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Near-miss density map for safe navigation of ships

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ABSTRACT

The purpose of the present study was to identify ship near-miss areas and determine the relative densities of the areas. The findings were used to develop a near-miss density map for safe ship navigation and the prevention of collision between passing ships. This study used big data of merchant vessel and fishing boat location for 1 year in 2014. The databases were interpolated using a time unit of seconds to extract near-misses between ships based on data for exactly the same time. Furthermore, to determine near-misses, the distance and time to closest point of approach were calculated for different pairs of approaching ships. The near-miss density of each grid of the map was depicted by means of the RGB color code. The concept was validated by using it to depict the distributions of actual collision accident locations that occurred in the southern coastal sea of Korea between 1997 and 2016. The highest near-miss area was found to be in the approach of Busan Port, where actual collision accidents also occurred most frequently. The results showed that 73.3% of the near-misses in the study area involved fishing boats. In addition, out of the 25 collisions that actually occurred in the study area in 2014, 19 (76.0%) were related to fishing boats, and this was reflected by the map developed in the present study. The findings of the study can be used to develop a special near-miss density nautical chart for use as a navigation safety material by deck officers. Such chart would facilitate the exercise of precaution in passing through dangerous areas.

1. Introduction

Approximately 90% of the world's trade is carried out by sea, and the volume of cargo and number of ships entering and leaving ports continue to increase with economic growth (United Nations, 2014). This growth of maritime traffic has been accompanied by increased risk of marine accidents. In sea areas with congested traffic, ships often execute close passages and the frequencies of collision are high.

According to Heinrich's law, a major accident does not occur suddenly but is the consequence of a number of minor events, which serve as a precursor signal of the impending accident. These minor events are characterized as being causes or precursors of the accident and are commonly referred to as near-misses (Bird and Loftus, 1976; Heinrich et al., 1980). A near-miss is a situation in which there is the danger of collision between ships approaching each other, but with no collision eventually occurring, either due to deceleration, or evasion by the change of course (Reason, 2016).

Because the number of actual marine accidents is usually very small, it is very difficult to verify a model for evaluating the probability of collision based on previous marine accidents (Inoue and Kawase, 2007; Debnath et al., 2011). Further study is required to determine whether actual collisions and the availability of its data could be more useful than the near miss density map; however, if we were to conduct our study on real accidents, an extremely large dataset (over 20 years of real collision density map) would be required. Since real accident database is not available in this particular study area, and the real collision frequency is extremely low, near-miss spatial analysis based on the location of a ship can be employed and potentially dangerous locations can be found. Another important reason for using near-miss analysis is that near-misses occur frequently and such analysis requires less than one year data. It is thus more reasonable to assess the area of interest based on near-misses that might have caused marine accidents. The International Maritime Organization (IMO) requires shipping companies to prepare and submit detailed reports on near-misses (International Maritime Organization, 2008). Apart from the fact that near-miss reporting is a basic requirement, it also contributes to improve the economy and the maritime industry because it promises to stimulate improved crew and ship performance, which can reduce associated costs (International Maritime Organization, 2008). Companies are, however, reluctant to report near-misses due to overloading, overwork, and other incriminating causes (Van der Schaaf and Kanse, 2004).

Previous studies visualized the main sea routes by simply plotting the Automatic Identification System (AIS) tracks. This method is, however, limited by the inability to plot the relative degrees of dangers in different areas. In this sense, Willems et al. (2009) developed a

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means of visualizing the main routes of ships in the coastal sea of the Netherlands based on the kernel density and taking the speed variations into consideration. Arguedas et al. (2014) plotted the main routes of the Strait of Dover by extracting waypoints taking the changing courses of passing ships into consideration. Shelmerdine (2015) expressed frequent main traffic flows based on a simple density of the AIS trajectories in Shetland. Vettor and Soares (2015) plotted ten main routes based on the density of ships passing through the North Atlantic Sea. Zhang et al. (2016) simplified AIS tracks using the Douglas–Peucker algorithm. Breithaupt et al. (2017) plotted the boundaries of the main routes between ports on the Atlantic coast of the USA. Wu et al. (2017) mapped a variety of latitude and longitude grids with intervals of 1′, 10′, and 60′ to portray the global ship traffic density. In the above studies, although the ship tracks were accumulated and the determined traffic densities were high, the actual collision danger levels were low in areas where the passages are separated by safe water buoys or where there is traffic separation scheme (TSS). This suggests that the cumulative density cannot be used to assess the risks of ship collision.

Meanwhile, in a previous study on ship near-misses, Jiacai et al. (2012) digitized passing dangers by segmenting the areas in Xiamen, China. They, however, did not plot their results. Silveira et al. (2013) and Kim et al. (2014) presented the location distribution of ship near-misses in the coastal sea, but could not determine the relative density of the different areas because the data used was two-dimensional data. In addition, Zhang et al. (2015) utilized AIS data, which did not reflect the flow of fishing boats without AIS.

To overcome the limitations of these previous works, this study proposes the use of density in depicting the spatial distribution of the locations of frequent ship near-misses in the southern coastal sea of Korea in 2014, taking into consideration the traffic flow of fishing boats. The near-miss density map was developed by means of the RGB color code. The rest of this paper is structured as follows. Section 2 describes the methodology of the present study, while section 3 explains the employed mathematical model. Subsequently, the experimental results are presented in results and discussion in section 4. Finally, a summary of the work and the conclusion drawn are presented in section 5.

