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工學碩士 學位論文

선박용 강풍경보 레벨 결정 알고리즘에 관한 연구

A Study on Decision Algorithm of Vessel's Strong Wind Warning Levels

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선박용 강풍경보 레벨 결정 알고리즘에 관한 연구

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초록

일반적으로 선박이 사용한 해양기상정보는 주로 NAVTEX, 기상 팩스와 라디오방송 등 무선통신 장비를 통해 얻었다. 이러한 정보들의 범위는 국가나 지역이 때문에 선박에 대해 범위가 너무 커서 정확도가 너무 낮다. 따라서 선원들은 좌초나 선체 및 화물 손상과 같은 해상 사고를 예방할 때 이런 정보를 사용하지 않다. 또한 정확도 이렇게 낮은 정보에 의거하여 경제적인 최적의 항해 계획을 수립할 수 없다.

본 연구는 2010년부터 2015년까지 한국의 해상 사고를 분석한 결과에 따라 사고의 65%가 강한 바람과 파도로 인한 것임을 발견했다. 그리고 약 20.7%의 좌초 및 전복 사고는 악천후가 주요 원인이었다는 것도 발견했다. 만약 풍속의 변화를 2~3 시간 전에 선원들에게 미리 제공할 수 있다면 그러한 사고를 예방할 수 있었을 것이다.

본 논문에서는 2007년부터 2016년까지 한국의 항구 및 해안에서 일어난 8건의 좌초 사고를 대상으로 분석하였다. 먼저, 10분간의 평균 풍속 (좌초 고가 발생한 전후 각 24시간의 풍속)을 수집하여 강풍과 좌초 사고의 상관관계를 분석하였는데 풍속을 기준으로 경고 수준을 설정하는 것은 효과적인 방법이 아니라는 사실이 밝혀졌다. 풍속 데이터는 최소 제곱법 (1805년에 Legendre가 최초로 간결하고 명확하게 최소 제곱에 대한 설명을 한 것으로, 대상 데이터에 대한 최적선을 찾는데 널리 이용되고 있다)을 사용하여 처리

한 다음 지수함수를 사용하여 풍속을 더 자세히 분석할 수 있다. 최종적으로 완전한 예방 작업을 할 수 있도록 2~3시간 전에 풍속의 변화를 확인할 수 있는 선박의 강풍 경고 시스템을 개발하는 것이 목적이다.

이 시스템을 적용할 때의 중요한 장점은 추가 장비 없이 선상풍력계에서 풍속 데이터를 빠르고 쉽게 얻을 수 있다는 것이다. 그리고 이 논문에서 분석된 풍속은 지금까지 축적해온 풍속 데이터로부터 추산되기 때문에 정보의 정확도는 기상 조건에 따라 달라질 수 있다.

키워드: 기상 정보, 강풍 경보, 해양 사고, 풍속계, 최소 제곱법

A Study on Vessel’s Strong Wind Warning System

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Abstract

The marine climate information which provides to vessels is mainly furnished by radio device such us NAVTEX, Weather Fax., radio broadcasting, and others. Nevertheless, they provide widely information for nation or region. It is the reason why many seafarers are disinclined to use the information to prevent the marine accidents such as grounding, hull and cargo damage, and cannot make a decision on optimal and economical navigation plan considering weather conditions.

After analyzing the marine accidents which happened in Korea between 2010 and 2015, this paper finds out that 65% of all marine accidents were caused by strong wind and high seas. And about 20.7% of all grounding and capsizing accidents were due to severe marine weather. If the changing trend of wind speed could be alerted to seafarers 2 or 3 hours in advance, the accidents which were caused by strong wind would be avoided.

Eight grounding accidents which happened from 2007 to 2016 in Korean ports and coast are analyzed in this study. Firstly, this study attempts to determine whether the wind speed can be used as a criterion to determine the degree of danger. Hence, it analyzes the 10-minute average wind speed before and after the accidents to find out the correlation of strong wind and grounding accidents; secondly, this study uses least squares method to process the wind speed data (the first clear and concise exposition of the method of least squares was published by Legendre in 1805, which is widely used to find the best fit line to target data), and then expand exponential function to further analysis the wind speed. Eventually, this study develops the vessel's strong wind warming algorithm that can estimate the changing trend of strong wind.

A significant benefit of applying this warning system is that this system is simple and fast, and this system can obtain the wind speed data from the shipborne anemometer without any additional equipment.

Key Words: weather information, strong wind warning, marine accident, anemometer, least squares method

Chapter 1. Introduction

1.1 Background and Purpose of This Study

Shipping is the most international of all the world's great industries, every year about 90% of international trade is done by it, and it is also one of the most dangerous industries. The maritime accidents, undesired abnormal events of a ship that often result in the loss of life or major injury to the person on board and generate various types of property damage. Marine accident has been a major issue in the international maritime community since shipping began (LUO, M, F., and SHIN, S, H. 2016).

After the statistics and analysis of the marine accidents which happened in Korea between 2010 and 2015 (shown in Table 2.1), this study finds out that about 65% of all marine accidents were caused by strong wind and rough seas. And about 20.7% of all grounding and capsizing accidents were due to severe marine weather. If the marine weather can be forecasted 2 or 3 hours before, most of the accidents that caused by strong wind and rough sea could be avoided.

Table 1. 1 Statistics of marine accidents between 2010 and 2015

	2011	2012	2013	2014	2015	Total
Collision	185	182	182	192	162	903
Hull Damage	10	10	9	14	10	53
Grounding	20	13	9	16	12	70
Capsizing	14	10	10	5	7	46
Fire Explosion	16	17	23	19	30	105
Sinking	8	11	9	7	8	43
Engine Trouble	2	9	3	5	14	33
Death and Injury	19	16	15	25	37	112
Others	7	4	2	11	25	49
Total	281	272	262	294	305	1414

The marine weather information which providing for vessels is mainly offered by radio devices which are NAVTEX, Weather Fax., and others. Nevertheless, the information they provide is always national or regional, the precision of this wide range information is very low. It is the reason why many seafarers are disinclined to use the information to prevent marine accidents such as grounding, hull and cargo damage, and the seafarers cannot make an optimal and economical navigation plan considering this kind of low precision weather information.

Due to the low precision weather information and the high-frequency marine accidents caused by strong wind, this study attempts to develop the vessel's strong wind warning system which is based on the wind anemometer installed on the bridge. As a result, the accuracy of the alarming information can be accurate to the surrounding area of the ship. This study analyzes the 10-minute average wind speed when the grounding accidents happened in the anchorage of Korean ports. And this paper has already developed the vessel's strong wind warning system that can estimate the changing trend of strong wind speed 2 hours before. Based on the alert information provided by this system, vessels can have enough time to do the preventive work for the coming strong wind.

