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Features and Challenges of AI for Enhancing Sensor Performance in Naval Systems

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Abstract

Intelligence, smart sensors are very much required to link with naval systems in current era to take autonomous decision making and enhancing the capabilities of existing systems. Artificial Intelligence (AI) based algorithms and deepcatch models are making predominant changes in the existing sensing technologies with much more precision in a real-time environment which will revolutionize Navy. But there are lot of challenges and features during the incorporation of AI in the performance upgradation of naval platforms. The latest improvement in the AI proactive real-time intelligence algorithms exceeding the human intelligence capability with the help of Merlin Deep Learning (DL) methods/models to extract and analyse the sensor parameters reading from the naval systems. Nowadays, Internet of Things (IoT) sensors installed with Reinforcement Learning (RL) algorithms are used to detect and process the object information in the naval systems. This paper discuss the key factors involved in the incorporation and upgradation of current sensor systems with their issues, challenges, benefits and features. The ideas and concepts presented in this paper are merely intended to provoke and stimulate thinking about human–machine interaction teams that would function on the AI-enabled battlefield of the future.

Keywords: Sensors, AI, Deep learning, IoT, Reinforcement learning.

1. Introduction

AI-based naval platform automation technology [1] has suddenly become very much important to military forces from the year 2017. It is anticipated that autonomous sensors in naval systems are expected to raise the standard of efficiency and safety in the upcoming autonomous maritime military operations [1, 2] in the dense maritime traffic and in shallow waters. This article examine the issues of sensors and sensing methods for autonomous marine navigation and various operational needs of a flagship like autonomous fast intercept boat (AFIB) [1]. Automation of sensors with the help of AI is aimed at increasing the safety and efficiency of existing naval systems. It includes the sensors required for ship positioning, Radio Detection and Ranging (RADAR) functioning, Light Detection and Ranging (LiDAR) equipped with photo-sensors functioning, Electronic Chart Display and Information System (ECDIS) and other sensors that can scan and sense the status of operational environment. The Multi-sensor Perception Systems (MPS) are aiming to upgrade with AI techniques to increase sensing capability, that is, targets that cannot be detected with one sensor may be detectable with another sensor in the system within a quick time. The perception system is mainly used to monitor the integrity of the sensor system and fuse terabytes of data using AI techniques [2] and reducing the time for taking decisions. Because, in recent years, AI-based intelligent data capturing and analyzing algorithms [1] have achieved huge success in academia, industry and defence applications. Figure-1 shows the existing multi-sensor perception system. This system integrate the data coming from different kinds of sensor devices connected with it like cameras, RADAR, LiDAR and measurement units placed in different parts of the ship functionalities to improve the situational awareness during sailing and combat operations as shown in figure-1 below.

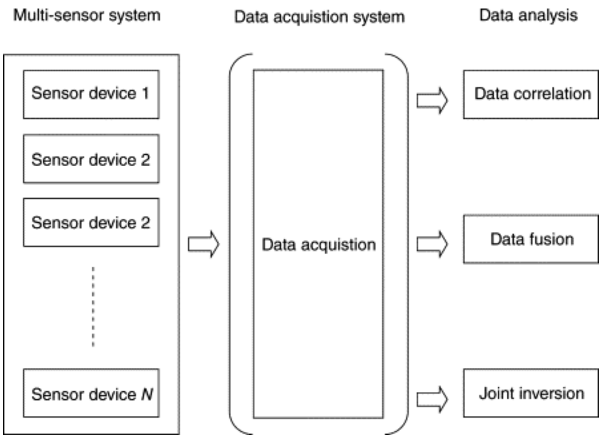

Figure 1. Multi-sensor Perception System

Navigating by AI using data from the vessel's on-board sensors, cognitive RADARs and cameras is a crucial task in the roaring sea. Under this situation, we set our mind to review the relevant background studies, tools, research, equipment, and techniques available and that are appropriate and suitable for lethal autonomous weapon sensing systems and perimeter security systems [1] in naval ships with the objective to propose the features and challenges of AI during the tenure. This paper is has been structured as follows. First, we present the existing sensor technology for naval systems from the study carried out. Second, we assess the Key Performance Indicators (KPIs) for transitioning the current technology to meet AI based demands. Third, we review the proposed sensor technologies in different forms that are relevant for upgradation with the features and technical challenges. Lastly, we conclude the paper with the summary of suggestions and recommendations from the inferences, for future direction of testing and validation. Because, applying AI to improve the speed and accuracy of battlefield decision-making by automating control systems, developing predictive intelligence to speed up repairs, battlefield surveillance and reconnaissance data fusion [1] challenges are directly linked with the enhancement of remote sensors in the naval ships and systems [3].

