International Journal of Electrical and Computer Engineering (IJECE)
Vol. 99, No. 1, Month 2099, pp. 1~1x
ISSN: 2088-8708, DOI: 10.11591/ijece.v99i1.pp1-1x

Design and Simulation of GPS, Compass, and Fuel Data Acquisition System for Ambulance Ship Path Planning

Ryan Satria Wijaya[1], Rizki Munandar[2]
[1]Departement of Robotic Engineering, Major of Electrical Engineering, Politeknik Negeri Batam, Batam, Indonesia
[2]Departement of Robotic Engineering, Major of Electrical Engineering, Politeknik Negeri Batam, Batam, Indonesia

Article Info

Article history:

Received month dd, yyyy
Revised month dd, yyyy
Accepted month dd, yyyy

Keywords:

Ambulance Ship
Navigation Data Acquisition
Path Planning

ABSTRACT

Maritime ambulance vessels play a critical role in providing emergency medical services in archipelagic regions, where accurate navigation information and fuel monitoring are essential. This study presents the design and simulation of a navigation data acquisition system integrated with a web-based ship navigation platform for ambulance ship path planning. The proposed system consists of a microcontroller-based hardware module and a web-based navigation simulation. The hardware module is implemented using an STM32 Bluepill microcontroller integrated with a GPS receiver, a digital compass with tilt compensation, and a fuel flow sensor to acquire ship position, speed, heading, and fuel consumption data. The acquired data are formatted into structured serial messages and transmitted via serial communication. Due to the absence of on-vessel deployment, the structured hardware data format is used as a reference input for the web-based simulation. The web platform applies a hybrid RRT* + A* path planning approach to generate safe sailing routes that avoid land obstacles. The simulation visualizes ship movement, navigation status, estimated travel distance, estimated time of arrival (ETA), and fuel consumption. The results demonstrate that the proposed system is capable of acquiring navigation and fuel data and providing a comprehensive visualization of ambulance ship navigation behavior. This system serves as a functional prototype and a foundation for future real-time integration in maritime ambulance operations.

Corresponding Author:

Ryan Satria Wijaya
Department of Robotics Engineering, Major of Electrical Engineering, Politeknik Negeri Batam, Batam, Indonesia
Email: ryan@polibatam.ac.id

1. INTRODUCTION

Maritime ambulance vessels are essential for emergency medical services in archipelagic regions such as Indonesia, where operations strongly depend on accurate navigation information, travel time estimation, and fuel availability[1][2][3]. Navigation errors or delays can significantly reduce the effectiveness of emergency response in sea-based medical transport. In this study, route planning is specifically designed to support emergency ambulance ship operations in non-port and near-shore areas, without relying on predefined international shipping lanes or traffic separation schemes.

Recent advances in maritime sensors, including GPS receivers, digital compasses, and fuel flow sensors, enable real-time acquisition of ship position, speed, direction, fuel consumption and operational parameters[4][5][6][7][8]. Microcontroller-based platforms are widely adopted for such applications due to their low cost, flexibility, and capability to process sensor data efficiently. Web-based visualization platforms and digital maps have been increasingly utilized to support route analysis and navigation monitoring[9][10][11]. In addition, ship navigation behavior analysis using AIS-based position, speed, and heading data has been widely studied for maritime monitoring and decision-support applications, including navigation behavior prediction and uncertainty-aware motion estimation[12][13].

However, many existing studies focus either on hardware-based monitoring systems or on standalone navigation simulations, with limited attention to integrated frameworks that connect navigation data acquisition with web-based path planning visualization[14]. In practical deployments, direct real-time integration between onboard hardware and web platforms often faces technical and deployment constraints, making simulation-based approaches a practical intermediate solution. This study addresses this gap by designing and simulating a navigation data acquisition system integrated with a web-based ship navigation platform for ambulance ship path planning. The proposed system combines a microcontroller-based navigation and fuel monitoring module with a web-based simulation implementing a hybrid RRT* + A* path planning method[15][16], providing visualization of ship movement, navigation status, estimated travel distance, estimated time of arrival (ETA), and fuel consumption, and serving as a practical foundation for future real-time deployment.

2. METHOD

This study adopts a system design and simulation approach to develop a navigation data acquisition system and a web-based path planning simulation for ambulance ship operations. The proposed method focuses on the realization of a functional prototype system, consisting of a hardware-based navigation and fuel monitoring module and a web-based ship navigation simulation platform. The overall methodology is divided into four main stages: system architecture design, hardware data acquisition, web-based path planning simulation, and navigation parameter calculation.

