AUTOMATION AND ARTIFICIAL INTELLIGENCE IN WIND-ASSISTED SHIP'S PROPULSION

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Abstract: *In the dynamic landscape of maritime technology, the integration of automated systems and artificial intelligence (AI) with wind-assisted ship propulsion is revolutionizing the efficiency and sustainability of seaborne transportation. By combining the age-old practice of harnessing wind power with cutting-edge automation and AI capabilities, the maritime industry is charting a course towards greener, more cost-effective, and technologically advanced propulsion systems. Most modern wind-assisted propulsion systems (WAPS) now utilize state-of-the-art intelligent control and automation systems to operate in a safe manner and without the requirement for additional crew. A combination of advanced aerodynamics, automation, computer modelling and modern materials is unlocking a new generation of innovative sail systems for ocean-going ships. This article explores the convergence of automated systems and AI in WAPS, unravelling the benefits, challenges, and the transformative potential of this synergy.*

Keywords*: Maritime transport, sustainable shipping, wind-assisted ships propulsion, ship automation, artificial intelligence*

АВТОМАТИЗАЦИЯ И ИЗКУСТВЕН ИНТЕЛЕКТ В КОРАБНОТО ЗАДВИЖВАНЕ С ПОМОЩТА НА ВЯТЪР

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Резюме: *В динамичния пейзаж на морските технологии, интегрирането на автоматизирани системи и изкуствен интелект (AI) с вятърно задвижване на кораби революционизира ефективността и устойчивостта на морския транспорт. Чрез комбиниране на вековната практика за използване на вятърна енергия с авангардни възможности за автоматизация и AI, морската индустрия начертава курс към по-*

екологични, по-рентабилни и технологично напреднали системи за задвижване. Повечето модерни системі за задвижване с помощта на вятър сега използват най-съвременни интелигентни системи за управление и автоматизация, за да работят по безопасен начин и без изискване за допълнителен екипаж. Комбинацията от усъвършенствана аеродинамика, автоматизация, компютърно моделиране и модерни материали отключва ново поколение иновативни системи за платна за океанските кораби. Тази статия изследва конвергенцията на автоматизираните системи и AI в задвижването на кораби с помощта на вятър, разкривайки ползите, предизвикателствата и трансформиращия потенциал на тази синергия.

***Ключови думи**: Морски транспорт, устойчиво корабоплаване, задвижване на кораби с помощта на вятъра, корабна автоматизация, изкуствен интелект*

1. Introduction

Ship propulsion concepts which use energy harvested from wind as an additional source of propulsive power are of great interest for the shipping industry, addressing both environmental and business considerations. Usage of such hybrid propulsion concepts is dependent on seamless integration with current systems and processes on board. An intelligent system, monitoring the wind-assisted propulsion system, assisting the vessel's crew in its use and enabling automated, energetically optimized operation makes more widespread use of such technologies feasible. Special focus is given to the approach used in the system architecture's design for data acquisition, processing and storage as well as visualization using the system's human machine interface (HMI). Ultimately, this system helps further increase the fuel-saving potential of wind-assisted propulsion systems. Several innovative wind propulsion systems have been developed and successfully in operation to augment traditional engine power. Among them, the most notable are rotors, suction wings (ventifoils), hard and soft sails, kites [1].

2. Automation in ship’s WAPS

The maritime industry is undergoing a transformative shift towards sustainability, driven by the urgent need to reduce greenhouse gas emissions and mitigate climate change. One promising avenue for achieving this is the integration of wind-assisted propulsion systems on ships. These systems harness wind energy to complement traditional engines, thereby reducing fuel consumption and emissions. As the industry embraces this green transition, the role of

automation becomes increasingly pivotal in optimizing the efficiency and safety of wind-assisted propulsion systems. [2]

