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Abstracts

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Presentation Abstracts

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A Parametric Design Framework for Toroidal Propellers: Multi-Objective Optimisation for Efficiency, Cavitation, and Underwater Radiated Noise

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Abstract

Improving propeller efficiency while reducing cavitation and underwater radiated noise remains an important challenge in both commercial and naval marine propulsion. Toroidal propellers offer a promising alternative to conventional propellers because their closed-loop blade geometry can weaken tip vortex formation, which is closely linked to cavitation, energy loss, and noise generation. However, their geometric complexity makes repeatable modelling and systematic optimisation difficult. This research develops a fully parametric design framework for toroidal propellers to enable controlled investigation of geometry–performance relationships under open-water conditions. The blade geometry is generated from a closed-loop reference line with smoothly varying geometric distributions, allowing consistent control of parameters such as pitch, chord, thickness, skew, and loop shape. Hydrodynamic and cavitation performance are evaluated using an unsteady CFD methodology based on the RANS equations, sliding mesh modelling, and a cavitation model suitable for vapour prediction. The numerical approach is validated against the benchmark INSEAN E1619 propeller. The framework is then coupled with a multi-objective NSGA-II optimisation procedure to explore trade-offs between thrust, efficiency, and cavitation performance. Results show that optimised toroidal configurations can improve propulsive efficiency and reduce cavitation intensity relative to the baseline propeller within the investigated design space. Flow-field analysis further indicates that the toroidal topology redistributes tip vortex structures, contributing to lower wake losses and reduced cavitation-prone regions. Initial acoustic postprocessing also suggests a reduction in radiated noise levels. Overall, the study demonstrates that parametric modelling combined with CFD-based multi-objective optimisation provides a practical route for the design of quieter and more efficient advanced propellers. Future work will extend the framework to broader operating conditions, include higher-fidelity acoustic assessment, and investigate structural and manufacturability constraints for real-world marine applications.

Keywords: Toroidal propeller, cavitation, parametric design, multi-objective optimisation, underwater radiated
noise, CFD, NSGA-II

A Nonlinear Multibody Finite-Element Framework for Container-Stack Response under Roll Excitation

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Abstract:

Deck-stowed container stacks are increasingly exposed to severe roll-induced loading as stack heights and securing-system complexity increase. This can lead to larger uplift and lashing demand, while simplified static and quasi-static approaches may underestimate these responses. Under such conditions, behaviour is governed not only by global stiffness but also by nonlinear mechanisms such as twistlock clearance, uplift, and intermittent contact between adjacent stacks. This study develops a nonlinear transient finite-element framework in OpenSeesPy for predicting container-stack response under imposed roll-type excitation. The model is first benchmarked against the Lloyd's Register single-stack case for an 11-container arrangement under roll amplitudes of ±5°, ±10° and ±15° with a 12 s period. A reduced beam-based representation is adopted to preserve the essential stiffness and dynamic behaviour while keeping repeated transient analyses computationally efficient. The framework is then extended to a multibody formulation by introducing localised stack-to-stack interaction through nonlinear Kelvin-Voigt spring-damper contact elements at adjacent corner castings. This enables efficient representation of inter-stack contact without the expense of full surface-contact modelling. Preliminary parametric results indicate that single-stack and multibody predictions remain close when interaction is weak but diverge once roll excitation and stiffness scaling increase; In the present comparison set, this transition occurs at approximately a stiffness scaling factor of 1.25. These results suggest that multibody modelling becomes necessary beyond a threshold interaction level for reliable prediction of uplift and lashing demand. The validated simulation workflow will be used in future parametric studies and to generate training data for surrogate models aimed at faster assessment of container-stack response.

An Integrated AI-Based Framework for System-Level Hull–Propeller Optimization under Practical Data Constraints

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ABSTRACT

Background: Ship propulsion efficiency is critical to maritime operations, directly affecting fuel consumption, operational costs, and environmental emissions. Conventional design approaches optimize hull and propeller independently, neglecting their hydrodynamic interaction and failing to achieve system-level efficiency.

