Applying Artificial Intelligence for improving Situational awareness and Threat monitoring at sea as key factor for success in Naval operation

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***Abstract*. The vast and dynamic maritime domain demands constant observance and accurate information for successful naval operations. However, traditional methods struggle to keep pace with the ever-increasing complexity and data overflow. The paper explores how Artificial Intelligence (AI) presents a transformative opportunity, significantly impacting naval operation by enhancing Situational awareness (SA) and Threat monitoring (TM). It is analyzed the impact of AI across three key areas: enhanced data processing and analysis, improved anomaly detection and predictive capabilities, and real-time decision support. By analyzing key principles, tactics, and procedures for AI implementation, it is explored the process how these capabilities can convert into practical applications and benefits. Examples like AI-powered maritime surveillance and predictive systems for naval assets demonstrate solid benefits of this technological progress. Additionally, in the paper are envisioned future operational scenarios where AI-driven autonomous systems and dynamic route optimization become commonplace. The analysis demonstrates how AI can be a critical factor in moving naval operations into a new era of efficiency and proactive threat management. However, responsible development and ethical considerations remain of paramount importance.**

***Keywords: Artificial Intelligence, Naval operation, Situational awareness, Threat monitoring*.**

I. INTRODUCTION

Situational awareness (SA) and threat monitoring (TM) are critical components of naval operations, playing a pivotal role in maintaining security, operational effectiveness and strategic advantage at sea. Their importance can be defined across several key dimensions like support of informed decision-making and strategic planning, understanding the real-time status of the operational environment, including the location, capabilities and intentions of both friendly and potential adversarial forces. Effective TM enables early detection of potential threats and what is more it is crucial for timely response, allowing naval forces to mitigate threats before they can affect maritime operations or escalate into larger conflicts [1]. There are several operational gaps in traditional SA and TM approaches in naval operations and the application of Artificial Intelligence (AI) - driven tools is one of the successful approaches to improve these processes.

II. MATERIALS AND METHODS

A. *Situational awareness and Threat monitoring as a Key Factors for Naval Operation*

Situational awareness and threat monitoring are foundational to the success of naval operations. They enhance decision-making, ensure force protection, enable effective threat response and provide a strategic advantage, thereby playing a vital role in maintaining maritime security and stability [2]. These two pivotal elements in naval operations are supporting the safety, efficiency and effectiveness of maritime forces. These components are crucial for several reasons: Situational awareness is Enhancing Decision-Making as it provides naval commanders and personnel with a comprehensive understanding of the environment in which they operate. This includes knowledge of the location, status and intentions of both friendly and adversarial forces, as well as relevant civilian entities at sea. Accurate and timely information allows for informed decision-making, enabling strategic planning and tactical responses to dynamic situations [1]. At the same time Threat Detection (Threat monitoring) is essential for the early detection of potential threats, ranging from conventional military assets like warships, submarines and mines to asymmetric threats such as piracy, terrorism, smuggling and illegal fishing. Early detection enables naval forces to assess threats accurately and initiate appropriate countermeasures (Threat Response), thereby mitigating risks and preventing escalation. It allows commanders to make tactical decisions that are critical for mission success. Moreover, maintaining

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SA is key to protecting naval assets and personnel (Force Protection) from both military and non-military threats. This includes not only direct attacks but also environmental hazards and navigational risks. Effective monitoring and awareness mechanisms ensure that forces remain alert and prepared to respond to any incident, ensuring the safety and integrity of naval operations. In an era of joint and combined operations, situational awareness facilitates interoperability and coordination among allied forces in multidimensional battlespace [3]. Sharing a common operational picture enhances the ability of multinational forces to operate cohesively, coordinate actions and achieve shared objectives, thereby amplifying collective defense capabilities [4]. Furthermore, superior situational awareness provides a strategic advantage by enabling naval forces to anticipate adversary actions, exploit vulnerabilities and maneuver effectively in the maritime domain. This advantage is critical in both conventional warfare scenarios and in countering non-traditional threats. In addition to its military applications, situational awareness is crucial for crisis management and humanitarian assistance operations. It enables naval forces to quickly assess situations, such as natural disasters or maritime accidents and provide timely and effective aid, thereby saving lives and mitigating the impact of crises. Maintaining high SA and demonstrating the capability to monitor and respond to threats can serve as a deterrent to potential adversaries. It signals readiness and the ability to project power when necessary, contributing to stability and peace in international waters. To sum it up, SA and TM are indispensable for modern naval operations, enabling forces to navigate the complexities of the maritime environment effectively, respond to emerging threats promptly and conduct operations that support national and international security objectives [5].

