Journal of Computer Technology and Software

ISSN: 2998-2383

Vol. 4, No. 12, 2025

A Data-Mining-Driven Human-Computer Interaction System for Integrated Ship Navigation Guidance

Bruno Jouvencel
University of Central Missouri, Warrensburg, USA
bruno.jouvencel89@outlook.com

Abstract: This study designs a human-computer interaction system for integrated ship navigation guidance based on data-mining technologies. The system accurately extracts effective navigation information to support safe and reliable ship navigation. By collecting both navigation and environmental data, the method employs adaptive K-means clustering to mine critical guidance features and construct an optimal navigation information set. The resulting guidance information is used to build a maritime environment map, while an improved genetic algorithm is applied to generate optimal ship-route plans and produce real-time guidance commands. Through the control and display module, the system outputs intuitive navigation-control results, enabling efficient human-computer interaction. Experimental results demonstrate that the proposed system effectively supports integrated ship-navigation guidance, accurately extracts key navigation and environmental information, optimizes route planning, avoids obstacles, and ensures navigation safety.

Keywords: Data mining; integrated ship navigation guidance; human-computer interaction; clustering algorithms; genetic algorithms; route planning

1. Introduction

Integrated navigation systems play a vital role in ensuring the safety of ship operations, and their application can effectively enhance the overall level of navigation automation. Incorporating human-computer interaction technology into integrated navigation systems can further improve navigation performance and provide clear guidance results for ship operators[1-3]. To achieve a highly interactive and user-friendly experience, the development of a visually appealing human-computer interaction interface is essential for ship-navigation systems. Previous studies[4] designed a human-computer interaction system that recognizes hand gestures through deep-learning techniques, extracting key posture features and classifying them using convolutional neural networks to complete interaction tasks. This system effectively identifies gestures and enables reliable human-computer interaction.

Other research[5] proposed a human-computer interaction system utilizing single-depth cameras to track hand gestures and targets, combined with tactile repositioning methods to enhance the continuity of interaction operations. This approach reduces the impact of hand shaking and improves interaction accuracy. However, both systems suffer from limitations in information extraction, as they contain large amounts of redundant information that negatively affect the interaction process. Consequently, they cannot fully meet real-time requirements and are unable to guarantee the safety of ship navigation.

To address these issues, a human-computer interaction interface system for integrated ship-navigation guidance must provide accurate and valuable information[6] while reducing the influence of redundant data and improving interaction performance. Therefore, this study proposes a data-mining-based human-computer interaction interface for integrated ship-navigation guidance to support safe and reliable ship operations.

2. Ship Integrated Navigation Human-Computer Interaction System

According to the principle of modular openness, a fully integrated ship-navigation human-computer interaction system is designed with a layered architecture, as illustrated in Figure 1. The system begins with a voice-input module that allows the user to issue control commands, which are then transmitted wirelessly to the onboard PC. The design of the voice module draws on the work presented in [6], which emphasizes the importance of robust user-input processing and satisfaction modeling in human-computer interaction systems. This ensures accurate command recognition even under challenging marine noise conditions.

Once the commands are received, the navigation-integration module collects real-time navigational and environmental data from onboard sensors. These data are then processed by a PC-based navigation information mining module, which employs an adaptive K-means clustering algorithm to dynamically extract critical features under varying maritime conditions. This approach reflects the adaptive learning framework introduced in [6], where data-driven clustering enhances the responsiveness and adaptability of interaction systems.

With the optimal navigation dataset obtained, the system advances to the route-planning phase. A maritime environment map is first constructed, and an improved genetic algorithm is applied to generate an optimal navigation route and complete the ship-guidance process. This routing mechanism benefits from the hybrid optimization strategies proposed in [6], which are shown to improve real-time coordination between system and user.

