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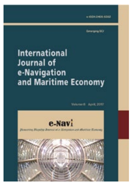

Original article

A New Approach for Improving Performance of the SV1 Service of the SMART-Project☆

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Abstract

The SV1 service - NAMAS(Navigation Monitoring & Assistance Service) collects ship's position data in all South Korean waters, and predicts the next positions, calculates the CPAs between ships within a certain distance, evaluates basic collision risk and each vulnerability, then integrates to the navigational collision risk. This paper describes the functions and background chosen in the navigation risk solving system; Data characteristics, framework of navigation risk solving system, and data structures and methods for efficient computation for CPA calculations and detecting accident risk situations.

Keywords: SMART-Navigation Project, Collision Risk, CPA, AIS

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1. Introduction

The SMART-Navigation project aims to expand IMO's e-Navigation concept to develop specialized services for Korean maritime traffic environment. It started in 2016 and aims to complete the first stage by 2020. The SMART-Navigation project is divided into three activities, which consist of 13 Work Packages [1][2].

The WP1 aims to develop the SV1 service - NAMAS(Navigation Monitoring & Assistance Service). The SV1 service determines the risk of collision and the risk of ship grounding based on the location information of ships and other information that related to vulnerability and provides prior warnings. It is also possible to check whether an accident occurred based on the accumulated location information. If a routing plan is delivered in advance, it can monitor the ship whether it is outside the planned route [3].

Many studies have been conducted in maritime domain to avoid or prevent collisions. They basically used the CPA(Closest Point of Approaches) and Time to CPA calculations and tried to solve the problem in a variety of approaches[4-16]. There are also many collision prevention studies using anomaly detection or machine learning methods [17-24]. In particular, there have been many studies on the avoidance of collision by unmanned ships [25-27].

However, there are fundamental differences between these studies and the SV1 service. Collision avoidance studies targeting unmanned ships or navigators operating a single vessel collect information only for ships within a certain range, with their own vessels at the center. The SV1 service, however, collects information on ships in all South Korean waters. Other studies use various sources of information such as AIS(Automatic Identification System), Radar, CCTV, and so on, but the SV1 service can only use location information via AIS (or LTE-M in future). In addition, in the collision avoidance studies targeting unmanned ships, it is possible to select and exe-cute actions to be taken next, and feedback the results, but the SV1 service only observes and provides an alarm, and sufficient time must be elapsed to confirm changes in the ship's motion [28].

This paper describes the functions and background chosen in the collision risk and ship grounding risk assessment process of the SV1 service. This paper is organized as follows; Section 2 describes data characteristics for the SV1 services including position data and static data; Section 3 shows the framework of navigational collision risk solving system based on vulnerability and some changes and experiments to improve the performance and accuracy; Section 4 presents new data structures and methods for efficient computation for CPA calculations and detecting accident risk situations.

2. Data Characteristics for the SV1 Services

2.1 Location Data for the SV1

The GICOMS(General Information Center on Maritime Safety & Security) provides ship location information for the SV1 service[28]. Philpp Last et al. have shown that because of exceeding reporting intervals the AIS system is in most cases insufficient as a standalone data source for continuous vessel tracking and collision avoidance in real time applications [29]. Clément Iphar et al. introduced issues on the AIS system; errors in the messages (human-error etc.), falsifications in the messages, spoofing of messages [30]. However, AIS is the most realistic method available to the SV1 service.

AIS data provided by the GICOMS has another issue. GICOMS collects and process-es information from several land stations. Each station delivers the location information of the vessel and timestamp (the received time locally) to the GICOMS center, where there may be more than one station that receives the location information of one vessel. Currently, GICOMS removes data that has same location information and same timestamp. Thus, situations can occur where duplicate location information that has different timestamp arrives delayed or, in severe cases, later trans-mitted location data arrives faster. Figure 1 provides examples of duplicated position data and inconsistent position data.

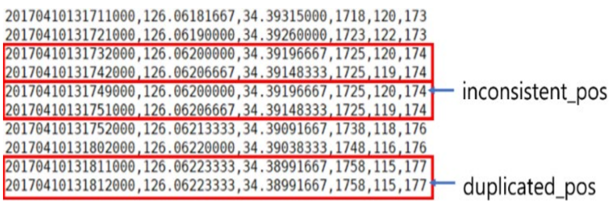

Figure 1: An example of duplicated position data and inconsistent position data

If the data arrive in the normal order and the value of COG(Course over Ground) is 172.5 degrees, the longitude value of the next arrived data must be greater than the previous data, and the latitude value that arrives next must be less than the previous data. However, in the fifth line you can see that the delay of the redundant data caused the opposite situation.