B. Operational gaps in traditional approaches to Situational Awareness and Threat Monitoring in Naval operations

There are several challenges in traditional approaches to SA and TM in naval operations, driven by the complexity of the maritime environment, technological limitations and evolving threats. First of all, is Data Overload when during Naval operations is generated vast amounts of data from various sources, including radar, sonar, satellites and intelligence reports. The complete volume of information can overwhelm traditional analysis methods, leading to delays in processing and potential gaps in SA. Naval forces often rely on a variety of legacy systems and sensors that may not be fully compatible with each other. Integrating data from these disparate sources into a coherent operational picture is a significant challenge, obstructing effective decision-making. Moreover, the maritime domain is by its nature dynamic, with rapidly changing conditions and high degrees of uncertainty. The physical environment of the sea, including weather conditions, underwater geography and the vastness of the ocean, poses natural challenges to monitoring and awareness. Traditional methods may be limited in their ability to account for these factors effectively and may struggle to adapt quickly to new information or unexpected situations, potentially compromising SA [6]. Also, while traditional systems can collect and store data, they may lack the capability for real-time analysis and interpretation. This delay can be critical in fast-moving situations where immediate responses are required to mitigate threats. At the same time, as naval operations become increasingly dependent on digital systems, they become more vulnerable to cyber threats. Traditional security measures may not be sufficient to protect against sophisticated cyber attacks aimed at disrupting SA and command and control systems. What is more, Naval forces face a broad spectrum of threats, including asymmetric tactics employed by non-state actors, piracy, terrorism and cyber warfare. Traditional approaches may not be designed to detect or respond effectively to these unconventional threats. Maintaining comprehensive SA requires significant resources, including advanced sensors, surveillance assets and skilled personnel. Budgetary and operational constraints can limit the ability of naval forces to deploy these resources effectively. Also, Joint and coalition operations are integral to modern naval strategy, demanding interoperability among diverse forces [3]. Achieving integrated communication and data sharing between different countries and branches of the military remains a challenge, affecting SA. Reliance on manual processes and human interpretation of data can introduce errors and biases into SA and TM. Fatigue, cognitive overload and the limitations of human decision-making under stress can further impact the effectiveness of traditional approaches. Addressing these challenges requires innovative solutions that use advance in technology, such as AI, machine learning and automated systems, to enhance the speed, accuracy and adaptability of SA and TM in naval operations.

C. Applying Artificial Intelligence in Naval operation

In recent years, modern technologies have developed rapidly, which in turn also greatly affects naval activities. AI technologies have significantly enhanced SA and TM in naval operations by providing advanced capabilities for data analysis, decision support and operational efficiency. AI-driven tactics significantly enhance SA in naval operations by using advanced computational techniques like predictive analytics, pattern recognition, machine learning and more. These tactics enable forces to interpret complex data, anticipate future scenarios and make informed decisions promptly. There are a few key AI-driven tactics for enhanced SA like: Predictive Analysis, Pattern Recognition, Machine Learning and Deep Learning, Natural Language Processing (NLP), Sensor Fusion, Decision Support Systems, Cybersecurity, Human-AI Collaboration, etc. After analyzing of the researched topic, the following key factors can be summarized for AI's contribution in Naval operation:

a) Data Fusion and Analysis

AI algorithms can integrate, process and analyses vast amounts of data from sensor networks with diverse sources, including satellites, radar, sonar, unmanned and ship-based sensors, like automatic identification system - AIS. AI also integrates data from above mentioned sensor networks and Internet of Things (IoT) devices deployed on naval assets and maritime infrastructure. This integration facilitates the continuous monitoring of operational environments and asset conditions. By employing algorithms that can process and fuse data in real-time, AI

provides a comprehensive and integrated operational picture, enabling more accurate situational awareness of both the physical and electronic environments. This capability enhances SA, allowing naval forces to monitor vast ocean areas efficiently and detect subtle changes or threats that might be overlooked by human operators.