Motivation: Three fundamental challenges limit practical propulsion optimization: (1) sequential design creates efficiency plateaus by ignoring bidirectional hull-propeller coupling, (2) AI-based integrated design requires large-scale training data that remains scarce in shipbuilding, and (3) data generation faces a scale-accuracy trade-off between computationally efficient low-fidelity methods and accurate but expensive high-fidelity CFD simulations.

Objectives: This study develops the Intelligently Synergized Propulsive System (ISPS), an AI-driven framework enabling system-level hull-propeller optimization under realistic data and computational constraints.

Method: ISPS integrates four coupled phases: (1) hierarchical geometric parameterization for hull and propeller, (2) coupled performance calculation using physics-based methods across the parametric design space, (3) multi-fidelity dataset generation combining theoretical predictions and historical data with strategically allocated CFD evaluations, and (4) AI-driven optimization employing hydrodynamic predictor and conditional generative models, with trust region filtering (TRF) strategy to identify critical design points requiring high-fidelity validation, ensuring prediction accuracy while maintaining computational feasibility.

Results: The framework achieves system-level optimization through simultaneous hull-propeller coupling evaluation, overcomes data scarcity by combining physics-based synthetic data with historical records for AI training, and balances accuracy with computational efficiency through TRF-guided strategic deployment of expensive high-fidelity evaluations.

Conclusion: ISPS offers a practical solution for integrated hull-propeller design that addresses the limitations of traditional sequential methods while remaining computationally feasible for engineering applications.

Future Work: Future work will implement all framework components to develop a fully functional optimization system and extend capabilities to off-design operating conditions including varying sea states and operational profiles.

Shipborne Wave Measurements Using Ultrasound Technology Onboard RV 'The Princess Royal'

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Abstract

Historically, wave parameters estimation was based on the subjective estimation of experienced mariners, whilst currently data is collected by equipment which is located at great distances from the actual shipping routes and which incurs high maintenance costs. The accurate estimation of the sea state is essential for vessel operations, offshore engineering, and environmental monitoring and the recent revision of ISO15016, as well as ISO19030, incentivises the adoption of data based on environmental measurements including wind and waves.

In this study, real-time measurements of the sea water level, taken with the vessel at zero forward speed, were performed onboard Newcastle University's 18m RV 'The Princess Royal' by using vessel-mounted ultrasound technology. The obtained spectral shape, peak frequency and the significant wave height were validated using simultaneous data provided by the Newbiggin Datawell directional WaveRider Mk III buoy by using frequency and time domain analysis. The results indicated a satisfactory agreement in the spectral shape with rather larger differences between peak frequency and the significant wave height due to the different technologies, distinct environmental conditions, separate locations and specific dynamic responses between the vessel and the meteorological buoy.

The outcome of this study shows that the ultrasound-based wave measurements technique provides a reliable quantitative assessment of wave parameters. The wave data is fundamental to determining the added wave resistance, hence normalisation of the power-speed performance of ships, and ultrasound-based wave measurements offer guidance on their use as a complementary or alternative technology to buoy-based systems in stationary vessel applications. Further measurements are expected to be conducted for improving the time-synchronisation with the Newbiggin buoy data and providing reliable data for ship performance analysis using data-driven models, and empirical method validation.

Key Words:

Shipborne wave measurements, ultrasound technology, kinematic sensors, wave spectrum, significant wave height

AI-Driven Prediction of Biofouling-Induced Resistance for Sustainable Hull Management

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Abstract

Biofouling accumulation on ship hulls is one of the major factors increasing hydrodynamic resistance and fuel consumption in maritime transport. As fouling develops over time, it can significantly reduce vessel efficiency and increase greenhouse gas emissions. Therefore, understanding and predicting the resistance increase caused by biofouling is essential for improving hull maintenance strategies and operational efficiency.

This research develops a hybrid framework combining Machine Learning (ML) and Computational Fluid Dynamics (CFD) to investigate biofouling-induced resistance and support sustainable hull maintenance. A training dataset will first be generated through CFD simulations across different ship types, operating speeds, and fouling conditions in order to quantify the hydrodynamic impact of biofouling.

The generated dataset will then be used to train ML models capable of predicting power increase or speed loss due to biofouling based on inspection inputs, eliminating the need for repeated CFD simulations. The resulting ML framework will be integrated into practical applications, such as automated biofouling impact assessment, enabling more efficient hull-cleaning optimisation.