1.2 Literature

In the maritime community, a huge effort has been directed to reduce or eliminate the maritime accidents. And due to the strong wind's threats to the people on board, the ships, the cargo, and the marine environment, many countries have issued a severe weather warning in order to protect their marine transportation infrastructure and save their people at sea.

In recent years, different wind speed forecasting models have been developed, including the linear time series analysis approaches ARIMA models, Kalman filters and more recent machine learning techniques which are support vector machines and various forms of neural networks such as multi-layer feedforward neural networks and recurrent neural networks. These methods have its own improvements and characteristic.

Lysiane et al (2016) carried out an automatic gale warning proposals for Swiss lakes and regional aerodromes based on genetic programming, the evolutionary algorithm, which is a machine learning technique inspired by the evolution theory of species, constructs, evaluates, selects and improves algorithmic expressions - actual Java methods - aiming for forecasting maximal gust intensity within the next hours. 20 such evolution runs were performed once for each warning object, leading to an ensemble of 20 Java methods specific to each site. These 20 methods build a probabilistic forecast for the occurrence of wind gusts at a specific lake or aerodrome in the next hours. But this warning system was designed specifically for the lake and aerodrome, and it was developed for the weather station that needed lots of additional equipment. For that reason, this alarm system is not suitable for shipborne use.

Pelikan, E. and Eben, K (2010) proposed a physical model which was based on the NWP (Numerical Weather Prediction) models, and it provides the wind speed forecasting by using the mathematical models of the weather and topological data like pressure, humidity, temperature and wind direction. These models often include many complex variables. Therefore, it is very difficult to collect all the information mentioned above and it's hard to be put into use.

Hu, J. M., Wang, J. Z. and Ma, K. L. (2015) developed a hybrid forecasting approach that consisted of the EWT (Empirical Wavelet Transform), CSA (Coupled Simulated Annealing) and LSSVM (Least Square Support Vector Machine) for enhancing the accuracy of short-term wind speed forecasting. The EWT was employed to extract true information on a short-term wind speed series, and the LSSVM, which optimizes the parameters using a CSA algorithm, is used as the predictor to provide the final forecast. Moreover, this study uses a rolling operation method of the prediction processes, including one-step and multi-step predictions, which can adaptively tune the parameters of the LSSVM to respond quickly to wind speed changes. The model designed in this paper can forecast any changing trend of wind speed a half-hour before, but for marine accidents, the strong wind is the main cause, and the low wind speed does not have too much significant effect. Hence, the efficiency of this wind forecasting model is not high.

YVES QUILFEN et al (2010) proposed a high wind model which is provided for estimating maritime near-surface wind speed from satellite altimeter backscatter data during high wind conditions. The model was built using coincident satellite scatter meter and altimeter observations obtained from QuikSCAT and Jason satellite orbit crossovers in 2008 and 2009. The new wind measurements are linear with inverse radar backscatter levels, a result close to the earlier altimeter, high wind speed model of Young (1993). The high wind model could estimate the wind speed from 0 to 20 m/s, but this model is based on the satellite, this model requires very harsh equipment and technical conditions, and the cost of using this model is high. Consequently, the applicability of the model is poor.

1.3 Methodology and Contents

This paper studied and discussed the advantages and disadvantages of the genetic programming model, numerical weather prediction model, hybrid forecasting approach model, and a high wind model in the application of wind speed prediction. But all wind speed prediction models discussed above are not suitable for use on board. Therefore, this paper aims to develop a wind speed prediction model that suitable for ship use, and this model should satisfy the following conditions;

i. be able to forecast any changing trend of the wind speed in the near future,

ii. base on the measured wind speed data from the shipborne anemometer,

iii. Let seafarers have enough time carry out sufficient preparation for the coming strong wind.

The main contents of this article and the arrangement of each chapter are as follows:

The first chapter introduces the background of this research and the various existing wind speed prediction models, analyzes the advantages and disadvantages of each model and introduce the wind speed prediction method adopted in this study.

The second chapter introduces the main factors that cause marine accidents and makes the correlation analysis of strong winds and grounding accidents on eight ship stranded accidents.

The third chapter contains the research process of wind speed prediction algorithm. This paper mainly uses the least squares method to process 10-minute average wind speed (24 hours wind speed before and after the grounding accidents happened), and then uses the exponential function to further emphasizes the wind speed data and gradient values.

Chapter four contains the concluding remarks and further prospects on this topic.

Chapter 2. Analysis of Grounding Accidents

Since ancient times, all human activities in the sea are inseparable from navigation. The sea provides abundant treasure and unlimited resources for the survival and development of mankind. Whether engaged in marine fishing and breeding or engaged in passenger and cargo transport at sea, carrying out the national defense and military activities in the oceans, conducting scientific expeditions to the oceans, or developing resources such as seabed oil and mineral deposits. The navigation safety is the basis and precondition of human understanding, exploitation, and exploitation of the ocean.

2.1 The Factors that Caused the Marine Accident

Sailing safety has always been a great concern to the shipping industry. For a long time, various shipping countries in the world have done a great deal of work on ship safety. However, with the rapid development of the shipping industry in recent years, accidents such as ship collision, stranding, fire, explosion, and the pollution have occurred frequently which was already caused serious consequences. Comprehensive analysis of these marine accidents, it could acquire the conclusion that the main factors affecting the safety of ship navigation are human factors, ship factors, and environmental factors.

2.1.1 Human Factors

The human factor mainly refers to the accidents caused by the misoperation of the crews, weak sense of responsibility or the shortage of professional skills of the crews. IMO states in the ISM Code that about 80% of all the accidents at sea were caused by human factors. And about 80%

of all human factors can be controlled through effective management, by strengthening the internal management of the company and the safety management of the ship (Li, C.G., 2016).

2.1.2 Ship Factors

Ship factors include the ship's quality and the ship management. The ship's quality and seaworthiness are the prerequisites for the safe navigation of ships. The ship's quality includes all kinds of fire-fighting and life-saving equipment, mechanical and electrical equipment, safety measures, navigational equipment in the cab and various automatic systems in the cabin that operating normally or not.

2.1.3 Environmental Factors

Marine weather issues are very serious element that cannot be ignored during the vessel' s sailing, they are current wind speed and direction, air pressure, rainfall, ocean current, fog, temperature, and others. Among them, the strong wind is one of the most main factors that results in the marine accidents at sea. The strong wind can cause the waves, as a result it could alter the movement of ships. Especially when the vessel was anchored in the harbor or sailing near the coast in the low speed, the strong wind can lead to serious grounding accidents like the eight grounding cases analyzed in this paper.

2.2 Grounding Cases Study

This study analyzed eight grounding cases which happened between 2007 and 2016 in Korean ports and coast, and the wind speed information are from the Korea Meteorological Administration website (www.kma.go.kr).

