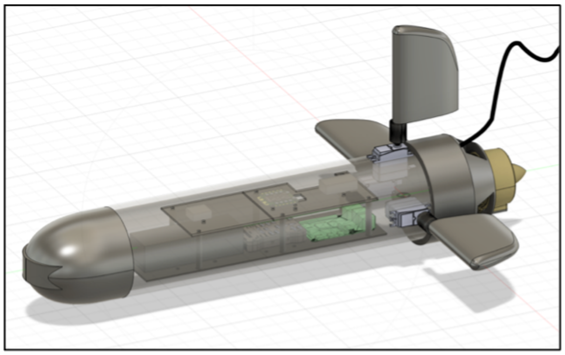

Fig. 2. COTS tethered UUV prototype used to validate vehicle integration, tethered communication, and fly-by-wire control assumptions.

to-intercept pipeline rather than assuming perfect detection or target knowledge. Each scout's sonar return is first evaluated using a simplified active-sonar signal-to-noise model,

$$\mathrm{SNR} = SL - 2TL + TS - NL + DI,$$

where source level, two-way transmission loss, target strength, noise level, and directivity index determine whether a target is observable at a given range. We then convert SNR into stochastic ping-level detection probability using

$$P_{\mathrm{detect}} = \left(1 + e^{-0.5(\mathrm{SNR}-12)}\right)^{-1},$$

so that detection depends probabilistically on environmental and geometric conditions rather than on a fixed range threshold. Noisy detections from multiple scouts are fused through an Extended Kalman Filter, with

$$K = PH^T \left(HPH^T + R\right)^{-1},$$

producing a continuously updated estimate of target position, velocity, and covariance. The interceptor then computes a predicted intercept point by solving

$$\left(\|V_t\|^2 - v_{\max}^2\right) t^2 + 2\left(\mathrm{rel} \cdot V_t\right) t + \|\mathrm{rel}\|^2 = 0,$$

where the smallest positive root defines the earliest feasible intercept time. Finally, interceptor steering is governed by proportional navigation,

$$a_{\mathrm{lat}} = NV_c\dot{\lambda},$$

which commands lateral acceleration as a function of closing velocity and line-of-sight rate. Together, these models allow the simulation to evaluate how sensor noise, missed detections, target speed, scout geometry, tether constraints, and interceptor maneuverability affect localization error, time-to-intercept, and probability of successful interdiction. Various scenarios are constructed to examine variations in target speed, detection range, environmental conditions, and response layer composition, i.e., number of sensing scouts and interceptors, and how they affect probability of successful interception, mean time-to-intercept, and failure modes.

Preliminary results suggest that the KRAKEN architecture provides significant advantages in coordination reliability, latency, and engagement precision compared to untethered approaches, particularly in communication-constrained environments. The system is most effective against low- to medium-speed UUV threats, which are the majority of those observed today. Results further suggest multi-scout configurations significantly reduce localization error and improve interdiction success rates, while tether constraints introduce trade-offs in maneuverability that must be accounted for in system design.

KRAKEN's distributed sensing layer is designed to ingest cues from heterogeneous maritime platforms, including USVs, ROVs, AUVs, towed arrays, and buoy-fixed sensors with multimodal sensing (e.g., sonar, LiDAR, electro-optical, acoustic, inertial). Upon sufficient cueing, the control node dispatches tethered scouts for closer target localization and uses fiber-optic links to maintain low-latency command, telemetry, and sensor fusion where acoustic or RF communications are degraded. A tethered interceptor is then launched toward a dynamically updated predicted intercept point, with ultra-short baseline (USBL) tracking supporting relative localization of deployed agents.

This work offers a systems-level contribution to the OCEANS community by integrating underwater vehicle design, multi-agent coordination, sensor fusion, and marine security into a unified response architecture. KRAKEN addresses a critical operational gap in subsea defense by extending maritime domain awareness systems toward coordinated, real-time response under communication constraints. Beyond infrastructure and vessel protection, the architecture may also inform search-and-rescue, underwater surveillance, and resilient AUV/ROV coordination in degraded communication environments.

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