

Usability of Marine Geographic Information System Software for User Area of Interest Analysis Using Eye-tracking Equipment

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With the localization of S-100 standards-based marine geographic information system (GIS) software, it is necessary to develop user-friendly software suitable for various types of user expansion. In this study, the usability of S-100-based marine GIS localized software was demonstrated with the use of the marine GIS software under development using eye-tracking equipment. In this study, area-of-interest (AOI) analysis was performed for each user by setting a scenario for the use of the marine GIS software after selecting a manufacturer based on proficiency and making a wear eye-tracking sensor. Analyzing AOI enabled an evaluation of the usability of the main user interface of the marine GIS software.

1. Introduction

Korea is surrounded by the sea on three sides and requires a geographic information system (GIS) suitable for the domestic marine environment to accumulate marine information of a consistent scale and standard for the entire sea area.

GIS for land development and utilization has been localized GIS software by more than 70%, and there is no burden on companies to conduct R&D. However, marine GIS technology is dependent on foreign GIS.⁽¹⁾ From the perspective of maritime territorial management, GIS localization technology development is underway to collect, construct, and analyze scientific data reflecting domestic marine characteristics suitable for a real-time information processing environment.⁽¹⁾ Moreover, the International Hydrographic Organization (IHO) is developing product standards in various fields, including the S-101 next-generation electronic visibility standard based on the S-100 4.0 standard. The S-100 standard is a standard framework for data product specifications, which are standardized specifications for marine-related data such as bathymetry and seafloor topography.⁽²⁾ The main goal of the S-100 standard is to support a wide variety of ocean-related digital data sources, including imagery and gridded data, enhanced metadata specifications, and flexible maintenance schemes such as unrestricted encoding formats.^(3,4) This enables the development of new application software by advancing traditional

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sources of hydrographic information such as high-density bathymetry, seabed classification, marine GIS, and maritime limits. In general, the usability evaluation of software refers to quality control in order to accurately diagnose and evaluate the developed software and prevent possible accidents in advance.⁽⁵⁾ In addition, such usability evaluation is essential in software development with a focus on user satisfaction and software stability.

The S-100 standard enables the integration and utilization of various types of marine data beyond the constraints and limitations of the existing hydrographic data exchange standard, S-57. As a standard framework for data, the S-100 standard is for data product specifications, which are standardized specifications for marine-related data such as bathymetry and seabed topography. Each data product specification is based on the S-100 standard and includes, for example, a data model, an application model, metadata, and encoding standards.⁽⁶⁾ Data product specifications (Table 1) are developed through the standard production bodies of IHO, International Association of Marine Aids to Navigation and Lighthouse Authorities, and International Maritime Organization in accordance with the type of information. In Fig. 1, each standard is numbered S-10x, S-20x, S-30x, etc.⁽⁶⁾.

Currently, Korea continues to participate in IHO on a national basis and is an international leader in the standardization of next-generation electromagnetic properties. Unfortunately, there is a lack of research on practical and applied technologies, and standardization is completely dependent on foreign commercial software, as shown in Fig. 2.

Korea does not have its own marine GIS software and relies mainly on CARIS (Teledyne Geospatial CARIS Software) GIS software for major marine information management functions, such as data processing, seabed topography production, original map production functions, basic editing, and source input, and a few marine information utilization services that borrow terrestrial GIS technology.

Table 1
Product specifications under development or published by IHO.

No.	Title
S-101	Electronic navigational chart (ENC)
S-102	Bathymetric surface
S-103	Subsurface navigation
S-104	Water level information for surface navigation
S-111	Surface currents
S-121	Marine limits and boundaries
S-122	Marine protected areas
S-123	Marine radio services
S-124	Navigational warnings
S-125	Marine navigational services
S-126	Marine physical environment
S-127	Marine traffic management
S-128	Catalogue of nautical products
S-129	Under keel clearance management
S-130	Polygonal demarcations of global sea areas
S-131	Marine harbor infrastructure
S-164	IHO test data sets for S-100 ECDIS