This website provides 1-minute and 10-minute average wind speed data, and because most of the world's meteorological departments use the 10-minute average wind speed recommended by the World Meteorological Organization (WMO). And the calculation method for the 10-minute average wind speed is: measures ten minutes' wind speed at a height of ten meters above the surface and then takes an average. For the wide commonality of this warning system. Consequently, this paper is based on the analyses of 10-minute average wind speed. Through the wind speed analysis of the eight grounding cases, this paper attempts to develop a strong wind warning algorithm that can forecast the upcoming strong wind.

Table 2.1 shows the grounding time, gross tonnage, atmospheric pressure at sea level and the maximum wind speed information of the eight grounding vessels.

Table 2.1 The information of the 8 grounding ship

No	Ship's name	Accident time	Gross Tonnage	Atmospheric pressure at sea level (hPa)		Max. Wind Speed
				Max.	Min.	m/s
1	TIAN HE	2007.03.04 22:00	5,500	1022.5	1001.3	15.6
2	CAI XIN	2012.08.23 13:00	2,900	1013.0	1009.6	36.3
3	JE HAE	2013.02.01 16:17	3,026	1030.9	1014.5	12.5
4	FU SHENG HAI	2013.07.02 21:40	30,000	1010.5	1000.2	12.6
5	CHEN LU 15	2013.10.15 15:40	8,461	1021.0	1013.0	9.6
6	BUM JIN	2013.11.25 03:55	2,302	1023.4	997.6	14.6
7	OCEAN TANGO	2016.04.17 01:02	3,525	1013.1	993.0	21.3
8	MI NAM	2016.10.05 09:00	1,321	1019.4	983.7	29.4

According to different wind speed observation locations, the wind speed varied a lot. Therefore, for the accuracy of the strong wind warning system, the wind speed data analyzed in this paper were collected from the wind speed observation station that closest to the ship' s grounding location. Table 2.2 provides grounding places and wind speed observation places of the eight grounding accidents.

Table 2.2 Grounding and wind speed observation places of 8 grounding accidents

No	Ship's name	Grounding place	Wind speed Observation place
1	TIAN HE	Coastal area of Taejongdae, Busan	Dongsam-dong, Yeongdo-gu, Busan
2	CAI XIN	Casarri Beach, Yaksan-myeon, Wando-gun	Bulmok-ri, Gunoe-myeon, Wando-gun
3	JE HAE	Coastal area in front of Jung-ri ,Yongdo-gu	Dongsam-dong, Yeongdo-gu, Busan
4	FU SHENG HAI	2kmsouthof coastal area of Taejongdae, Busan	Dongsam-dong, Yeongdo-gu, Busan
5	CHENG LU 15	900m northeast of Pohang Yeongil Bay Harbor	Songdo-dong, Nam-gu, Pohang
6	BUM JIN	Coastal area of seul-do, Dong-gu, Ulsan	Bukjeong-dong, Jung-gu, Ulsan
7	OCEAN TANGO	Coastal area in front of Jung-ri, Yongdo-gu, Busan	Sinseon-dong3-ga, Yeongdo-gu, Busan
8	MI NAM	The dock of Udu-ri, Dolsan-eup, Yeosu	Goso-dong, Yeosu

2.2.1 Correlation Analysis of Strong Wind and Grounding Accidents

First of all, this study analyzes the wind speed data before and after the grounding accidents in order to find out any relation between the changing trend of wind speed and the accidents. Figure 2.1 - 2.16 show the 10-minute average wind speed curve when the eight grounding accidents happened.

Figure 2.1 Grounded general cargo ship 'TIAN HE'

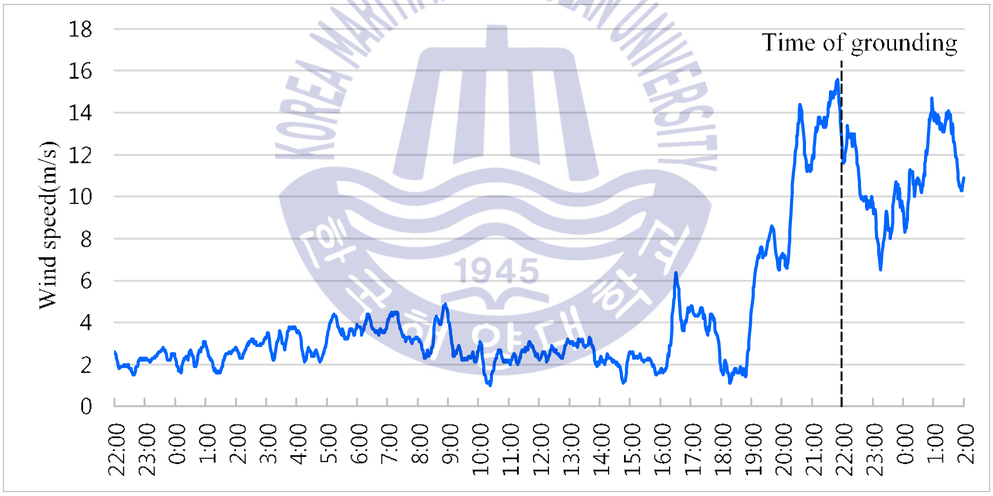

Figure 2.2 10-minute average wind speed before and after the 'TIAN HE' accident

As shown in Figure 2.1, the cargo ship 'TIAN HE' (GT 5,500 tons) was stranded by strong wind near the sea area of Taejongdae Busan on 04 March 2007 and caused very serious damage to the hull. Figure 2.2 shows that from 22:00 to 19:00 the wind speed was lower than 7 m/s and the wind speed change rate was relatively steady. However, from 19: 00 the wind speed continued to increase rapidly, up to 21:50 the wind speed reached its maximum—15.6 m/s, and then 10 minutes later the stranding accident happened.

Figure 2.3 Grounded general cargo ship 'CAI XIN'

