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Enabling digital twins in the maritime sector through the lens of AI and industry 4.0

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A B S T R A C T

Sustainability and environmental compliance in ship operations is a prominent research topic as the waterborne sector is obliged to adopt "green" mitigation strategies towards a low emissions operational blueprint. Fuel-Oil-Consumption (FOC) estimation, constitutes one of the key components in maritime transport information systems for efficiency and environmental compliance. This paper deals with FOC estimation in a more novel way than methods proposed in literature, by utilizing a reduced-sized feature set, which allows predicting vessel's Main-Engine rotational speed (RPM). Furthermore, this work aims to place the deployment of such models in the broader context of a cutting-edge information system, to improve efficiency and regulatory adherence. Specifically, we integrate B-Splines in the context of two Deep Learning architectures and compare their performance against state-of-the-art regression techniques. Finally, we estimate FOC by combining velocity measurements and the predicted RPM with vessel-specific characteristics and illustrate the performance of our estimators against actual FOC data.

1. Introduction

Port logistics can often be a complex and challenging process, with various barriers and obstacles that can impede the smooth flow of goods and cargo (Sarkar & Shankar, 2021). One of the key challenges in port logistics is route optimization, which involves finding the most efficient and cost-effective way to transport goods from the port to their destination. Optimal ocean route planning is strongly connected to the fuel oil consumption (FOC) of sea vessels and the minimization the CO_2 emissions that reduce cost and the environmental footprint of Shipping. Among other factors, this approach aids jointly towards the efficient and robust ship tracking, weather forecasting, and emission control. The existing spatiotemporal data-driven solutions are employed upon a multitude of features, from vessel tracking devices and structural properties of the ship, to features that capture weather and internal machinery condition. Vessel monitoring and tracking can be performed using Synthetic Aperture Radar (SAR) images and data from the Automatic Identification System (AIS) (Zhao, Ji, Xing, Zou, & Zhou, 2014) or other surveillance systems (Chen et al., 2020). The spatial dimension that completes the vessel monitoring focuses on local conditions, such as the waves and currents that affect the cost of overseas movement, while the temporal aspect monitors environmental and ship-system conditions and examines how they evolve with time.

The multitude of data-driven methods that are employed in modern Information Systems for vessel monitoring and route optimization fuse features from multiple sensors onboard (Filippopoulos et al., 2022). However, there are many cases where ships share the minimum monitoring information (e.g. AIS messages, noon reports), essentially offering little more than their position and (implicitly) their speed over ground (SOG). FOC is highly affected by the velocity of the vessel and the weather conditions of the voyage. Furthermore it is closely related to the rotational speed, of the vessel's Main Engine (M/E) (Avgouleas, 2008), measured in Revolutions Per Minute (RPM). The latter determines the rotational speed of the propeller that produces the required thrust. This implies that the optimal route problem can be significantly optimized and restructured, if a good predictive model for RPM is made available, and the vessel's velocity can be a useful feature in this direction. Throughout the manuscript, scalar values of speed V are utilized in sections concerning model employment and experimental evaluation. The term velocity is used only as a reference to the reader, to indicate that

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