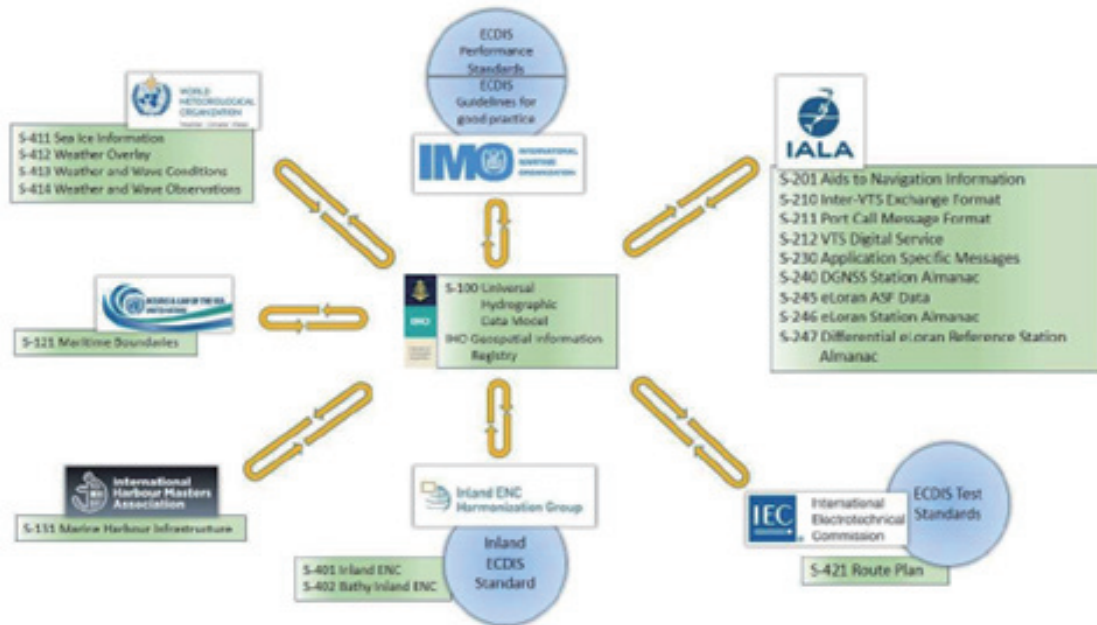


Fig. 1. (Color online) S-100 standard production organizations.

Type	Marine Information Processing	Basic Processing	Input Data	Editing
User	Hydrographic Engineer	Chart Engineer	Chart Engineer	Chart Engineer
Source Data	Data Processing Raw Data, Vertical Datum, Tide Correction, 1m DEM	Editing Marine Information System	Input Source Data Prototype of ENC	Drawing Chart HPD, Paper Chart, S-57 ENC, S-101 ENC
	Data processing and conversion	Review	Quality Inspection	Quality Inspection Paper Chart, S-57 ENC, S-101 ENC
Tools	Foreign technology Data Processing, caris, Edit ENC, A, AUTODO	Foreign technology Editing, caris	Foreign technology Input Source Data, caris, Quality Inspection	Foreign technology Drawing, caris, Quality Inspection
Application	Application of Editing ENC	Application of source input for ENC	Use to create ENC	E-Nav, Supporting MSP, Marine Information

Fig. 2. (Color online) South Korean marine GIS software depends on foreign technology.

In response to this problem, a localized marine GIS software based on S-100 is currently being developed to analyze domestic marine characteristics. With the introduction of marine GIS network standards for the civilian utilization of R&D achievements, a system is being built by freely combining a variety of middleware and engines with applications and web services of various functions. The purpose is to open, share, and utilize standardized data by providing web services, Open API, and APIs for electronic nautical charts and seabed topography produced using marine GIS and nautical charting technologies.

As shown in Fig 3. the goal is to share maritime information and the S-100 standard. Various navigation information and analysis services are provided to maritime-related service workers to enable policy making, system development, and the expansion of new services utilizing maritime information. To popularize the maritime information industry market and create an industrial ecosystem to enable private-company-led maritime services, we will expand the target audience of users to expand the usability of software from professional-oriented use to civil, academic, and research-oriented use in the future. The S-100 standard and the marine GIS software developed through it are being upgraded every year to meet the data product specifications.

The localization technology of marine GIS software will produce various software development outputs for civilian use in the future, and the quality evaluation of software verified for usability and expandability will be required.

In this study, we aim to identify usability issues with maritime GIS software using an eye tracker and find ways to improve them. An eye tracker is a sensor that focuses on the pupil of the