2.1. System Architecture

The proposed system architecture consists of two main subsystems: a hardware navigation data acquisition subsystem and a web-based ship navigation simulation subsystem. The hardware subsystem is responsible for acquiring ship navigation and fuel consumption data, while the web subsystem visualizes ship movement, navigation status, and path planning results.

The hardware module is built using an STM32 Bluepill microcontroller as the main processing unit. It is connected to a GPS Neo-M8N module, a digital compass sensor (HMC5883L) with tilt compensation using IMU BNO055, and a pulse-based fuel flow sensor. Navigation and fuel data are processed by the microcontroller and formatted into structured serial messages. The processed data are transmitted to a Mini PC via serial communication using RX–TX lines through an FTDI Type-C to USB interface with a baud rate of 115200 bps. Although serial data reception on the Mini PC has been successfully implemented, direct deployment on an actual ambulance vessel has not yet been conducted. Therefore, the transmitted data structure is used as a reference format for the web-based simulation[17].

The web-based subsystem visualizes ship navigation behavior using simulated vessel movement based on predefined routes. It displays ship position, speed, heading, fuel usage, estimated travel time, and navigation status. This separation allows independent validation of both hardware and software subsystems while maintaining a consistent data structure. The overall system architecture and data flow are illustrated in Figure 1.

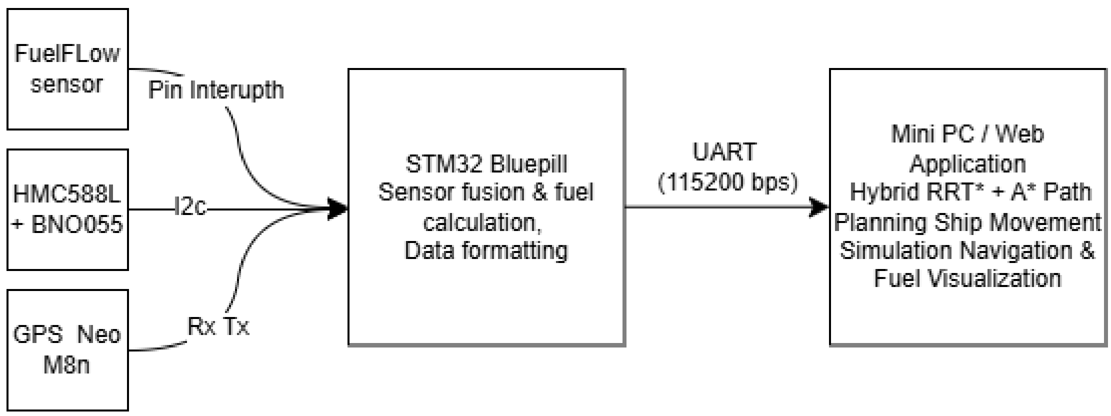

Figure 1. Block diagram of the proposed navigation data acquisition system integrated with a web-based ship navigation simulation

2.2. Hardware Navigation and Fuel Data Acquisition

The hardware module is designed to acquire ship navigation and fuel consumption parameters in real time. The GPS Neo-M8N provides latitude, longitude, Speed Over Ground (SOG), and Course Over Ground (COG) data at a sampling rate of 10 Hz. This sampling rate is selected to ensure smooth and responsive position tracking suitable for vessel navigation. Heading information is obtained using a digital compass sensor (HMC5883L). To improve heading accuracy during vessel motion, tilt compensation is applied using roll and pitch data obtained from the IMU BNO055, which is a commonly used approach to reduce orientation-related errors in navigation systems[18][19]. The overall hardware prototype used in this study is shown in Fig. 2.

Figure 2. Prototype of the integrated navigation and fuel data acquisition module, consisting of an STM32-based sensor unit, GPS receiver, fuel flow sensor, and a Mini PC with a front-mounted display for web-based ship navigation simulation.

Fuel consumption is further measured using a pulse-based fuel flow sensor, where each pulse corresponds to a fixed fuel volume constant. Fuel data are sampled at a frequency of 1 Hz to provide stable fuel flow estimation and minimize noise caused by insufficient pulse counts at higher sampling rates. Fuel flow rate and accumulated fuel consumption are calculated based on pulse accumulation within a fixed time interval.

2.3. Data Formatting and Serial Communication

All navigation and fuel data are formatted into two structured serial messages, namely AIS data and fuel data. This formatting is designed to resemble simplified Automatic Identification System (AIS) information for navigation monitoring purposes.

