

Development of Algorithm for the Decision of Ship's Strong Wind Warning Levels

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Abstract : Marine weather information provided for vessels is mainly offered by radio devices such as NAVTEX, Weather Fax, and others. However, the information is too general for large areas, and lacks more detail. So, many seafarers are disinclined to use the information to initiate proper readiness of vessels' safety, avoiding marine accidents such as grounding, hull and cargo damage, but cannot develop an optimal and economical navigation plan, considering the inadequate level of low precision weather information. The purpose of this paper is to develop a strong wind warning system, based on the digital anemometer installed on the bridge. This study analyzed the data on 10-minutes average wind speed, when the vessel's grounding accidents happened in Korean ports. Results reveal that the vessel's strong wind warning algorithm, can estimate the growing of wind speed two-three hours in advance.

Key words : Weather Information, Strong Wind Warning, Marine Accident, Anemometer, 10-minutes Average Wind Speed

1. Introduction

Marine accidents, undesired abnormal events of a ship that often result in loss of life or major injury to any person on board and in various types of property damage, have been a major issue in the international maritime community since shipping began (Luo and Shin, 2016). Usually the marine accidents are not caused by only a specific factors, but are caused by a combination of various causes.

Investigation into the causes of shipping accidents show that over 30% of the accidents are caused by poor weather(Faulkner, 2004). And as reported by Korean Maritime Safety Tribunal, about 17% of the operation errors of grounding, capsizing and sinking happened between 2013 and 2017 were caused by severe marine weather and readiness mishaps.

The marine weather information which provides for vessels is mainly offered by radio device such as NAVTEX, Weather Fax., and others. However, the information is too general for the wide area and lacks more detail. So many seafarers are disinclined to use the information to make a proper readiness of vessels safety avoiding some marine accidents such as grounding, hull and cargo damage, and cannot make an optimal and economical navigation plan considering this kind of low precision weather information.

In recent years, a number of new wind speeds forecasting methods have been proposed. The physical models are usually based on the NWP(Numerical Weather Prediction) models, which provide the wind speed forecasting by using the mathematical models of the weather and topological data like pressure, humidity, temperature and wind direction(Pelikán et al., 2010). Erdem(2011) built the traditional-linked ARMA models and vector ARMA models for wind speed forecasting. Cadenas(2007) presented the wind speed prediction models based on the ARIMA and artificial neural network methods. These models can obtain the wind speed forecasting by the linear or non-linear functions but often require many complex variables. Therefore it is sometimes very difficult to collect all the information mentioned above and put into practice.

The purpose of this paper is to develop a strong wind warning algorithm for the vessels anchored near coast or anchorage. This study has analyzed 10-minutes average wind speed data measured meteorological observatories near the water areas some grounding accidents happened in Korean ports, and developed the algorithm that could forecast the changing trend of strong wind a few hours before.

A significant benefit of applying this algorithm is that it can calculate the strong wind warning levels based on the wind speed data from the shipboard anemometer without

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some additional equipments. This algorithm will be very helpful in forecasting the coming strong wind and decreasing the probability of marine accidents.

2. Correlation analysis of strong winds and grounding accidents

Usually the poor weather and severe sea states have been considered as affecting factors on the likelihood of grounding, stranding, sinking accidents, etc. However, under changing weather conditions, the sea surface is too complex to predict, especially on a small time-scale (Kharif et al., 2009). Wind sea waves are directly produced by local growing winds, and when the waves spread without receiving further energy from wind, they gradually grow to a swell. So the wind sea waves and strong winds have been considered as one of the important affecting factors on the likelihood of grounding accidents. In this study, authors selected the 8 grounding accidents which occurred in Korean ports and coastal area from 2007 to 2016, and analyzed to identify any pattern or correlation between the time of the grounding accidents and the weather environment.

Table 1 shows the brief information on the cases including ship's name, accident time and places, maximum wind speed and atmospheric pressure in the range of 24 hours before and after the accidents. In this study, the wind speed data at one minute intervals, which are the

basis of the algorithm development, were gathered from the web-site of Korea Meteorological Administration. The web-site provides 10-minutes average wind speed, and because the most foreign meteorological agencies use the 10-minute average wind speed to produce the weather information which is recommended by the World Meteorological Organization (10-minute average wind speed : measures ten minutes at a height of ten meters above the surface and takes an average). Therefore, 10-minutes average wind speed data are the fundamental resource for calculating the strong warning algorithm. And also, the wind speed data for each accident was collected from the nearest meteorological observatory to compare and analyze the accident occurrence and wind speed change patterns at that time.