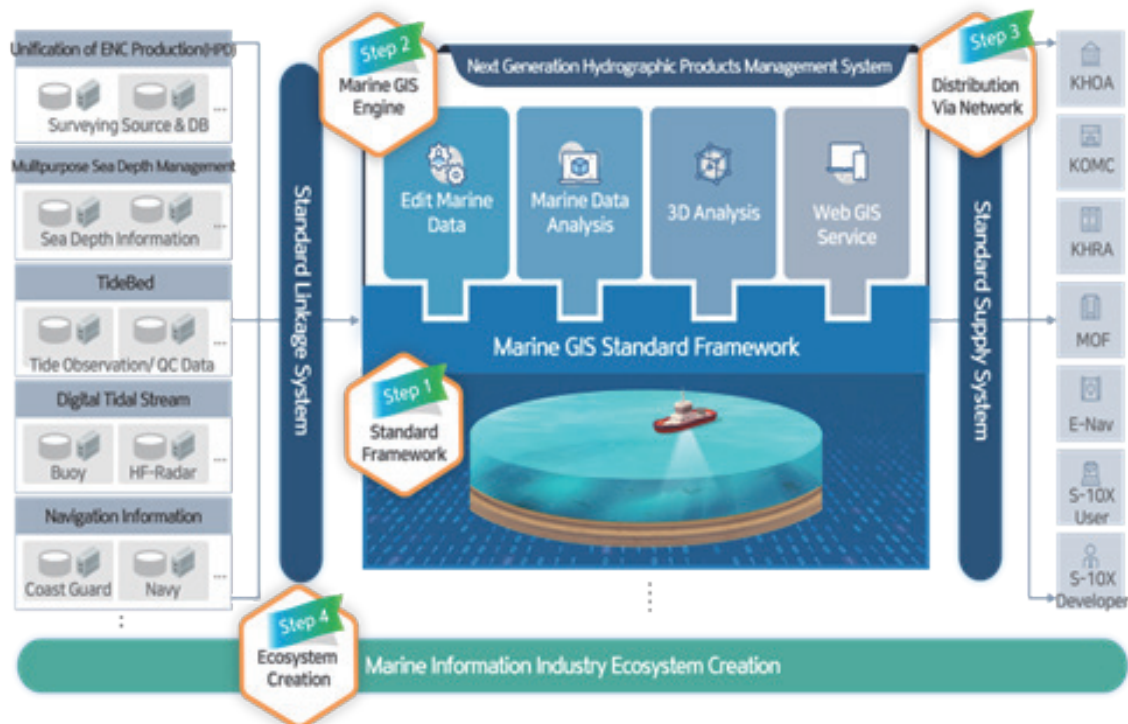


Fig. 3. (Color online) Usability extension process for Korean maritime GIS software.

participant's eye and determines the direction and concentration of the gaze by measuring either the distance to where the eye is focused or the motion of the eye.

While there are many studies in which similar experiments have been applied to numerous types of equipment and systems, in the marine GIS field, various graphical user interface (GUI) designs have been made by different manufacturers without considering the usability by cartographers. There are more than 30 different electronic chart display and information system (ECDIS) manufacturers in the market today, all with different GUIs. Eye tracking is widely used for user interface design, and its purpose and usefulness are not much questioned.⁽⁷⁾ If the goal of usability evaluation is to assess whether a user interface enables a human to carry out a specific task or operation, eye movements might provide valuable insight into the human behavior.

AOI was investigated by conducting experiments on the equipment functions included in the radar and ECDIS used in the ship's navigation tasks and the information displayed on the screen.

To improve the interface of navigation equipment, the results of experiments on a certain type of voyage simulation equipment to investigate the AOI of navigators while on duty were discussed. The results were analyzed by having two navigators perform scenario-based navigation simulations for about 20 min while wearing eye-tracking goggles. The equipment and AOI used by real-world sailors were previously studied to identify frequently used features and information.^(8–12)

2. Method

2.1 S-100 marine GIS software

In this study, e-navigation software refers to the software and e-navigation editor prototype. The main function of the software is to select the nautical chart to be edited and load it into the system. It is possible to select a file with the extension *.000 (S-101) to load into the nautical chart and control the nautical chart file. Point, line, and surface objects can be added and edited. The screen organization of the software is shown in Fig. 4.

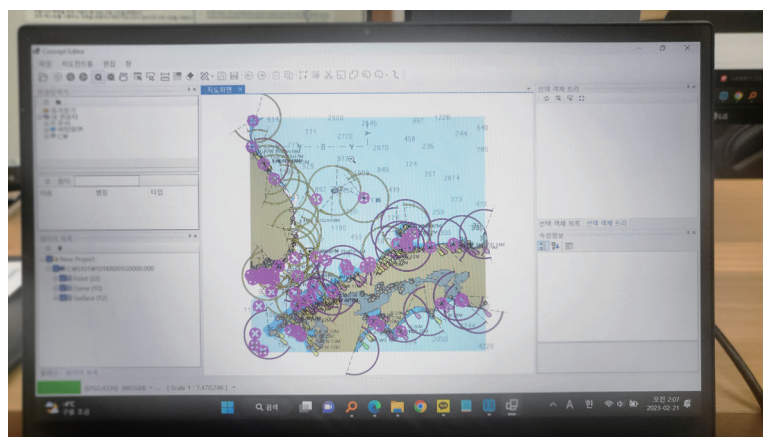


Fig. 4. (Color online) S-100 GIS software layout and main menu.