Rotor automation in WAPS: Wind-assisted propulsion has witnessed resurgence in the maritime industry as a means to reduce fuel consumption and environmental impact. Among the various technologies, Flettner rotors have gained attention for their simplicity and effectiveness. Advanced wind sensors and real-time data integration are crucial components of rotor automation. These systems continuously monitor wind conditions to optimize the orientation and rotation speed of the rotor for maximum thrust. Automated Flettner rotor systems utilize dynamic positioning algorithms to adjust the rotor's angle based on the vessel's course, speed, and prevailing wind direction. This ensures optimal wind capture and propulsion efficiency. Automated feedback control mechanisms are employed to maintain stability and prevent excessive loading on the vessel's structure during turbulent conditions or rapid changes in wind speed. Coordinating the operation of rotor automation with a vessel's existing propulsion and navigation systems requires careful integration to avoid conflicts and ensure seamless operation. Ensuring the structural integrity of the vessel under varying wind conditions is a challenge that necessitates rigorous engineering and safety assessments. Flettner rotors may have limitations in certain wind conditions, and automated systems must be capable of adjusting to these conditions to maintain optimal performance. Flettner rotor automation stands at the forefront of innovations in wind-assisted propulsion, offering a practical and effective solution for reducing the environmental impact of maritime transportation. As technology continues to advance and industry collaboration strengthens, automated rotor systems are poised to play a pivotal role in achieving a more sustainable and efficient future for the shipping industry.

Ventifoil control automation: Ventifoils are innovative devices that use automated, retractable sails to capture and harness the power of the wind to enhance the efficiency and sustainability of maritime transportation. These systems are designed to be installed on ships, particularly large cargo vessels, to reduce fuel consumption and emissions. The key to unlocking the full potential of Ventifoils lays in sophisticated control automation systems. Wind sensors play a crucial role in Ventifoil control automation. These sensors continuously monitor wind speed and direction, providing real-time data to the control system. This information is essential for making accurate decisions regarding the deployment and adjustment of the Ventifoils. The heart of Ventifoil control automation is a sophisticated control system, which processes data from various sensors and employs algorithms to determine the optimal sail configuration. It automatically adjusts the Ventifoils to capture the maximum amount of wind

energy while ensuring the safety and stability of the vessel. Ventifoil control automation is seamlessly integrated with a ship's navigation systems, allowing the automated control system to consider factors such as the ship's route, speed, and cargo load when optimizing the Ventifoil configuration. This ensures that the technology enhances overall efficiency without compromising the vessel's safety or schedule. Remote monitoring capabilities enable ship operators to track the performance of Ventifoils in real-time. Additionally, diagnostic features allow for proactive maintenance, minimizing downtime and ensuring the continued reliability of the Ventifoil control automation system. They provide ships with increased flexibility in adapting to varying wind conditions. The automated system ensures optimal sail configurations, allowing vessels to navigate efficiently in different weather scenarios.

Sail control automation in WAPS: Wind-assisted propulsion, often integrated with conventional engines, has gained renewed interest in the maritime industry as a sustainable and cost-effective means of reducing fuel consumption and emissions. The efficient utilization of wind power requires advanced sail control automation systems. Sail control automation is at the forefront of innovations in wind-assisted propulsion, offering a sustainable solution to the maritime industry's environmental challenges. As technology continues to evolve, the integration of advanced automation systems will play a crucial role in maximizing the benefits of wind power for commercial shipping. The industry's commitment to embracing these technologies will be vital in achieving a more sustainable and efficient maritime future.

Coordinating sail adjustments with the vessel's navigation system is a complex task that requires seamless integration to avoid conflicts. Ensuring the reliability of automation systems and implementing redundancy measures is critical for the safety of the vessel and its crew. Advanced sensor technologies coupled with real-time weather forecasting play a crucial role in sail control automation. These systems analyze wind direction, speed, and other relevant factors to optimize sail adjustments. Automated sail control systems utilize dynamic positioning algorithms to adjust sails based on the vessel's position, course, and wind conditions. This ensures optimal wind utilization for propulsion.