The serial data format is defined as:

```
$AIS,latitude,longitude,SOG,COG,heading
$Fuel,accumulated_fuel,fuel_flow_rate
```

An example of the transmitted data is:

```
$AIS,1.119356,104.048484,5.12,98.8,90.1
$Fuel,1.2680,3.56
```

The $AIS message represents ship navigation parameters, including position, speed, and heading, while the $Fuel message represents accumulated fuel consumption and instantaneous fuel flow rate. These messages are transmitted periodically via serial communication to the Mini PC and are used as reference inputs for the web-based simulation. The AIS data format used in this study represents a simplified navigation message structure and does not correspond to official AIS transponder data.

2.4. Web-Based Ship Navigation Simulation and Path Planning

The web-based simulation platform was developed using HTML, CSS, and JavaScript, with Leaflet and OpenStreetMap (OSM) for map visualization. Ship navigation behavior is represented through animated vessel movement along planned routes. Land–sea separation is performed using OpenStreetMap data obtained via the Overpass API[20][21][11], where land polygons are treated as non-navigable areas and marine regions as safe navigation zones. GeoJSON is used to represent spatial obstacles and navigable areas in the simulation[22][23][24]. The simulation displays AIS-based navigation data and fuel information, while navigation routes are generated exclusively within safe marine areas using GeoJSON-based obstacle representation.

Path planning is implemented using a hybrid RRT* and A* approach. The A* algorithm alone is limited by its dependency on predefined graph structures[14][15][16], while RRT* alone becomes computationally expensive for long-distance inter-island navigation[15]. Therefore, a hybrid strategy is adopted, where RRT* connects the ship's initial position to the nearest navigation graph node, A* determines the optimal route between graph nodes, and RRT* connects the final graph node to the destination point, as commonly adopted in hybrid sampling- and graph-based planning frameworks[14]. The navigation graph is generated offline by distributing nodes randomly within safe marine areas, validating node connections to avoid land collisions, and storing the finalized graph structure in GeoJSON format, which follows general graph-based path planning principles[25]. This approach significantly reduces computation time during simulation.

To clarify the logical flow of the proposed hybrid path planning strategy, Algorithm 1 presents the pseudocode of the web-based ship path planning process implemented in this study. The pseudocode summarizes the integration of land–sea separation, offline navigation graph utilization, and the hybrid RRT* + A* planning method used to generate safe sailing routes for ambulance ship navigation. In this study, RRT* is used for local connection between continuous space and graph nodes, while A* is applied for optimal path search on the pre-generated navigation graph.

Algorithm 1. Hybrid RRT* and A* Path Planning for Ambulance Ship Navigation

Input:
- Start position S
- Goal position G
- Land obstacle polygons (GeoJSON)
- Pre-generated navigation graph (nodes and edges)

Output:
- Safe sailing route P

```
Load land obstacle polygons and navigation graph
Determine nearest graph node Ns to start position S
Determine nearest graph node Ng to goal position G
if Ns = Ng then
    P ← {S, G}
else
    P1 ← RRT*(S, Ns)
    P2 ← A*(Ns, Ng)
    P3 ← RRT*(G, Ng)
    P ← concatenate (P1, P2, reverse(P3))
end if
Validate route P against land obstacle polygons
Return safe sailing route P
```

The pseudocode illustrates the integration of land–sea separation, offline navigation graph utilization, and the hybrid RRT* + A* planning method. By restricting sampling and graph traversal to navigable marine areas, the algorithm ensures collision-free route generation while reducing computational complexity compared to standalone RRT* exploration. This method enables efficient and collision-free route generation for ambulance ship navigation while maintaining computational feasibility for web-based simulation environments.

RRT* Local Connection Metric:

In the proposed path planning framework, the Rapidly-exploring Random Tree Star (RRT*) algorithm is employed to explore the continuous configuration space and establish local connections between sampled nodes while minimizing path cost through a rewiring process, as expressed in Equation (1).

$$d(x_i, x_j) = \|x_i - x_j\| \tag{1}$$

where x_i and x_j represent two nodes in the continuous configuration space, and $d(\cdot)$ denotes the Euclidean distance metric used for tree expansion and rewiring in RRT*.

A* Cost Function:
For global path search on the navigation graph, the A* algorithm evaluates each node based on a cost function that combines the accumulated path cost and a heuristic estimate to the goal, as expressed in Equation (2).

$$f(n) = g(n) + h(n) \quad (2)$$

where $g(n)$ is the accumulated path cost from the start node to node n, and $h(n)$ is the heuristic cost estimating the distance from node n to the goal.