By providing rapid performance predictions and supporting optimal cleaning strategies, this approach aims to reduce operational costs, improve energy efficiency, and contribute to more sustainable maritime transportation.

LLM-empowered technology evolution analysis of remote operation centres of MASS

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Abstract

Remote Operation Centres (ROCs) are critical shore-based infrastructure that support Maritime Autonomous Surface Ships (MASS) through remote supervision, control, and human-machine cooperation. However, existing research on ROC technologies remains fragmented, typically focusing on isolated technological functions. As a result, a significant research gap remains in understanding how these technologies interact and co-develop within ROCs to support maritime autonomy as an integrated system. To address this gap, this study develops a Large Language Model (LLM)-based patent analysis framework to identify ROC-related technologies and analyse their structural interdependencies using complex network analysis.

This research develops a three-stage framework that combines patent screening, LLM-assisted technology topic identification, and network-based analysis to examine ROC technologies as an integrated system. First, patent records are retrieved from Google BigQuery using keywords and subsequently screened to retain ROC-relevant patents. Second, LLM-assisted topic identification is applied to the retained full patent texts to derive a structured set of ROC technology topics and a patent-to-topic mapping for subsequent network construction. Third, a weighted co-occurrence network is constructed and analysed using complex network metrics to evaluate the interconnections and co-development of ROC technologies.

The analysis identified 22 ROC technology topics from 973 ROC patent documents. Among these technologies, Maritime Data Communication (MDC), Remote Control and Teleoperation (RCT), and Remote Condition Monitoring (RCM) emerged as the most prevalent technologies, while Human-Machine Interface (HMI) and Maritime Positioning and Navigation (MPN) also showed high patent activity during the study period. Analysis of key network metrics further confirms that MDC, RCT, and RCM occupy central positions within the ROC technology landscape. Further temporal analysis shows that ROC-related patenting activity and technological convergence accelerated after 2018, with the strongest network connectivity observed during 2020-2023.

In this study, an LLM-based method is developed to identify ROC-related technologies from patent data, thereby enabling a systematic mapping of the ROC technology landscape. By further constructing a technology network, the connections and co-development relationships among these technologies are revealed. These contributions establish a systematic and quantitative framework for identifying and evaluating ROC system technologies, while providing new insights into key technological components and their interdependencies. The findings provide practical guidance for future ROC architecture design and offer evidence-based support for identifying emerging forms of human-autonomous collaboration in ROCs, as well as for informing future remote-operator competency requirements and tailored training suggestions.

2D Ocean Wave Field Prediction by Wave Attention Method

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Abstract

Accurate ocean wave forecasting is crucial in maritime and coastal applications. Accurate predictions of wave conditions enhance the safety and efficiency of marine structures. Reliable wave forecasting systems also play a vital role in disaster warning systems, contributing to environmental protection and sustainable ocean resource utilization.

However, in real-world scenarios, wave data is usually sparse and irregularly distributed due to limitations in sensor deployment and measurement costs. This results in a lack of direct observations in many regions. Therefore, it is essential to develop models capable of predicting wave conditions at unobserved locations based on available measurements.

This study proposes a novel framework of spatial-temporal extrapolation, Physical-Informed Wave Attention Network (PI-WAN). The model is designed to forecast significant wave height at unobserved coordinates in future time steps, based on those with historical data. The proposed wave attention mechanism captures the intrinsic propagation patterns of ocean waves adaptively. This model identifies the dominant wave patterns, and reconstructs the underlying physical processes at the global scale. This mechanism leads to accurate and physically consistent predictions of global patterns, and then infers the wave states of coordinates without historical data.

The model is evaluated by statistical metrics, including MAE (Mean Absolute Error), RMSE (Root Mean Square Error), and MAPE (Mean Absolute Percentage Error). The proposed model PI-WAN achieves the MAE of 0.77, RMSE of 1.06, MAPE of 18%, lower than the state-of-the-art algorithm Spatial-Temporal Graph Attention Network (ST-GAT). Experimental results demonstrate the accuracy and reliability of prediction at unobserved coordinates, as well as its potential for broader application.

