

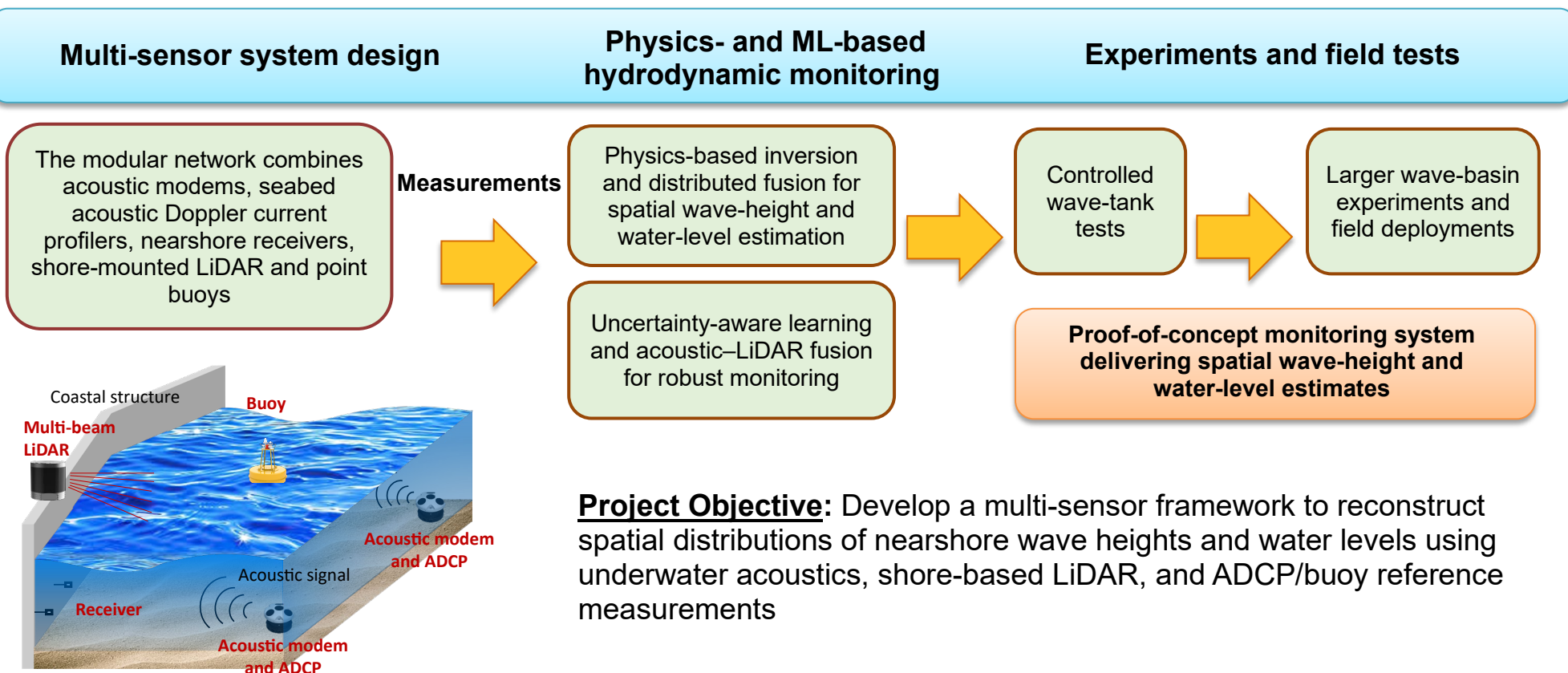
REAL-TIME MONITORING OF SPATIAL DISTRIBUTION OF NEARSHORE HYDRODYNAMICS THROUGH MULTI-MODAL SENSOR FUSION

Abstract

Singapore's nearshore zones experience complex interactions among waves, tides, and storm surges that pose challenges for coastal safety and infrastructure resilience. Existing monitoring methods, such as buoys and single-point ADCPs, provide limited spatial coverage and are costly to maintain. This project aims to develop a real-time, reliable, scalable, and cost-effective system for monitoring nearshore hydrodynamics. The proposed solution includes acoustic-based and LiDAR-based sensing, integrating multi-modal measurements with data-fusion to capture wave and water level dynamics across space and time. A modular acoustic framework with battery-powered acoustic modems, seabed ADCPs, and shore-mounted receivers will be developed to reconstruct spatial fields of wave heights and water levels using distributed data-fusion algorithms and event-triggered telemetry.

In parallel, a complementary data-driven modeling framework will provide uncertainty-aware, real-time estimation of wave heights from raw acoustic returns and auxiliary measurements, ensuring robust performance when physics-based inversion is degraded. LiDAR measurements will provide an independent reference to cross-check and complement the acoustic-based system, particularly under challenging conditions. Multi-modal data from the acoustic and LiDAR components will be integrated through advanced deep-learning fusion to enhance monitoring accuracy and reliability. Based on a staged validation and performance assessment strategy, in which laboratory wave-tank experiments provide controlled and repeatable baseline testing and iterative algorithm/model refinement, while larger-scale wave-basin experiments at TCOMS and field deployments in Singapore waters assess more representative hydrodynamic and site-specific operating conditions, the project will establish an end-to-end data pipeline, from sensing, transmission, processing, inference, and visualization to API access, to deliver robust, high-resolution, real-time spatial monitoring of nearshore wave heights and water level fluctuations.

The resulting system will provide a replicable reference model for continuous monitoring of nearshore hydrodynamics, with the potential to strengthen Singapore's coastal protection capabilities, improve early-warning systems, and support operational decision-making.



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