Hybrid RRT* + A* Path Optimization Objective:
The overall path planning objective is formulated as an optimization problem that seeks the shortest feasible sailing path under navigability constraints composed of consecutive path segments generated by the hybrid RRT* and A* process, as expressed in Equation (3).

$$P^* = arg \min_{P \in \mathcal{P}} \sum_{k=1}^{M-1} d(p_k, p_{k+1}) \quad (3)$$

where P^* denotes the optimal sailing path, $\mathcal{P}$ represents the set of feasible paths, p_k and p_{k+1} are consecutive path points, and $d(\cdot)$ denotes the Euclidean or geodesic distance.

2.5. Ship Movement Simulation and Navigation Parameter Calculation

The calculation of distance, speed, and travel time is performed to support ship movement estimation and the determination of the Estimated Time of Arrival (ETA) in the web-based simulation. Ship movement is simulated by animating vessel motion along the final planned route at a predefined cruising speed of approximately 22 knots, which is treated as a fixed operational parameter during the simulation. The animation is updated every 20 ms (≈50 FPS) to ensure smooth visualization.

During the simulation, several navigation parameters are updated dynamically, including ship position (latitude and longitude), heading, traveled distance, estimated time of arrival (ETA), and accumulated fuel consumption. In contrast, parameters such as cruising speed and fuel flow rate are predefined and remain constant throughout the simulation. Navigation status is updated based on the vessel's operational phase and categorized into three states: At Anchor, Under Way Using Engine, and Moored. Fuel consumption is calculated incrementally based on the traveled distance and the predefined fuel flow rate, enabling visualization of remaining fuel throughout the voyage. The distance, speed, and travel time calculations are based on the path planning results, which generate a sequence of trajectory points from the initial position to the final destination. The total sailing distance is calculated by summing the distances between consecutive points along the planned trajectory, as expressed in Equation (4).

$$D_{total} = \sum_{i=1}^{N-1} d(P_i, P_{i+1}) \quad (4)$$

where P_i and P_{i+1} represent consecutive latitude–longitude coordinate points along the trajectory, and N denotes the total number of trajectory points. The distance between two points is calculated using a geodesic distance formulation (e.g., great-circle distance), which accounts for the curvature of the Earth. In the simulation, the ship speed is assumed to be constant to simplify movement analysis. To comply with maritime navigation standards, the ship speed is expressed in meters per second and converted to knots, as shown in Equation (5).

$$V_{knot} = V_{\frac{m}{s}} \times 1.943 \quad (5)$$

The total travel time is calculated as the ratio between the total sailing distance and the predefined ship speed, as shown in Equation (6), where $V_{\frac{m}{s}}$ represents the ship speed in meters per second.

$$T = \frac{D_{total}}{V_{\frac{m}{s}}} \quad (6)$$

The Estimated Time of Arrival (ETA) is obtained by adding the calculated travel time to the initial simulation time. During the ship movement simulation, the ETA value is dynamically updated as the traveled distance increases along the planned route.

2.6. Testing and Data Collection

Testing was conducted to verify the functional operation of both subsystems. Hardware testing focused on validating sensor data acquisition, serial data transmission, and data formatting using a serial monitor, while web-based testing focused on route generation, ship movement animation, navigation parameter updates, and fuel consumption visualization. The collected data consist of serial output logs from the hardware subsystem and navigation, route, distance, ETA, and fuel consumption data from the web-based simulation. The evaluation emphasizes functional correctness and system integration rather than quantitative accuracy benchmarking.

3. RESULTS AND DISCUSSION

This section presents the results obtained from the implementation and testing of the proposed system, consisting of the hardware navigation and fuel data acquisition module and the web-based ship navigation and path planning simulation. The discussion focuses on demonstrating system functionality, data consistency, and the integration between hardware design and simulation outputs.

3.1. Hardware Navigation and Fuel Data Acquisition Results

The hardware module was implemented and tested to acquire ship navigation and fuel consumption data. During testing, the STM32 Bluepill microcontroller continuously read data from the GPS, digital compass, and fuel flow sensors and transmitted the formatted output via serial communication. The GPS Neo-M8N module provided stable latitude, longitude, Speed Over Ground (SOG), and Course Over Ground (COG) data at a sampling rate of 10 Hz. Heading information obtained from the HMC5883L digital compass, combined with tilt compensation using the IMU BNO055, produced consistent heading values within the expected range of 0°–360°, reducing fluctuations caused by roll and pitch commonly encountered in maritime environments. Fuel consumption data were acquired using a pulse-based fuel flow sensor at a sampling rate of 1 Hz. The accumulated fuel consumption increased proportionally over time, while the fuel flow rate remained stable under constant operating conditions. This sampling configuration provided reliable fuel flow estimation without excessive noise caused by low pulse counts. A sample of the acquired navigation and fuel data is presented in Table 1. These results demonstrate that the hardware subsystem is able to generate structured navigation and fuel consumption data in a consistent format, which is used as an illustrative example of the data output for subsequent system integration and simulation.