Design and Hydrodynamic Analysis of a New Web-type Mooring System

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Abstract

Y-type branching is an effective load-bearing topology, which can be pervasively observed in nature, such as on leaf and wing venation, spider webs, etc. It offers multiple concurrent load paths to share loads. Inspired by the anchoring system of spider webs, a novel Web-type taut-mooring system consisting of main lines and Y-type branches is proposed in this study. It is supposed to reduce anchors on the seabed, hence reducing the cost of installation. The objective of this study is to evaluate the performance of this Web-type mooring system when it applies to moor offshore floating platforms. The hypothesis for this new mooring system includes: 1) reduce the motion responses of a platform, and 2) achieve peak shaving in mooring-line tensions via load diversion from a main line to its branches. This new Web-type mooring system is then applied to moor OC6, a semi-type floating offshore wind turbine. Numerical simulations are performed to compare a conventional radial mooring layout against the proposed Web-type one under an equivalent pretension, axial stiffness, immersion angle, fairlead geometry, and draft. Dynamic responses are computed using OrcaFlex with consideration of the second-order wave loads in the time domain calculations. The simulations results show that the motion responses, including surge, heave and pitch, do not present a notable difference with the new Web-type mooring across various sea states and headings. However, the yaw motion exhibits a modest increase with the new layout, causing by a reduced yaw lever and enhanced surge/sway–yaw coupling effect. Most importantly, the Web-type layout delivers a systematic load redistribution: the tension on main lines is subject to a significant reduction under various heading conditions, while the two adjacent sub-lines absorb substantial mooring tension, evidencing effective peak shaving effects by Web-type layout. Overall, the biomimetic topology of the new Web-type mooring layout shows an excellent performance in mitigating mooring line tension while enabling potential anchor-count reduction. It could offer a safe and environmentally mooring solution for very large floating systems, such as floating PV farms.

Selective catalytic reduction systems for ammonia dual-fuel combustion in heavy-duty engines

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Abstract

Among the low-carbon alternatives for the decarbonisation of heavy-duty transport, ammonia (NH3) offers strong potential when blended with diesel. While ammonia combustion in engines has been studied extensively, its exhaust clean-up has received far less attention, a critical barrier to adoption. This project addresses that gap by investigating how catalyst-based after-treatment systems, originally designed for diesel exhaust, perform under the altered conditions of ammonia combustion. Ammonia combustion introduces new challenges for current catalysts, including higher amounts of Nitrous oxide (N2O), a potent greenhouse gas, as well as double the water vapour, which impacts the catalyst's performance and durability. Most importantly, these catalysts rely on injecting ammonia using urea, or Adblue, to treat NOx emissions. Using ammonia directly as a fuel raises the possibility of using residual ammonia in the exhaust for NOx reduction, potentially eliminating the need for Adblue. This project, led by the University of Sheffield in collaboration with Eminox Ltd. and Interkat Catalyst GmbH, specialists in catalyst manufacture and installation, focuses on three complementary approaches. Gas-phase and surface kinetic modelling using ANSYS Chemkin-Pro predicts emissions from ammonia diesel dual-fuel combustion and simulates catalyst conversion behaviour. Laboratory testing validates the mechanism, measuring catalyst efficiency, ammonia slip, and N_2O formation under controlled conditions. Since the exhaust gas temperature of ammonia derived exhaust is lower, catalysts that could not be used earlier with the higher temperatures from diesel are considered. Materials characterization using electron microscopy links catalyst composition to performance. This dual simulation–experiment framework highlights limitations in current reaction mechanisms for diesel exhaust treatment, which neglect N_2O pathways and assume water vapour is inert, underscoring the need for reaction mechanisms specific for ammonia combustion.

Results to date reveal significant discrepancies between predicted and measured catalyst behaviour, as well as evidence of accelerated degradation under ammonia-derived exhaust conditions. Detailed testing shows that equimolar concentrations of ammonia and nitric oxide (NO) promote efficient NO reduction; however, deviations in exhaust composition have a strong influence on performance. In particular, excess oxygen, excess ammonia, or elevated temperature increase the undesired conversion of ammonia to nitrogen dioxide, thereby lowering the overall NO_x conversion efficiency. This behaviour is critical because, unlike diesel engines which typically operate under fuel-lean conditions, ammonia
combustion achieves lower NO_x emissions when operated fuel-rich. Under these conditions, sufficient ammonia slip is available in the exhaust to reduce NO without AdBlue. These results not only highlight the limitations of diesel-optimised catalyst formulations when exposed to ammonia exhaust but also underline the need to adapt catalyst design for the specific chemical environment of low-carbon fuels.