This survey is made by the clear study of existing research papers with the evidences of outcomes conducted by various authors in the domain of sensor applications in naval systems. The goals and objectives of this survey is fixed for the upgradation of existing systems to adapt to the future technology enhancements and divided into six main sections. The entire paper explains the various concepts, techniques, benefits, challenges, applications and limitations of sensors used in

naval systems. Some of the solutions to overcome the challenges and limitations by the use of AI mechanism also surveyed. A total of around 20 research papers and technical articles were selected for survey pertaining to AI techniques from Springer, IEEE, ACM Digital Library, Science Direct, Elsevier, etc.

2. Overview of Sensors and Related Work

Autonomous and intelligent sensor machine condition monitoring systems for shipboard equipment, especially for the engine, using deepcatch and online diagnostics [1] are foreseen to lower the possibility of risk by the human errors in the critical and sensitive naval operations. Deepcatch is an intelligence mechanism used in AI to connect the status of machineries to the processing cloud for real-time tracking and management, to increase the operational efficiency of the sensor system. It might make it possible to implement new kinds of robotic operations during the design, testing and implementation phase of the systems for preventive maintenance [1]. Novelty can be introduced in the existing systems by integrating advanced material technologies for the nanostructures used and implementing data-driven signal processing methods. Sophisticated computer vision and processing, extensive data analytics, IoT combined with particular elements of cloud computing will make the autonomous sensor systems more effective in naval systems [3]. AI assisted sensing is mainly aiming for autonomy in navigation to improve the safety and efficiency, enhancing real-time geospatial situational awareness [1] functions in the autonomous ships, and sensor fusion for autonomous engine monitoring to assess the engine health continuously and control using advanced sensor systems in future [2]. Figure.2 shows the sensor system in the ship.

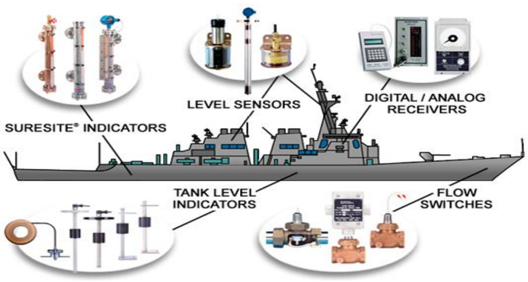

Figure 2. Sensor System [4]

Sensor systems in the modern naval ships like site indicators, level sensors, tank level indicators, cameras, RADAR, LiDAR etc. are integrated into a single system for navigation, propulsion and monitoring during sailing and combat operations as shown in the figure-2 above.

2.1 Navigation and Position Sensors

The navigation sensors like high resolution (HR)/infrared (IR)/thermal cameras, high end X band (8 to 12 Ghz) RADAR, LiDAR, chirp-based eco-sounder and maritime high capacity radio relay (HCRR) communication sets [1] are doing a critical role in the ships especially in the coastal area operations and during port approach time [2]. In severe weather conditions, meta-surface technology [5], global navigation satellite systems (GNSS), gyrocompasses, gyroscopes and accelerometers are the primary sources of getting the accurate location and position, heading and movement data of the ships for autonomous navigation and stable direction reference in stealth operations. By including the autonomy of sensors based on AI techniques, in future, positioning of ship, phased array multi-beam RADAR for convolutional neural network (CNN) based target detection, anomaly detection in maritime vessel traffic, angular estimation [1] and collision avoidance, and additional sensors that monitor 360^{o} view of surrounding environment and providing multi-dimension information can also influence and control the operation of other components within the propulsion and steering systems. By analyzing the movement data and patterns received from the sensors, and using satellite images, AI-enabled sensors help to identify ships those even disable their tracking systems.