The maximum wind speed at the time of 'CAI XIN' accident was 36.3m/s, but it was only 9.6m/s in the case of 'CHENGLU 15', so there can not be any meaningful relationship between the maximum wind speed and accident occurrence. Of course, the stronger the wind speed, the higher the likelihood of marine accidents such as stranding. However, this cases alone does not necessarily mean that the maximum wind speed and the possibility of accidents are linear. Therefore, authors analyzed the change of 10-minutes average wind speed at each accidents.

Fig. 1, Fig. 2 and Fig. 3 show the curve of 10-minute average wind speed during 48 hours when the grounding

Table 1 The information of 8 grounding accidents

No	Ship name	Grounded time	Gross tonnage	Atmospheric pressure sea level(hpa)		Max. wind speed(m/s)	Grounded place
				Max.	Min.		
1	TIAN HE	2007.03.04 22:00	5,500	1022.5	1001.3	15.6	Coastal area of Taejongdae, Busan
2	CAI XIN	2012.08.23 13:00	2,900	1013.0	1009.6	36.3	Casarri Beach, Yaksan-myeon, Wando-gun
3	JE HAE	2013.02.01 16:17	3,026	1030.9	1014.5	12.5	Coastal area in front of Jung-ri, Yongdo-gu
4	FU SENG HAI	2013.07.02 21:40	30,000	1010.5	1000.2	12.6	2 km south of coastal area of Taejongdae, Busan
5	CHENGLU 15	2013.10.15 15:40	8,461	1021.0	1013.0	9.6	900m northeast of Pohang Yeongil Bay Harbor
6	BUM JIN	2013.11.25 03:55	2,302	1023.4	997.6	10.1	Coastal area of seul-do, Dong-gu, Ulsan
7	OCEAN TANGO	2016.04.17 01:02	3,525	1013.1	993.0	21.3	Coastal area in front of Jung-ri Yeongdo-gu Busan
8	MI NAM	2016.10.05 09:00	1,321	1019.4	983.7	29.4	The dock of Udu-ri, Dolsan-eup, Yeosu

accidents happened in Table 1.

The graphs show that the accidents did not always occur during the time when wind speed reach at its maximum. 'FU SENG HAI', 'CHENGLU 15', 'CAI XIN', 'BUM JIN' were grounded a few hours after the maximum wind speed appears. Others were grounded near the peak strength of the wind speed. Although the maximum 10-minutes average wind speed of 'CHENGLU 15' was

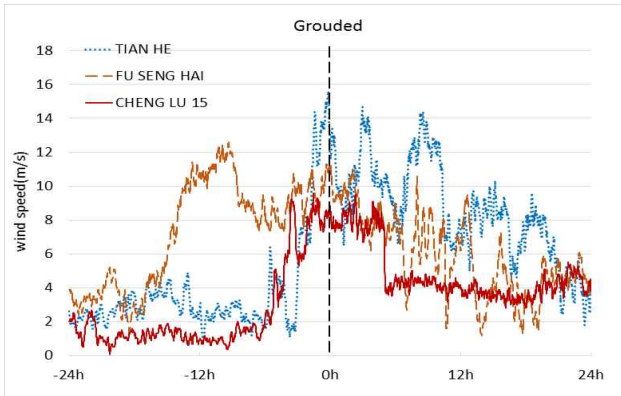


Fig. 1 48 hours wind speed curve of grounding accidents ('TIAN HE', 'FU SENG HAI', 'CHENGLU 15')

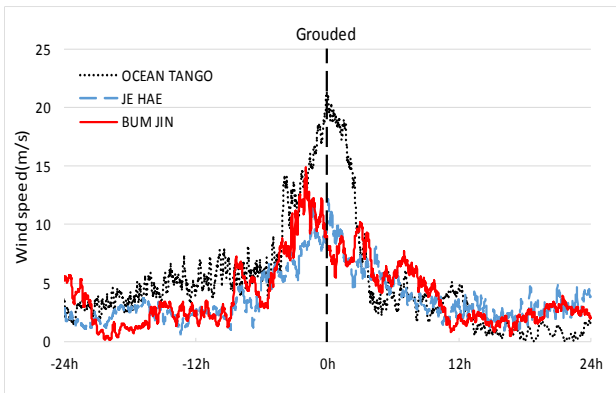


Fig. 2 48 hours wind speed curve of grounding accidents ('OCEAN TANGO', 'JE HAE', 'BUM JIN')