Table 1: Summary of AIS Position Data (05/2017 ~ 04/2018)

mo/yr	ship_no	r_pos_no	v_pos_no	inv_pos	inv_csog	dup_err	int_err	inc_err
05/17	302,741	711,015,798	641,147,003	14,519,044	8,092,172	35,795,502	10,366,938	1,095,139
06/17	287,512	691,587,796	620,400,758	14,598,863	8,622,784	37,615,044	9,596,048	754,299
07/17	288,087	684,088,760	616,776,005	12,907,483	10,314,986	34,645,703	9,002,160	442,423
08/17	284,543	681,849,873	612,291,153	18,477,561	9,904,473	31,741,438	9,123,846	311,402
09/17	365,107	699,278,349	622,854,483	20,346,343	10,648,502	34,789,701	9,946,452	692,868
10/17	284,863	648,408,793	577,500,091	15,591,104	10,586,624	34,949,859	9,381,554	399,561
11/17	258,414	649,647,267	582,393,035	16,998,526	9,726,486	30,344,909	9,697,898	486,413
12/17	239,046	654,182,011	585,171,249	15,985,491	10,909,202	32,495,094	9,198,786	422,189
01/18	219,601	602,070,823	537,412,013	11,931,882	12,003,440	32,528,849	7,889,745	304,894
02/18	180,302	495,316,477	442,211,115	8,455,301	8,609,560	28,878,214	6,784,039	378,248
03/18	287,616	630,100,889	566,798,991	10,944,246	8,880,460	34,378,222	8,496,712	602,258
04/18	315,077	635,455,954	569,553,358	11,032,915	7,194,148	37,175,040	9,729,416	771,077
Avg (mon)	276,076	648,583,566	581,209,105	14,315,730	9,624,403	33,778,131	9,101,133	555,064
Avg (day)	9,076	21,323,295	19,108,245	470,654	316,419	1,110,514	299,215	18,249

Table 2: Summary of V-Pass Position Data (01/2017 ~ 12/2017)

mo/yr	ship_no	r_pos_no	v_pos_no	inv_pos	inv_csog	dup_err	int_err	inc_err
01/17	310,610	197,397,484	88,747,349	-	3,382	108,387,225	89,118	170,410
02/17	282,352	175,854,924	78,437,934	-	3,192	97,188,836	82,929	142,033
03/17	265,640	155,608,327	66,357,026	-	2,884	89,086,175	70,443	91,799
04/17	413,876	241,164,090	109,750,251	-	4,794	131,162,205	108,782	138,058
05/17	453,166	274,187,751	127,591,422	-	4,055	146,296,270	160,481	135,523
06/17	437,669	271,730,170	125,777,642	-	4,385	145,498,938	317,607	131,598
07/17	421,708	259,501,413	115,087,126	-	3,149	143,538,552	759,757	112,829
08/17	439,803	271,151,983	121,764,157	-	5,366	148,606,401	659,662	116,397
09/17	500,688	304,891,792	138,074,946	1	3,982	165,887,522	785,567	139,774
10/17	459,081	230,191,395	100,166,295	-	5,367	129,624,364	264,945	130,424
11/17	448,041	271,658,149	118,945,910	-	4,108	152,042,634	510,042	155,455
12/17	371,690	224,312,676	99,381,109	-	3,304	124,692,946	103,077	132,240
Avg (mon)	400,360	239,804,180	107,506,764	0	3,997	131,834,339	326,034	133,045
Avg (day)	13,163	7,883,973	3,534,469	0	131	4,334,280	10,719	4,374

The Table 1 gives a summary of AIS position data from May 2017 to April 2018, and the following Table 2 gives a summary of V-Pass position data from Jan. 2017 to Dec. 2017. “r_pos" means the number of reserved position data; “v_pos” means the number of valid position data which used to analysis; “inv_pos” means the number of data which has invalid longitude or latitude(181.0 or 91.0); “inv_csog” means the number of data which has invalid SOG(Speed Over Ground-102.3) or invalid COG(361); “int_err” means the number of data which disobeyed the sending interval; “dup_err” and “inc_err” are explained in Figure 1.

