SUSTAINABLE MATERIALS, PROCESSES AND SYSTEMS FOR ENERGY TRANSITION

DM 630/Vulkan S.r.l. - Development of a Digital Twin Framework for Battery and Fuel Cell-Powered Propulsion Systems in Maritime Vessels

Funded By	VULKAN ITALIA S.R.L. [P.iva/CF:01318430061] Ministero dell'Università e della Ricerca - MUR [P.iva/CF:96446770586] Politecnico di TORINO [P.iva/CF:00518460019]

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Context of the research activity	This research aims to develop a Digital Twin framework for battery- and fuel cell-powered propulsion systems in maritime vessels, focusing on promoting energy efficiency and intelligent management of zero-emission propulsion. The primary objective is to create an experimental propulsion prototype with an electric motor powered by batteries and hydrogen fuel cells. This prototype will undergo bench testing, and a Digital Twin will be developed to acquire real-time propulsion data, optimize control techniques, and predict component ageing. Progetto finanziato dal PNRR a valere sul DM 630/2024 - CUP: E14D24002340004

	The maritime industry is undergoing a significant transformation driven by the urgent need to reduce greenhouse gas emissions and improve energy efficiency. Battery and fuel cell technologies have emerged as viable solutions for developing zero-emission propulsion systems, offering a sustainable alternative to traditional fossil fuel-powered engines. However, the integration of these technologies into cohesive propulsion systems requires advanced management and optimization strategies to maximize their potential. Digital Twin (DT) technology, which involves creating a virtual replica of physical systems to simulate and optimize their performance in real-time, presents a promising approach to address these challenges. By leveraging DT, it is possible to enhance the operational efficiency, reliability, and longevity of propulsion systems, contributing to the broader goals of sustainable mobility and environmental stewardship in the maritime sector. The primary objective of this PhD program is to develop a comprehensive

Objectives	Digital Twin framework for battery- and fuel cell-powered propulsion systems in maritime vessels. This framework aims to promote energy efficiency, intelligent management, and predictive maintenance of zero-emission propulsion systems. The specific objectives of the research are as follows: • Development of Experimental Prototype: Design and construct an experimental propulsion prototype equipped with an electric motor powered by batteries and hydrogen fuel cells. This prototype will serve for developing and testing the Digital Twin framework. • Bench Testing and Data Acquisition: Conduct bench testing of the propulsion prototype to collect real-time data on its performance. Key parameters such as energy consumption, power output, efficiency, and component health will be monitored and recorded. • Digital Twin Formulation: Develop a Digital Twin of the propulsion system using the acquired data. This virtual model will replicate the physical system's behavior and dynamics, enabling real-time simulation and analysis. • Optimization and Control Techniques: Utilize the Digital Twin to determine optimized control and management techniques for the propulsion system. These techniques will aim to enhance energy efficiency, reduce operational costs, and improve overall system performance. • Predictive Maintenance and Ageing Prediction: Implement predictive maintenance algorithms within the Digital Twin framework to forecast the ageing and degradation of on-board components. These involve the following PhD program: 1. Prototype Design and Construction: Design and build an experimental propulsion prototype for the Digital Twin framework. Select appropriate batteries, hydrogen fuel cells, and an electric motor based on performance requirements and compatibility. Design the propulsion system layout, including integration of sensors and data acquisition systems for real-time monitoring. Construct the prototype, ensuring all components are properly installed and configured. 2. Bench Testing and Data Collection: Gather real-time performance data from the experimental prototype to inform the development of the Digital Twin. Conduct a series of bench tests under operating conditions to collect data on energy consumption, power output, efficiency, and component health. Analyze the data to identify performance trends, inefficiencies, and areas for potential optimization. 3. Digital Twin Development: Develop a Digital Twin model that accurately replicates the behavior and dynamics of the physical propulsion system. Create a virtual model of the propulsion system using the collected data, incorporating simulation and analytical capabilities. Validate the Digital Twin by comparing its performance with that of the physical prototype under similar conditions. Ensure real time communication between the digital model and the real transmission. 4. Optimization and Control Strategy Implementation: Utilize the Digital Twin to formulate and test optimized control and management techniques for the propulsion system. Develop algorithms for optimizing energy efficiency, reducing operational costs, and improving system performance. Implement these algorithms within the Digital Twin and evaluate their effectiveness through simulation. Apply the most effective strategies to the physical prototype and assess their real-world performance. 5. Predictive Maintenance and Ageing Analysis: Integrate predictive maintenance capabilities into the Digital Twin framework to forecast component ageing and facilitate proactive maintenance. Develop predictive maintenance algorithms based on historical performance data and component degradation patterns. Integrate these algorithms into the Digital Twin model to enable real-time ageing prediction and maintenance

	scheduling. Validate the predictive maintenance system by comparing predicted and actual component ageing and performance data. The research aims to provide a significant contribution to the field of zero emission propulsion for the nautical sector. The anticipated outcomes of this PhD research are: • Digital Twin Framework: A Digital Twin for battery- and fuel cell-powered propulsion systems. • Improved Energy Efficiency and Proactive Maintenance: Enhanced control techniques that significantly improve the energy efficiency of maritime propulsion systems. Maintenance strategies that reduce downtime and maintenance costs by forecasting component ageing. • Sustainable Mobility Contribution: Innovations supporting the transition to sustainable maritime transport, reducing environmental impact.

Skills and competencies for the development of the activity	The ideal candidate should have a background in marine propulsion system and mechatronics. Proficiency in experimental prototyping, numerical modelling and data analysis is beneficial. Experience with modern control techniques applied to marine propulsion systems. The candidate should possess strong analytical skills, attention to detail, and the ability to work independently and collaboratively in an interdisciplinary and international research environment.