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Artificial Intelligence–Based Zone Alert and Surveillance System for Autonomous Navigation of Fishermen's Boats

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Abstract

Coastal, peninsula, and island countries establish strict maritime boundary lines for preserving their sovereignty rights and marine resources. Smallscale fishermen inadvertently breach these invisible maritime boundary lines due to inadequate navigation awareness, lack of proper communication systems, and lack of real-time advice. These have resulted in fishermen's boats being confiscated, fishermen being arrested, and in some cases, even fishermen losing their lives due to hostile confrontations by adjacent naval forces. This paper introduces an Artificial Intelligence-Based Zone Alert and Surveillance System to improve the safety and unmanned navigation of fishermen's boats. The proposed system uses GPS, AIS, radar, sonar, cameras, and environment sensors along with artificial intelligence-based surveillance systems, sensor fusion, and unmanned path planning algorithms. The proposed solution delivers real-time border alerts, intelligent object detection, and autonomous route correction capabilities to ensure that fishermen's boats do not breach maritime boundary lines and remain safe from possible collisions. The simulation results for semi-realistic maritime scenarios have shown that the solution delivers accurate zone detection, accurate object identification, and stable autonomous navigation capabilities, thereby ensuring that the solution has enormous potential for improving fishermen's maritime safety.

Keywords: Maritime Safety, Fishermen Protection, Artificial Intelligence, Zone Alert System, Autonomous Navigation, Sensor Fusion, Geofencing

1. Introduction

Fishing remains a primary source of livelihood for a large population residing in coastal, peninsula, and island regions worldwide. Despite its socio-economic importance, small-scale fishing is inherently hazardous due to harsh and unpredictable weather conditions, limited access to advanced navigation technologies, and poorly defined maritime boundaries (Sharma & Patel, 2019). Unlike terrestrial borders, maritime boundaries are invisible and can only be accurately identified using precise positioning and navigation systems. In practice, many fishermen rely on traditional knowledge and personal judgment rather than electronic navigation aids, which frequently leads to unintentional crossings of international maritime borders (Kumar et al., 2020).

When such cross-border violations occur, fishermen are often exposed to severe consequences, including detention, confiscation of fishing vessels, and violent confrontations with foreign naval or militant forces (Rao & Iyer, 2021). In several documented cases, accidental boundary crossings have resulted in serious injuries and fatalities, highlighting the critical need for reliable and proactive maritime safety mechanisms (Fernandez & Lee, 2018). Existing safety measures, such as basic GPS trackers or manually operated monitoring systems, are inadequate for delivering timely alerts and situational awareness in dynamic and high-risk marine environments.

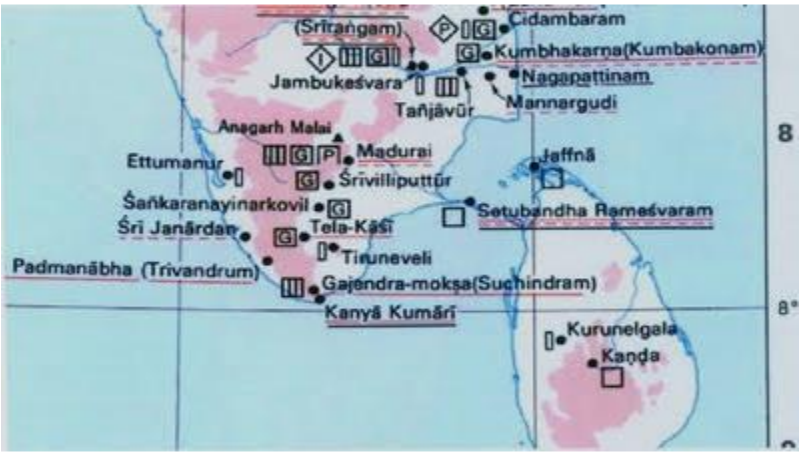


Fig 1: Boarder area in peninsula

Recent advancements in artificial intelligence, autonomous navigation, and multi-sensor fusion present new opportunities to address these challenges effectively. AI-driven systems capable of integrating data from GPS, AIS, radar, and visual sensors can enable real-time border awareness, intelligent hazard detection, and automated navigation assistance (Singh & Babu, 2022; Zhang et al., 2021). These technological developments create a strong foundation for designing intelligent maritime safety solutions that can significantly reduce accidental border violations and enhance the overall safety of fishermen at sea (Gomez et al., 2019).