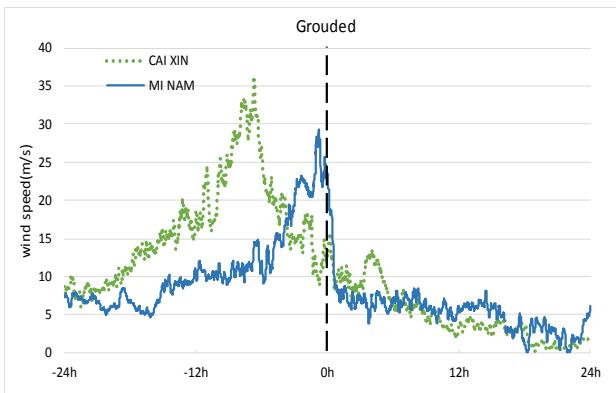


Fig. 3 48 hours wind speed curve of grounding accidents ('CAI XIN', 'MI NAM')

recorded as the lowest among them, her accident patterns and situation was similar to others. Therefore, it might be not appropriate to evaluate the stage of upcoming strong wind which could prevent the accidents of the ship simply by the strength of the wind.

Because there are so many factors which can affect ship's grounding accident, such as the ship's shape, the quantity of loading cargo, holding power of the anchor and cable, depth of water area, and geographical features of the coast, and others.

However, it is very difficult to develop an algorithm that can predict the possibility of a grounding accident in real time reflecting all the above factors. There are also some limitations on collecting necessary information related to such elements.

So many countries such as the United Kingdom and the U.S.A have issued the strong wind warning based on the forecasted wind speed. But the warning information is inferred from historical weather data, it means the accuracy of the information can vary depending on wind speed of the time.

In the case of 'BUM JIN', the 10-minute average wind speed value increased about 6m/s in the range of 30 minutes and then decreased slowly again. It might be somewhat unreasonable to predict the occurrence of strong wind near future only by the large change in such a short time range. Because it can make too much frequent warning on strong wind and be useless to seafarers. Therefore, it will be more efficient and practical to judge the sing of weather deterioration by analyzing the data for the range of several hours rather than the short time.

3. Algorithm for wind warning

It would be essential to issue valuable warnings which let the seafarers have enough time to do right decision making and prohibit the grounding, stranding, dragging anchors, etc. So this study has developed the algorithm that could make 4 warning levels consist of 'Attention(blue)', 'Warning(yellow)', 'Alert(orange)' and 'Critical(red)' and announce the first warning at least 2 hours before. And also the wind warning levels are calculated based on the changing trend of 10-minutes average wind speed.

In this paper, the basic algorithm for calculating process of the warning levels is described with the data of 'OCEAN TANGO' accident. Fig. 4 shows the curve of

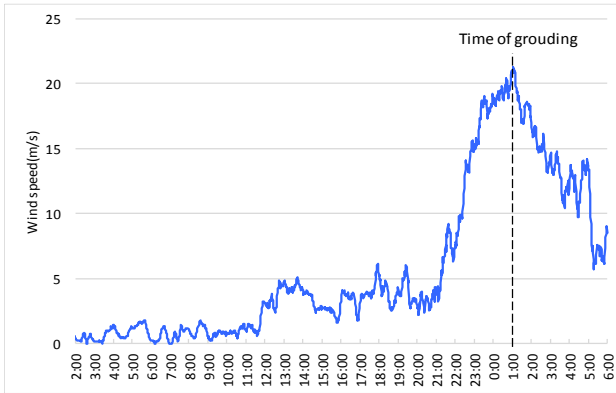


Fig. 4 10-minutes average wind speed of ‘OCEAN TANGO’ accident

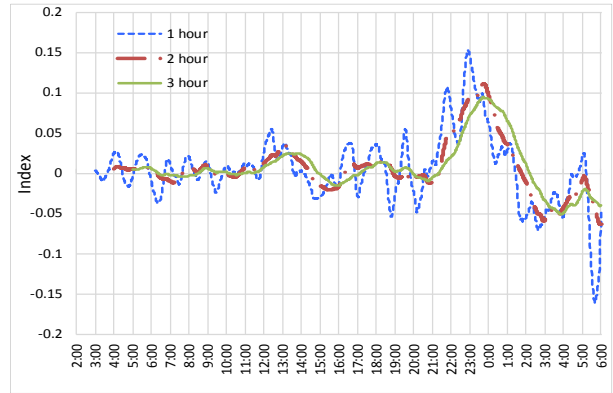


Fig. 5 Gradients curve for the different calculation units(OCEAN TANGO)

10-minutes average wind speed for 28 hours of ‘OCEAN TANGO’ case. At first, the trend of wind speed change is obtained by using the method of least squares which is a process to find the best fit line to target data(Wolberg, J. 2006).