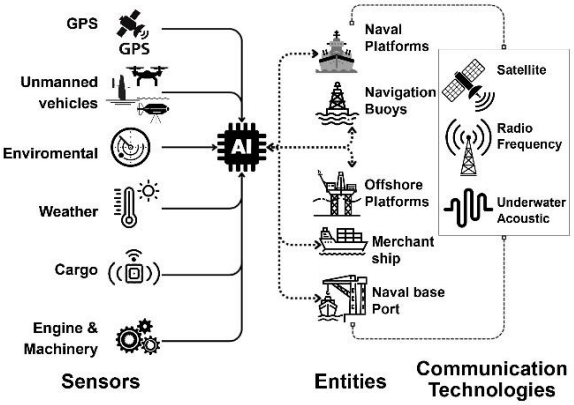

Fig. 1. Model of AI-driven Data Fusion and communication lines

b) Automated Threat Detection

Machine learning and pattern recognition models, a subset of AI, are trained to detect anomalies, classify objects and identify potential threats with high accuracy. These models can differentiate between civilian and military assets, detect unusual behaviour indicative of piracy or terrorism and identify environmental hazards, significantly reducing the response time to potential threats, including asymmetric ones like unmanned aerial vehicles (UAVs), mines or swarms of small boats. Machine learning models can learn from historical data to identify patterns associated with different types of threats, improving accuracy and reducing false positives. AI models are trained to recognize normal patterns of maritime traffic and environmental conditions. Any deviation from these patterns (Anomaly Detection), such as an unusual navigational route or speed, can be flagged as a potential threat, triggering further analysis or immediate action. AI can classify objects based on their "signatures" or unique characteristics captured by sensors (Signature Recognition). For example, the acoustic signature of a submarine or the radar cross-section of a surface vessel can be used to identify and classify potential threats. Regarding Target Identification and Classification could be used AI systems trained on vast amounts of imagery and sensor data that can automatically identify and classify contacts as civilian, commercial or military assets, significantly speeding up the decision-making process. What is more, Adaptive Learning Systems continually learn from new data, improving their accuracy and effectiveness over time. This capability is crucial for adapting to evolving sea threats and operational environments. Machine Learning and Deep Learning could support Image and Voice Recognition. Deep learning models are particularly effective in image and voice recognition tasks, useful for ISR (Intelligence, Surveillance, Reconnaissance) missions at sea. They can process satellite imagery or intercept communications to gather actionable information. For example, to identify specific vessel types, recognize patterns indicative of hostile intent and even detect concealed or camouflaged objects. On the other hand, using Natural Language Processing (NLP) techniques can automatically analyze vast quantities of text data from news, social media and other open sources to gather information (Open Source Intelligence - OSINT), identify potential threats and understand sentiment and intentions.

c) Predictive Analysis

AI leverages historical data and predictive analytics to forecast future threats and trends. Machine learning algorithms excel at detecting anomalies in vast sea datasets, identifying unusual ship movements, electronic signatures or communication patterns that could indicate threats like piracy, smuggling or enemy activity. Predictive analytics can identify patterns that precede attacks or aggressive maneuvers, allowing preemptive action. This capability allows naval forces to anticipate adversarial moves, plan defensive strategies and position assets strategically, enhancing preparedness and strategic decision-making. For naval operation this can be a game-changer, enabling proactive rather than reactive approaches, allocating resources more effectively and preparing for potential security challenges [7].