2.2 Analysis of AOI

The experimental equipment used in this study is shown in Fig. 5. The eye tracker was Tobii-pro-glasses 3. The device consists of eye-tracking goggles and a control unit for storing gaze dates.⁽¹³⁾

To improve the usability of S-100-based marine GIS software, in this study, we aimed to understand whether users' eyes are drawn to the features and work areas of the software used in daily work. The test was based on the following planned scenarios: a novice nautical technician and an experienced nautical technician participated in the experiment, and performed the intended tasks on the basis of the basic scenario shown in Table 2 to test the performance time and observation results.

Application scenarios were created on the basis of the basic scenario to measure the usability of the software. The usability of each application scenario was measured by adding specific scenarios for distance and area measurements in measurement function No. 6 of the basic scenario in Table 2. The specific scenarios are shown in Fig. 6, where the distance between Ulleungdo and Dokdo was measured, and in Fig. 7, where the area of Jodo Island in Yeongdo-gu, Busan was measured. The main measurement scenarios are editing point, line, and area objects, and scenarios 11 through 14 were performed for each object. Editing point, line, and plane objects is similar to adding properties. The main measurement scenario is a function that reflects

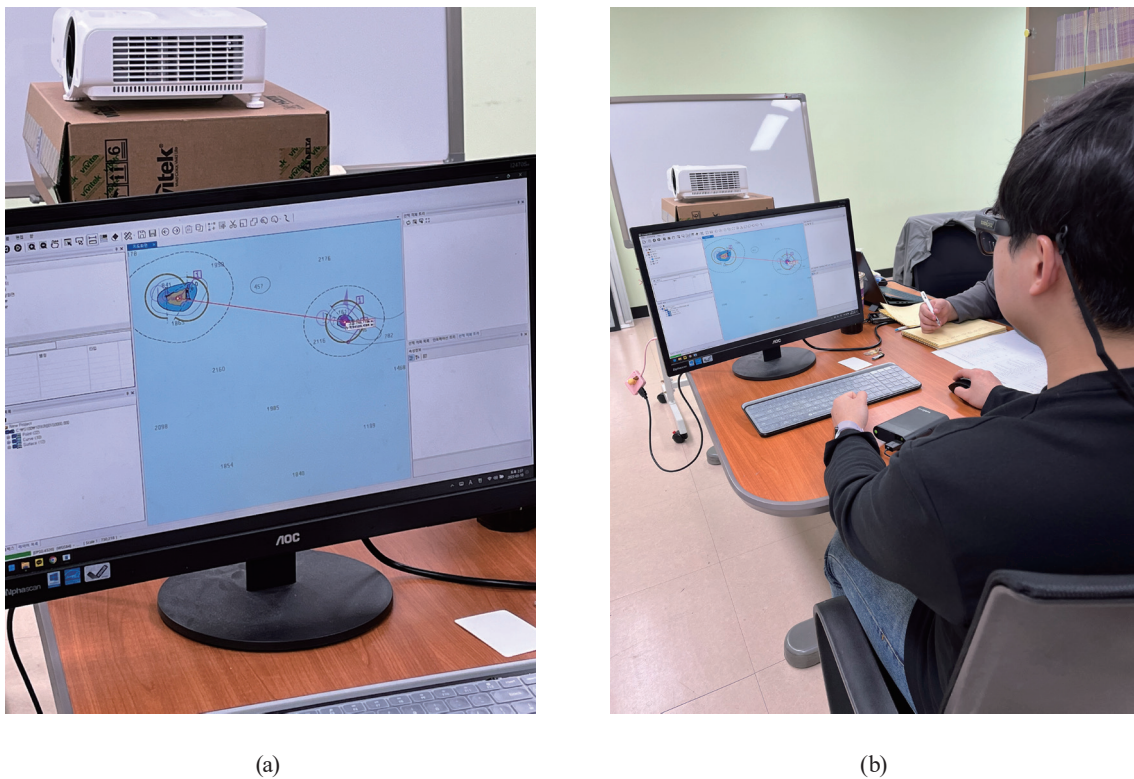


Fig. 5. (Color online) (a) Device screen for experimentation and (b) experiment with Tobii pro glasses.

Table 2
S-100-based marine GIS software test scenarios.