2.2 Object and Visual Sensors

Identifying Low Observable Marine Objects (LOMO) is a significant technical challenge for navigating vessels autonomously via on-board naval systems. AI-based intelligent digital cameras with stereo camera setup [1] placed in the ship can be currently employed for object detection, categorisation, positioning and ranging in autonomous sensor systems [2] as well as assist low-speed manoeuvring of ship in real-time. High resolution IR cameras placed outside the ship sense thermal radiations especially during night. AI-equipped CNN based vision detection [1] and enhancement technique will enhance the performance of the visual sensors in the naval visual systems. Especially, high sensitivity cameras with Quantum-Well IR Photo-detector (QWIP) and detector arrays from Mercury Cadmium Telluride (MCT) are employed to address the effects of atmospheric chemical reaction [6]. AI-
powered mechanisms and ML models are used for automated object detection and tracking.

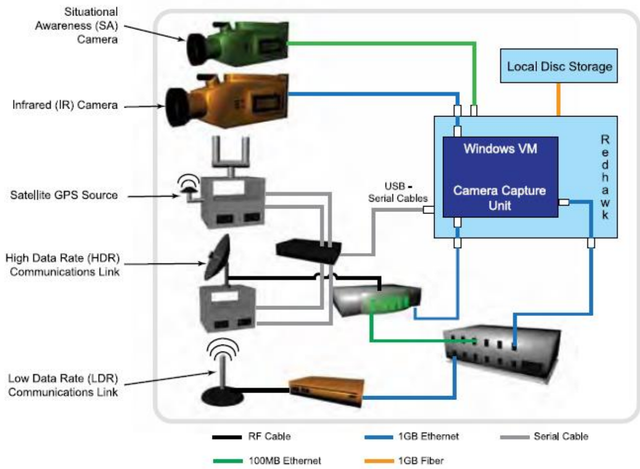

Figure 3. Visual Sensor System [6]

Figure.3 shows the visual sensor system with transmission units in the modern ships for intelligent, vision-based surveillance and monitoring. Nowadays, Unmanned Surface Vehicles (USV) and Unmanned Underwater Vehicles (UUV) are largely used in unmanned, critical operations fitted with sophisticated visual sensors for real-time image and video capturing [1] and sharing of information in hazardous environments. To preserve fine-grained information under low-light environment and to reduce noise, AI based discrete wavelet transform based loss function is employed [7] with the visual sensor systems as shown in the figure-3. This system uses situational awareness cameras for providing real-time visual data from ship surroundings, IR cameras for providing small objects and vessels around the ship, Global Positioning System (GPS) source connected with satellites, high data rate (HDR) communication link to connect with satellites and AI based signal processing units to improve the situational awareness during low-visibility sailing conditions and combat operations.

2.3 Depth Sensors

Low-power, short-range acoustic communication sensors, echo-sounders and pressure-based sensors are having much importance in the underwater domain awareness [1] and warfare operations with suitable networking protocols [8] for environmental data collection and navigation. Supernodes with buoys and robotic submersibles provides enhanced network connectivity and establishing several locations for multiple data collection in the underwater acoustic network environment for seabed mapping, hazards detection, locating submarines and integrating them with autonomous underwater vehicles (AUV). AI based underwater nodes are used nowadays to self-configure and coordinate with each other for their different functionalities, such as time synchronization, localization, Medium Access Control (MAC) and routing with the help of data analytics.

2.4 Radar Sensors

In early days, since RADAR systems were used basically for ship and aircraft detection, sensor systems have developed with advanced techniques and they have come to the way for self-defence and protection in the sea during middle age [6]. The performance enhancement of high-resolution naval systems and integrating the RADAR into the suite of existing sensor system for picking up near-range small target images [1] and videos of live monitoring of counter terrorism operations with zero blind-spots is an essential requirement in the current era for providing more accurate clarity in small objects and structural detection. The maximum detection range for a target depends on the receiver sensitivity in the ship, and the transmitter power from the continuous wave RADAR (CW-RADAR), pulsed RADAR (P-RADAR), digital array RADAR (DA-RADAR) or dual band RADAR (DB-RADAR) equipped with phased array MIMO antenna systems [5] and supercomputers which are enabling electronic scanning, beam steering and improved signal processing at S band (2 to 4 Ghz) and X band frequencies [2, 6]. Figure.4 shows the functions of radar sensor system used for target illumination, target tracking [1] for complex naval scenarios, Air Traffic Control (ATC), surface search and navigation, environmental monitoring and mapping [5], missile tracking, navigation and collision avoidance using microwave pulses. DB-RADAR is the vital sensor for ATC in naval and air missions to detect, range and display surrounding objects of ships and aircrafts even in darkness and poor visibility conditions. It consists of a rotating antenna mounted on the ship, transceiver, display which are working on S and X band of frequencies for providing real-time data of targets during sailing and combat operations. The comparative study of different sensors used in the naval systems are given below in table-1.

