TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 19
Number 3
September 2025

DOI: 10.12716/1001.19.03.09

Analysis of Boat's Operator Action Using Gaze-data

N. Yoshida[1], Y. Imai[2], K. Minami[3] & H. Seta[2]
[1] *National Institute of Technology, Toba College, Toba, Japan*
[2] *Tokai University, Tokyo, Japan*
[3] *Tokyo University of Technology, Tokyo, Japan*

ABSTRACT: In Japan, obtaining a small boat operator's license requires both theoretical and practical training, as well as mandatory renewal courses every five years. However, many operators have limited practical experience, making safe navigation a challenge for beginners. This study aims to analyze the differences in gaze patterns between novice and experienced operators using eye-tracking technology, highlighting key behavioral distinctions. Eye tracking data was collected from 14 operators, including novices and experienced individuals. Gaze movements were recorded in a 360-degree field of view to measure gaze duration and frequency. Heatmaps and grid-based Areas of Interests (AOI) were generated to analyze patterns of gaze shifts and movement directions. The results indicated significant differences in gaze behavior, field of view, memory retention, and decision-making between novice and experienced operators. Experienced operators process information more efficiently, leading to safer navigation, whereas novices exhibit narrower focus and slower reaction times. Integrating eye tracking data into training programs can enhance beginners' navigation skills.

1 INTRODUCTION

In Japan, to obtain a driver's license, most people take over 24 hours of classroom instruction and over 31 hours of practical instruction, as well as examinations. To obtain a first-class boat operator permit, you must have over 24 h of classroom instruction as well as 12 h of practical instruction. In addition, a renewal class is necessary every five years for both driver's license and boat operator permits. In Japan, people must pass an exam for a small boat and obtain permission from the boat's operator. People study written lessons for more than 24 hours with on-board training, and they maneuver small ships with less than 20 gross tonnages. Operators must take lessons for the renewal permits every five years. It is difficult for operators to practice with experts after passing an examination. The novices cannot steer well, assess weather information, do safety-checks, and look out for safety navigation in case of "something wrong." I analyzed the movement, time, and frequency of gaze-plotting during steering due to being a novice, similar to experts. None of the groups used glasses. In this study, the gaze plot was defined as the point at which the operator looked hard. I considered the operators' improved performance, what they were interested in, and where they looked from gaze plotting. In the European Union, there is no uniformity in obtaining a permit to operate small vessels, except for fishing boats; in many cases, especially small boats and yachts, a permit for a small boat is not required. [1] In this study, the operators were placed on eye-tracking devices. My purpose is to determine where and when operators steer and look out during the maneuvers. Figure 1 shows a small experimental boat," AKEBONO," belonging to NIT, TOBA College in JAPAN. (LOA= 6.62 m, B= 2.56 m, G/T= 2.8 tons)

1.1 *Defined Lookout*

Lookout is defined by the international and domestic regulations in each country. Look-out by COLREG is to the COLREG, seafarers aboard every vessel shall always maintain a proper look-out by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions to make a full appraisal of the situation and the risk of collision. As mentioned above, the role, importance, and job descriptions of watchkeeping in merchant vessels were explained. However, the implementation method is explained only in terms of international conventions, and no specific examples are provided. [2] Although not found in general merchant vessels, the following description of the lookout method in the U.S. Navy was found. It explains that effective visual searching does not come naturally; a lookout must learn through practice and allow your eyes to move in short steps from object to object, and you can really see what is there. [3][4]