Category	Function	Test scenarios
1	Use main user interface	1. Main screen description - Menu area, toolbar area, layer (explorer) area - Dataset, selection object information, attribute information area
2	Open the electronic nautical file selection	1. Select a path using a file explorer (open) 2. Check selection file list 3. Add files to layer
3	Open FC/PC	1. Select the file path in the settings 2. Select FC/PC used
4	Zoom in/out, move map	1. Zoom using the mouse wheel 2. Left-click map by selecting map movement; right-click map movement
5	Select object	1. Select an object by specifying an area by clicking or dragging the mouse 2. Check the information of the object in the selected location 3. Check the information of the selected object
6	Use measurement function	1. Distance/area measurement - For distance measurement, select more than one point - Select three or more points for area measurement - Double-click the final point. 2. Initialize the distance/area measurement result screen
7	Edit start/end	1. Click the edit start button 2. Enable the edit button 3. Exit the edit mode - Confirm save before shutdown - Save and exit *Save editing history to that file
8	Add point objects	1. Select additional objects 2. Select the point tab and select the object 3. Add points 4. Create object 5. Input attribute information (complete upon completion of attribute information change)
9	Add linear objects	1. Additionally select linear objects 2. Select line object 3. Designate the starting point 4. Add points (two or more locations) 5. End the final point selection input by double clicking 6. Create ship objects 7. Input attribute information (complete upon completion of attribute information change)
10	Add area object	1. Select add area object 2. Select area object 3. Specify the starting point 4. Add points (at least three positions are required) 5. Double-click to end the final point selection input 6. Create an area object 7. Enter attribute information (complete when attribute information change is completed)
11	Add object properties	1. Select object 2. Select list property information by mouse right button click 3. Select add property 4. Enter property information
12	Edit attribute	1. Select objects 2. Change the properties

Table 2
(Continued) S-100-based marine GIS software test scenarios.

Category	Function	Test Scenarios
13	Move an object	<ol style="list-style-type: none"> 1. Select object movement 2. Select object 3. Move objects with a mouse click
14	Delete object	<ol style="list-style-type: none"> 1. Select object deletion 2. Select object 3. Delete objects
15	Edit vertex	<ol style="list-style-type: none"> 1. Start editing vertex (select any linear/plane object) 2. Add vertex - Select/delete vertex - Select/move vertex
16	Split object	<ol style="list-style-type: none"> 1. Select an object (select any linear/plane object) 2. Draw a line where you want to split the object 3. Segment object
17	Merge objects	<ol style="list-style-type: none"> 1. Select object merge 2. Select objects to merge 3. Merge objects
18	Buffer object	<ol style="list-style-type: none"> 1. Select object buffer 2. Select the object to apply the buffer 3. Drag and drop by applying a buffer
19	Add hole object	<ol style="list-style-type: none"> 1. Select additional hole object 2. Select the object to add a hole 3. Add a hole figure to the object
20	Edit hole object	<ol style="list-style-type: none"> 1. Select hole object decomposition 2. Select objects to decompose 3. Decompose holes in selected objects
21	Edit spline	<ol style="list-style-type: none"> 1. Start editing spline 2. Select edit line 3. Specify the edit position 4. Choose an editing location 5. Quit editing with spline
22	Execute/cancel	<ol style="list-style-type: none"> 1. Redo/undo

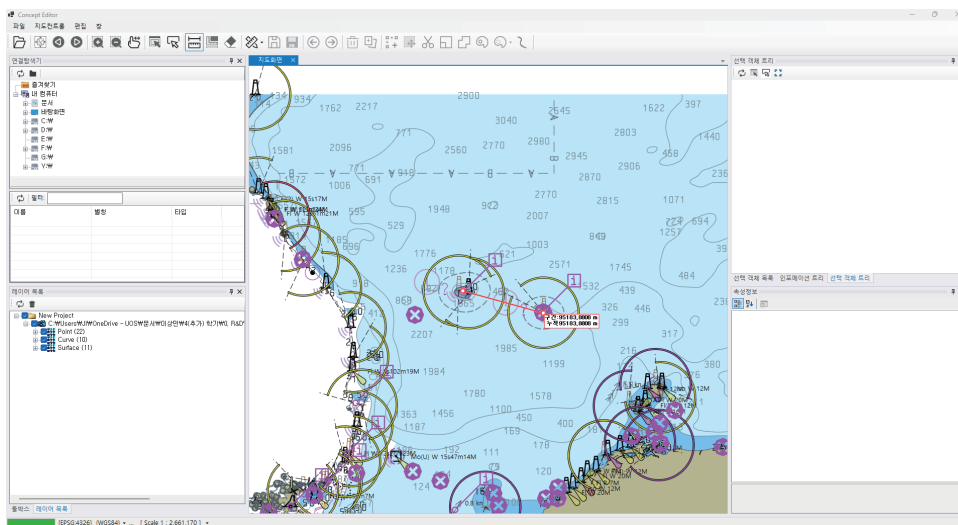


Fig. 6. (Color online) Measurement of distance between Ulleungdo and Dokdo.