3. AI based Sensors

Currently, the efforts are in place to exploit the developments of AI techniques and methods for military requirements, including cyber security and warfare, surveillance, reconnaissance, intelligence analysis and control, iSentinel-intelligent automated threat tracking and identification system [1],

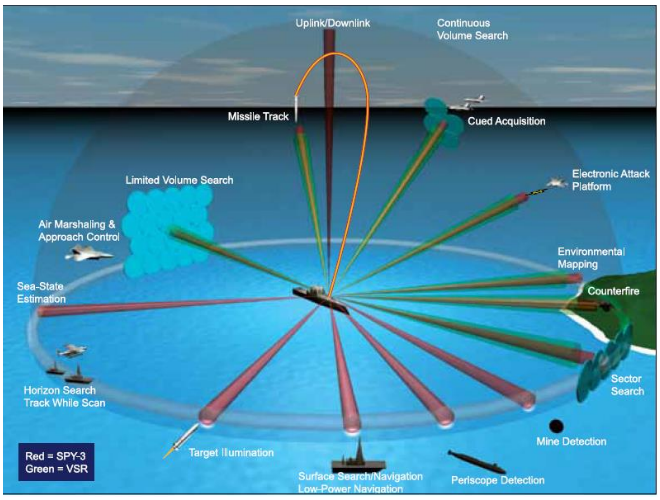

Figure 4. RADAR Sensor System [6]

Table-1 Comparative Study of Sensors

Sensor Type	Names	Usage
Navigation/ Position Sensor	HR/IR/Thermal Cameras RADAR LiDAR Ecosounder HCRR Sets GNSS Gyrocompass Gyroscope Accelerometer	Location Finding Autonomous Navigation Target Detection Traffic Detection Collision Avoidance Ship/Vessel Identification
Object/Visu	HR/IR Cameras	Object Detection

al Sensor	QWIP Cameras AI-based Cameras	Ranging and Tracking Sensing Thermal Radiations Sensing Atmospheric Chemical Reactions Real-time Image/Video
Depth Sensor	Acoustic Sensor Ecosounder Pressure Sensor Buoys AUV	Underwater Domain Awareness Submarine Detection Hazards Detection Navigation
Radar Sensor	CW-RADAR P-RADAR DA-RADAR DB-RADAR	Near Range Targets Small Targets Structure Detection Air Traffic Control

underwater mine warfare, command and control, education and training [9]. AI exists across all areas of information including land, sea, air and space for every tier of political, strategic, operational and tactical military warfare systems. Machine learning (ML) models, RL algorithms [1] which includes advanced graphics processing units, real-time surveillance monitoring systems [1], early warning of enemy aircraft intrusion activity recognition and classification, unmanned electronic control system of disseminated parallel control computing (DPCC) used for unmanned aerial vehicles (UAV), unmanned ground vehicles (UGV), USVs etc. [1] and relevant digital models helps to eliminate time delay and to interact with the noisy environment with higher throughput, which are used to enhance the performance of the human-machine interfaces, that is, sensors [3] and easily finding stealthy submarines, mines and drones in sea water environments.

Situational awareness using internet of battle things (IoBT), smart helmet [1], gives enhanced decision-making as it provides leaders and personnel with a thorough comprehensive grasp of knowledge in their operational environment [3]. To do the decision-making effectively, without error, the AI assisted, block chain based, intelligent sensing data processing techniques will be much more useful in future [4]. This encompasses understanding the position, condition and objectives of both allied and opposing units, along with pertinent commercial interests at sea. Such information can be delivered by utilizing AI methods and fusing the data from multi-mode maritime surveillance sensors [1] for ships, cruisers, tankers, such as, Automatic Identification Systems (AIS)/GNSS using deep darshak (ML/AI-based platform), images, and audio signals. AI-based visual attention scenario identification model harnesses advanced DL-CNN techniques by processing real-time trajectory images [5] from various sources, including drones, strategically focusing on critical details within these visuals [10] and making as intelligent, autonomous systems for detecting threats through predictive monitoring and analysis [1].