Table 1. Example of hardware navigation and fuel data output format

No.	Parameter	Unit	Sample Value	Sensor
1	Latitude	Degree	1.119356	GPS
2	Longitude	Degree	104.048484	GPS
3	Speed Over Ground (SOG)	Knots	5.12	GPS
4	Course Over Ground (COG)	Degree	98.8	GPS
5	Heading	Degree	90.1	Compass
6	Fuel Consumption	Liter	1.2680	Fuel Flow
7	Fuel Flow Rate	Liter/hour	3.56	Fuel Flow

These results indicate that the hardware subsystem can produce structured navigation and fuel consumption data in a consistent format, which is suitable for use as reference input in the proposed simulation framework.

3.2. Serial Data Formatting and System Integration Results

The defined serial data format was implemented and transmitted from the STM32 Bluepill to the Mini PC using serial communication at a baud rate of 115200 bps. Two structured messages, namely $AIS and $Fuel, were generated periodically during operation. The $AIS message encapsulates essential navigation parameters, including ship position, speed, course, and heading, while the $Fuel message represents accumulated fuel consumption and instantaneous fuel flow rate. The use of a structured and consistent data format simplifies data interpretation and enables seamless integration with external systems, such as web-based visualization platforms. Although real-time deployment on an actual vessel has not yet been conducted, the successful transmission and reception of serial data demonstrate that the hardware system is functionally ready for integration with higher-level monitoring or simulation systems.

3.3. Web-Based Path Planning Simulation Results

The web-based simulation effectively visualized ship navigation behavior within an archipelagic environment. Land and sea areas were clearly distinguished using GeoJSON-based spatial data, ensuring that planned routes did not intersect land obstacles. The hybrid RRT* and A* path planning approach was able to generate safe and feasible sailing routes between selected departure and destination points. The use of a pre-generated navigation graph significantly reduced computation time, allowing route generation to be completed within 5 s in most cases. The resulting routes remained entirely within navigable marine areas and avoided all land obstacles, demonstrating the effectiveness of the proposed path planning strategy. Figure 3 illustrates the safe marine navigation area generated from OpenStreetMap data using the Overpass API, where land areas are identified and excluded from navigation, while the remaining region represents allowable sailing areas for the ambulance ship. This spatial representation serves as the basis for navigation graph generation and hybrid RRT* and A* path planning. To summarize the main characteristics of the proposed path planning process, the key parameters and outcomes of the route generation are presented in Table 2. The table highlights the selected path planning method, route safety status, and computation time obtained during the simulation.

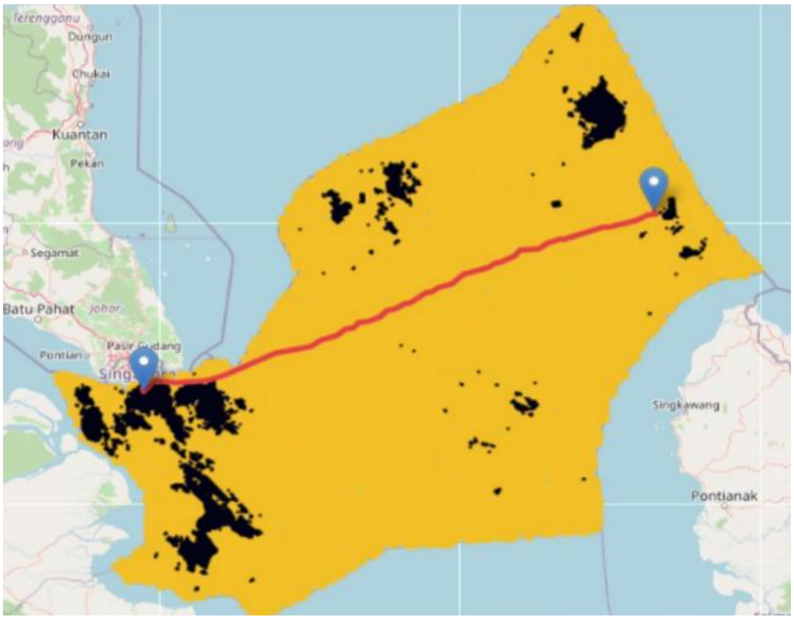

Figure 3. Navigable marine area and land obstacles used for ship path planning

Table 2. Path planning parameters

No.	Parameter	Value
1	Path Planning Method	Hybrid RRT* + A*
2	Route Status	Safe (no land collision)
3	Computation Time	< 5 s