The gradient of fit line means the simple trend of change in a specific period. Let

$$y = kt + c \quad (1)$$

$$\bar{t} = \frac{1}{n} \sum_{i=1}^n t_i \quad (2)$$

$$\bar{y} = \frac{1}{n} \sum_{i=1}^n y_i \quad (3)$$

$$k = \frac{\sum_{i=1}^n (t_i - \bar{t})(y_i - \bar{y})}{\sum_{i=1}^n (t_i - \bar{t})^2} \quad (4)$$

where t is time, y is wind speed, \bar{t} is mean time, \bar{y} is mean wind speed and k is slope and c is constant.

The gradients can be obtained by changing the unit of calculation with hourly basis. Meanwhile, it limits the calculation unit within 1 hour to 6 hours for the purpose of finding out the best curve.

Fig. 5 and Fig. 6 show the gradient curves of 6 cases and the phenomenon in which the fluctuation of the gradients becomes larger as the calculation range becomes shorter. Analyze the other seven accidents, it's get the familiar result. Therefore, 6-hour unit is applied as the calculation period for the method of least squares.

In Fig. 7, 6-hour gradient curve and 10-minute average wind speed curve are displayed together to check whether the gradient value can be used as the index of the strong

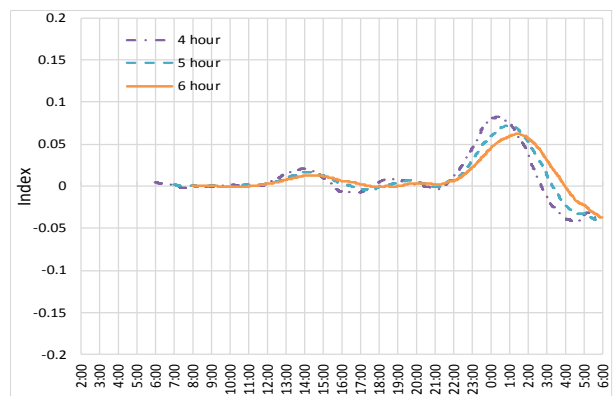


Fig. 6 Gradient curves for the different calculation units(OCEAN TANGO)

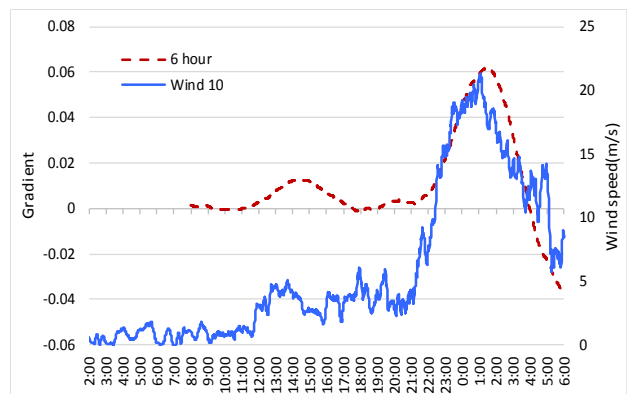


Fig. 7 6-hour gradient and wind speed curves(OCEAN TANGO)

wind warnings. Although it can indicate the changing trend of wind speed well, the gradient values can tend to be somewhat larger at low wind speed zone under 5m/s from 08:00 to 21:00. It means that only using the gradient values as the warning index, it may not fit in with the reality.

The low wind speeds do not have too much impact on the accidents, but the high wind speed is one of the main causes of the grounding accident. Therefore this study uses the exponential function to process wind speed and gradient values that can decrease the low wind speed and increase the high wind speed to get wind speed index(WSI) and gradient index(GI). The final warning index(WI) is obtained as the product of the wind speed index and the gradient index, and can be given by

$$WI = GI \cdot WSI = (a^{10^3 \cdot m}) \cdot (b^v) \tag{5}$$

where m is 6-hour gradient value, v is 10-minutes average wind speed. The base a is set to about 1.122 so as to be an GI 10 when the 6-hour gradient value is 0.02, and the base b is set to about 1.185 so as to be an WSI 30 when the 10-minutes average wind speed is 20m/s.

Fig. 8 shows the calculation result of the gradient index, wind speed index and warning index for ‘OCEAN TANGO’. We define the numerical range of each warning level as shown in Table 2.