Finally, the communication module transmits the control results to the display module, enabling the system to clearly and accurately present the final guidance output to the user interface:

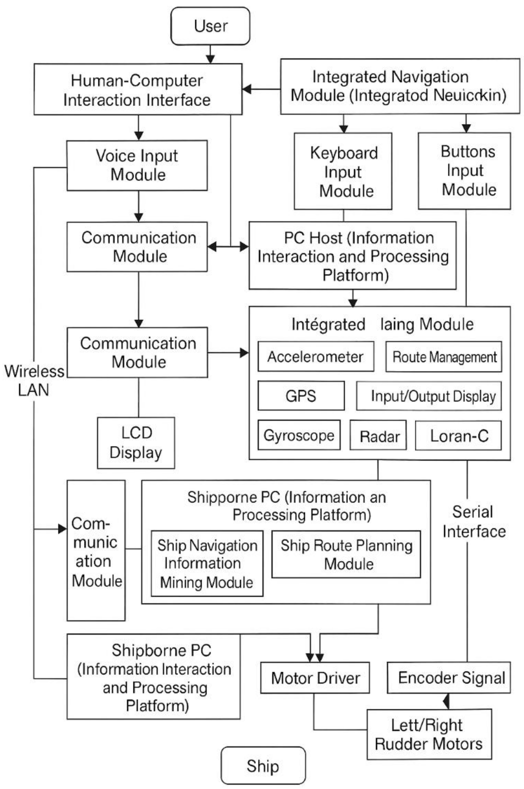

Figure 1. Man-machine interface system of ship integrated navigation

2.1 Ship Integrated Navigation Module

The integrated ship-navigation module collects real-time navigation data and environmental information from the vessel, and its structure is illustrated in Figure 2. This module is designed using embedded-computing technology and primarily includes embedded processors, FLASH, SDRAM, and other components. It provides functions for displaying and storing navigation and environmental information, as well as marine chart data. In addition, it is capable of processing real-time navigation information and environmental data collected by navigation devices[7-8].

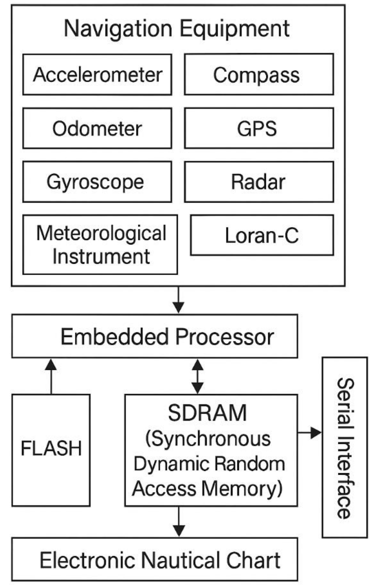

Figure 2. Ship integrated navigation module

2.2 Ship Navigation Information Mining Based on Data Mining

An adaptive K-means clustering algorithm is applied to the real-time navigation data and environmental information collected from the ship. The purpose is to extract valid navigation information and environmental data and generate an optimal ship-navigation information set. In the information-mining process, for convenience, all navigation and environmental data are collectively referred to as navigation information. Assume that two navigation information samples are $i(x_1, y_1)$ and $j(x_j, y_j)$, and their distance is denoted as d. By comparing the observed navigation information with the true value, the difference between them yields an error value, which serves as the basis for clustering ship-navigation information.

(1) Randomly select m initial objects $(G_1, G_2, ..., G)$ within the (x, y) domain as the initial cluster centers, where $(G_1, G_2, ..., G)$ represents the initial centroid set. Determine the number of navigation-information clusters K.

(2) Based on Eq. (1), compute the distance from each navigation information sample to each centroid $(G_1, G_2, ..., G)$. Assign each sample to the class whose centroid is closest to it.

(3) Randomly select a non-centroid G_r and compute the value E using Eq. (2). Replace G_r with G'^{m} if E continues to decrease, and repeat the process.

(4) Repeat steps (2) and (3) until the error no longer changes. At this point, the cluster centers remain fixed, and the clustering process is complete.

The output consists of the K cluster centers and their corresponding classes, representing the effective clustering results of the navigation and environmental data. Based on these clustering outcomes, an optimal navigation-information set is generated.