Automated sail control systems optimize the utilization of wind energy, reducing the reliance on fossil fuels. This leads to significant fuel savings and a subsequent decrease in greenhouse gas emissions, contributing to the industry's sustainability goals. Automation enhances the safety of wind-assisted vessels by providing precise control and response mechanisms in rapidly changing conditions. While the initial investment in automation technology may be substantial, the long-term benefits include reduced fuel costs, lower

maintenance expenses, and extended vessel lifespan. These factors contribute to a positive return on investment for shipowners.

Kite control automation in WAPS: Among the various technologies employed, kite-based systems have gained prominence due to their efficiency and versatility. Historically, kites have been used for centuries, but modern applications in maritime propulsion began in the early 21st century. Kite propulsion systems have evolved from manual control to sophisticated automated solutions, offering a promising avenue for reducing fuel consumption and emissions. Advantages of kite-assisted propulsion are that kites can harness high-altitude winds, providing a substantial thrust that contributes to increased fuel efficiency and they can be retrofitted to various vessel types, making them a versatile option for both new builds and existing fleets. Advanced wind sensors and GPS technology play a pivotal role in kite control automation. Real-time data on wind conditions and vessel position enable precise adjustments to optimize kite performance. Kite control systems utilize algorithms for automated flight control, adjusting the kite's angle and altitude to maximize propulsion efficiency. Automated systems include safety features such as emergency retraction and monitoring to ensure the kite's proper functioning and prevent potential hazards. But there are some challenges in kite control automation – unpredictable weather conditions pose challenges for kite control systems, requiring adaptive algorithms to optimize performance therefore seamlessly integrating kite control automation with a vessel's navigation and propulsion systems demands careful engineering to avoid conflicts and ensure smooth operation.

3. Artificial Intelligence in ship's WAPS

Artificial intelligence is defined as the understanding of the thinking structure of the human being and trying to develop the computer processes that will reveal the like [3]. The maritime industry is undergoing a transformative shift towards sustainable and technologically advanced solutions. WAPS, integrated with AI, is emerging as a key player in this evolution, augmented by AI will optimize their performance, enhance safety, and reduce environmental impact. AI's ability to process vast amounts of data in real-time enables adaptive decision-making presents a valuable addition to traditional WAPS. AI algorithms analyze real-time weather data, vessel parameters, consider wind patterns, weather forecasts, and vessel characteristics to recommend optimal routes, maximizing the use of wind energy and minimizing fuel consumption. AI-driven predictive maintenance models monitor the condition of WAPS components, ensuring timely interventions and preventing unexpected failures. AI systems learn from historical data and adapt to the specific characteristics of a vessel, improving

performance over time and under various operating conditions, the algorithms help vessels extract the maximum energy from the wind, translating into reduced reliance on conventional propulsion systems.

AI finds application in every WAPS: AI algorithms can optimize rotor control, adjusting the pitch and orientation of the blades in real-time based on wind conditions, ensuring that the rotor extracts the maximum amount of energy from the wind while minimizing stress on the turbine components. These algorithms can be employed to make real-time decisions regarding the deployment and adjustment of Ventifoils based on complex environmental factors, and by analyzing data from various sensors, including wind speed, ship speed, and navigational information, AI can optimize the sail configuration for maximum energy capture while ensuring the safety and stability of the vessel. Based on real-time data from sensors AI algorithms can dynamically control the positioning and adjustment of sails, allowing for optimized sail configurations, taking into account factors such as wind speed, direction, and the vessel's speed – the result is improved energy capture and overall propulsion efficiency.

AI can enhance the accuracy of wind forecasting, providing valuable information about upcoming wind patterns, thus enables the WAPS to anticipate changes in wind speed and direction, optimizing the positioning for optimal energy capture. AI enables adaptive control strategies that respond dynamically to changing environmental conditions, so the WAPS can continuously adapt its operations to maximize energy production and respond to unexpected challenges.

Despite all the advantages still there are some drawbacks for AI in WAPSs: AI systems heavily rely on accurate and reliable data, so inaccurate or incomplete data can lead to suboptimal decision-making; integrating AI with existing ship systems, including navigation and propulsion, requires careful planning to ensure seamless operation and avoid conflicts.