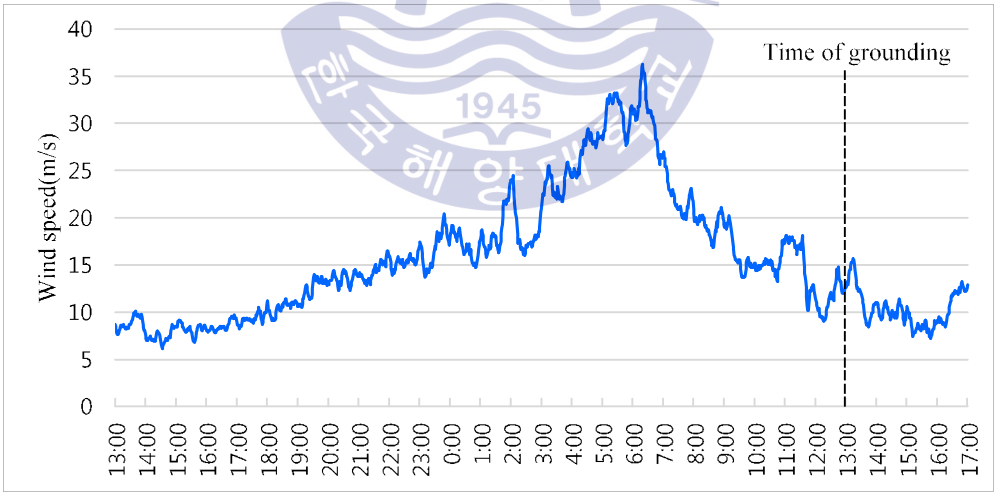

Figure 2.4 10-minute average wind speed before and after the 'CAI XIN' accident

On 23 August 2012, the cargo ship 'CAI XIN' (GT 2955 tons) was stranded by strong wind and high seas in Casarri Beach, Yaksan-myeon, Wando-gun, Yeosu Korea. Figure 2.3 shows the situation in the rescue scene, more than 35.4 tons of oil spilled from ‘CAI XIN’, and this accident caused huge marine pollution. As shown in Figure 2.4 from 13:00 to 6:00 the wind speed was continuing to increase and at 6:00 the wind speed reached its maximum—36.3 m/s. From 6:00 to 16:00 the wind speed had been decreasing, and the grounding accident was occurring more than six hours after the maximum wind speed appeared.

Figure 2.5 Grounded general cargo ship ‘JE HAE’

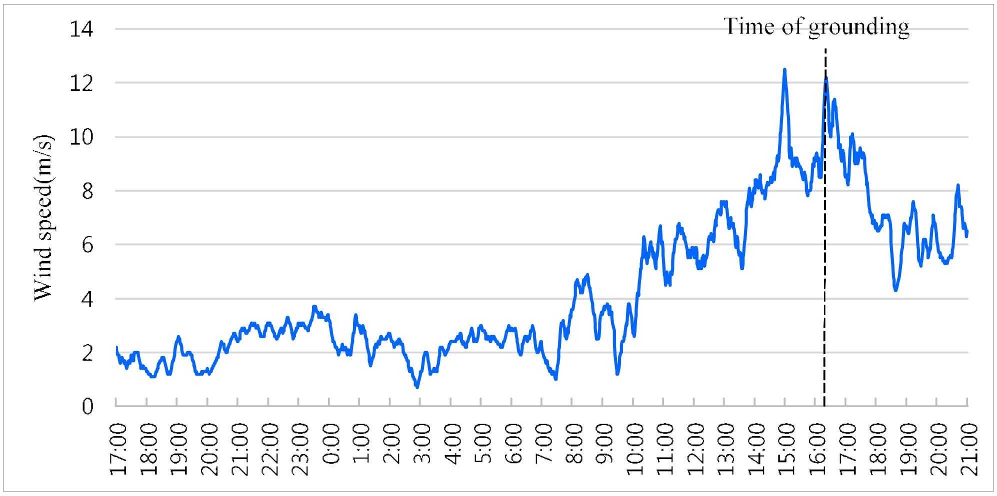

Figure 2.6 10-minute average wind speed before and after the 'JE HAE' accident

On 01 February 2013, the cargo ship 'JE HAE' (GT 3026 tons) who anchored in Busan Port was stranded by the strong wind. Figure 2.6 shows the fact that from 17:00 to 9:30 the wind speed was under 5 m/s, but from 9:30 to 15:00 the wind speed was keeping increasing and reached its maximum wind velocity 12.5 m/s at 15:00. There were two strongest wind speed point in this accident and the 'JE HAE' accident occurred near the second largest wind speed point. The grounding time occurred one and a half hours after the first strongest point appeared.

Figure 2.7 Grounded bulk carrier 'FU SHENG HAI'

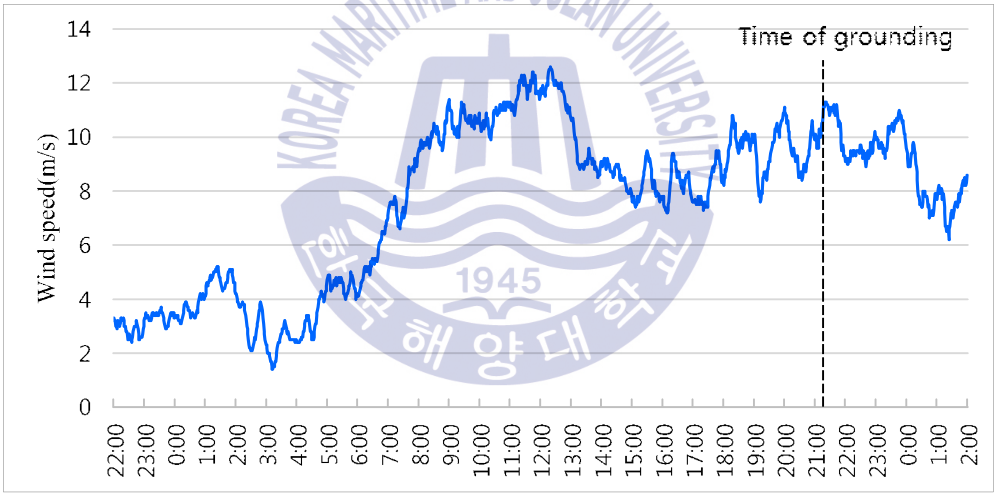

Figure 2.8 10-minute average wind speed before and after the 'FU SHENG HAI' accident

On 07 February 2013, the bulk carrier 'FU SHENG HAI' (GT 30000 tons) who was anchored in Busan Port stranded by the strong wind and wave, there were 26 mariners on board and 19 of them were saved. Analyzing from Figure 2.8, it can find the fact that the grounding accident happened almost 9 hours after the maximum wind speed occurred and from 3:00 to 12:20 the wind speed was keeping increasing. At 12:20 the wind speed reached its maximum number 12.6 m/s.