1.2 *Boat on Instruction Manual in JAPAN*

We researched how operators should LOOK OUT instruction manual. The instruction manual for the small boat renewal course states that the operator must always maintain a proper lookout, in accordance with maritime regulations, to determine whether a collision is imminent or to assess the vessel’s surrounding conditions. Looking Out is always performed at sea, such as anchoring, stopping, and sailing. A safety Check was performed before performing the different actions. Operators are required to monitor the vessel’s current position while anchoring, stopping the engine, and sailing. Their actions include starting the engine, adjusting speed, changing course, and other maneuvering tasks. Operators learn lookout procedures from instructional materials designed for instructors, which emphasize that "the captain must check the surroundings and maintain a lookout in accordance with maritime regulations, considering the risk of collision with other vessels." Maintaining a proper lookout is essential during mooring, anchoring, and sailing. A safety check must be conducted before any maneuver and includes confirming the vessel’s current position while at anchor, with the engine stopped, or under way. The movements of the operators are defined as” Ahead Engine”, ” Alternative Speed,” and” Changing Course.”

Figure 1. Experimental small boat “AKEBONO”

1.3 *License and Training in JAPAN*

In Japan, to obtain a driver’s license, most people take over 24 hours of classroom instruction and over 31 hours of practical instruction, as well as examinations. To obtain a first-class boat operator permit, you must have over 24 h of classroom instruction as well as 12 h of practical instruction. In addition, a renewal class is necessary every five years for both driver’s license and boat operator permits. In the classroom, trainees study the responsibilities of a captain, traffic rules, and general maneuvering; in practical instruction, they receive training about checks before departure, basic handling, and advanced handling.

2 METHOD OF ANALYSIS

Eye tracking was used as a method to measure the behavior of the operators. Eye tracking was chosen as a means to investigate the direction and object that the operators were paying attention to. Previous studies of automobiles and aircraft using eye tracking have investigated the field of view, experience, and eye tracking movement of automobile drivers.[5][6][7] As eye trackers become small and remote, we could easily measure on small vessels, and Sematic Gaze Mapping allows the operator's behavior to be visualized. [10]

The measurement in this study is the method of the following.

1. Twenty operators participated in the measurements. There were two groups: novices and experts.
2. Operators wearing gaze-plotting tools maneuver at the port.
3. The gaze plot of the operators draws a view of 360°.
4. Time and number of gaze plots were calculated from the recorded data.
5. The operators heard about their movements from the recorded data.
6. The heat maps and grid AOI were calculated from the gaze-plotting data.
7. The order of the gaze plotting was calculated.

The directions from the small boat were” front,”” left, ”” left back,”” right,”” right back,” and” back,” every 60 °, as shown in Figure 2. The novices had the First or Second Permit of the Boat’s operator within two years, and the experts had the First Permit of the Boat’s operator with their duties. The training teacher stood for safe navigation as she always steered during the measurement.

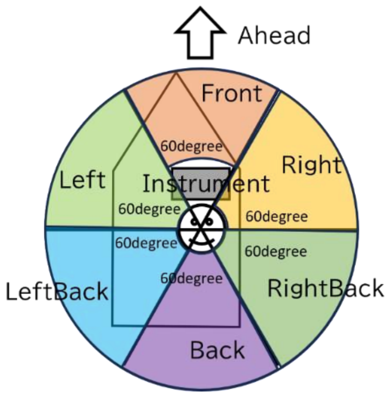

Figure 2. Boat’s direction in this experiment

3 RESULT OF ROUTE AND TIMELAPSE

Position data were obtained from GPS data. Time-lapse data were calculated from gaze-plotting data.

3.1 *Introduction to the entire route*

The route in this measurement was shown in Figure 3 and was explained below.

1. The operators check the crossing of the municipal ferry and the same- and opposite-course vessels after starting. There is an island on the port side.
2. The operators check the municipal ferry from port side to port side in narrow areas halfway around this route.
3. The area to end around this route is a larger area in which the operators check the position of the other ships.
4. Figure 4 and Figure5 showed the result that one of them steered when and for what purpose.