AI-Driven Generation of Ship Hull Forms and Internal Structures from Principal Design Inputs

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Abstract: This presentation introduces an artificial intelligence framework for the rapid generation of ship hull forms and internal structural arrangements during the concept design stage. Traditional preliminary ship design often relies on iterative manual processes and designer experience, limiting the speed at which alternative concepts can be explored. The proposed methodology aims to automate this early-stage workflow by linking principal design inputs directly to external geometry and internal structural layout.

The first component of the framework uses a multi-modal denoising diffusion probabilistic model (DDPM) conditioned on basic ship particulars, such as principal dimensions and key design parameters, to generate realistic three-dimensional hull forms. Trained on a database of existing vessel geometries, the model is able to produce diverse hull candidates that satisfy specified design requirements while maintaining practical geometric characteristics.

The second component focuses on structural arrangement generation. Additional inputs, such as cargo hold configuration and frame spacings, are supplied to an ANN model that automatically defines the primary internal structure of the ship. The result of the generated internal structure will then be validated by a physics-informed neural network.

The presentation will discuss how combining generative AI with analytical modelling can create an efficient pathway from initial design particulars to structurally informed ship concepts. The approach has the potential to reduce concept design time, broaden design-space exploration, and support naval architects in the development of future intelligent ship design systems.

A Reproducible AIS-Driven Architecture for Modelling and Optimising Electric Vessel Charging Network in the UK

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Abstract

The transition to maritime operations with lower emissions requires modelling approaches that can link real vessel activity to their environmental effects, energy demands, and infrastructure demands. Current methods often treat AIS data processing, emissions estimation, charging analysis, and grid assessment separately, limiting transparency and reducing their suitability for real-world implementation. This study presents a modular, configuration-driven framework that unifies these components within a reproducible workflow. The structure is composed of four tiers: AIS processing for extracting movements and classifying behaviours; fuel-based emissions modelling using a standard carbon calculator, including a diesel factor of 2.66kg CO_2e per litre; estimating energy and charging demand; and assessing grid impacts to produce inputs for optimisation. All assumptions are stored in configuration files to ensure the workflow remains auditable and flexible. A harbour-scale case study demonstrates the AIS and emission components, producing movement-resolved outputs and a foundational CO_2e inventory for a mixed fleet. Although the charging and grid components are not implemented in this study, their interfaces and data pathways are defined to support electrification studies. The framework offers a structured approach for analysing vessel operations and provides the outputs required for planning charging infrastructure and assessing potential impacts on distribution networks in port settings.

Decarbonising the Inland Waterways – A strategic Approach to Sustainable Transportation

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Abstract

Decarbonisation of inland waterway transport is often framed as a propulsion challenge, with research and policy focused on replacing conventional engines with low- or zero-emission alternatives. While propulsion technology is important, this framing risks overlooking a more fundamental limitation: an insufficient understanding of when, where, and how much energy is demanded during inland waterway operations.

Unlike deep-sea shipping, inland waterway vessels operate within constrained and dynamic environments characterised by frequent manoeuvring, variable duty cycles, significant hotel loads, and strong dependence on local context such as traffic density, current, tidal effects, and port interactions. These factors produce uneven and spatially concentrated energy demand profiles that are poorly represented by distance-based or average-power assumptions commonly used in decarbonisation studies.

This presentation outlines the development of a transparent minimum viable model designed to reconstruct propulsion energy demand from observed vessel behaviour using a physics-based methodology. The model establishes a clear causal link between vessel movement data and inferred propulsion power, energy consumption, fuel use, and emissions under operational conditions. Early results from the model are presented, with validation currently underway. The emphasis at this stage is methodological integrity, internal consistency, and physical interpretability, providing a structured foundation for future refinement and empirical verification.