Figure 2.9 Grounded freighter 'CHENGG LU 15'

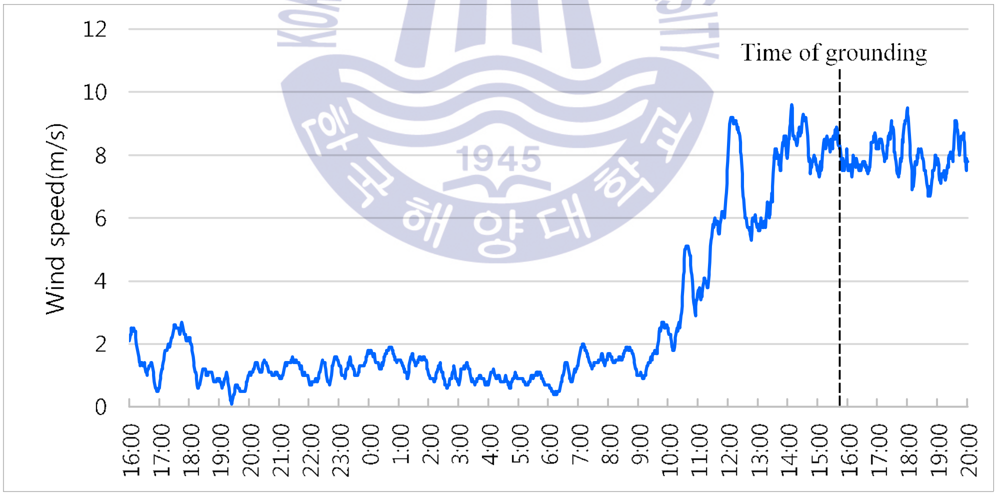

Figure 2.10 10-minute average wind speed before and after the 'CHENG LU 15' accident

As shown in Figure 2.9, the freighter 'CHENG LU 15' (GT 8461 tons) sank about 0.5 nautical miles off South Korean Pohang port's northeast breakwater in a severe storm on October 15th 2013. This vessel was anchored on outer road, but the vessel's anchor was dragged and then hit the breakwater. Figure 2.10 shows that the wind speed up to its maximum value of 9.6 m/s at 14:08 and the grounding time of 'CHENG LU 15' was about 2 hours after the maximum wind speed occurred. From 16:00 to 10:00 the wind speed was under 3 m/s, and the wind speed changes were relatively stable. However, from 9:00 to 12:00 the wind was keeping increasing and from 9:00 the wind speed changes have fluctuated remarkably.

Figure 2.11 Grounded oil tanker 'BUM JIN'

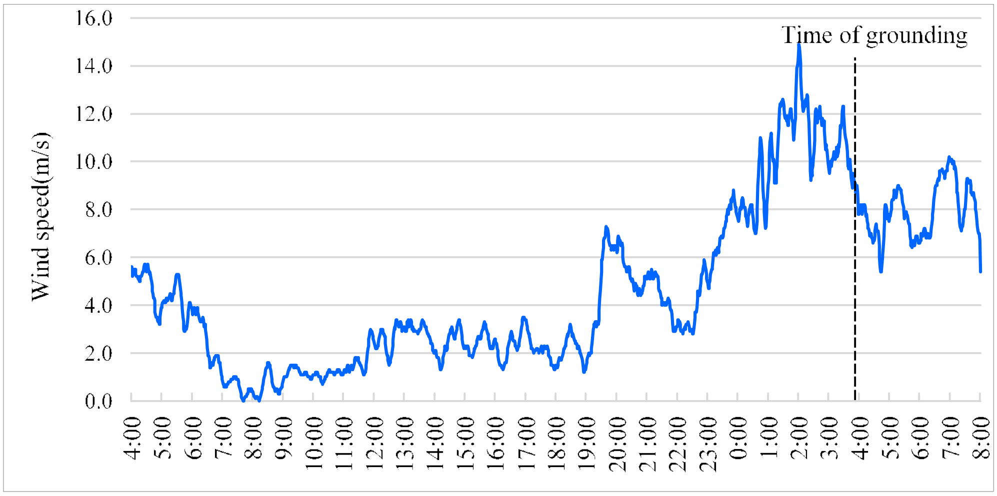

Figure 2.12 10-minute average wind speed before and after the 'BUM JIN' accident

On 25 November 2013, the oil tanker 'BUM JIN' (GT 2302 tons) anchored in Ulsan port was stranded by strong wind and high seas. As shown in Figure 2.11, the oil tanker 'BUM JIN' was seriously destroyed and eventually lost its transport function. On the same day, another two oil tanker ship grounded at Ulsan coastal sea, they are ZHOU HANG 2 (GT 4675 tons) and 'CS CRANE' (GT 7675 tons) which caused very serious marine pollution and ecological pollution. Figure 2.12 shows that the wind speed reached its maximum value of 14.9 m/s at 2:01 and the grounding accident happened almost two hours after the maximum wind speed appeared. From 8:00 to 19:00 the wind speed was under 4 m/s and during this period of time the wind speed changing smoothly. However, from 19:00 the wind speed began to change dramatically, at 2:01 the wind reached its maximum value.

Figure 2.13 Grounded car carrier 'OCEAN TANGO'

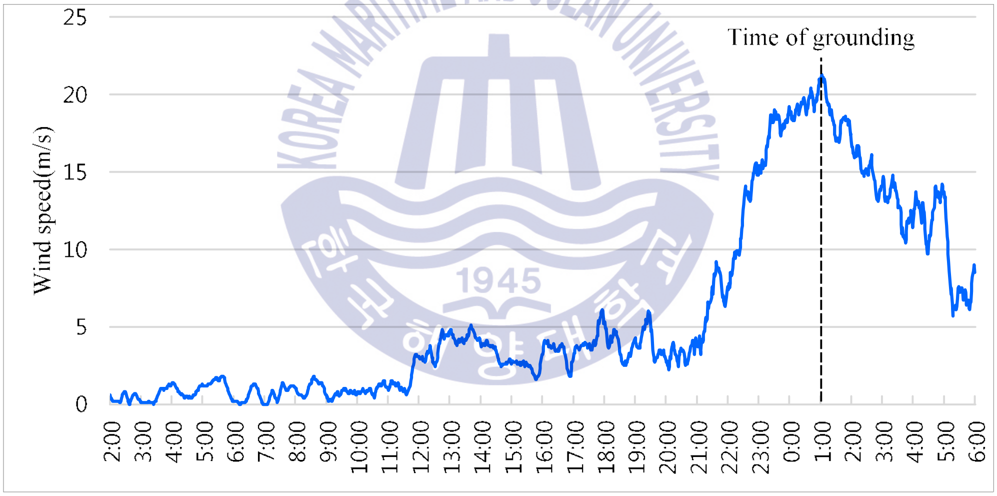

Figure 2.14 10-minute average wind speed before and after the 'OCEAN TANGO' accident

As shown in Figure 2.13, the car carrier 'OCEAN TANGO' (GT 3525 tons) which was anchored at Young-do area, grounded by strong wind and high seas on 17 April 2016. For this grounding accidents, more than 38,000 liters of oil spilled from her and caused enormous economic losses and serious environmental pollution. Figure 2.14 shows the facts that the grounding accident occurred near the strongest wind speed point for the car carrier ‘OCEAN TANGO’. From 2:00 to 21:00 the wind speed was under 6 m/s and the speed changes were very stable. Whereas from 21:00 the wind speed continued to increase rapidly and reached its maximum velocity at 01:03, between 21:00 and 6:00 the wind speed change rate was severe.