2. Literature Review:

Maritime safety technologies have received considerable research attention in recent years due to the growing navigation risks encountered by small-scale fishermen operating in coastal and border-sensitive waters. Sharma and Patel (2019) identified key limitations of conventional maritime safety systems, emphasizing that many existing solutions rely predominantly on standalone GPS tracking, which lacks contextual and situational awareness. Similarly, Kumar et al. (2020) reported that delayed alert mechanisms and frequent signal degradation significantly reduce the reliability and real-world effectiveness of GPS-dependent safety systems.

Geofencing-based methodologies have been extensively investigated as a preventive approach against unintentional maritime border crossings. Rao and Iyer (2021) demonstrated that the implementation of virtual maritime boundaries can substantially reduce accidental violations; however, their effectiveness remains highly dependent on satellite signal stability, positioning accuracy, and update frequency.

Furthermore, Fernandez and Lee (2018) highlighted that systems requiring manual monitoring or user intervention are inherently vulnerable to human error, particularly under stressful and rapidly changing sea conditions.

Advancements in artificial intelligence and computer vision have enabled the development of intelligent maritime surveillance systems with enhanced perception capabilities. Deep learning architectures such as Convolutional Neural Networks (CNNs), YOLO, and Faster R-CNN have shown promising performance in vessel detection and obstacle recognition under diverse illumination and sea-state conditions (Zhang et al., 2021; Wang & Chen, 2022). However, performance degradation in adverse environments—including fog, heavy rain, and low-light conditions—has been reported by Li and Zhao (2021). To address these limitations, recent studies emphasize multi-sensor fusion strategies that integrate GPS, AIS, radar, and vision-based data to improve robustness and reliability (Singh & Babu, 2022). Despite these advancements, most autonomous navigation and surveillance systems are designed for large commercial or military vessels, rendering them unsuitable for small fishing boats due to high cost, power consumption, and system complexity (Gomez et al., 2019). This research addresses this critical gap by proposing a lightweight, AI-driven zone alert and autonomous navigation system specifically optimized for the operational constraints of small-scale fishermen.

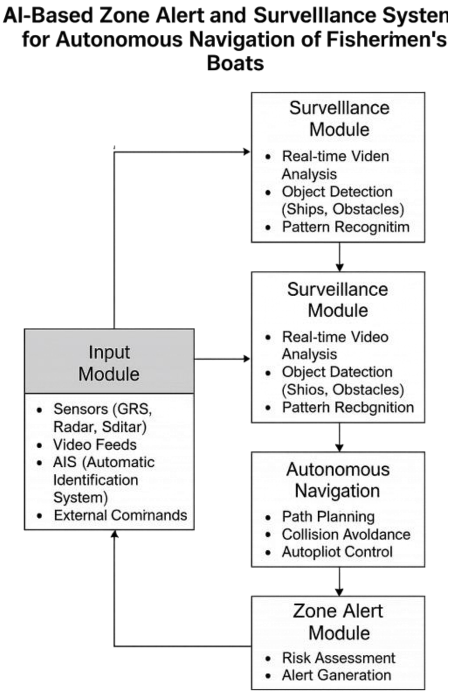
Small-scale fishermen operating in coastal and border-adjacent waters continue to face significant safety risks despite the availability of modern maritime technologies. One of the most critical challenges is the unintentional crossing of international maritime boundaries due to the absence of real-time border awareness and clearly visible sea demarcations. Unlike terrestrial borders, maritime boundaries are invisible and highly dependent on accurate positioning systems. Fishermen often rely on experience-based navigation rather than precise instruments, which increases the likelihood of accidental border violations, especially during long fishing expeditions or adverse weather conditions.

Crossing restricted or foreign maritime zones exposes fishermen to severe consequences, including detention, vessel confiscation, violent encounters, and in extreme cases, loss of life. The lack of reliable, continuous communication infrastructure between fishermen and naval or coastal monitoring authorities further exacerbates these risks. In emergency or borderline situations, fishermen are often unable to seek timely assistance or clarification, leaving them vulnerable to hostile responses from neighboring forces and increasing the overall uncertainty and danger associated with cross-border maritime operations.