d) Enhanced Decision-Making

AI technologies have significantly improved the efficiency of naval operations by automating the analysis of sensor data, leading to quicker and more accurate decision-making processes. AI supports decision-making by providing actionable insights, recommendations and automated decision aids [8]. By analyzing complex scenarios and considering numerous variables, AI systems can suggest optimal courses of action, helping commanders make informed decisions quickly under various conditions [8].

e) Improved Surveillance and Reconnaissance

AI is a key enabler for unmanned systems - aerial, underwater and surface vehicles (UAVs, UUVs, USVs) and enhance surveillance and reconnaissance missions. AI algorithms enable these assets to navigate autonomously, avoid obstacles and identify areas of interest for further investigation, extending the reach, duration and effectiveness of naval surveillance efforts. These systems can conduct data gathering and even perform initial threat assessments autonomously. In the littoral zone, unmanned systems operated by AI can operate stealthily, avoiding detection while providing persistent surveillance. This is particularly beneficial for monitoring in politically sensitive areas or environments where human deployment is risky or infeasible. AI enables the real-time processing of sensor data, crucial for timely threat detection. This capability allows naval forces to react promptly to potential threats, enhancing maritime security and operational readiness. In this way they reduce risks to human life and increase the areas covered.

f) Cybersecurity and Information Warfare

In the digital and information age, SA extends to cyberspace and the electromagnetic spectrum. Monitoring communications, detecting electronic signatures and understanding the informational environment are critical for maintaining an operational advantage and ensuring cybersecurity. In the domain of cybersecurity, AI tools monitor network traffic and detect anomalies that could indicate cyber threats. AI-driven cybersecurity measures

are essential for protecting critical naval communication and operational systems from hacking, espionage and sabotage. That tools strengthen cybersecurity measures, detecting and neutralizing threats more efficiently [9].

g) Logistics Optimization

AI also plays a crucial role in optimizing the allocation of resources, including personnel, ships and surveillance assets. It can predict equipment failures before they occur by analyzing data from sensors and maintenance logs, enabling preventative maintenance and reducing downtime. Through sophisticated modelling and simulation, AI systems can recommend the most efficient deployment of naval resources, optimize supply chains and logistics, ensuring maximum coverage and operational effectiveness [10].

h) Training and Simulation

AI-powered simulations and virtual training environments offer realistic, scalable training opportunities for naval personnel. These tools can simulate a wide range of scenarios, from routine operations to complex combat situations, enhancing readiness and operational skills without the risks and costs associated with live training exercises. These tools support continuous learning and skills development, ensuring that forces are prepared for any challenge.

To sum it up, AI-driven technologies significantly contribute to SA and TM in naval operations by providing comprehensive data analysis, enhancing threat detection and prediction, supporting decision-making and optimizing resource allocation. As AI technology continues to evolve, its role in naval operations is expected to grow, offering even more sophisticated tools for ensuring maritime security and operational success.

D. Procedures for integrating AI tools with naval operation protocols

Integrating AI-driven tools into naval operation protocols involves a series of methodical procedures designed to ensure that AI technologies enhance

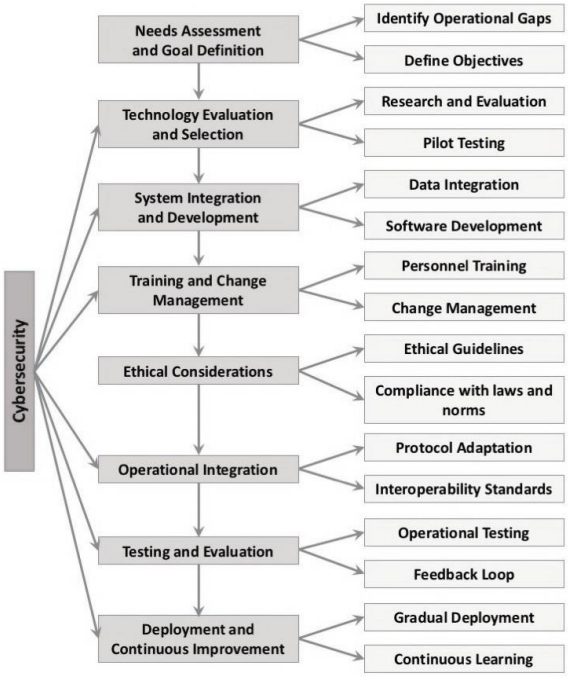

Fig. 2. Structured approach for integrating AI tools within Naval operation protocols