Figure 2.15 Grounded passenger ship ‘MI NAM’

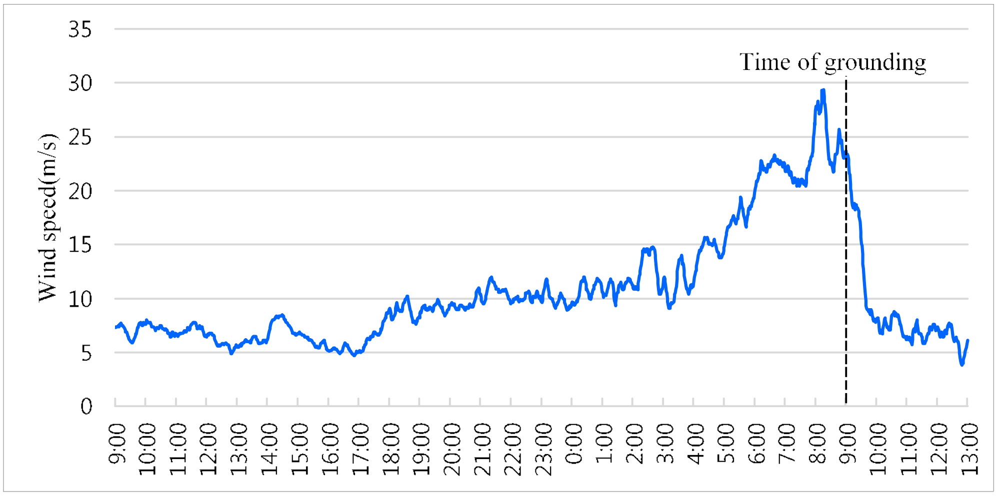

Figure 2.16 10-minute average wind speed before and after the ‘MI NAM’ accident

As shown in Figure 2.15, the passenger ship ‘MI NAM’ (GT 1321 tons) anchored in Yeosu Expo new port was grounded by the breakwater while being pushed by a strong gust because of the typhoon ‘CHABA’ On 04 May 2016. Figure 2.16 shows the wind speed curve before and after the passenger ship ‘MI NAM’ accident, for this grounding case, the accident happened almost one hour after the maximum wind speed appeared. From 17:00 to 07:58 the wind has maintained an increasing trend, and up to the maximum wind speed at 07:58. From 03:00 to 13:00 the wind speed changes were fluctuated severely.

Analyzing the eight grounding cases above, it can acquire the conclusion that the accidents did not always occur near the strongest point of wind. For the cargo ship ‘TIAN HE’ and the car carrier ‘OCEAN TANGO’, the grounding accidents happened near the maximum wind speed, and for the other six cases, the accidents occurred a few hours after the maximum wind speed appeared. And for the eight grounding accidents, the grounding wind speed varied a lot from each other. Thus, making alarming level only based on the wind speed does not a good and effective method. However, for the eight grounding accidents, the wind speed has changed very quickly during a specific time period. Hence, this paper attempts to use wind speed changing rate to carry on the further analysis for the eight grounding accidents.

Chapter 3. Development of the Strong Wind Warning Algorithm

3.1 The Basic Method of Wind Speed Changing Trend Prediction

In recent years, different kinds of wind speed changing trend forecasting methods have been developed, which is including Kalman filtering method, linear trend method, random time series method, least squares method, and the others.

The linear trend method is to assume that the variables that are to be predicted are linear in relation to time, and based on this to predict the future trend. But sometimes there is no linear relationship between wind speed and time.

Using the Kalman filter algorithm, the wind speed is used as the state variable to establish the state space model, which can realize the wind prediction. However, it is difficult to establish the Kalman state equation and the measurement equation. And this method can be used to predict the online wind speed when the noise statistical characteristics are known. But the statistical characteristics of the noise are often difficult to obtain.

The implementation of random time series method is relatively simple and requires only a single wind time series to model, but the accuracy of the prediction depends on the order of the model, the low order has low prediction accuracy, and it is difficult to calculate the parameters of the model with the high order number.

The least squares method is a mathematical optimization technique. It matches the best function of finding the data by minimizing the squared error. Using the least square method, the unknown data can be obtained easily, and the sum of squared error between the obtained data and the actual data is minimized. Therefore, this paper uses the least squares method to process the wind speed data.

3.2 Design of the Strong Wind Warning Algorithm

3.2.1 Wind Speed Changing Trend Calculation Method

At first, the wind speed changing trend is obtained by least squares method. The least squares method is a process to find the best fit line to the target data (Miller). The gradient of the fit line means the simple changing trend in a specific period. This study mainly used the Excel's Linest function to process the wind speed data and obtain the gradient values. This study uses 8 computing units to acquire 8 kinds of gradient values. Meanwhile, the computing units are 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, 6 hours, 7 hours and 8 hours. Eqs.(3-1)-(3-5) is the formula for seeking wind speed changing rate by the linear least squares method.

$$y = kt + c \qquad (3-1)$$

$$\bar{t} = \frac{1}{n}\sum_{i=1}^{n} t_i \qquad (3-2)$$

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

$$b_0 = \bar{y} + b_1 \bar{t} \tag{3-4}$$

$$k = \frac{\sum_{i=1}^{n}(t_i - \bar{t})(y_i - \bar{y})}{\sum_{i=1}^{n}(t_i - \bar{t})^2} \tag{3-5}$$

where is t time, y is wind speed, $\bar{t}$ is mean time, $\bar{y}$ is mean wind speed , c is the constant and b_1 is the slope.

Table 3.1-3.2 show the calculation method of wind speed changing rate, and the calculation unit varied from 1 hour to 8 hours. Figure 3.1 - 3.8 show the gradient values and wind speed curves.

Table 3.1 Wind speed changing trend calculation method (1-4 hours calculation unit)

Wind speed	1 hour	2 hour	3 hour	4 hour	Time
V1					8:00
V2					7:59
…					…
V60	Index(Linest(V1:V60))				7:00
…	…				…
V120	Index(Linest(V61:V120))	Index(Linest(V1:V120))			6:00
…	…	…			…
V180	Index(Linest(V121:V180))	Index(Linest(V61:V180))	Index(Linest(V1:V180))		5:00
…	…	…	…		…
V240	Index(Linest(V181:V240))	Index(Linest(V121:V240))	Index(Linest(V61:V240))	Index(Linest(V1:V240))	4:00
…	…	…	…	…	…
V300	Index(Linest(V241:V300))	Index(Linest(V181:V300))	Index(Linest(V121:V300))	Index(Linest(V61:V300))	3:00
…	…	…	…	…	…
V360	Index(Linest(V301:V360))	Index(Linest(V241:V360))	Index(Linest(V181:V360))	Index(Linest(V121:V360))	2:00
…	…	…	…	…	…
V420	Index(Linest(V361:V420))	Index(Linest(V301:V420))	Index(Linest(V241:V420))	Index(Linest(V181:V420))	1:00
…	…	…	…	…	…
V480	Index(Linest(V421:V480))	Index(Linest(V361:V480))	Index(Linest(V301:V480))	Index(Linest(V241:V480))	0:00
…	…	…	…	…	…
V1680	Index(Linest(V1621:V1680))	Index(Linest(V1561:V1680))	Index(Linest(V1501:V1680))	Index(Linest(V1441:V1680))	4:01
V1681	Index(Linest(V1622:V1681))	Index(Linest(V1562:V1681))	Index(Linest(V1502:V1681))	Index(Linest(V1442:V1681))	4:00