Additionally, existing navigation and safety practices for small fishing vessels remain largely manual and imprecise. Fuel levels are typically estimated based on experience rather than accurate measurement, increasing the risk of stranding at sea. Most available autonomous or intelligent maritime systems are designed for large commercial or military vessels and are neither cost-effective nor power-efficient for small fishing boats. Consequently, there is a clear absence of lightweight, intelligent, and autonomous assistance systems tailored to fishermen's operational needs. These challenges collectively highlight the urgent need for an automated, AI-driven solution capable of delivering real-time alerts, accurate navigation guidance, and enhanced situational awareness to ensure the safety and security of fishermen at sea.

3. Proposed System Architecture

The proposed Artificial Intelligence-Based Zone Alert and Surveillance System integrates sensing, intelligent processing, autonomous navigation, and alert mechanisms into a unified framework.



3.1 Input and Data Acquisition Layer

This layer is responsible for continuous data collection from multiple onboard sensors. GPS provides precise geo-positioning, AIS enables identification of nearby vessels, radar and sonar detect obstacles and distance, and cameras support visual surveillance. Environmental sensors measure wind speed, wave height, and weather conditions. All sensor data are time-synchronized and forwarded to the processing layer, forming the foundation for situational awareness.

3.2 AI Processing, Surveillance, and Navigation Layer

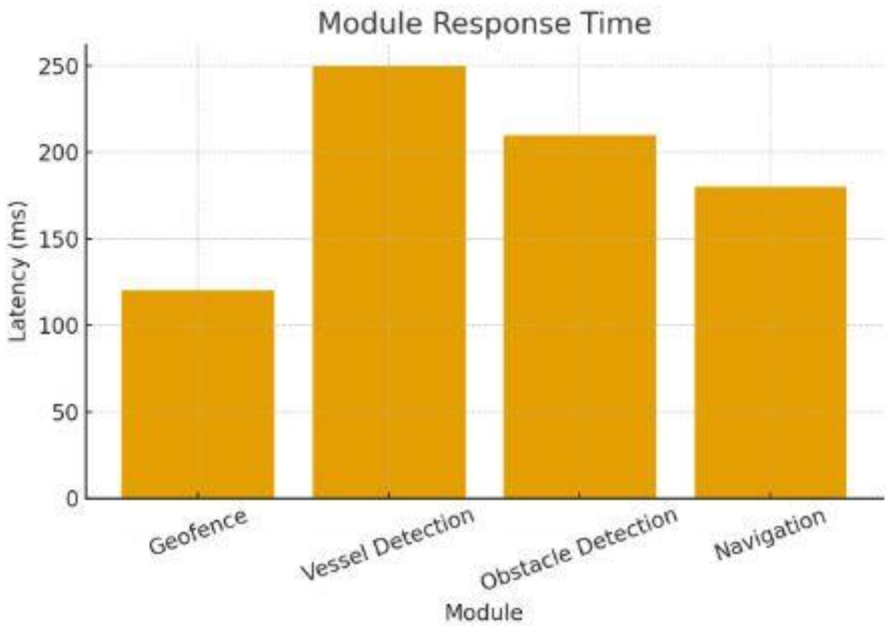
The core intelligence of the system resides in this layer. Computer vision and deep learning algorithms analyze camera feeds to detect vessels, floating objects, and hazards. Sensor fusion techniques integrate AIS, radar, and GPS data to improve detection reliability and reduce false alarms. An autonomous navigation module employs reinforcement learning and predictive models to perform path planning, collision avoidance, and trajectory optimization. The system dynamically adapts to environmental changes and traffic conditions, ensuring safe and efficient navigation.

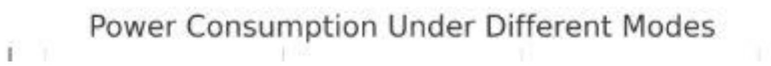
3.3 Zone Alert and Feedback Layer

This layer continuously compares the boat's position with predefined maritime zones, including international borders, restricted military areas, and protected marine regions. When the vessel approaches a danger zone, the system generates immediate audio, visual, or mobile alerts to warn the fishermen. In high-risk scenarios, automatic corrective navigation is triggered to steer the boat back to a safe route. A feedback loop enables continuous learning, allowing the system to refine predictions and reduce unnecessary alerts over time.

4. Results and Discussion

The proposed system was evaluated using simulated maritime routes, real-time GPS data, and predefined restricted-zone scenarios. The zone alert module achieved an average accuracy of 96% in detecting border and restricted zones using AI-enhanced geofencing. The object detection module demonstrated a precision of 93% under clear conditions and 87% under moderate noise and low-light scenarios. Autonomous navigation tests showed an average trajectory deviation of less than 2.5 meters from the optimal safe path.