3.4. Ship Movement Simulation and Navigation Information Results

Ship movement along the planned route was simulated using animated vessel motion at a predefined cruising speed of approximately 22 knots, representing a realistic and safe operating speed for ambulance vessels. The animation was updated every 20 ms (≈50 FPS), producing smooth and continuous ship movement. During the simulation, navigation information such as ship position (latitude and longitude), speed, heading, estimated time of arrival (ETA), navigation status, and fuel parameters was dynamically updated and displayed. The navigation status transitioned sequentially through three operational states, namely At Anchor, Under Way Using Engine, and Moored. Figure 4 shows the result of the web-based ship navigation simulation, where the sailing route generated using the hybrid RRT* + A* approach remains entirely within navigable marine areas and avoids land obstacles. The simulated vessel follows the planned route while navigation information and fuel consumption are continuously updated, confirming the correct integration between path planning, navigation data representation, and ship movement simulation.

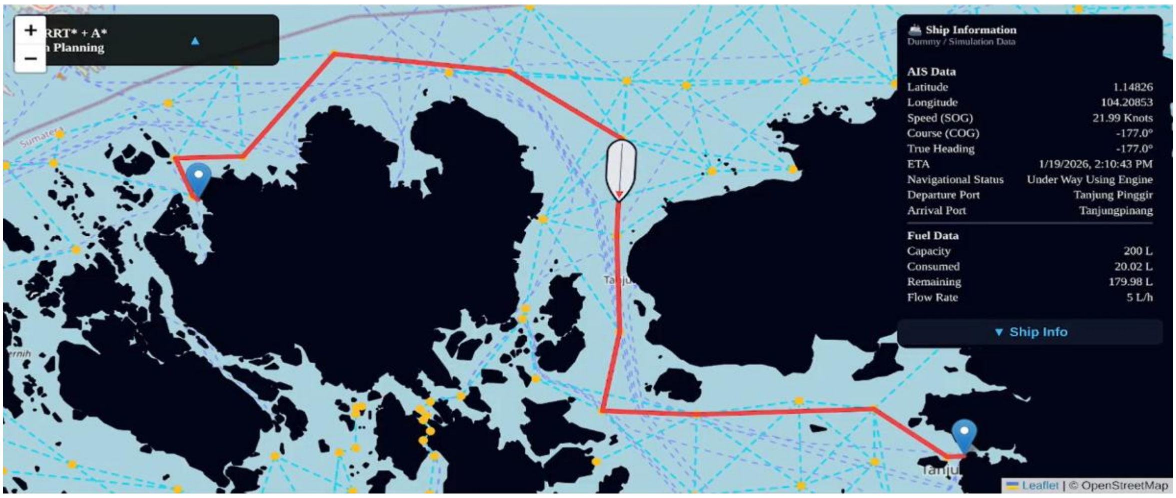

Figure 4. Web-based ship navigation simulation showing the hybrid RRT* + A* planned route, land–sea separation, simulated ship movement, and navigation information including AIS-based position, ETA, and fuel consumption

3.5. Analysis of Distance, Travel Time, and Fuel Consumption

Based on the generated sailing route, the total travel distance obtained from the simulation was approximately 184 km. With a constant ship speed of 22 knots (≈11.21 m/s), the estimated travel time was approximately 4 hours and 31 minutes. The Estimated Time of Arrival (ETA) displayed in the web-based simulation was consistent with the calculated travel time, which aligns with common ETA estimation approaches in maritime navigation systems. Fuel consumption during the simulation was calculated using a predefined fuel flow rate of 5 L/h. Over the estimated travel duration, the total fuel consumption reached approximately 22.57 L, while the remaining fuel was continuously updated during the simulation. Table 3 summarizes the distance, speed, travel time, and fuel consumption results.

Table 3. Summary of simulation results

No.	Parameter	Value
1	Speed Over Ground (SOG)	21.99 knots
2	Ship Speed	11.21 m/s
3	Fuel Flow Rate	5 L/h
4	Fuel Consumed	22.57 L
5	Estimated Travel Time	± 4 h 31 min
6	Estimated Travel Distance	± 184 km
7	ETA	14 Jan 2026, 15:38:31

These results demonstrate that the simulation can consistently estimate navigation parameters based on the planned route and predefined operational conditions.