Table 3.2 Wind speed changing trend calculation method (5-8 hours calculation unit)

Wind speed	5 hour	6 hour	7 hour	8 hour	Time
V1					8:00
V2					7:59
…					…
V60					7:00
…					…
V120					6:00
…					…
V180					5:00
…					…
V240					4:00
…					…
V300	Index(Linest(V1:V300))				3:00
…	…				…
V360	Index(Linest(V61:V360))	Index(Linest(V1:V360))			2:00
…	…	…			…
V420	Index(Linest(V121:V420))	Index(Linest(V61:V420))	Index(Linest(V1:V420))		1:00
…	…	…	…		…
V480	Index(Linest(V181:V480))	Index(Linest(V121:V480))	Index(Linest(V61:V480))	Index(Linest(V1:V480))	0:00
…	…	…	…	…	…
V1680	Index(Linest(V1381:V1680))	Index(Linest(V1321:V1680))	Index(Linest(V1261:V1680))	Index(Linest(V1201:V1680))	4:01
V1681	Index(Linest(V1382:V1681))	Index(Linest(V1322:V1681))	Index(Linest(V1262:V1681))	Index(Linest(V1202:V1681))	4:00

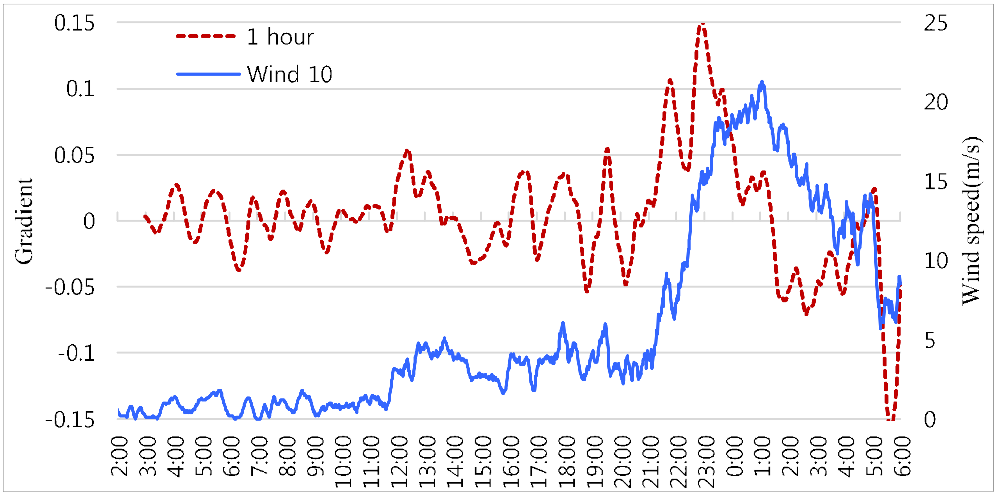

Figure 3.1 1 hour gradient and wind speed curve (OCEAN TANGO)

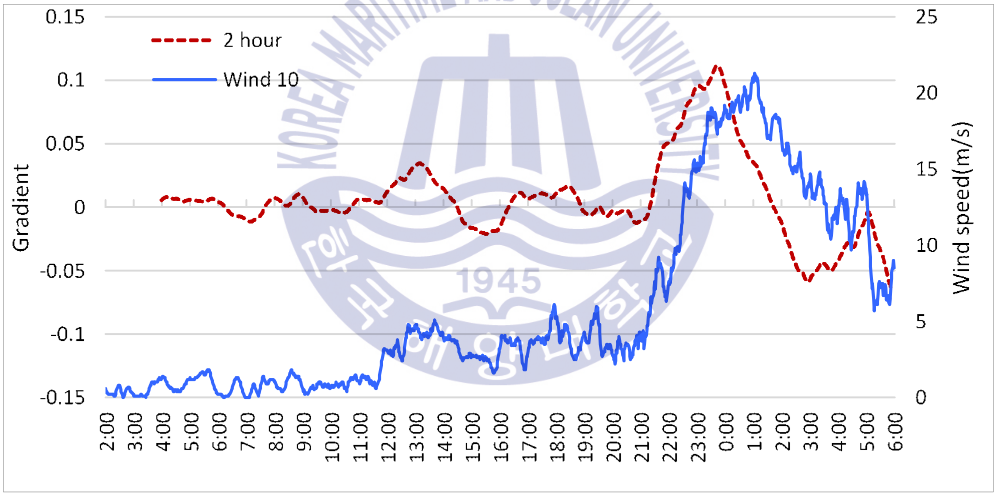

Figure 3.2 2 hours gradient and wind speed curve (OCEAN TANGO)

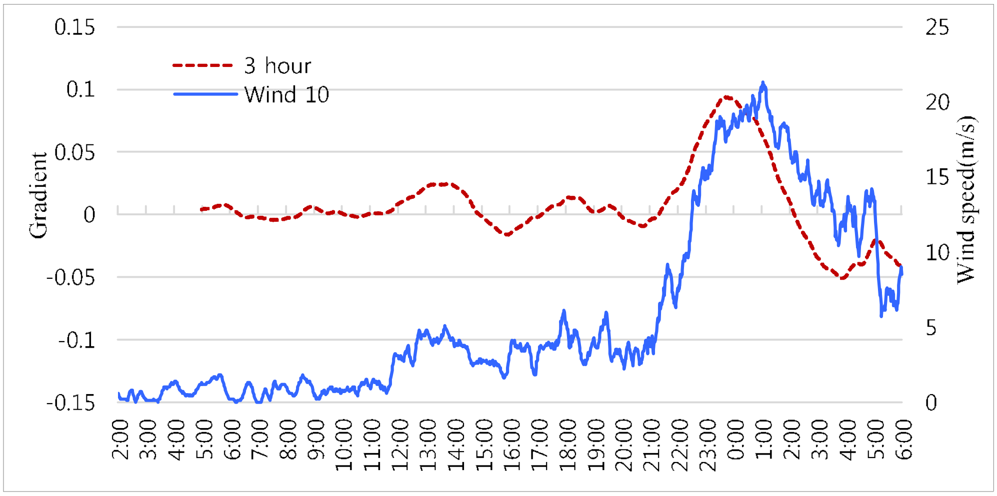

Figure 3.3 3 hours gradient and wind speed curve (OCEAN TANGO)