4. Automation and AI for advanced ship energy management systems

Advanced automation technologies are revolutionizing the way vessels consume energy, optimize operations, and contribute to a more sustainable maritime industry. Automation is transforming power distribution on ships through the implementation of smart grids. By dynamically allocating resources based on real-time requirements, smart power distribution systems enhance efficiency, reduce energy waste, and contribute to overall fuel savings. Automation is a driving force in the evolution of advanced ship energy management systems, offering a multitude of benefits ranging from improved efficiency to enhanced safety and environmental sustainability. By factoring in real-time variables, AI ensures that vessels

take the most fuel-efficient paths, avoiding adverse weather and sea conditions. This not only reduces fuel consumption but also minimizes the environmental impact of shipping operations. [4] AI can be employed to develop intelligent strategies for harvesting wind energy efficiently.

Automated systems monitor energy demand in different sections of the vessel and distribute power accordingly. Automation in ship energy management extends to engine control and performance optimization, automated systems continuously monitor and adjust engine parameters, such as fuel injection and combustion, to maximize efficiency. This dynamic optimization ensures that engines operate at peak performance levels, minimizing fuel consumption and reducing emissions. Automation is transforming energy storage and retrieval systems on ships, incorporating advanced battery management systems. These automated systems monitor energy storage levels, charging, and discharging cycles, ensuring optimal usage. By automating the management of onboard energy storage, vessels can strategically utilize stored energy during peak demand periods, contributing to overall fuel efficiency. [5]

Incorporating AI into WAPS control systems could potentially lead to more autonomous operations, AI algorithms could handle not only WAPS's components adjustments but also navigation, collision avoidance, and other aspects of ship control. As AI continues to evolve, its application in optimizing wind-assisted propulsion systems will play a pivotal role in reshaping the future of the shipping industry. Embracing these technological advancements can lead to a more environmentally friendly and economically sustainable maritime sector.

5. Conclusions

The synergy of automation and AI with WAPS holds immense promise for a sustainable maritime future. Automation in WAPS marks a significant stride towards sustainable shipping. By seamlessly integrating advanced technologies, the maritime industry can achieve higher levels of efficiency, reduce its environmental footprint, and navigate a course towards a cleaner and more sustainable future. As technology continues to evolve, embracing automation in wind-assisted propulsion becomes not just an option but a necessity for a greener and more resilient maritime sector.

There are lots of benefits of automated systems and AI integration: automated systems ensure precise adjustments to sail and rotor configurations, maximizing energy capture from the wind, AI-driven optimization enhances overall efficiency, leading to increased fuel savings, AI algorithms process data in real-time, making swift decisions on sail adjustments and propulsion methods. This real-time adaptability enhances the reliability and effectiveness of

wind-assisted propulsion, automated integration simplifies operational complexities, allowing crew members to focus on strategic decision-making, enhanced operational efficiency results in reduced crew workload and increased safety. [6]

Despite the promising advantages, challenges such as regulatory frameworks, upfront costs, and technological integration complexities need to be addressed. As the industry moves forward, collaboration between stakeholders, including shipowners, technology developers, and regulatory bodies, will be crucial in standardizing practices and ensuring a smooth transition to automated wind-assisted propulsion.

The integration of automated systems and artificial intelligence with wind-assisted ship propulsion represents a paradigm shift in the maritime industry. By leveraging the capabilities of advanced technologies, vessels can navigate more efficiently, reduce environmental impact, and pave the way for a sustainable future on the high seas. As AI continues to evolve and become an integral part of maritime operations, the synergy with wind-assisted propulsion systems is set to redefine the standards of efficiency, safety, and environmental stewardship in the maritime domain. Continuous developments in AI, including reinforcement learning and neural networks, will further enhance the adaptive capabilities of wind-assisted propulsion systems. Industry-wide collaboration is crucial for sharing AI-driven insights and best practices. Joint efforts in research and development will accelerate the adoption of automated and AI-driven propulsion technologies.

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