3.6. Discussion

The results demonstrate that the proposed system successfully realizes an integrated navigation data acquisition and simulation framework for ambulance ship operations. The hardware subsystem is capable of acquiring and formatting navigation and fuel consumption data in real time, while the web-based simulation effectively visualizes ship movement, navigation status, and key operational parameters. Although real-time integration between the hardware subsystem and the web application has not yet been implemented, the use of simulation-based data that follow the same structure as the hardware output enables meaningful evaluation of navigation behavior under controlled conditions. This architectural separation also provides flexibility for future system expansion, including real-time data streaming, the integration of additional sensors, and more advanced navigation analysis. It should be noted that the proposed system is intended as a simulation-based decision-support tool for emergency ambulance ship operations, particularly in accessing remote or non-port areas, and does not replace or interfere with official maritime navigation systems or international shipping regulations. Overall, the results confirm that the proposed system fulfills its intended role as a design and simulation platform for ambulance ship navigation, path planning, and fuel monitoring in archipelagic environments. However, the current study is limited to simulation-based evaluation and does not yet address real-time latency, sensor noise, and environmental disturbances that may arise during on-vessel deployment.

4. CONCLUSION

This study successfully designed and simulated a navigation data acquisition and web-based ship navigation system for ambulance ship operations in archipelagic environments. The proposed system integrates a microcontroller-based navigation and fuel monitoring module with a web-based simulation platform for ship path planning. The hardware module acquires GPS-based position, speed, course, compass-based heading with tilt compensation, and fuel consumption data, which are transmitted using structured serial messages, while the web-based platform visualizes ship movement, navigation status, estimated travel distance, estimated time of arrival (ETA), and fuel consumption. The implementation of a hybrid RRT* and A* path planning approach enables the generation of safe sailing routes that avoid land obstacles while remaining within navigable marine areas. Although real-time hardware-to-web integration has not yet been implemented, the use of simulation-based data consistent with the hardware output structure provides a valid and practical framework for evaluating navigation behavior. Therefore, the proposed system serves as a functional prototype and a foundation for future development, including real-time integration, on-vessel deployment, sensor accuracy evaluation, and the incorporation of additional maritime sensors and adaptive path planning strategies to enhance system reliability and applicability in real-world ambulance ship operations.

REFERENCES

[1] J. S. Dillard, W. Maynard, and R. Kashyap, “The Epidemiology of Maritime Patients Requiring Medical Evacuation: A Literature Review,” *Cureus*, vol. 15, no. 11, 2023, doi: 10.7759/cureus.49606.

[2] S. Jiang, L. Liu, P. Peng, M. Xu, and R. Yan, “Prediction of vessel arrival time to port: a review of current studies,” *Marit. Policy Manag.*, vol. 00, no. 00, pp. 1–26, 2025, doi: 10.1080/03088839.2025.2488376.

[3] C. Maervoet, T. Vanelslander, and M. Vervoort, “Data analysis for more accurate cargo ship ETA’s: a model for ETA deviation prediction,” *WMU J. Marit. Aff.*, vol. 23, no. 3, pp. 293–327, 2024, doi: 10.1007/s13437-024-00341-w.

[4] A. Stateczny, W. Kazimierski, and P. Burdziakowski, “Sensors and System for Vehicle Navigation,” *Sensors*, vol. 22, no. 5, pp. 1–6, 2022, doi: 10.3390/s22051723.

[5] A. S. Nagesh, C. Aparna, and M. C. S. Rao, “A GPS- enabled Fuel Sensor based Vehicle Tracking System for Fleet Management using the Internet of Things,” *Scalable Comput. Pract. Exp.*, vol. 26, no. 1, pp. 34–47, 2025, doi: 10.12694/scpe.v26i1.3479.

[6] G. Xu, Y. Shi, X. Sun, and W. Shen, “Internet of things in marine environment monitoring: A review,” *Sensors (Switzerland)*, vol. 19, no. 7, pp. 1–21, 2019, doi: 10.3390/s19071711.

[7] Z. Liu, B. Zhang, M. Zhang, H. Wang, and X. Fu, “A quantitative method for the analysis of ship collision risk using AIS data,” *Ocean Eng.*, vol. 272, p. 113906, 2023, doi: https://doi.org/10.1016/j.oceaneng.2023.113906.

[8] T. Uyanık *et al.*, “Data-Driven Approach for Estimating Power and Fuel Consumption of Ship: A Case of Container Vessel,” 2022. doi: 10.3390/math10224167.

[9] Z. Usta, Ç. Cömert, and A. T. Akın, “An interoperable web-based application for 3d city modelling and analysis,” *Earth Sci. Informatics*, vol. 17, no. 1, pp. 163–179, 2024, doi: 10.1007/s12145-023-01167-5.