This approach enables the timely detection of potential dangers, even in complex environments, with the primary objective of significantly enhancing situational awareness for military personnel by fusing vast amount of data from various optical and thermal sensors for making accurate understanding of maritime environment. Figure.5 shows the functions of electro-optic (EO) sensor system. This system is connected with cameras, IR sensors, sensors to detect threats from anti-ship missiles, UAVs and speed-boats in cluttered environments, as shown in the figure-5. It gives 360° situational awareness with high resolution images for long-range identification of naval vessels and for engaging targets well in advance. Integrating the AI based sensors and fire control systems into existing naval systems will

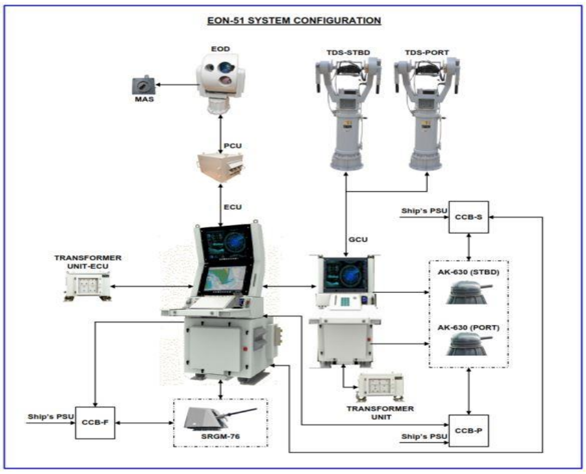

Figure 5. Electro-optic Sensor System [7]

take a time and will be very much challenging due to the operational speed, data processing capabilities, full autonomy in weapon systems and unmanned maritime systems [11].

3.1 Object Detection

Indigenously developed ML and facial pattern recognition models [1], a subset of AI, are trained to detect anomalies, classify objects and identify potential threats with high accuracy [3]. These models can differentiate between commercial and military assets, detect unusual behaviour indicative of piracy or terrorism and also detect environmental risks, significantly cutting down the response time to potential dangers, including asymmetric ones like swarms of small boats, UAVs, and mines. Nowadays, a DL based CNN [1, 5] approach is suggested in naval systems for underwater object detection and classification [10].

For underwater object detection, the vision sensors are installed on the underwater robot for network structure improvement. In actual field operations, the standard approach struggles in performing well in detecting small objects, because the typical dataset utilized in experiments consists of normal images that are high-quality and well-lit. For underwater detection, the objects are always overlapped by other things, such as rocks and corals, and the underwater vision is always vague, the clarity is low. Under these conditions, the network structure should retain more original features. In deep CNN, the more layers always extract features that are more abstract, and the deep semantic information can be extracted more clearly. On the other hand, the fewer layers can retain more representation information. The deep semantic information and the representation information can be combined to give a more accurate detection [12].

3.2 Object Identification

Object identification and classification of is performed in ships by ranging and validation of results tally within a redundant subset of sensor data [2]. Another application, target identification and classification could be used AI systems [1] trained on vast amounts of imagery and sensor data that can automatically recognize and categorize contacts as commercial or military assets, significantly speeding up the decision-making process especially in Mine Counter-Measure (MCM), Remote Mine-Hunting (RMH), UUVs, Intelligence, Surveillance and Reconnaissance (ISR) operations [3, 11]. Automatic target classification of mines has been a critical task for which the high performance Deep Neural Networks (DNN) and RL methods are required [1, 13]. DL-based AI systems have now achieved a significant outperformance than humans in tests and operations involving image classification [3].

3.3 Climate Sensors

With the help of AI assistance, on-board sensors and communication protocols that can help in collecting data and transmit them to the nearest sensor data processing unit [1] especially in undersea sensing and warfare operations [6, 13] for machinery management, mission planning, ensuring internal operational safety, outside domain situational awareness and environmental compliance. These systems integrate with IoT devices and satellites to measure and monitor temperature, humidity and air quality in the surroundings, enabling condition-based predictive maintenance for ship platforms [1], early warnings for disasters, forecasting and management.