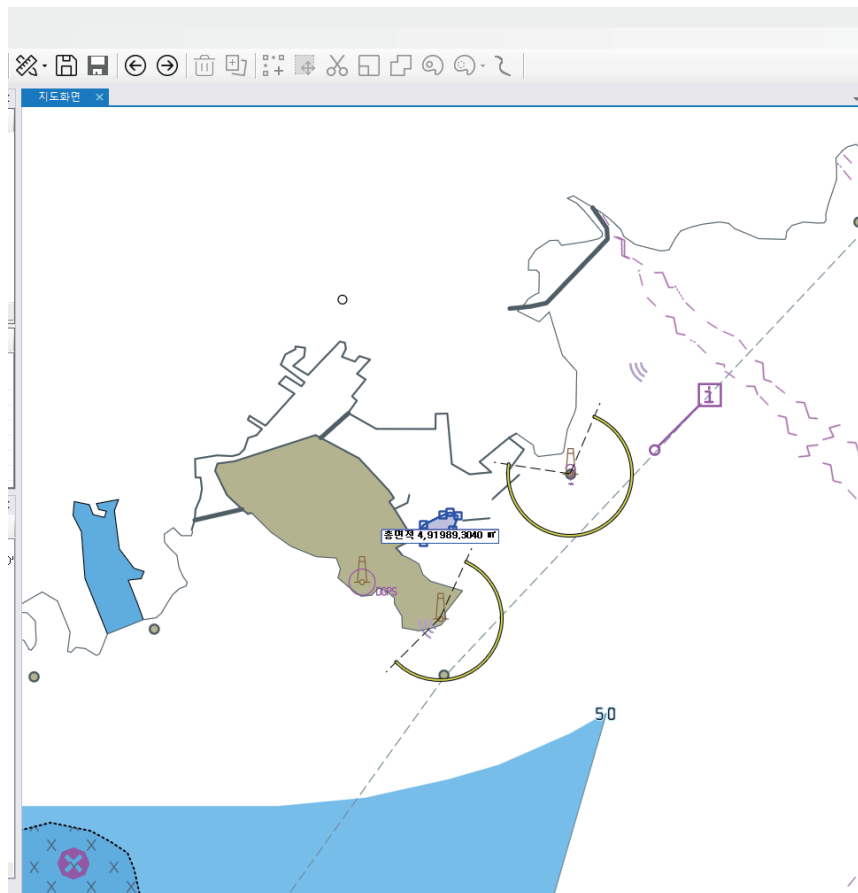


Fig. 7. (Color online) Measurement of illuminated area in Yeongdo-gu, Busan.

the characteristics of the ocean, and the common functions of editing point, line, and plane objects correspond to adding attributes, checking and editing attribute information, and moving and deleting objects. Face objects can be split and merged, and face object editing functions include editing splines, adding and deleting holes, and splitting and merging face objects.

2.3 Application test scenarios

The distinctive characteristics of marine GIS software are the implementation of feature and attribute management using the definition of feature catalogue (FC), and the implementation of depiction information management using the definition of portrayal catalogue (PC). Marine GIS features include map adjustment, screen display, and measurement functions in screen control. In addition, there are layer management and spatial data attribute management functions and characteristics. As shown in Fig. 8, the core features of marine GIS software are spline layer support, arc support, depth notation support, and symbol support for nautical charts.

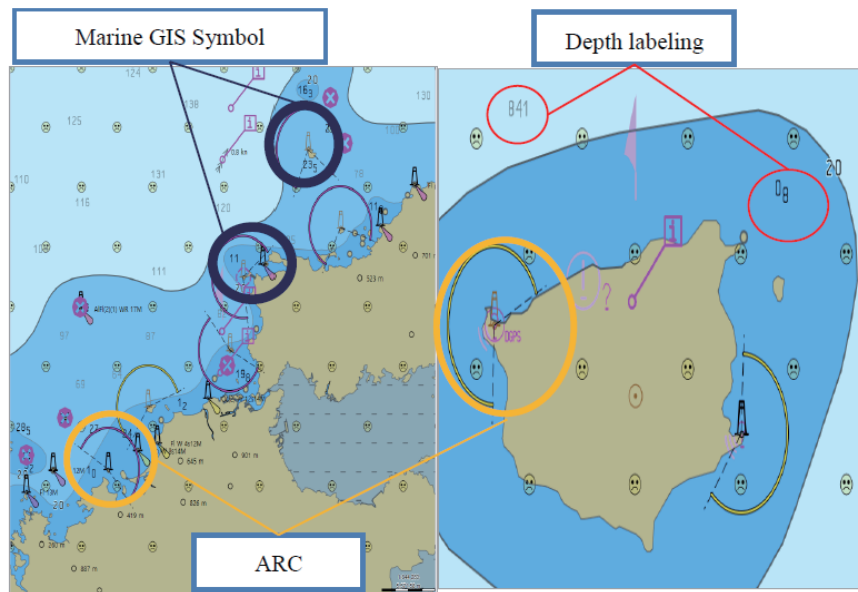


Fig. 8. (Color online) Marine feature styles.