Although there are more ships reporting their location using V-Pass than those using AIS, the "r_pos_no" value of vessels using V-Pass is smaller because of the different reporting intervals of the two devices; nominal reporting interval of AIS Ships over 14 knots and changing courses is 2 seconds, while that of V-Pass is 30 seconds. Currently, V-Pass information is not used for anti-collision, anti-grounding analysis due to inaccuracies resulting from the large reporting interval. At the end of phase 1 of SMART-Navigation project, LTE-M equipment with a reporting cycle of 1 second is expected to be available for analysis [1]. When the values of SOG were 0(engine stopped situation), ships using V-Pass sent the same values as the previous information, which resulted in high "dup_err" values, while some of ships using AIS sent invalid(undefined) values, which resulted in high “inv_pos” and “inv_csog” values.

2.2 Static Data for the SV1

The GICOMS is the source of static data for SV1 services. The GICOMS collects static data by AIS #5 and #24 messages, and from other authorities. The Table 3 shows the number of vessels classified by ship type from April 2017 to April 2018. The number of ships with type number 70 ~ 79(Cargo) was 21,727. The number of ships with type number 30(Fishing) was 20,271. The number of fishing boats that reported its location using V-Pass was 48,993 in 2017. Therefore, nearly 70,000 fishing boats are operating in South Korean waters [3][28].

Table 3: Number of ships classified by type (04/2017 ~ 04/2018)

Ship Type	Identified	Reported
10 ~ 19	73	51
20~29	141	129
30	20,557	20,271
31,32	350	339
33~36	484	455
37	1,819	1,814
40~49	152	131
50	123	116
51	136	120
52	1,548	1,503
53~59	444	424
60~69	809	761
70~79	21,727	21,462
80~89	6,796	6,696
90~99	1,162	1,111
Total	56,438	55,496

3. Framework of Navigation Risk Solving System

The Figure 2 shows the framework of navigational collision risk solving system based on vulnerability (considering fishing boats activities) [31][32].

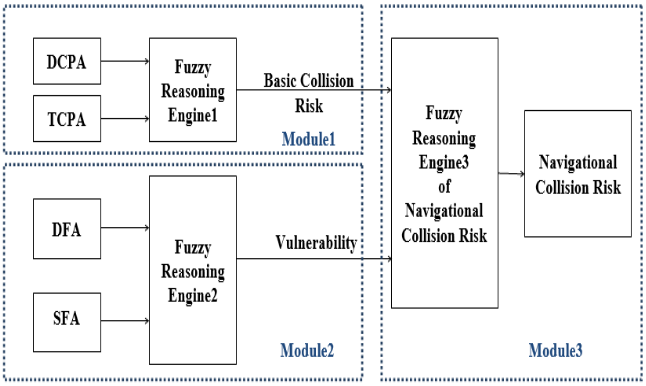

Figure 2: Structure of the Navigational Collision Risk Solving System [32]

Firstly, DCPA(Distance to CPA) and TCPA(Time to CPA) evaluating collision risk and supporting decision making, are used to calculate the collision risk. This basic collision risk can be obtained by designing the membership functions and rules of DCPA and TCPA. Secondly, in fuzzy reasoning engine 2, the distance to fishing area and the size of fishing area are used to calculate vulnerability. Finally, basic collision risk and vulnerability of fishing area are integrated to infer navigational collision risk. There are 6 modules to evaluate vulnerabilities [32].

3.1 Changes in Module 1

DCPA and TCPA are simultaneously considered for solving basic collision risk to offer a reasonable and applicable collision risk assessment. Module 1 developed in 2018 implemented using the following equations.

$$DCPA = \frac{D(V_O \sin\alpha - V_t \sin\beta)}{\sqrt{V_O^2 + V_t^2 + 2V_O V_t \cos(\alpha+\beta)}} \quad (1)$$

$$TCPA = \frac{D(V_O \cos\alpha - V_t \cos\beta)}{V_O^2 + V_t^2 + 2V_O V_t \cos(\alpha+\beta)} \quad (2)$$

where VO is Own Ship (OS) velocity, Vt is Target Ship (TS) speed, Distance (D) is the distance from OS to TS, α is the relative bearing of TS based on OS and β is relative bearing of OS based on TS[31][32].