A new class of multimission, sensors-on-body mounted ships may be designed in future with AI techniques like deepsight machine vision system for gathering atmospheric visibility factors like temperature, precipitation, relative humidity, wind speed, wind direction [1], and oceanographic real-time data in joint maritime operations, ashore and air operations together will improve weather prediction, sea-state prediction, maritime prediction, wave intensity prediction and iceberg prediction. These sensors feed very critical information to warships, submarines, AUVs, and coastal border surveillance stations. Deepsight is an AI based data identification and security engine which detects the attacks in real-time with the help of analysing larger amount of sensitive data coming from sensors and perception layers to activate weapons. Similarly, merlin is a DL framework which will process the terabytes of data coming from the different

sensors mounted on ships within short period and helps to upgrade the existing sensor systems into high speed, high performance naval sensor systems for future applications.

3.4 Location Sensors

AI-powered smart marine environments will coordinate the surface and underwater sensors using intelligence grid and chimera-22 AI smart camera [1].

GNSS, electronic compasses, inertial navigation systems (INS) are used as location sensors in naval systems for precise positioning of ships, vessel identification and monitoring using automatic identification systems (AIS) [1], underwater detection using AI-equipped sound navigation and ranging (SONAR), surface and air surveillance using RADAR and navigation and domain situation awareness using LiDAR. AI-equipped systems will adapt to changing, new ocean conditions for safe navigation and improving intelligence. Diverse fish locomotion patterns are being measured during the sailing. AI-based CNN techniques are used to enhance underwater vision in the naval systems [1, 13]. DL models, especially recurrent neural networks (RNN) might be more capable of doing the analysis of a ship's trajectory with given the large volume of datasets [2].

3.5 Pressure Sensors

Pressure sensors are critical in naval systems to ensure the safety in applications which including monitoring and control. They provide stability in fuelling systems and hull integration applications. They are mainly used in applications like depth control in underwater vehicles, hydraulic system management, monitoring harsh marine environmental conditions around the locations and controlling of air-based system on board. They should withstand all operating conditions like saltwater, corrosion, major vibrations and extreme different kind of temperature during the continuous operations. The optical microphone is used as a pressure sensor which is converting the oscillations of the air pressure into electrical signals [2].

DNN oriented techniques are used to reduce the wind noise and may be used to enhance the performance of the sensors fitted in the naval systems in future. AI elevates these sensors with predictive environmental intelligence in surface, sub-surface and air domains helps for early detection of potential faults of the systems, reducing the equipment downtime and giving fleet level consolidated visibility [1]. Particularly, marine sensors are fully deployed in AUVs, USVs and AI-enabled remotely operated vehicles (ROV) [1] and forming the central intelligence system for navigation, mapping and inspection. Figure.6 shows the ROV sensor system which act as an underwater robot used for identifying, inspecting, repairing and maintaining subsea structures deployed in naval operations. This is equipped with a highly advanced cameras, sensors and tools connected via cables from the surface ships for power transmission and real-time data transmission from the underwater environments in mission critical operations where human beings are not able to enter, as shown as the figure-6.

Figure 6. ROV Sensor System [1]

3.6 Photomultipliers

High sensitivity silicon photomultipliers conjunction with scintillators and photomultiplier tubes (PMT) are integrated into digital optical modules used in underwater telescopes and underwater experimental optical communication links mainly for low light conditions to provide high gain with low noise capability [14]. These modules are arranged in a string layout with a specified separation to provide high speed data transmission up to 20 Mbps at the depth between 120 to 700 metre. The strings have 15 m separating distance at depths lying between 745 m to 1270 m. They are very much useful in underwater survey systems (USS) during the stealth operations to monitor and measure the light continuously in marine environments when the vessel moves into the deep water and in real-time radio activity monitoring trials.