3. Discussion

Figure 9 shows a heat map of AOI on the S-100 GIS software screen. Heat maps are visualizations and representations of the eye tracking data, and could also be defined as the presentation of the spatial distribution of eye-movement data.⁽¹⁴⁾ Examples of attention maps are heat and focus maps. These attention maps are generated by the eye tracking software. Heat maps show areas with many fixations, or data samples are highlighted with warm colors (red) and regions with less data are marked with colder colors (yellow).

This figure shows that at the time of the experiment, the heat map on the screen was centered on the area where the map was displayed, and editing was performed. Operations are mainly performed on the picture area rather than text. The next area that is mainly checked is the area where the list and information of the selected object can be checked. It is considered that the main gaze area was formed because the object selection list was partially undeletable at the time of the scenario test, and the object selection operation was executed by selecting the exact center of the symbol.

Figure 10 shows the number of eye movements in AOI. The advanced nautical technician had 470 forward and backward eye movements, whereas the novice nautical technician had 250 forward and backward eye fixations. When there was a delay or error during the scenario demonstration, the gaze remained in one place. Therefore, it can be concluded that the higher the proficiency level, the more focused the gaze and the better the understanding of the exact function of the software behavior.

Analyzing the gaze plot shown in Fig. 11 reveals differences in nautical charting behavior between experienced and novice chartists. The circles indicate where the gaze lingers, with fewer circles indicating less time spent. Also, larger circles indicate a longer

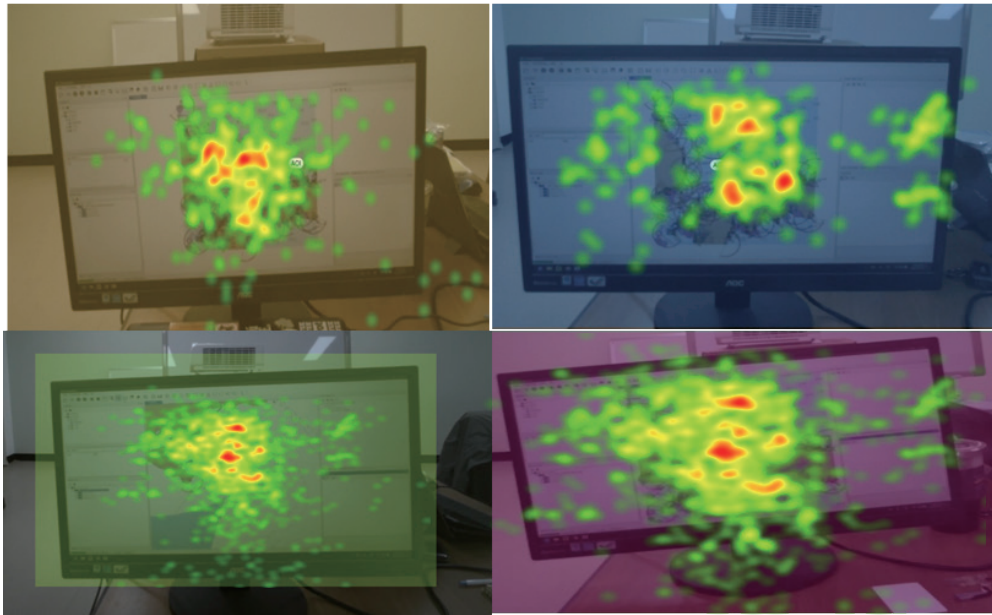


Fig. 9. (Color online) User AOI on S-100 GIS software screen.

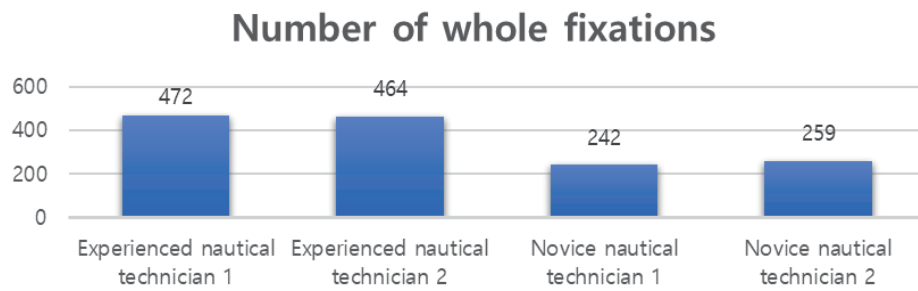
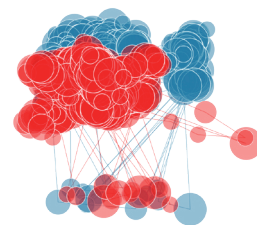


Fig. 10. (Color online) Comparison between experienced and nautical technicians in terms of number of fixations.