Figure 3. Testing route in this experiment

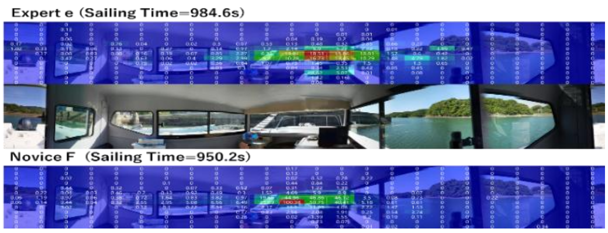

Figure 4. Heat map in Novice and Expert

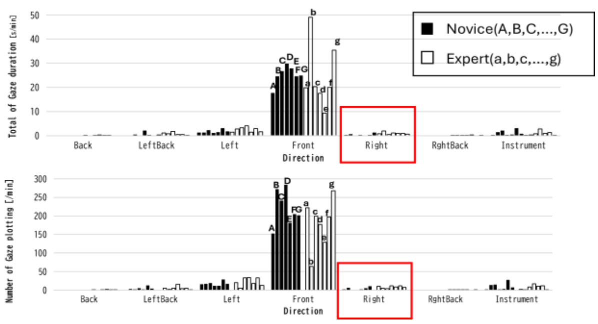

Figure 5. Total of gazing time and number of gaze plotting

3.2 *Introduction to area SA: from point S to point A*

The SA area lies between points A and point B in figure 3. This area has the following characteristics.

1. The SA is a route for ferries and other ships. There are many crossings, the same course, and opposite course ships.
2. The experts navigated the center of the sea area due to the island on the port side.
3. Novices navigate the starboard side of the sea area.

The experts observed other ships rather than shallow areas, and the novices observed shallow areas rather than other ships.

3.3 *Introduce to the area AB: from A to B*

Area AB lies between points A and B in figure 3. This area has the following characteristics.

1. Area AB is a narrow, curved route. The operators navigated near SAKATE Island.
2. The experts alternated faster than the novices off the Maruyama saki lighthouse and the novice alter quickly. The experts had enough time to steer in the narrow sea and navigate the port side off SAKATE Island.

3.4 *Introduce to the area BG: from B to G*

1. The operators move straight between B and G and search for Point G.
2. Operators navigate the best route. Each operator chooses a different route.

Operators steered to the surroundings of the large sea. The heat maps of the experts and novices were compared. I cannot understand the characteristics of the two groups because of the large red area, where the operators watch the gaze point for a long time. I made the Grid AOI the operator's gaze point area.

- The novices had a smaller gazing range in the upper direction. The experts gazed at three areas from the front, while the novices gazed at two areas from the front.
- The novices gazed at the nautical instruments for a longer time than the experts. Boat operators require physical standards .
- Even if the visual acuity of one eye is less than 0.5, the other eye must have a visual field of 150 degrees or better in both directions and a visual acuity of 0.5 or better.
- Visual acuity must be 0.5 or better in both eyes.

As the inspection standards were seen, the standards for boat operators are based on eyesight. Therefore, it is important for the operators to gaze over a certain range and observe what they can see. According to the permit standard, for an operator to progress, or she must be able to see over a large area and have eyesight to obtain the necessary information for navigation. Experts are more skilled than novices because they see a larger area.

4 RESULT OF GAZING POINTS.

The heat map Results are shown in Figure 4. The color was purple when the gazing time was long, and blue when the gazing time was short. The novices and experts are shown in purple on the front side. This shows that they looked forward to the front most often. Since the heat map was not provided numerical results, the area was divided the area of the eyesight range into a grid to evaluate the gaze time and frequency in each direction. The number of gazes and the gazing time were calculated for each area. The characteristics of each operator are described in the following subsections.

4.1 *Result of gazing time and number of gazing points.*

Since there were no significant differences between the two groups in gaze duration and the number of gaze points in each direction, except for the "Port side," the number of gaze transitions between directional pairs were analyzed, as shown in Figure 5 and Table 1. Table 1 confirms the absence of significant differences between the practitioner (faculty) and novice groups. During maneuvering, operators primarily directed their gaze toward the front, starboard, and other surrounding areas; however, in an actual operation, the operator is not looking at each side only, but rather, in relation to each other, monitoring how the surrounding situation changes over time. Because the situation changes from moment to moment, the subject must pay attention not only to the front, but also to each direction. Therefore, in this analysis, in addition to the calculation of the number and duration of the gazing point, the number of times, and for each direction, the gazing point that moved between the seven directions was calculated.