[10] M. Beňo and M. Ölvecký, “Measuring the performance of techniques for dynamic 2D animation in web browsers,” *J. Appl. Math. Stat. Informatics*, vol. 20, no. 2, pp. 77–110, 2024, doi: 10.2478/jamsi-2024-0009.

[11] T. Horbiński and D. Lorek, “The use of Leaflet and GeoJSON files for creating the interactive web map of the preindustrial state of the natural environment,” *J. Spat. Sci.*, vol. 67, no. 1, pp. 61–77, Jan. 2022, doi: 10.1080/14498596.2020.1713237.

[12] X. Xu, B. Wu, Â. P. Teixeira, X. Yan, and C. G. Soares, “Integration of Radar Sequential Images and AIS for Ship Speed and Heading Estimation Under Uncertainty,” *IEEE Trans. Intell. Transp. Syst.*, vol. 25, no. 6, pp. 5688–5702, 2024, doi: 10.1109/TITS.2023.3338293.

[13] T. Liu and J. Ma, “Ship Navigation Behavior Prediction Based on AIS Data,” *IEEE Access*, vol. 10, pp. 47997–48008, 2022, doi: 10.1109/ACCESS.2022.3172308.

[14] Y. Song and X. Cao, “Review of Intelligent Ship Path Planning Algorithms,” *Front. Manag. Sci.*, vol. 3, no. 1, pp. 90–101, 2024, doi: 10.56397/fms.2024.02.10.

[15] D. U. Jang and J. S. Kim, “Development of Ship Route-Planning Algorithm Based on Rapidly-Exploring Random Tree (RRT*) Using Designated Space,” *J. Mar. Sci. Eng.*, vol. 10, no. 12, 2022, doi: 10.3390/jmse10121800.

[16] R. Zhen, Q. Gu, Z. Shi, and Y. Suo, “An Improved A-Star Ship Path-Planning Algorithm Considering Current, Water Depth, and Traffic Separation Rules,” *J. Mar. Sci. Eng.*, vol. 11, no. 7, 2023, doi: 10.3390/jmse11071439.

[17] K. C. Ugwoke, N. A. Nnanna, and S. E. Y. Abdullahi, “Simulation-based review of classical, heuristic, and metaheuristic path planning algorithms,” *Sci. Rep.*, vol. 15, no. 1, pp. 1–36, 2025, doi: 10.1038/s41598-025-96614-2.

[18] R. Mardiyanto, R. Adyatma, M. N. Cahyadi, and D. Kuswidiastuti, “Experimental Evaluation of Dual GPS for Heading Determination as a Compass Replacement in Unmanned Vehicles to Mitigate Electromagnetic Interference,” in *2023 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation (ICAMIMIA)*, 2023, pp. 212–215. doi: 10.1109/ICAMIMIA60881.2023.10427565.

[19] F. O. Silva, L. P. S. Paiva, and G. S. Carvalho, “Error analysis of accelerometer-and magnetometer-based stationary alignment,” *Sensors*, vol. 21, no. 6, pp. 1–21, 2021, doi: 10.3390/s21062040.

[20] OpenStreetMap contributors, “OpenStreetMap.” Accessed: Jan. 17, 2026. [Online]. Available: https://www.openstreetmap.org

[21] OpenStreetMap contributors, “Overpass API.” Accessed: Jan. 17, 2026. [Online]. Available: https://wiki.openstreetmap.org/wiki/Overpass_API

[22] OpenStreetMap contributors, “Overpass Turbo GeoJSON.” Accessed: Jan. 17, 2026. [Online]. Available: https://wiki.openstreetmap.org/wiki/Overpass_turbo/GeoJSON

[23] I. P. Solihin, K. Boro, Desrial, and K. Priandana, “Optimization of GeoJSON Data in Python for Enhancing Precision Fertilization in Oil Palm Plantations Using on-Board Computer Units,” in *2024 International Conference on Informatics, Multimedia, Cyber and Information System (ICIMCIS)*, 2024, pp. 754–759. doi: 10.1109/ICIMCIS63449.2024.10956923.

[24] Y. Watequlis Syaifudin *et al.*, “Utilizing OpenStreetMap for Collaborative Mobile Reporting System in Irrigation Infrastructure Management,” *J. Electr. Eng. Mechatron. Comput. Sci.*, vol. 8, no. 1, pp. 45–60, 2025, [Online]. Available: http://jurnal.unmer.ac.id/index.php/jeemecs

[25] H. Ma, “Graph-Based Multi-Robot Path Finding and Planning,” *Curr. Robot. Reports*, vol. 3, no. 3, pp. 77–84, 2022, doi: 10.1007/s43154-022-00083-8.