(DCPA, TCPA) → Basic collision risk (3)

In 2019, the basic collision risk was calculated by applying the equation (4) announced by J. Lisowski. This change improves the situation in which the same risk value comes, even though there is a difference in the size or speed of the two vessels involved in one situation.

Thus, the risk of ships with easy avoidance action is reduced, and the risk of large and slow vessels is increased.

$$R = \left[a_1\left(\frac{DCPA}{Ds}\right)^2 + a_2\left(\frac{TCPA}{Ts}\right)^2 + a_3\left(\frac{D}{Ds}\right)^2\right]^{-\frac{1}{2}} \quad (4)$$

where D is current distance between the own ship and the target ship, Ds is safe distance of approach(a radius of the circle-shaped domain), Ts is the time necessary to perform a collision avoidance maneuver, a_1, a_2, a_3 are weight coefficients[4][5].

Bias 1 was added to Equation 4 and modified to Equation 5. Therefore, the resulting value is between 0 and 1. We use 3L as the radius of ship-domain, where L is the length(A+B) collected by AIS. If there is no static data for the ship, default value can be used. Tactical diameter is the distance traveled by the midship point of a ship from the position at which the rudder order is given to the position at which the heading has changed 180 degrees from the original course, and tactical diameter should not exceed 5L[33]. We use these requirements to calculate the Ts, so Ts is the time required to go 7.5L at the current SOG of the ship.

$$R = \left[a_1\left(\frac{DCPA}{Ds}\right)^2 + a_2\left(\frac{TCPA}{Ts}\right)^2 + a_3\left(\frac{D}{Ds}\right)^2 + 1\right]^{-\frac{1}{2}} \quad (5)$$

Using the results of the 2018 implementation, a_1, a_2, a_3 were adjusted to give the calculation result of 0.3 for a 15 knots speed, 150 meters length, 1.5 nautical miles of DCPA, and10 minutes of TCPA. These values will be modified by feedback in 2020.

3.2 Divide-and-Conquer method for CPA calculation

As mentioned in Section 1, the SV1 service covers all ships in the entire area of South Korea. The CPA calculations are essential for ship collision-related analysis, but CPA calculations among all ships in the entire area are unnecessary. We use divide-and-conquer method as follows.

(1) Divide the entire area into certain sizes (d x d), make pairs only with ships within each area, and calculate the CPAs of those pairs.

(2) Move by 1/2 d on the x-axis to separate the areas, make pairs again with only ships within each area, and calculate CPAs of newly added pairs.

(3) Move by 1/2 d on the y axis to separate the areas, make pairs again with only ships within each area, and calculate CPAs of newly added pairs.

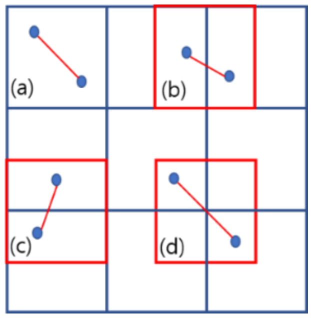

Figure 3: Cases in Divide-and-Conquer CPA calculation

As a result, CPAs are calculated for all pairs of ships within an area of a certain size. In Figure 3, (a) shows the CPA calculation of a pair of ships within one area; (b) the CPA of a pair of ships within an area adjacent to each other on an x-axis; (c) the CPA of a pair of ships within an area adjacent to each other on the y axis; and (d) the CPA of a pair of ships in an area adjacent diagonally.

3.3 Experiments for AIS position prediction

Xin-ping Yan et al. suggested new CPA calculation method in [34]. They introduced the prediction of the movement using the four factors; COG, SOG, COS(Change of Speed), and ROT(Rate of Turn). They used Exponential smoothing model for SOG and COG predicting and following equations to calculate the distances of ship movement [34].

$$\begin{cases} d_{x_{n(m)}} = \sum_{k=1}^{m} \int_{t_{k-1}}^{t_k} \left[v_{k-1} + (v_k - v_{k-1})\frac{t - t_{k-1}}{t_k - t_{k-1}}\right] \sin\left[c_{k-1} + (c_k - c_{k-1})\frac{t - t_{k-1}}{t_k - t_{k-1}}\right] dt \\ d_{y_{n(m)}} = \sum_{k=1}^{m} \int_{t_{k-1}}^{t_k} \left[v_{k-1} + (v_k - v_{k-1})\frac{t - t_{k-1}}{t_k - t_{k-1}}\right] \cos\left[c_{k-1} + (c_k - c_{k-1})\frac{t - t_{k-1}}{t_k - t_{k-1}}\right] dt \end{cases} \quad (6)$$

where k is the ordinal number of the ship position among m predicted positions, $2 \le k \le m$, $d_{x_{n(m)}}$ is the horizontal distance between position $[x_n, y_n]$ and the m^{th} predicted position, $d_{y_{n(m)}}$ is the vertical distance between position $[x_n, y_n]$ and the m^{th} predicted position,