1. Novices and experts performed the same number of movements from A to B.
2. The gaze point moves from the front side to the other side and from the other side to the front side of the AOI.
3. There were many instances where the expert's gaze point moved from the port side to the front side.
4. Numerous times, the novice's gaze point moved from the nautical instrumental side to the front.
5. The experts looked forward to the nautical instrumental side for a shorter time than the novices. The gaze point of the expert moved between the port and the front sides many times.
6. One of the expert groups with a license for practical instruction on boats maneuvered once a week on another vessel using this measure.
7. To understand the operator's determination, the results of the time-lapse gaze data were used to measure the operator's intention when gazing in a direction other than in front of the operator.

5 RESULT OF HEARING EVERY MANEUVER

The expert kept watching the wide area and explained the object that he looked at. They were able to understand their behavior while maneuvering and explain their performance. They remembered their maneuvers, other ships, surroundings, weather, sea conditions, the objects on the sea, and their feelings in Figures 6, 7, and 8. Novices carry out lookouts for small areas, and they cannot look at other ships, buoys, or objects on board. They cannot decide whether other ships, buoys, or objects are dangerous to their boats. They believe that boat operators have many tasks, so novices do not notice something that is too dangerous or prevent it. Many novices cannot understand the behavior they perform or explain their maneuvers.

Table 1. Significant difference each direction

Number of gazing points

	Back	LeftBack	Left	Front	Right	RightBack	Instrument
All	×	×	×	×	○	×	×
SA	×	×	×	×	×	×	×
AB	×	×	×	×	×	×	×
BG	×	×	×	×	○	×	×

Gazing times

	Back	LeftBack	Left	Front	Right	RightBack	Instrument
All	×	×	×	×	○	×	×
SA	×	×	×	×	×	○	×
AB	×	×	×	×	×	×	×
BG	×	×	×	×	×	×	×