(a)



(b)

Fig. 11. (Color online) Gaze plot when using S-100 GIS software.

gaze duration.⁽¹⁵⁾ The red and blue colors in the left figure indicate that the advanced nautical chartist has a short gaze duration and is utilizing a large amount of information. The green and light blue colors in the right figure indicate that the novice nautical chartist is looking at the screen for a long time and has a high input time delay on the keyboard used to enter information.

4. Conclusions

In this paper, we presented the results of an experiment with an eye-tracking device to investigate AOI in order to improve the interface of S-100-based marine GIS software. We analyzed the results of a scenario-based software simulation with two navigators wearing goggle-type eye trackers. The scenarios were based on the basic operation of the nautical chart editor and application scenarios, and the obtained results were analyzed. In the experiment, we analyzed the AOI of the software features used by the nautical chart maker, and as a result, it was possible to identify the frequently used features and information. However, this experiment is limited by the small number of subjects, and because it is based on test scenarios, it is possible that the differences between experts and novices may disappear when the test is repeated. This result can be used as a basis for research on whether the software provides many functions and information displays, but is conveniently arranged for use by nautical chart producers or developers, and is considered to help improve the usability.

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References

- 1 S. Lee, T. Choi, J. Kim, and Y. Choi: *J. KAGIS* **25** (2022) 17. <https://doi.org/10.11108/kagis.2022.25.3.017>
- 2 S. Lee, Y. Choi, J. Kim, B. Min, and W. Lee: *JDCS* **22** (2021) 1. <https://doi.org/10.9728/dcs.2021.22.8.1351>
- 3 S. Contarinis, A. Pallikaris, and B. Nakos: *J. Mar. Sci. Eng.* **8** (2020) 564. <https://doi.org/10.3390/jmse8080564>
- 4 S. Contarinis, B. Nakos, L. Tsoulos, and A. Palikaris: *J. Navig.* **75** (2022) 763. <https://doi.org/10.1017/S0373463322000327>
- 5 J. Jung, M. Jung, and S. Lee: *J. DCS* **19** (2018) 2019. <https://dx.doi.org/10.9728/dcs.2018.19.10.2019>
- 6 IHO S-100 Universal Hydrographic Data Model: <https://iho.int/en/s-100-universal-hydrographic-data-model>
- 7 F. Bjørneseth, L. Clarke, M. Dunlop, and S. Komandur: *Human Factors in Ship Design and Operation* (2014). <https://doi.org/10.3940/rina.hf.2014.17>
- 8 J. Jung, M. Jung, and S. Lee: *J. DCS* **19** (2018) 2211. <https://dx.doi.org/10.9728/dcs.2018.19.11.2211>
- 9 J. Kim, S. Lee, and M. Jung: *J. Mar. Sci. Eng.* **9** (2021) 57. <https://doi.org/10.3390/jmse9010057>
- 10 M. Jung and S. Lee: *Sea Technol.* **61** (2020) 25. <https://sea-technology.com/archives-2020>
- 11 S. Lee and M. Lützhöft: *Sea Technol.* **61** (2020) 18. <https://sea-technology.com/archives-2020>
- 12 H. Kim, C. Moon, and S. Lee: *JDCS* **19** (2018) 1. <https://doi.org/10.9728/dcs.2018.19.7.1289>
- 13 Tobii: *User's Manual Tobii Pro Glasses 3* (2016).
- 14 O. S. Hareide, R. Ostnes, and C. F. V. Mjelde: *Understanding the Eye of the Navigator* (2016). https://www.researchgate.net/publication/313449343_Understanding_the_Eye_of_the_Navigator
- 15 N. Debnath, M. G. Peralta, C. H. Salgado, L. Baigorria, D. Riesco, G. Montejano, and M. Mazzi: *EPiC Ser. Comput.* **75** (2021) 11. <https://doi.org/10.29007/1gnk>

- 16 J. Franca and S. Soares: *Int. J. Enterpr. Inf. Syst.* **1** (2015) 60. <https://doi.org/10.5220/0005369100600070>
- 17 N. Debnath, M. Peralta, C. Salgado, L. Baigorria, D. Riesco, G. Montejano, and M. Mazzi: *EPiC Series in Computing* **75** (2021) 11. <https://doi.org/10.29007/1gnk>
- 18 H. Sim, Y. Son, C. Son, C. Yoo, S. Jun, and W. Lee: *KSCG* **27** (2014) 1. <https://doi.org/10.22819/kscg.2014.27.3.025>
- 19 G. Vieira and F. Mandarino: *IHR* **26** (2021) 39. <https://journals.lib.unb.ca/index.php/ihr/article/view/33119/1882528476>
- 20 <https://journals.lib.unb.ca/index.php/ihr/article/view/33119> (accessed November 2021).

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