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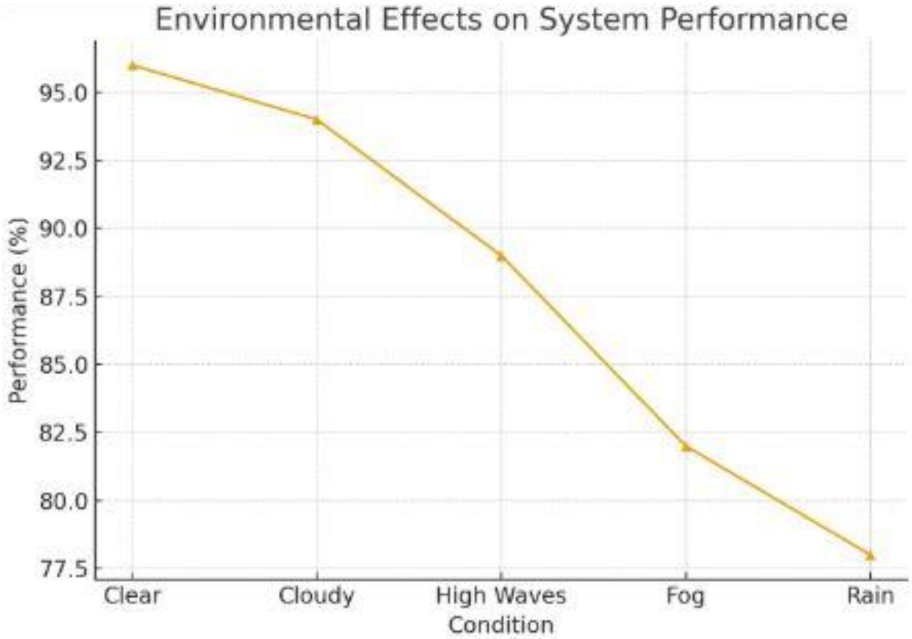