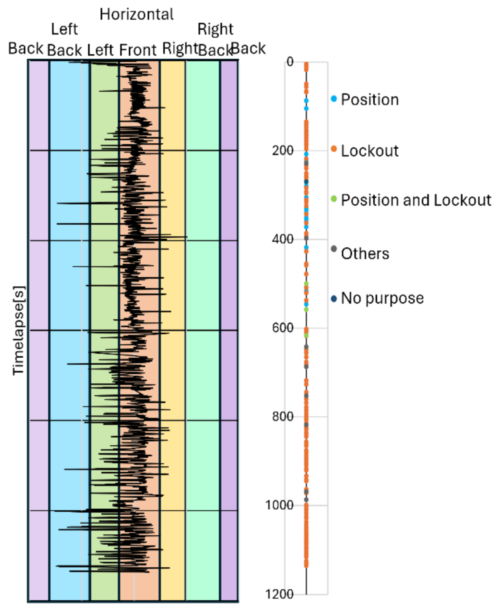

Figure 6. Behaver of the novice's horizontal gazing point and his purpose

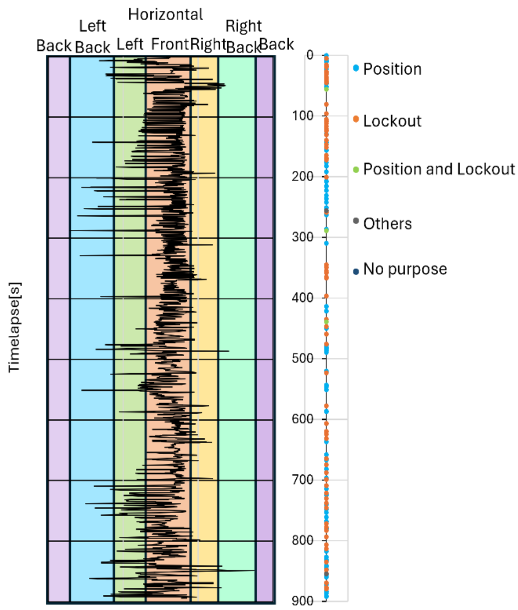

Figure 7. Behaver of the expert's horizontal gazing point and his purpose

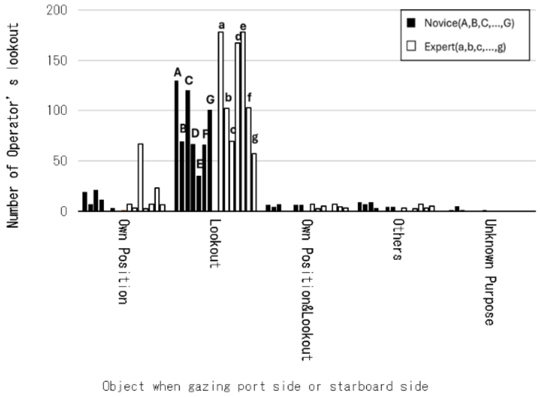

Figure 8. The purpose of operator lookout to port side and starboard side

6 DISCUSSIONS

The table shows the difficulty levels for each area: SA, AB, and BG. The characteristics of each area are as follows.

1. A larger value is more difficult to obtain, whereas smaller values are easier to obtain.
2. Evaluation items included information on the navigable area, weather, sea conditions, and own vessel speed, and on other vessels: number, congestion, size, type, and distance from the vessel.
3. Because there are linear vessels and ports in the SA area, inland vessels often arrive and depart from ports. The largest vessels were in the BG area because the BG area has the largest SG area. The characteristics of the novices and experts in maneuvering during hearing research are presented in Table 2.

From 7 persons to 10 persons applied d to “○”, from 4 persons to 6 persons applied to “△”, and from 0 persons to 3 persons applied to “×” in every content. The contents were as follows: remembering how I maneuvered, explaining why I performed that maneuver, remembering where I altered the course after this voyage, prioritizing maintaining speed, checking something unrelated to the maneuver, asking about that course during the maneuver, and checking the surroundings during the maneuver. The experts were able to remember and explain the maneuvers and reasons for performing them. First, they responded that they could hardly remember the event; however, when they viewed the video of the maneuver, they recalled their behavior and were able to provide an account of the event and their intentions during the measurement. In the beginning, they responded that they could hardly remember the maneuver, but when they watched the record of the maneuver, they explained their behavior and were given an account of the event and their intentions. However, after that maneuver, the novices could not remember much about the maneuver or explain their steering. According to them, they could avoid objects with the steering wheel but could not remember the maneuvers. The experts can provide information about their ships and surroundings. However, the novices had little experience. Novices do not have a good order of priority for steering information to understand their navigational surroundings. Although they could assess the state of the boat at the time of measurement, the necessary information at the time was not utilized.