Initial results show that vessels operating on the same waterway, and even along identical routes, can exhibit markedly different energy demand profiles depending on operational behaviour and duty cycle composition. These findings challenge assumptions underpinning static energy infrastructure solutions and highlight risks of infrastructure misalignment and stranded investment if demand variability is not properly accounted for.

By improving visibility of operational energy demand, the research provides a defensible foundation for data-led infrastructure planning and a more credible pathway to zero-emission inland waterway transport.

A Multi-Factor Machine Learning Framework for Accurate and Efficient Sea Surface Temperature Forecasting in the Equatorial Ocean

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ABSTRACT

Sea surface temperature (SST) in the equatorial ocean is a key driver of air–sea interactions, climate variability, and marine ecosystem dynamics. Accurate and efficient SST forecasting is therefore essential for climate prediction and sustainable marine resource management. While recent machine learning (ML) approaches have improved forecasting skill, many rely on increasingly complex model architectures, large datasets, and high computational cost, with limited attention to the relative importance of feature engineering, model design, and validation strategy. This study proposes a time-aware, multi-factor machine learning framework to systematically evaluate the contributions of feature engineering, model architecture, and validation strategy to SST prediction performance. Using multi-source oceanographic and climate datasets, we compare linear (ARIMA) and nonlinear (XGBoost) models under multiple input configurations, temporal window settings, and cross-validation schemes. The results demonstrate that model architecture and validation strategy exert a greater influence on forecasting performance than feature complexity. In particular, expanding (time-aware) cross-validation significantly improves predictive accuracy and robustness compared to fixed validation approaches. Among the tested models, XGBoost consistently outperforms ARIMA, achieving a minimum RMSE of 0.49 °C using a six-year lag window and a multi-variable input configuration (SST, longitude, ONI, and DMI). Importantly, the findings reveal that simpler, computationally efficient models can achieve comparable or superior performance to more complex approaches when supported by appropriate feature selection and validation design. This challenges the prevailing emphasis on model complexity in SST forecasting. The proposed framework provides a scalable and operationally viable solution for SST prediction in equatorial regions and offers practical guidance for balancing accuracy, efficiency, and robustness in geophysical machine learning applications.

Keywords: computational efficiency, Multi-factor ML framework, time-aware validation, model architecture, feature engineering, equatorial ocean

Non-causal Economic Model Predictive Control for WEC Systems

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Abstract

Wave energy is a promising renewable resource due to its high energy density and relatively strong predictability, yet the practical deployment of wave energy converters (WECs) remains constrained by limited energy conversion efficiency and the need to maintain safe operation under varying sea states. To address these challenges, this study develops a non-causal economic model predictive control (EMPC) framework for a point absorber WEC that directly optimises energy conversion while accounting for both hydrodynamic and electrical dynamics. A unified wave-to-wire model is established to integrate the mechanical and electrical subsystems, and short-term wave prediction is generated using an autoregressive model updated by recursive least squares. Based on the predicted wave excitation, a non-causal EMPC scheme is formulated to maximise energy extraction rather than conventional tracking performance. To enhance practical feasibility, a hard constraint on the rate of change of PTO force is introduced to reflect actuator and electrical limitations, while observer-based state estimation, tightened constraints, and terminal set design are incorporated to ensure recursive feasibility and robust constraint satisfaction. Simulation studies using real wave data from the Cornwall coast demonstrate that the proposed method significantly improves energy capture while preserving safe operation. Compared with a conventional MPC baseline, the proposed controller achieves an average energy gain of approximately 27.9%, with displacement, velocity, current, voltage, and PTO force rate all remaining within prescribed safety limits. These results show that the proposed framework effectively combines wave prediction, EMPC, and wave-to-wire modelling to improve both energy conversion performance and operational feasibility for WEC systems, while also providing a foundation for future hardware-in-the-loop validation, nonlinear model extension, and more advanced real-time wave prediction methods.