2.3 Ship Route Planning Based on an Improved Genetic Algorithm

Based on the generated optimal navigation-information set, a maritime environmental map for ship navigation is constructed. According to this environmental map, an improved genetic algorithm is applied to plan the ship route. The route-planning process is performed on the two-dimensional environmental map, where the objective is to determine the shortest path that avoids collisions with obstacles and ensures smooth navigation. The starting point of the route is denoted as A and the destination as B. The planned route lies between A and B, and the sequence of intermediate coordinates is expressed as $(x'_0, y'_0) \rightarrow (x'_1, y'_1) \rightarrow \ldots \rightarrow (x'_g, y'_g) \rightarrow (x'_h, y'_h)$, where A corresponds to (x'_0, y'_0), B corresponds to (x'_h, y'_h), and the points (x'_g, y'_g) $(g = 1, 2, \ldots, h-1)$ represent intermediate locations between A and B. The number of intermediate points is h, and only the points (x'_g, y'_g) must be encoded.

In the global geographic coordinate system xoy, ship-route coordinates are two-dimensional. By transforming from xoy to coordinate system XOY, the encoding redundancy is reduced. In XOY, the straight line between A and B is evenly divided along the X-axis into X_1, X_2, …, $X\ -1$. Under this transformation, route encoding is simplified into a one-dimensional encoding problem along the Y-axis. The detailed route-planning steps are as follows:

Step 1 Initialize the population. Using the optimal navigation-information set, construct the environmental map and select V×V grid points within the map. The generated route must pass through the centers of grid points and avoid all obstacle points.

Step 2 Determine whether the generated route is continuous. If the route is discontinuous, perform insertion processing to eliminate breaks. If the initial route is continuous, select a grid point adjacent to the route and insert a navigation segment. Before performing insertion, evaluate its fitness f. If the fitness value changes, the newly generated segment replaces the original one. To ensure continuity, deletion processing is applied to remove redundant route points and eliminate overlapping segments, reducing the number of nodes and improving the fitness f.

Step 3 Apply the roulette-wheel method to perform selection and obtain individual fitness values.

Step 4 Determine whether the maximum number of iterations Q_max has been reached. If Q_max is reached, proceed to Step 8; otherwise, continue to Step 5.

Step 5 Perform crossover and mutation operations. If crossover is successful, apply an optimization procedure and return to Step 4.

Step 6 Determine again whether the maximum iteration count Q_max has been reached. If so, proceed to Step 8; otherwise, return to Step 7.

Step 7 Perform population reconstruction and return to Step 6.

Step 8 Conduct smoothing operations by selecting midpoints between neighboring route points, denoted as H_1 and H_2. Connect H_1 and H_2 to form a smoothed navigation segment, reducing the ship's turning angle. This process is repeated four times to obtain the final smoothed planned route.

2.4 Design of the Ship Integrated Navigation Human-Computer Interaction Interface

Following the principle of usability, the design of the ship integrated navigation human-computer interaction interface focuses on meeting user requirements and improving operational efficiency. A usable interface enhances the interaction experience and supports effective ship-navigation tasks. The overall design process of the usable integrated navigation human-computer interaction interface is illustrated in Figure 3.

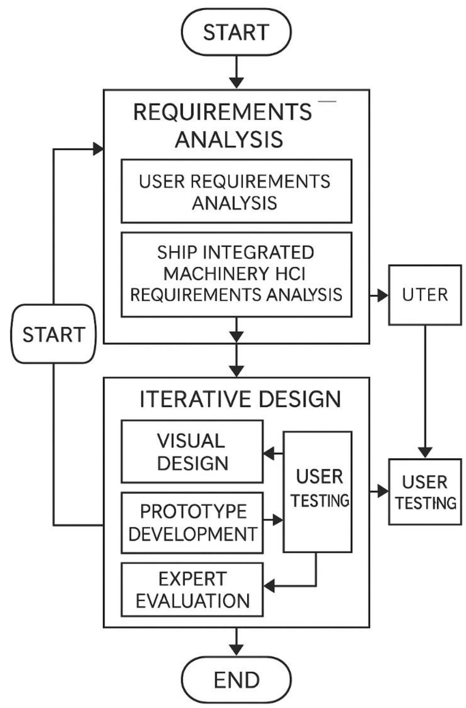

Figure 3. Design process of human-computer interaction interface for ship integrated navigation