7 CONCLUSION

This study analyzes operators’ maneuvering and behavior using a gaze-tracking device. Gaze data were collected from 14 operators licensed for less than two years and eight faculty members licensed for more than three years while they navigated a designated route. Because there was a significant difference in gaze duration and frequency when looking to the left, the front direction was divided into finer grids than those used in the heat map. Time and frequency of gaze were then analyzed within these detailed areas. A comparison of gaze point distribution showed that faculty members had a wider range of gaze points lasting more than one second. In the interview with the operators on viewing the measurement data, the novices did not remember their behavior and maneuvering. When reviewing the recorded footage, the experienced operators were able to explain their actions and intentions, whereas the novices were not. In the analysis of the sequencing gazing point, the experts gazed at the port side more frequently than the novices, and there were significant differences in the time and number of gazing points. In the analysis of the gazing point, it was found that the experts gazed at the instruments more frequently, while the novices gazed at the instruments for a longer time. This is in accordance with previous research on high-speed sea navigators and car drivers.[9][10] Students required more time to understand the information. When the measurement data were reviewed for each operator, it was found that some novices had prior experience maneuvering boats in their personal lives. Compared to novices who had not operated a boat since obtaining their license, these individuals focused more on the front, instruments, starboard, and port sides. They also spent more time looking at, and looked more frequently toward, the starboard side than the port side. The experienced operators, although unfamiliar with the specific boats used in the study, had navigated the measurement area with other vessels. As a result, they exhibited a narrower range of gaze and looked in fewer directions, likely because they already knew where to focus their attention while navigating. Among both novices and experts who had no prior experience with the measurement area or the vessels used, there was no clear pattern distinguishing those who gazed for extended periods from those who made multiple short glances. This variation appeared to depend on individual tendencies rather than experience alone. Novice and expert groups were also identified. The novices and experts were compared. There were significant differences in gaze time and frequency on the starboard side and the starboard back side between novices and experts. The area where the novices looked out for less than a second was calculated. The direction in which operators looked out from anywhere to another was analyzed because there was no definite difference in significant gaze at time and frequency. The analyzed gaze sequence was used to check the direction in which the operator looked at the sequence. The method counts when the gaze moves from one of seven directions (port back side, port side, front side, starboard side, starboard back side, back side, and nautical instrument side) in another direction. For example, if the gazing point moved from the front to the port side, it was counted once. If the gazing point moved to the front, it was not counted. A comparison of the median and average values from the gaze sequence analysis for novices and faculty members revealed that the most frequent gaze transitions in both groups were from the front to the port side and from the port side back to the front. These were followed by transitions between the front and starboard sides. While the number of times both groups looked from the starboard side to the front side and front side to the starboard side, both the average and median values for the front side to the port side and port side to the front side were more than 10 times higher for the experts, indicating that the experts were more likely to pass their gaze points in these directions. However, because the operator's intention for the maneuver could not be determined from these measurement results, an interview was conducted to confirm why this action was performed by viewing the recorded video from the operator's gaze point at the time of measurement with the individual. The interview research found that most experts could remember their maneuvering actions and explain the intent of their actions when they watched the recording, whereas most novices forgotten the intent of their actions and could not explain them. The other findings were as follows:

1. The experts crossed a safe distance, did not suddenly change courses, and maintained a clear course in the other vessel.
2. Novices have a long time to consider and change courses by avoiding maneuvering after approaching them.
3. Neither group was forced to stop during navigation.
4. If the boat collided with another boat would make a collision, the expert performed a change (slowing down or changing course) of the vessel in an early situation.
5. Novices are slower and take longer to make decisions than experts because they try to handle relationships with multiple boats and objects simultaneously.

Groups of novices and experts were distinguished. The novices and experts were compared. Novices and experts gazed at the time and frequency on the starboard side and the starboard back side. The area where the novices looked out for less than a second was calculated. The operators looking out from anywhere to another were analyzed because of the lack of definite significance of gazed time and frequency. The analyzed gaze sequence was used to check the direction in which the operator looked at the sequence. The method counts when the gaze moves from one of the seven directions (port back side, port side, front side, starboard side, starboard back side, back side, and nautical instrument side) to the other seven directions. For example, if the gazing point moved from the front to the port side, it was counted once. If the gazing point moved to the front, it was not counted. Comparing the medians and averages of the gaze sequence analysis for the novices and faculty members, the most frequent gaze points passed for both groups were from the front side to the port side and from the port side to the front side, followed by the front side to the starboard side and the starboard side to the front side. While the number of times both groups looked from the starboard side to the front side and front side to the starboard side, both the average and median values for the front side to the port side and port side to the front side were more than 10 times higher for the experts, indicating that the experts were more likely to pass their gaze points in these directions. However, because the operator's intention for the maneuver could not be determined from these measurement results, an interview was conducted to confirm why this action was performed by viewing the recorded video from the operator's gaze point at the time of measurement with the individual. The interview research found that most experts could remember their own maneuvering actions and explain the intent of their actions when they watched the recorded views, whereas most novices forgotten the intent of their actions and could not explain them. The other findings were as follows:

1. The experts crossed a safe distance, did not suddenly change course, and maintained a clear course to the other vessel.
2. The novices had a long time to consider and change course by avoidance maneuvering after approaching.
3. Neither group was forced to stop during navigation.
4. If one boat and another boat collided, the expert performed a change (slowing down or changing course) of the vessel in an early situation.
5. Novices are slower and take longer to make decisions than experts because they try to handle relationships with multiple boats and objects simultaneously .

The gazing time, duration, and sequence tended to be the same for novices and experts. The novices all had permits, so they passed the exam as boat operators. However, if the experts performed movements from 90 to 100 points, the novices performed movements from 60 to 100 points.

ACKNOWLEDGEMENT

In this study, boat operators looking to operate their boats are analyzed and discussed. The location of the gaze point, number of gaze points, total gaze time, and gaze sequence were calculated. There were no differences in the gaze-point analysis between students and faculty members, and interviews were conducted, which revealed differences. I thank the Japan Coast Guard, our boatyard staff, the Toba Maru crew, faculty members, our students, and external collaborators who consulted on the area during the boat maneuvering measurements, the Bioethics Committee for their permission to conduct the research, and my supervision of students for their cooperation regarding the content of this study.

REFERENCES

[1] J. L. Alonso-Enriquez, F. Piniella, J. I. Alcaide, "The Need for Unification and Harmonization in a Maritime Licensing Standard for Recreational Craft", TRANSNAV, 2020

[2] House. D. J, "SEAMANSHIP TECHNIQUES 3rd edition", 2012 Andrew. J. May, Tracy Ross, Steven. H. Bayer, 2012, Drivers' Information Requirements when Navigating in an Urban Environment, The Journal of Navigation, The Royal Institute of Navigation

[3] CENTER FOR SURFACE COMBAT SYSTEMS. U. S. Navy, "Lookout Training Handbook", NAVAL PERSONNEL DEVELOPMENT CENTER, Virginia, United States of America, 2007
[4] Department of Homeland Security United States Coast Guard, "Navigation Rules and Regulations Handbook", Washington, D. C , United States of America, 2020
[5] T. MIURA, "Visual search in intersections-An underlying mechanism", IATSS Research, vol. 16, pp.42-49, 1992
[6] D. Crundall, G. Underwood and P. Chapman, "Driving Experience and the Functional Field of View", Perception 28 (9), pp.1075-1087, 1999
[7] G. Underwood, P. Chapman, J. Underwood and D. Crundall, "Visual attention while driving: sequences of eye fixations made by experienced and novice drivers", Ergonomics, vol. 46, pp.629-646, 2003
[8] D. Martinez-Marquez, S. Pingali, K. Panuwatwanich, R. A. Stewart and S. Mohamed, "Application of Eye Tracking Technology in Aviation, Maritime, and Construction Industries: A Systematic Review", sensors, MDPI, vol. 21, no.13, 2021
[9] F. Forsman, A. Sjörs-Dahlman, J. Dahlman, T. Falkmer and C. Lee, "Eye tracking during high speed navigation at sea: Field trial in search of navigational gaze behaviour", Journal of Transportation Technologies, vol. 2, pp. 277-283, 12
[10] B. Muczyński, M. Gucma, M. Bilewski and P. Zalewski Using, "Using Eye tracking data for evaluation and improvement of training process on ship's navigational bridge simulator", Scientific Journals, Maritime University of Szczecin, vol. 33, no.105, pp75-78, 2013