In this study, we calculated the data of 8 grounding accidents to confirm that the algorithm could decide each warning level properly. The results are shown in Table 3, although the warning was issued too early in three cases, but it was found that this algorithm would be useful.

In the case of ‘CAI XIN’, the critical warning can be indicated about 5 hours and 50 minutes before, because the typhoon ‘BOLAVEN’ approached to the water area at that

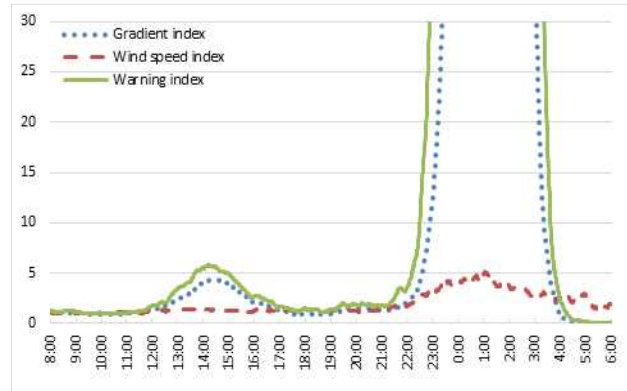


Fig. 8 The curve of gradient index, wind speed index, warning index (OCEAN TANGO)

Table 2 Warning index value of 4 warning levels

Level	Attention	Warning	Alert	Critical
Warning index	≤ 5	≤ 10	≤ 15	> 15

time. In the case of ‘TIAN HE’, the critical level can be issued 1 hour and 37 minutes before her accident. The critical level of ‘BUM JIN’ and ‘OCEAN TANGO’ can be indicated about 2 hours before their accidents. In the case of ‘FU SENG HAI’, the critical level can issue 13 hours and 40 minutes before, and ‘MI NAM’ and ‘CHENG LU 15’ can be notified more than 3 hours before their accidents.

If the above 8 vessels used the warning system based on this algorithm, 6 vessels can be warned of any upcoming danger at least 2 hours before and 2 vessels 1

Table 3 Test results of strong wind warning algorithm for 8 accidents

No	Ship name	Grounded time	Warning time				Time difference between accident and highest level
			Attention	Warning	Alert	Critical	
1	TIAN HE	2007.03.04 22:00	19:29	20:13	20:19	20:23	1h 37mins
2	CAI XIN	2012.08.23 13:00	18:59	19:33	19:51	20:10	16h 50mins
3	JE HAE	2013.02.01 16:17	11:29	14:31	14:37	No	1h 40mins
4	FU SENG HAI	2013.07.02 21:40	07:11	07:40	07:52	08:01	13h 39mins
5	CHENG LU 15	2013.10.15 15:40	11:26	11:58	12:05	12:20 13:26	3h 20mins
6	BUM JIN	2013.11.25 03:55	20:38	00:41	01:23	01:34	2h 21mins
7	OCEAN TANGO	2016.01.17 01:02	22:11	22:30	22:36	22:45	2h 17mins
8	MI NAM	2016.10.5 09:00	19:58 02:22	20:50 04:31	21:18 05:06	05:15	8h 45mins

hour and 30 minutes before. In conclusion, this algorithm will provide a strong wind warning, and help seafarers make timely decisions to prevent accidents.

4. Conclusions

Usually seafarers on watch in the bridge have checked and recorded the change of wind speed or atmospheric pressure to estimate the coming bad weather condition. But these precaution activities have largely relied on the knowledge and past experience of watch-keeping. So it can sometimes cause the crew to be distracted and also cause the marine accidents.

The purpose of this study is to develop the strong wind warning algorithm that can make prior alert to ship's crew members in readiness for the coming strong wind. So the 10-minutes average wind speed data were analyzed to obtain the changing trend of wind speed by the method of least squares. And the WSI and GI were developed because the steep wind speed changes in high wind speed could cause the more dangerous situation than a low wind speed range. WI obtained as the product of 2 indexes was used to determine 4 warning levels : attention(level 1, WI 5), warning(level 2, WI 10), alert(level 3, WI 15), critical(level 4, WI 20).

The strong wind warning algorithm was applied to 8 grounding accidents to find the applicability that could estimate the growing wind speed. We confirmed that it could be used to give an effective warning to watch-keepers who make enough preparation for any dangerous situations such as grounding accident and not under command. In future studies, we would like to apply atmospheric pressure at sea level to calculate more efficient warning index. Because it is known as well that the wind speed has a deep relation with degradation or change of air pressure.

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