Non-causal Model Predictive Control for Rigid-body Wave Energy Converters Based on Physics-Informed Neural Networks

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Abstract

The energy maximisation for Wave Energy Converters (WECs) is a non-causal problem where the current power take-off (PTO) force incorporates knowledge of future wave prediction to significantly boost energy harnessing. Since WECs are constrained by PTO limitation and other limitation regarding safe operations, model predictive control (MPC), as a well-known non-causal control algorithm, is considered as a proper algorithm to optimise the energy output subject to multiple constraints. However, MPC controller relies on an accurate model to generate maximum energy. Obtaining and utilising such fully known models is challenging due to the highly nonlinear dynamics and stochastic sea wave environment of WECs in various wave conditions. Traditional machine learning method can be a solution since they are able to model complex dynamical systems. However, they suffer from the requirement of a large amount of training data, which introduces significantly increased computational burden. To tackle these challenges, this research introduces a control framework that can utilise prior partial model information and have better sampling efficiency by integrating Physics-Informed Neural Networks (PINNs) with MPC to optimise the energy generation of WECs. As the benchmark of WECs control, the point absorber is chosen to evaluate the effectiveness of the proposed PINNs-MPC, in which several irregular sea wave scenarios are tested. The proposed method can be applied to other types of WECs by retraining the PINNs.

Turning Disturbances into Actuation: Hierarchical Environment-Assisted MPC for USV Fault Recovery

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Abstract

Thruster failures in unmanned surface vehicles (USVs), particularly twin-thruster configurations, can critically compromise mission completion by eliminating controllability in essential degrees of freedom. Conventional fault-tolerant control strategies attempt to redistribute control efforts while rejecting environmental disturbances as adversarial effects. This traditional approach fails catastrophically when severe actuator degradation leaves the system with insufficient control authority. To address this challenge, this research proposes a paradigm shift: strategically exploiting wind and wave dynamics as virtual actuators to restore control authority and facilitate emergency harbor returns.

The study introduces a hierarchical Environment-Assisted Model Predictive Control (EAMPC) framework. The architecture integrates an Extended Kalman Filter for real-time state estimation with a physics-informed recursive least squares algorithm to predict short-term environmental forces. A confidence-aware assistance policy sdetermines the extent to which these forces are utilized, scaling the factor based on fault severity and prediction reliability. These utilized forces are then incorporated directly into the model predictive controller's actuator allocation and prediction model. Concurrently, reachability-based trajectory planning leverages these beneficial disturbances to expand feasible navigation zones and generate optimal return paths.

Extensive validation was conducted through 320 trials in the Virtual RobotX environment across Sea States 2 to 5. The results demonstrated that the EAMPC framework achieved a 91.25% mission success rate under 95% thruster degradation. In contrast, conventional baseline methods completely fail, resulting in uncontrolled drift. Counterintuitively, the experiments revealed that moderate to rough sea conditions provided better fault recovery than calm seas, as higher sea states supplied sufficient environmental excitation to act as virtual actuators.

Ultimately, this work demonstrates that strategic environmental exploitation fundamentally transforms marine fault recovery capabilities. Future research will focus on validating results through physical USV sea trials, extending the framework to address multi-fault scenarios including sensor degradation, and integrating deep learning methodologies for long-horizon environmental prediction.

End-to-End Underwater Odometry Using Long Short-Term Memory Networks for Robust Autonomous Navigation

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Abstract

Reliable underwater localization remains a fundamental challenge in marine robotics, primarily due to the rapid attenuation of electromagnetic signals and the highly dynamic nature of subsea environments. Traditional navigation frameworks, such as the Extended Kalman Filter (EKF), rely heavily on precise kinematic modeling and are often sensitive to sensor noise and cumulative drift. This research proposes a deep learning-based end-to-end framework designed to enhance the localization accuracy of Autonomous Underwater Vehicles (AUVs) by leveraging Long Short-Term Memory (LSTM) networks.

The objective of this study is to develop a robust mapping between raw multi-modal sensor inputs and vehicle poses, bypassing the requirement for manual parameter tuning inherent in conventional dead-reckoning. The methodology utilizes an LSTM architecture, chosen for the superior ability to capture long-term temporal dependencies in sequential data. The network integrates raw data streams from a Doppler Velocity Log (DVL), an Inertial Measurement Unit (IMU), and a pressure sensor. By processing these inputs concurrently, the model learns to compensate for sensor biases and environmental disturbances that typically degrade traditional localization performance.