3. Experimental Results and Analysis

A certain vessel was selected as the experimental subject. The ship integrated navigation A certain vessel was selected as the experimental subject. The ship has a length of 204 m, a width of 23 m, a displacement of 47 000 t, and a full-load displacement of 57 000 t. The integrated navigation human-computer interaction system proposed in this study was applied to this vessel to verify the effectiveness of the designed system.

After the application of the proposed system, the homepage of the integrated navigation human-computer interaction interface appears as shown in Figure 4. When the vessel approaches the target location, the operator can click the integrated navigation module button to obtain the navigation information collection results and complete the interaction process. The operational results of the integrated navigation module are shown in Figure 5. By analyzing Figure 4 and Figure 5, it can be seen that the proposed system effectively displays the module operation buttons and presents the ship's target location. After operating the integrated navigation module, the system successfully collects the ship's navigation data and compares the GPS-based geographic coordinates with the actual measured positions. The small deviation indicates that the system can accurately gather navigation data and provide prompts to inform the operator whether the navigation equipment is functioning normally. In cases where the navigation equipment is unable to operate properly, the system can issue alerts for maintenance, preventing reductions in data-collection accuracy.

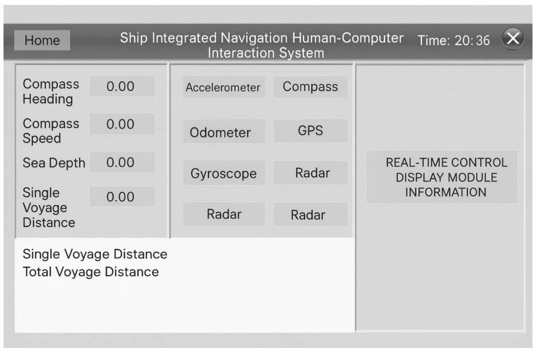

Figure 4. Home page of man-machine interaction interface system forship integrated navigation

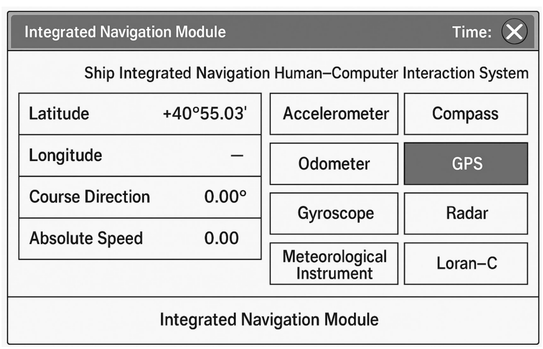

Figure 5. Operation result of integrated navigation module

The experimental results further show that the system enables efficient human-computer interaction for the integrated ship-navigation module, providing navigational convenience for vessel operators and helping them understand real-time navigation conditions. The mining results of the ship-navigation information and environmental information are shown in Figure 6. By analyzing Figure 6, it can be concluded that the system effectively extracts valid navigation and environmental information, and the mining results exhibit clear clustering boundaries without mixing. The experiments confirm that the proposed system can successfully mine and extract reliable navigation and environmental information.