operational capabilities without compromising security or effectiveness. These procedures typically include technological, operational and organizational dimensions, ensuring a trouble-free and effective integration. Here's a structured approach for integrating AI tools within naval operation protocols "Fig. 2": First of all, should be defined Needs Assessment and Goal Definition for such an operation. For that purpose it is needed to be Identified Operational Gaps. It is conducted a thorough assessment to identify areas within naval operations where AI can offer significant improvements, such as decision support, threat detection or logistics management. To define objectives it is needed clearly to define what the integration aims to achieve, including specific performance metrics or capabilities to be enhanced by AI. Secondly, Technology Evaluation and Selection should be done. It is done by researching and evaluating available AI technologies and tools that meet identified needs, taking into account factors such as compatibility with existing systems, scalability and cybersecurity implications. After that, there are Implemented pilot projects or trials (Pilot Testing) with selected AI tools to assess their effectiveness, usability and integration challenges in a controlled environment. System integration and development of the integrating software takes place next. AI tools need to be able to access and process data from existing naval data sources and sensor systems, implementing necessary interfaces or data processing pipelines. Artificial intelligence software is developed or customized to align with specific protocols and requirements for naval operations, incorporating user feedback from pilot testing. In addition, it is necessary to train the personnel and to manage changes in the system. It is important to train staff on the use and interpretation of AI tools, with a focus on how these tools develop existing protocols and decision-making processes. Change management strategies are implemented to address potential resistance and ensure smooth adoption of AI

technologies within the organizational culture. Cybersecurity protocols need to be put in place next. Robust measures are integrated to protect AI systems from potential threats and vulnerabilities, thereby ensuring the integrity of naval operations. Establishing ethical guidelines for the use of AI, especially for decision-making in combat scenarios, ensuring compliance with international laws and norms is also a priority [5]. Existing naval operational protocols need to be adapted to incorporate AI-driven insights and recommendations, including updates to command and control procedures. It is critical that AI tools adhere to interoperability standards for joint operations with allied forces, facilitating seamless collaboration. It is also important to conduct extensive testing under realistic operational conditions to evaluate the performance and impact of AI tools on naval operations. Feedback Loop is needed to establish mechanisms for continuous feedback from users to identify areas for improvement and upgrade AI tools accordingly. Gradual Implementation of AI tools into naval operations should be phased in, monitoring effectiveness and addressing issues as they arise. Next, it is important to use AI's capabilities to continuous learning from new data and experience, updating models and algorithms to improve performance over time. Once AI systems are deployed, it is necessary to organise Current Monitoring systems to track the effectiveness and impact of AI tools on naval operations. This will ensure that they continue to meet operational needs. It is also important to plan regular maintenance and updates for AI systems, taking into account advances in AI technology and adapting to evolving operational requirements. Integrating AI tools into naval operation protocols is a dynamic and ongoing process, requiring close collaboration between technology providers, operational personnel and decision-makers. By following these structured procedures, naval forces can effectively use the potential of AI to enhance SA, decision-making and operational efficiency.