The proposed model was rigorously validated in simulated and real-world environments. Initial evaluations were performed on high-fidelity simulation datasets to benchmark the network's predictive capabilities across diverse trajectories. Subsequently, real-world validation was conducted using self-collected datasets obtained from an outdoor pool. Preliminary results demonstrate that the LSTM-based odometry significantly reduces trajectory drift compared to standard navigation methods, such as EKF and factor graph optimization, showing greater resilience to sensor dropouts and non-linear noise.

In conclusion, this research highlights the efficacy of recurrent neural networks in translating raw sensor observations into accurate spatial coordinates for underwater platforms. Future work will focus on the integration of transformer-based architectures to further improve computational efficiency and the deployment of the system in unstructured open-ocean environments to test its generalizability against varying current conditions.

Intelligent Energy Management for Decarbonised Port Operations: A Deep Reinforcement Learning Framework Integrating Renewables, Battery Storage, and Stochastic Loads

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Abstract

Decarbonising maritime transport and port operations is a critical step toward meeting global climate targets. The increasing electrification of port activities introduces highly variable and uncertain energy demand, which conventional energy management systems (EMS) may struggle to handle effectively due to their inability to adapt to stochastic conditions in real time. This work proposes a smart port energy management framework that integrates renewable energy sources, battery energy storage systems (BESS), and stochastic port loads under a centralised decision-making architecture. The framework is tested through a representative case study of a UK island, characterised by high wind energy potential and remote grid constraints that create both operational opportunities and challenges. A Deep Reinforcement Learning (DRL)-based controller is developed to enable real-time energy dispatch and adaptive control, incorporating stochastic wind data from ERA5 reanalysis datasets, vessel load profiles, and a BESS model. The system integrates DRL to optimise port microgrid stability, renewable energy utilisation, and operational efficiency. Preliminary results demonstrate that the proposed DRL-based approach outperforms conventional rule-based strategies in electricity supply reliability and renewable energy integration, particularly under high wind penetration scenarios. The framework also exhibits strong flexibility to accommodate multiple energy input types and variable demand profiles. This work contributes to the development of intelligent EMS for smart port microgrids by combining realistic load modelling, stochastic renewable inputs, and learning-based control. Future work will extend the framework to consider battery degradation and grid stability.

From Reactive to Anticipatory Autonomy: Wave-Predictive Multi-Agent Control of Unmanned Surface Vehicles

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Abstract

Unmanned surface vehicles are increasingly deployed for maritime search and rescue, environmental monitoring, and offshore inspection. However, most existing autonomous navigation systems adopt a reactive paradigm, responding to wave-induced disturbances only after they occur. This leads to excessive lateral wave exposure, high energy consumption, and degraded mission performance in rough seas. This research proposes a shift from reactive to anticipatory autonomy, where USVs learn to predict and exploit wave dynamics for safer and more efficient multi-vessel coordination. The proposed framework integrates deep reinforcement learning with high-fidelity wave simulation in NVIDIA Isaac Sim. In the single-agent phase, a Proximal Policy Optimisation agent was trained with wave-aware observations, including wave height, frequency, and a novel encounter-angle-based lateral exposure predictor, to navigate through regular Airy waves. Compared to a reactive baseline without wave observations, the wave-predictive agent reduced lateral wave exposure by 49%, from 0.513 to 0.263, while maintaining equivalent task completion. This demonstrates that reinforcement learning agents can learn anticipatory heading adjustments to minimise broadside wave encounters. Building on these single-agent results, the current phase extends to multi-agent reinforcement learning using Independent PPO to coordinate three USVs in a cooperative rescue scenario with eight shared targets. Each agent receives a 19-dimensional observation comprising navigation states, wave conditions, teammate-relative positions, and global target information. Preliminary results show that agents learn emergent cooperative target allocation without explicit assignment, though a trade-off persists between rescue efficiency and wave-avoidance behaviour. Future work will upgrade the wave model from single-frequency Airy waves to JONSWAP irregular wave spectra for greater realism, transition from global wave observations to onboard IMU-based wave sensing, and validate the framework through physical wave tank experiments at UCL. This research contributes a systematic pathway from single-agent wave-aware navigation to multi-agent anticipatory coordination, with implications for the next generation of resilient autonomous maritime systems.