4. Automated Threat Detection

Modified or performance enhanced systems in the naval ships has greater potential for transition and adopting by the forces faster since the existing system was already proven and accepted by the fleet. The field of smart sensor technology demonstrates excellence in signal extraction, real-time data transfer, and gives flexibility in adaptation to the physical environment, which aids in retrieving data

that was previously thought to be unavailable [4]. AI and ML models allows the real-time processing of sensor data essential for prompt threat identification and detection [3] and filter background noise and interference coming from waves in the cluttered shallow-water environments. This capability allows naval forces to react promptly to potential threats, enhancing maritime security and operational readiness. Such technologies may lead to generate fully automated systems with lethal capabilities in future. AI-based techniques are being employed in the naval combat management system to execute complex and critical, unpredictable missions in the maritime battle-field [8].

4.1 Regional Proposal Network

Regional Proposal Network (RPN) gives potential area of object manifestation using DL in ship detection, maritime surveillance and reconnaissance operations. This significantly reduces the search area for objects in an image and efficiently identifying the potential target locations. It is particularly useful when objects (such as a small boat) cover just a very small amount of area in terms of pixels [2]. AI methods can be used to address the problems like finding anomalies in large maritime datasets, spotting odd ship movements, communication patterns that might point out dangers like hostile operations, smuggling and piracy [2, 4]. Consequently, Navy will get enhanced functionality experience in a dependable system for on-board monitoring and combat assistant with the help of federated learning algorithms [5].

5. Challenges and Solutions

Increasing cyber security threats and maintenance of complex system infrastructures are the big challenges in this era due to the rapid improvement of AI techniques. Modern approaches are using previous data analytics, analysing IoT sensor data, performing simulations for system failure prediction and automating routine tasks. The possibilities of major obstacles to use AI in military applications are discussed here during the incorporation of AI techniques for the enhancement of sensor performance and to provide effective technical solutions for sensor systems [6]. Especially, integration of unmanned, advanced, autonomous power monitoring systems [5] for automated power generation and distribution is one of the key technical solution in ships. Similarly, in addition to it, automation of the potential sensors such as depth-sensor, 3-dimensional SONAR, Radio Direction Finder (RDF) and visibility meter is the highly challenging task during the performance enhancement using AI techniques [2] for data-driven naval warfare. To do the automated measurement of depth by the ships, usage of hydrostatic pressure sensors and echo sounders is the good technical solution for providing real-time data during sailing and combat operations.

5.1 Interoperability of AI Models

The potential and efficacy of interoperability in naval systems are further increased by the design, development, testing, and evaluation of AI based sensor systems [6] for strategic necessity. This technical solution provides seamless data sharing between sensor systems, combining data from multiple sensors like cameras, RADAR and LiDAR for giving accurate information. In recent times, ships utilize AIS for electronic tracking of maritime vessels by seamless data sharing and analysis across different ship platforms for efficient decision making. To deal with it, lot of sensors are needed to integrate with the system for giving different inputs at various timing and DL algorithms and DNNs are required for the quick computation of parameters and reliable decision making [9]. The vessel speed and port locations are the vital parameters on the process to the training models. Similarly, the operation like MCM needs AUVs equipped with Synthetic Aperture Sound Navigation and Ranging (SA-SONAR) systems which need lot of sensor inputs for providing high accuracy location. By incorporating AI models, AUVs are empowered to learn and adapt, making autonomous real-time decisions without human intervention [10].

5.2 Availability of Data

To become AI enabled forces, the appropriate technical solution is, a military force needs access to multi-wavelength data coming from sensors, drones, autonomous vessels, include ML algorithms, computer vision and data analytics at anytime and anywhere [11] for enhancing situational awareness, predictive operations, speed and operational efficiency in lynx-u2 gun fire control systems [1]. Finding real-time, real-world, high-quality and sufficiently large datasets that may be used to train and improve AI models in military applications is extremely challenging due to security concerns. But the major issue in this is, as the tactical situation in the operational environment changes during the training of AI models, the data's relevance may rapidly diminish. Still, Generative Adversarial Networks (GAN) [1] is a generative model that can be used for semi-supervised learning where a small set of labeled data is combined with a larger set of unlabeled data to improve the performance of an AI model [9]. Another way of technical solution is to integrate autonomous systems for predictive maintenance

with AI assisted Wireless Sensor Networks (WSN) which supports for the data collection from wireless operation, self-configuration, and aiming to maximize the utility of AI-driven command and control in naval ships [8].