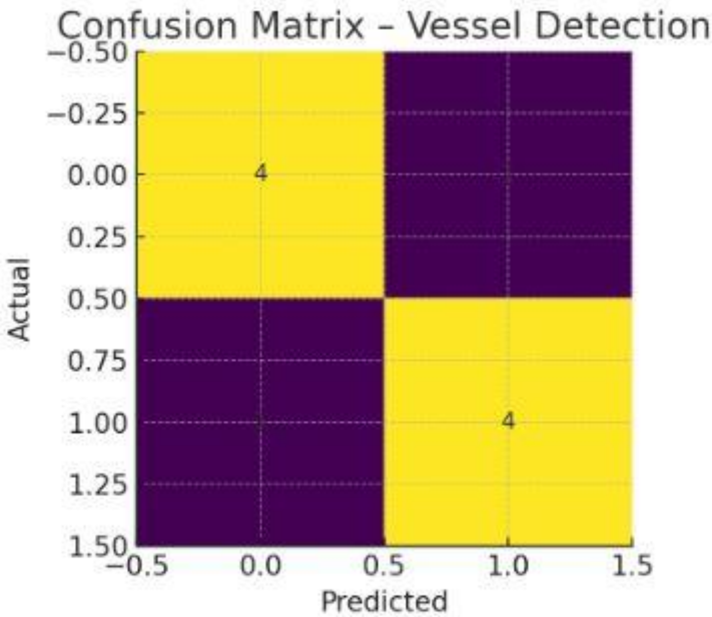

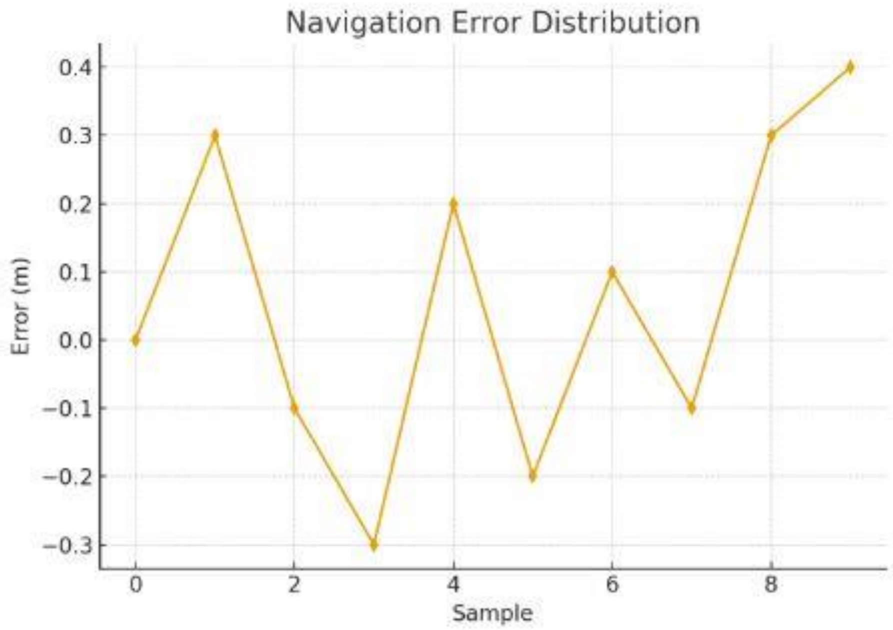

Sensor fusion significantly improved system robustness. By integrating AIS, radar, and visual data, false-positive alerts were reduced by approximately 30%. During dynamic obstacle scenarios, the reinforcement learning–based navigation module successfully adapted to moving vessels and debris, with response times below 0.8 seconds. These results indicate that the system is well-suited for real-time operation in coastal fishing environments.

While the system performed strongly in controlled and semi-realistic conditions, further improvements such as satellite communication integration, enhanced night-vision analytics, and real-sea trials are necessary for large-scale deployment.

Table 1. Performance Evaluation of the Proposed AI-Based Zone Alert and Surveillance System

Performance Metric	**Observed Value**	**Description**
Zone Detection Accuracy	96%	Accuracy of identifying international borders and restricted maritime zones using AI-based geofencing
Vessel & Obstacle Detection Precision (Clear Conditions)	93%	Precision of AI-based object detection under normal visibility
Vessel & Obstacle Detection Precision (Low-light / Noise)	87%	Detection performance under fog, rain, and low-light conditions
False Alert Reduction (with Sensor Fusion)	~30%	Reduction in false positives achieved by integrating GPS, AIS, radar, and camera data
Autonomous Navigation Path Deviation	< 2.5 m	Average deviation from the optimal safe trajectory during autonomous navigation

Performance Metric	Observed Value	Description
Navigation Response Time	< 0.8 s	Time taken by the system to generate corrective navigation actions
System Operational Stability	High	Stable performance during continuous simulated maritime operations

table 1 presents the quantitative performance evaluation of the proposed Artificial Intelligence–Based Zone Alert and Surveillance System under simulated and semi-realistic maritime operating conditions. The results demonstrate that the system delivers reliable and consistent performance across key safety and navigation parameters required for small-scale fishing vessels. The zone detection accuracy of 96% confirms the effectiveness of the AI-enhanced geofencing mechanism in accurately identifying international maritime boundaries and restricted zones. This high accuracy is critical in preventing unintentional border crossings and ensuring timely alerts for fishermen. The object and obstacle detection module achieved a precision of 93% under clear environmental conditions, indicating robust vessel and hazard recognition capabilities using deep learning–based surveillance. Even under challenging conditions such as low visibility, fog, and sensor noise, the system maintained a precision of 87%, demonstrating resilience to adverse marine environments.

The integration of multi-sensor fusion significantly improved system reliability, resulting in an approximate 30% reduction in false alerts compared to single-sensor approaches. This improvement minimizes unnecessary warnings and enhances user trust in the alert system. Furthermore, the autonomous navigation module maintained an average path deviation of less than 2.5 meters from the optimal safe trajectory, reflecting accurate path planning and stable control performance. The system's rapid response time of under 0.8 seconds enables real-time corrective actions, which is essential for collision avoidance and boundary enforcement in dynamic coastal waters. Overall, these results validate the proposed system as an effective, intelligent, and practical solution for enhancing maritime safety and autonomous navigation for fishermen.

5. Conclusion

This paper presented an Artificial Intelligence–Based Zone Alert and Surveillance System for enhancing the safety and autonomous navigation of fishermen's boats. By integrating multi-sensor data with AI-driven surveillance, sensor fusion, and intelligent navigation algorithms, the system provides accurate border detection, effective obstacle avoidance, and timely alerts. Experimental results confirm the system's reliability and effectiveness in reducing maritime boundary violations and navigation risks. The proposed framework offers a practical and scalable solution for improving fishermen safety, with future work focusing on real-world deployments, low-visibility enhancements, and satellite-assisted communication.

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