$v_{n(k)}$ is the k^{th} predicted SOG value when the current time is t_n, and $c_{n(k)}$ is the k^{th} predicted COG value when the current time is t_n.

It was necessary to verify that the position prediction method using 4 factors (COG, SOG, COS and ROT) is more accurate compared to the position prediction method using COG and SOG. Accuracy can be verified by comparing the differences between the predicted positions and the actual positions in each of the two methods.

Because the position prediction for all ships in the entire waters are necessary, performance is the most important consideration. We omitted the steps of predicting COG and SOG of individual vessels (skipped the exponential smoothing process in [34]), calculated COS and ROT only once with two position data, used them to obtain SOG and COG to calculate the next positions.

$$\begin{cases} d_{x_{n(m)}} = \sum_{k=1}^{m} \int_{t_{k-1}}^{t_k} \left[v_n + \frac{(v_n - v_{n-1})}{(t_n - t_{n-1})}(t - t_{k-1})\right] \sin\left[c_n + \frac{(c_n - c_{n-1})}{(t_n - t_{n-1})}(t - t_{k-1})\right] dt \\ d_{y_{n(m)}} = \sum_{k=1}^{m} \int_{t_{k-1}}^{t_k} \left[v_n + \frac{(v_n - v_{n-1})}{(t_n - t_{n-1})}(t - t_{k-1})\right] \cos\left[c_n + \frac{(c_n - c_{n-1})}{(t_n - t_{n-1})}(t - t_{k-1})\right] dt \end{cases} \quad (7)$$

If one MMSI number is used simultaneously by two or more vessels, there is a large difference between the predicted value and the actual value received. There were also significant differences in the situation where the vessels stopped and moved again. These cases were pre-examined in this comparison.

Contrary to expectations, method using four elements was not always more accurate. Observing AIS information on a single vessel, the Method 1(using 2 factors) was sometimes more accurate, and the Method 2(using 4 factors) was more accurate in other cases. There were also cases where the results of both methods were the same. Following Table 4 shows some examples of comparison test. "prd_no(1)" means the number of prediction by method 1; "avg_diff(1)" means the average difference in meter between the predicted position and received position; "more_acc(1)" means the number of cases which the difference by method (1) is less than that of method(2); "Ship type" and "Length" is collected by the AIS static data.

Table 4: Example of comparison test (3 ships at 2017. 4. 18)

	Ship#1	Ship#2	Ship#3
Ship_Type	71	70	30
Length(a+b)	161	178	104
rcvd_pos	11,836	5,493	2,082
valid_pos	10,994	5,273	1,298
prd_no (1)	10,991	5,270	1,297
avg_diff (1)	4.8	6.8	1.0
prd_no (2)	10,985	5,264	1,295
avg_diff (2)	5.1	7.3	1.1
more_acc (1)	4,803	1,064	557
more_acc (2)	5,487	903	450

Following Table 5 shows the result of comparison classified by ship length. "more_acc(1)" means that the number of ships whose results the number of situations more accurate in Method 1 are 10% more than those in Method 2; "almost_same" means the number of ships whose differences between the two methods are less than 10%. Ship types and vessel lengths were classified to ensure that they affected the results, but similar results were shown in all categories.

Table 5: Result of comparison (classified by ship length) (2017. 4. 18)

	more_acc(1)	more_acc(2)	almost_same
unknown	942	364	859
< 50	763	256	714
< 100	251	144	357
< 150	246	118	303
< 200	270	56	255
< 250	121	30	115
< 300	86	14	109
>= 300	57	17	105
Total	2,736	999	2,817

As a result of test, Method 1 was often more accurate, so it was decided to use Method 1 as it was. Since SV1 service is a real-time service, it will also help maintain overall system performance.