III. Results and Discussion

A. *Model of Situational Awareness of AI-assisted Naval operation*

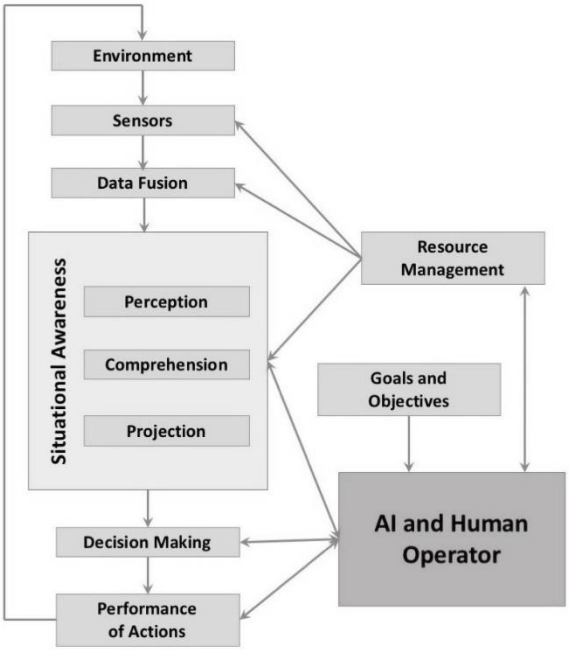

Fig. 3. Model of SA of AI-assisted Naval operation.

The integration of AI with existing naval operation frameworks represents a critical evolution in maritime defense capabilities. The algorithm of this operation is complex, involving technological, operational, and organizational adjustments. AI can enhance sensor fusion capabilities, integrating data from diverse sources such as radar, sonar, satellites, and intelligence reports to provide a comprehensive operational picture. This integration supports better decision-making by offering real-time, enhanced SA [11]. The first stage of attaining situational awareness is the perception of the status and attributes of the entities in the environment. For instance, a ship commander needs to differentiate important entities in the environment such as other ship, shore and warning buoy along with their relevant characteristics. The second stage of SA is the comprehension of the situation, which is based on the integration of disconnected level 1 SA elements. This is understanding of entities in the surroundings, in particular when integrated together, in connection to the operator's objectives. The third level of SA – Projection relates to the ability to project the future actions of entities in the environment at least in the near term. This is prediction or estimation of the status of entities in the surroundings in future.

Many naval operations rely on legacy systems with significant investments in infrastructure and training. AI technologies can be integrated into these systems through software upgrades and the addition of AI-driven analytics modules, thereby enhancing their capabilities without necessitating complete overhauls. AI can facilitate the shift towards more network-centric operations, where distributed sensor networks and platforms share data seamlessly across various assets. AI algorithms can process this data collectively, enabling more cohesive and informed responses to threats. At the organizational level, AI can

assist in strategic decision-making by providing comprehensive analyses of potential courses of action, including their likely outcomes and risks. This support helps commanders make more informed decisions, balancing tactical objectives with strategic goals. Integrating AI into naval operation frameworks is a multidimensional effort that requires careful planning, coordination, and adaptation. By addressing technological, operational, and organizational aspects, naval forces can use AI to enhance their capabilities, maintain strategic advantages, and address the evolving challenges of maritime security.

B. *Future development of Artificial Intelligence for improving Situational Awareness and Threat Monitoring at sea*

As these technologies continue to evolve, future developments could include more sophisticated sensor fusion algorithms, the integration of quantum computing for faster data processing, and the creation of more resilient Artificial neural networks (ANNs) capable of operating in adversarial conditions or with limited data [12]. The ongoing advancement in AI and machine learning promises to further enhance naval TM, ensuring that naval forces can effectively counter both conventional and asymmetric threats in increasingly contested maritime environments. It also should be account that potential adversaries are also beginning to use AI technologies, researching competitive AI tactics and developing countermeasures will be critical to maintaining strategic advantages. Future development will enhance AI's ability to support decision-making in environments with incomplete or ambiguous information represents a critical research area, especially for complex naval operations where uncertainty is a constant factor. Also, it will be broadening Integration of AI with existing Naval systems. Research into seamless integration methods for AI technologies with existing naval platforms and systems can ensure that advancements are more readily adopted and operationalized. Will be putted more efforts in developing frameworks and guidelines for the ethical use of AI in military contexts, including transparency, accountability and compliance with international laws, will be increasingly important. Exploring optimal ways for AI systems and human operators to interact and collaborate can enhance SA and operational effectiveness [10]. This includes human-machine interfaces that facilitate intuitive decision-making and control. In that way can be presented AI-generated insights in an understandable and actionable manner enables effective human-AI collaboration, ensuring that commanders can use AI recommendations without being overwhelmed by data. Collaboration between AI systems and human operators will keep the direction ensuring that AI supports rather than replaces human judgment. Also, will be increased Resilience against AI failures. Investigating methods to enhance the resilience of AI systems against failures or manipulations, ensure that naval operations can maintain integrity even when AI systems are compromised [10]. Will proceed efforts in utilizing AI to develop more sophisticated simulation environments for training naval personnel in complex, multi-threat scenarios can improve preparedness and adaptability. Regarding TM will be expanded the use of AI in monitoring and responding to environmental threats to maritime operations, such as climate change impacts, pollution and natural disasters. AI can also be applied to optimize naval supply chains and logistics, ensuring the efficient allocation of resources and materials in support of operational readiness. These directions underscore the dynamic nature of AI research within the naval domain, highlighting both the potential and the challenges of using AI to enhance maritime security and operational capabilities [7]. The continuous evolution of AI technologies promises to further transform naval operations, making ongoing research and development a critical priority.