5.3 Computing

Cloud based computing is especially important for AI enhancement, as ML requires more data and processing power than the AI system [3]. AI and the computing capability is a key enabler for unmanned systems nowadays, such as, UAVs, UUVs and USVs, to improve surveillance in crucial naval missions that necessitate real-time processing of sensor data with little time to take decisions [3].

Adding fog layer in Sensor–Cloud for following three objectives:

(1) Energy consumption can be decreased by the fog, malicious nodes can be quickly identified and misjudgement nodes can be recovered with a reasonable time delay.

(2) The fog layer can secure the whole WSNs from a global perspective and realize more functions, such as ensuring edge nodes credible and finding hidden data attacks.

(3) The fog layer can assist Cloud Service Providers (CSP) and Sensor Service Providers (SSP) in establishing trust relationship in a more comprehensive and credible means [15].

Quantum computing assisted communication is a novel research area that investigates the possibilities of replacing quantum channels with noiseless classical communication channels to achieve extremely high reliability in 6G. With the advancements of quantum computing, it is foreseen that quantum-safe cryptography should be introduced in the post-quantum world. The discrete logarithmic problem, which is the basis of current asymmetric cryptography, may become solvable in polynomial time with the development of quantum algorithms.

In order to attain very high dependability, quantum computing assisted sensor communication [5] is a novel research topic that explores the prospects of substituting noiseless classical communication channels for quantum channels in 6G. It is anticipated that the quantum-safe cryptography will be implemented in the post-quantum world due to the developments in quantum computing. The discrete logarithmic, problem, which is the basis of current asymmetric cryptography, may become solvable in polynomial time with the development of quantum algorithms [16].

5.4 Methods of Communicating with Submarines

The signal must travel through both air and water for communicating with the submarine. In order to reduce the attenuation in the transmit path, the researchers suggest that it would be possible to use two distinct carriers to send signals in the two media. For example, Translational acoustic-RF communication (TARF) uses both microwave and sound, the photo/thermo-acoustic (PA/TA) uses both laser/microwave and sound. Meanwhile, some other mediums such as magnetic, quantum, and neutrino are also experimented to realize submarine communication [17].

The fundamental idea behind magnetic communication is mainly based on the principle of electromagnetic induction, which uses the altered magnetic field at the transmitting end to transfer information. The received magnetic signal is transformed into an electrical signal for decoding by the receiving end using the magnetic induction principle. Quantum communication typically involves the use of entangled qubits, which are correlated in a way that any change in one qubit is immediately reflected in the other. Based on the three principles including uncertainty, measurement collapse, and unclonability in quantum mechanics, quantum communication provides absolute security guarantees that cannot be hacked by eavesdropping and computing [18].

A neutrino is a type of lepton that has nearly the speed of light with no charge and has a very small mass (less than millionth of an electron). It is difficult to detect and catch because of its interaction with other matter and its ability to freely flow through walls, mountains, human bodies, and even entire planets [19].

5.5 Simulation

Simulation has been used extensively in the military for studying the complex situations and environment, training the manpower and systems, engineering purposes like decision-making and real-time support [20] by enhancing data fusion and developing autonomous capabilities. Incorporating

AI models and virtual training environments with advanced techniques in the simulator applications such as flight simulator, ship simulator etc. is a critical task due to the assumption, processing of enormous amount of high-fidelity synthetic datasets, real-world images and intelligence analysis of existing and incoming sensor patterns as a risk free practice environment.

Although RL and GAN systems are utilized in most areas of the bridge operations and combat systems to do comprehensive analysis of sensor systems

where simulations are closely matching the real environments, they are most helpful in improving and optimizing the performance of naval systems using quantum computing [5] when they are able to create their own data and not rely on it being provided [3].

6. Conclusion and Outlook

Upgrading the performance of shipboard electronic sensor systems and addressing new issues have been ongoing concerns at present. These days, military forces throughout the world are experimenting applications with AI-enabled systems to observe and validate how these could be utilized for both peacetime and combat operations in the future among the countries. From the study of different sensor system performance in the naval systems, the recent development of AI based sensor systems integration will meet the needs of the Navy and the Nation in the coming century for strengthening our country's national security by enhancing deterrence and intrusion detection capabilities.

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