2. Materials and methods

2.1. Study area

According to the statistical yearbooks of the Korea Maritime Safety Tribunal presented in Table 1, ship collision accidents were more common in coastal seas (70.9%) than in ports (14.1%) during the period 2011 to 2015. In addition, Table 2 reveals that marine accidents in Korea were more frequent on the southern sea than on the eastern and western seas (Korea Maritime Safety Tribunal, 2016).

The southern sea of Korea is one of the most important shipping areas of the world, connecting major economies such as China, Japan, Russia, and South Korea. Increase in foreign trade in the region has led to an increase in port traffic. The ship traffic volume in this area is particularly high because the area contains large ports such as the Gwangyang Port and the Busan Port, which is among the world's top ten container ports (Song and Lee, 2006).

Table 1
Number of ship collisions in the Korean sea area.

Year	Port	Coastal sea	Ocean area	Total
2011	10 (11.5%)	58 (66.7%)	19 (21.8%)	87 (100%)
2012	13 (15.7%)	60 (72.3%)	10 (12.0%)	83 (100%)
2013	12 (16.2%)	48 (64.9%)	14 (18.9%)	74 (100%)
2014	10 (11.1%)	69 (76.7%)	11 (12.2%)	90 (100%)
2015	12 (16.9%)	52 (73.2%)	7 (9.9%)	71 (100%)
Average	11.4 (14.1%)	57.4 (70.9%)	12.2 (15.1%)	81 (100%)

Table 2
Number of marine accidents in the coastal seas of Korea.

Year	Western sea	Southern sea	Eastern sea	Total
2011	570 (41.8%)	542 (39.7%)	253 (18.5%)	1365 (100%)
2012	454 (40.0%)	508 (44.8%)	172 (15.2%)	1134 (100%)
2013	366 (47.6%)	293 (38.1%)	110 (14.3%)	769 (100%)
2014	405 (43.0%)	425 (45.1%)	112 (11.9%)	942 (100%)
2015	546 (35.6%)	783 (51.0%)	206 (13.4%)	1535 (100%)
Average	468.2 (40.8%)	510.2 (44.4%)	170.6 (14.8%)	1149 (100%)

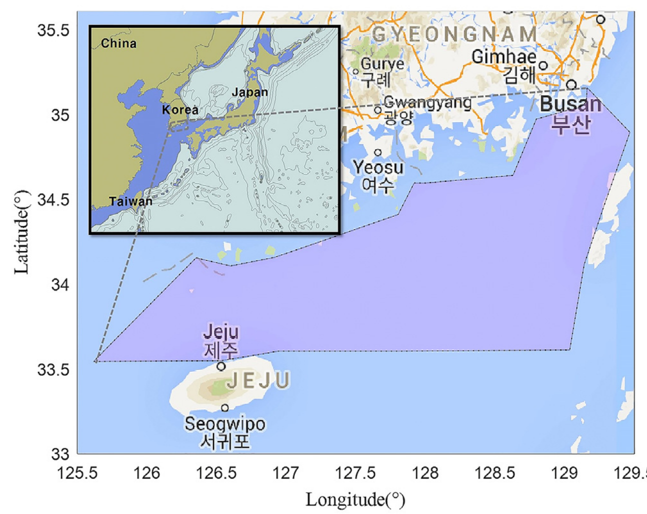

Fig. 1. Study area (South Sea of Korea).

The present study thus considered the southern coastal sea of Korea for the purpose of mapping the near-miss density. As shown in Fig. 1, the coastal area is located between latitudes 33.5° and 35° and longitudes 125.5° and 129.5°, with an area of approximately 28,576 km^2. This study excluded port areas because the interactions between merchant ships and pilot boats, tugboats, water supply ships, and oil supply ships at ports could be mistaken for collisions.

2.2. Installation of AIS

Since 2002, the IMO has mandated the installation of AIS on new passenger ships of more than 300 tons and cargo ships of more than 500 tons on international voyages. An AIS transmits information between ships and between ships and land stations via very high frequency (VHF) in the 160 MHz band. The transmitted information includes the ship's location, speed, course, name, type, destination, and dimension (International Maritime Organization, 1998; International Association of Lighthouse Authorities, 2000).

Between 2001 and 2008, 42 AIS stations were constructed on the coasts of South Korea. The present study utilized one-year data from January 1 to December 31, 2014. The data was obtained through the AIS national integrated system of the Ministry of Oceans and Fisheries of Korea.

2.3. Fishing boats location transmission device

Existing studies on near-misses of ships that do not follow the International Convention for the Safety of Life at Sea (non-SOLAS ships) are insufficient owing to the difficulty of acquiring their location data. In a review of studies on non-SOLAS ships, An (2016) proposed some concepts for e-Navigation services for non-SOLAS ships. Fukuda (2016) also predicted the tracks of fishing boats through a survey of fishermen, owing to the difficulty of acquiring data on non-SOLAS ships. Radar and visual observations are generally used to determine the route of fishing