Looking ahead, the potential of AI in naval operations includes further advancements in quantum computing, enhanced human-machine teaming and the development of AI strategies that can dynamically adapt to changing operational environments. As AI technology evolves, its role in naval operations is set to expand, offering unprecedented opportunities to enhance maritime security, operational efficiency and strategic advantage.

C. *Ethical and Legal considerations*

Using AI in naval operations involves a complex interaction of ethical and legal considerations. As AI systems become more integrated into defense mechanisms and operations, their potential to enhance security and operational efficiency is significant. However, these developments also raise important concerns that must be addressed to ensure responsible use. AI's role in decision-making processes, especially in critical scenarios involving potential threats, raises ethical questions about autonomy. The extent to which AI should be allowed to make decisions, particularly those involving lethal force, is a major concern. The principles of human oversight and control are paramount to ensure that decisions are made ethically and responsibly [8]. Moreover, AI systems are only as objective as the data they are trained on. There's a risk of continuing or even intensifying existing biases if the training data is not carefully selected. In naval operations, this could lead to unfair targeting or the overlooking of threats due to biased algorithms. Ensuring fairness and avoiding bias is essential for ethical AI use. Another important concern regard Transparency and Explainability. AI systems, particularly those based on complex algorithms like deep learning, often operate as "black boxes," making it difficult to understand how they arrive at certain decisions. In the context of naval operations, the lack of transparency and explainability can be problematic, especially when decisions need to be justified or reviewed. Ethical AI requires mechanisms to make its decision-making processes more interpretable. Also, when AI systems are involved in critical operations, determining accountability for decisions becomes challenging. In cases where AI leads to unintended consequences, it's essential to have clear frameworks for accountability and responsibility, ensuring that human operators remain ultimately responsible for decisions made with AI assistance.

The use of AI in naval operations must comply with international laws and norms. This includes principles of distinction, proportionality and necessity, which must guide the deployment and actions of AI systems. AI systems used in naval operations must operate within the established rules of engagement (ROE), which are

designed to regulate the use of force. Ensuring that AI systems can accurately interpret and apply ROE in complex, rapidly evolving situations is a significant legal challenge. The use of AI for surveillance and TM can raise sensitive issues regarding sovereignty and the rights of passage through territorial waters. AI systems must be designed to respect national borders and adhere to international agreements regarding maritime navigation. Also, it is a legal and ethical requirement to balance security needs with respect for privacy.

Developing robust frameworks for governance, oversight and accountability will help ensure that AI technologies are used in ways that are both legally obedient and ethically complete.

IV. Conclusion

Implementing of AI-driven tactics requires careful integration into existing naval operation frameworks, ensuring that AI systems complement and enhance human decision-making processes. By doing so, naval forces can significantly improve their SA, operational effectiveness and strategic agility in responding to both conventional and asymmetric threats.

AI's application in surveillance and reconnaissance missions at sea and in the littoral zone significantly enhances naval capabilities, providing unprecedented levels of situational awareness and operational flexibility. As technology evolves, continued research and development are essential to address challenges, maximize benefits and ensure the responsible use of AI in Naval operations.

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