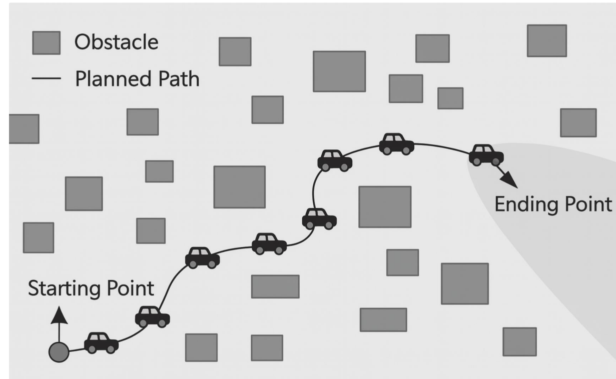

Figure 6. Mining results of effective ship navigation information and environmental information

The route-planning result generated by the proposed system is illustrated in Figure 7. By analyzing Figure 7, it can be observed that the system successfully completes the ship-route planning task. The planned navigation route effectively avoids obstacles, demonstrating that the system can reliably determine a safe sailing path. The results further indicate that the system can utilize the integrated navigation human-computer interaction interface to monitor the ship's navigation status in real time, thereby ensuring navigational safety.

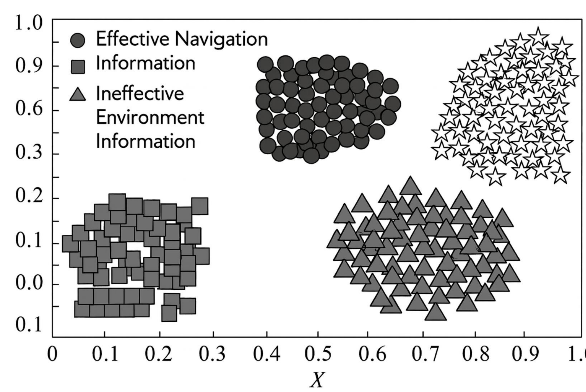

Figure 7. Ship path planning results

4. Conclusion

Human-computer interaction technology is one of the key factors that influence the overall performance of integrated navigation systems. High-quality interaction directly affects the efficiency of ship-navigation tasks. Therefore, this study designs an integrated ship-navigation human-computer interaction interface based on data-mining principles to enhance navigation effectiveness. The proposed system improves the performance of integrated navigation operations, enables crew members to obtain real-time navigation information, and helps them identify existing issues promptly. By doing so, unnecessary risks during maritime navigation can be avoided, ensuring the safety of ship operations.

References

[1] Song, R., Papadimitriou, E., Negenborn, R. R. and Van Gelder, P., "Safety and efficiency of human-MASS interactions: towards an integrated framework", Journal of Marine Engineering & Technology, vol. 24, no. 3, pp. 159-178, 2025.

[2] Curcio, J., Leonard, J., Vaganay, J., Patrikalakis, A., Bahr, A., Battle, D. and Grund, M., "Experiments in moving baseline navigation using autonomous surface craft", Proceedings of OCEANS 2005 MTS/IEEE, pp. 730-735, 2005.

[3] Bahr, A., Leonard, J. J. and Fallon, M. F., "Cooperative localization for autonomous underwater vehicles", The International Journal of Robotics Research, vol. 28, no. 6, pp. 714-728, 2009.

[4] Tian H., Ye Y. Big Data Clustering Analysis Method Based on Around-centroid Algorithm[J]. Application Research of Computers, 2020, 37(12): 3586-3589.

[5] Xuhong, T., Zhou, J., Shengjie, H., Sun, Y. and Luo, K., "Survey on Multi-Source Data Based Application and Exploitation Toward Smart Ship Navigation", Journal of Marine Science and Engineering, vol. 13, no. 10, p. 1852, 2025.

[6] Liu, R., Zhang, R. and Wang, S., "Graph Neural Networks for User Satisfaction Classification in Human-Computer Interaction", arXiv preprint arXiv:2511.04166, 2025.

[7] Xu, Y., Guo, Q., Tan, A., Xu, L., Tu, Y. and Liu, S., "Multi-objective route planning of museum guide based on an improved NSGA-II algorithm", Journal of Physics: Conference Series, vol. 1828, no. 1, p. 012051, 2021.

[8] Fallon, M. F., Papadopoulos, G., Leonard, J. J. and Patrikalakis, N. M., "Cooperative AUV navigation using a single maneuvering surface craft", The International Journal of Robotics Research, vol. 29, no. 12, pp. 1461-1474, 2010.