In addition, the Equirectangular projection method was chosen to convert latitude and longitude to the x-y coordinate system. When we used the Equirectangular method, we could see that the operating speed was three times faster than the 'haversine' formula. The difference between results using Equirectangular method and results using 'haversine' formula in calculating the next position of a vessel moving at low speed for a short period of time is not significant [35][36].

4. New Approach for CPA calculation and detecting accident risk situations

The following Figure 4 shows the data structure for efficient CPA calculations and vessel identification with high accident risk. Here one row contains the real (past) position data and the (future) predicted position data of one vessel, and one column contains the location of all ships at a specific time. A total of *2n* buffers are required in a row, since n buffers are used to predict vessel position for a period of time (*n* seconds) to calculate collision and stranded risks, and *n* buffers are used to determine if an accident occurred with accumulated actual data.

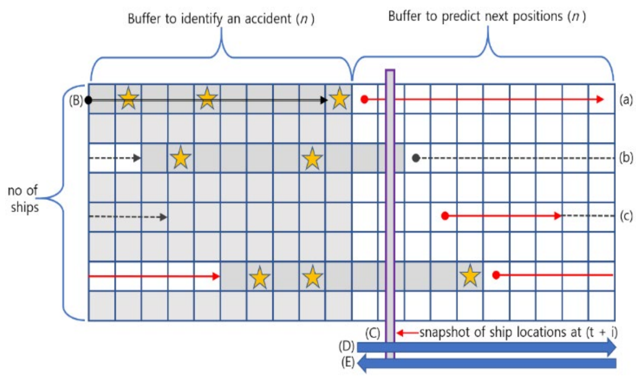

Figure 4: Position Prediction (a ~ c), Accident Identification(B), and Calculation of the CPA(C~E)

When the SV1 service receives the new position report ("star" marks in Fig. 4) from the vessel, it updates the current location of the vessel and predicts the n locations of the vessel ((a) in Fig. 4) (explained in section 3.3). In order to reduce the computational load, if the SOG is below the threshold value and there is no significant difference between the previously predicted and the newly reported position, it will only fill the existing value without computation ((b) in Fig. 4). This is especially useful in many cases where there are many ships with stopped engines.

During the predicting process, vessel grounding hazards can also be identified. If the predicted location of the vessel is in an area with a risk of stranded, the process of handling the risk of stranded vessel shall be carried out, and the remaining buffer will be filled by last predicted data ((c) in Fig. 4). Information about the stranded danger zone is provided from electronic nautical charts and other authorities.

After the prediction process, process to identify an accident is followed (B). It converts to vectors using accumulated actual position information, to check for sudden deceleration or abnormal movement. When abnormal conditions are identified, the process of handling accident occurrence is called.

Calculation of CPA can be processed by independent process or thread. Each process (thread) can calculate the distances for all pairs of ships within an area of a certain size at a specific time (C) (See section 3.2). After the calculation of distances (D), process to find the CPA is followed (E). Figure 5 shows the finding process. The mini-mum value ("star" marks in Fig. 5) for each row is the DCPA, and the difference be-tween index with that value and index at the time of analysis is the TCPA. In the figure 5, the index of data which has the minimum value of the distance between S1 and S2 vessels is b. Since the index of analysis is a, b – a is the TCPA.

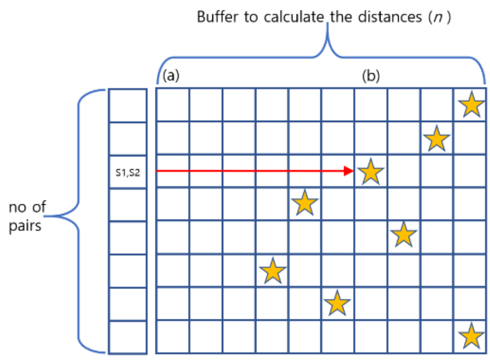

Figure 5: Finding TCPA between S1, S2

5. Conclusions

This paper introduced the functions and background chosen in the navigation risk solving system; Data characteristics and preprocessing, framework of navigation risk solving system, and new approach for CPA calculation and detecting accident risk situations. To reflect the size and speed of the vessel, the method of calculating the Basic Collision Risk was modified. Considering the accuracy and the performance, position prediction method using only COG and SOG, and Equirectangular projection were adopted. It proposed data structures and methods of processing to efficiently perform position prediction, determination of whether accidents occurred, and CPA calculations.

Performance improvement using multi-core and prediction of ship's route through machine learning are considered as follow-up studies.

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