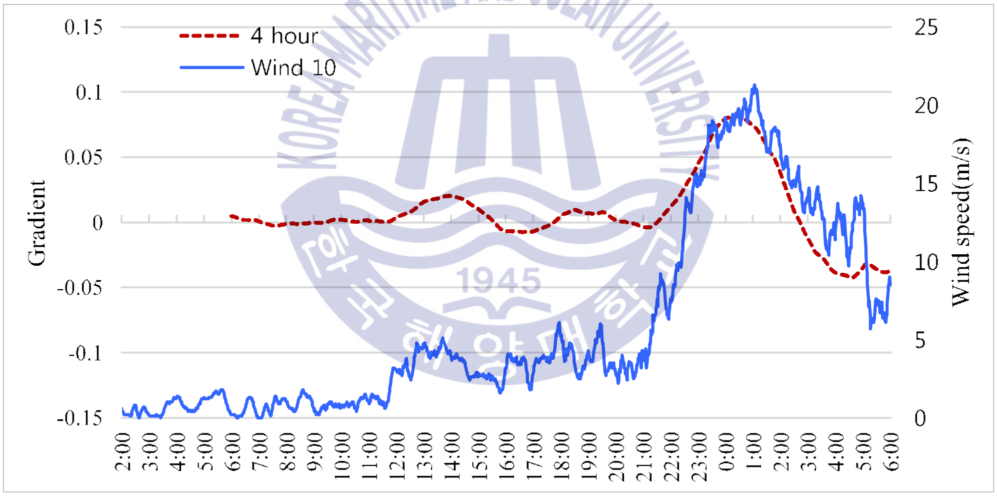

Figure 3. 4 4 hours gradient and wind speed curve (OCEAN TANGO)

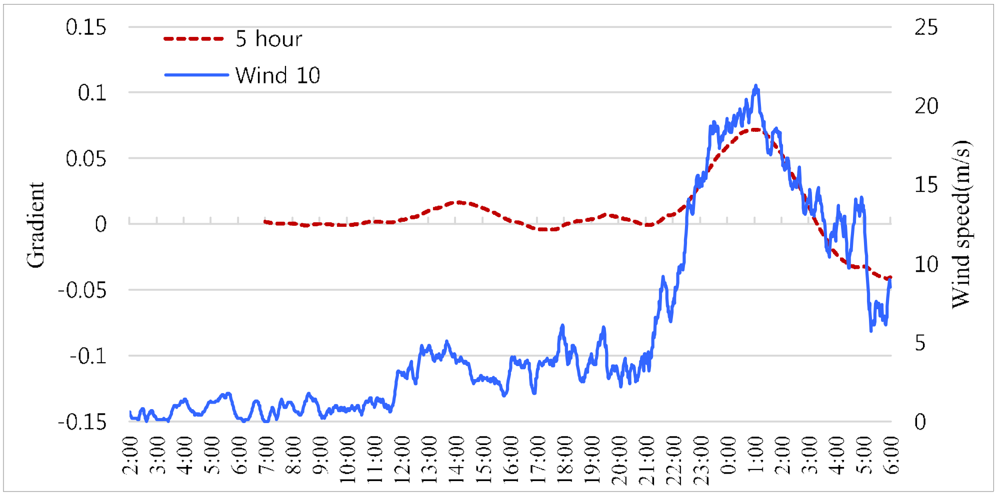

Figure 3.5 5 hours gradient and wind speed curve (OCEAN TANGO)

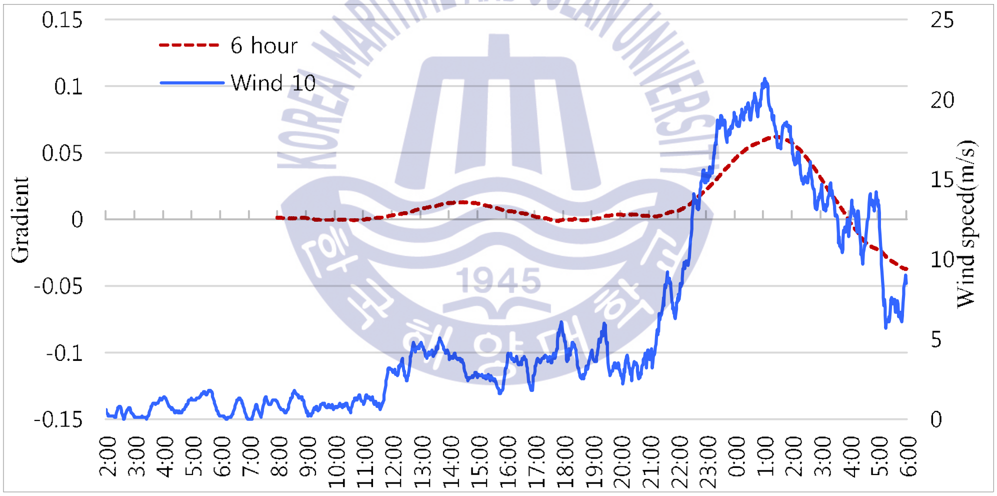

Figure 3.6 6 hours gradient and wind speed curve (OCEAN TANGO)

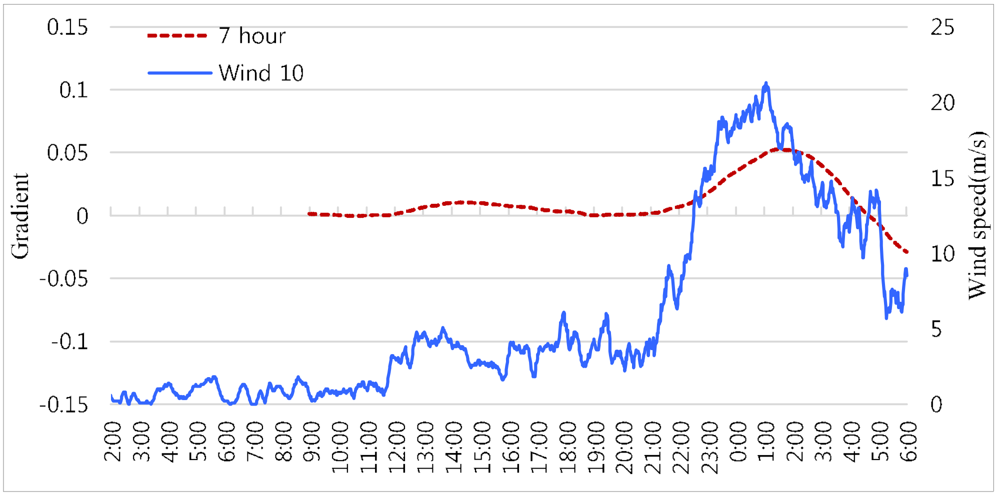

Figure 3.7 7 hours gradient and wind speed curve (OCEAN TANGO)

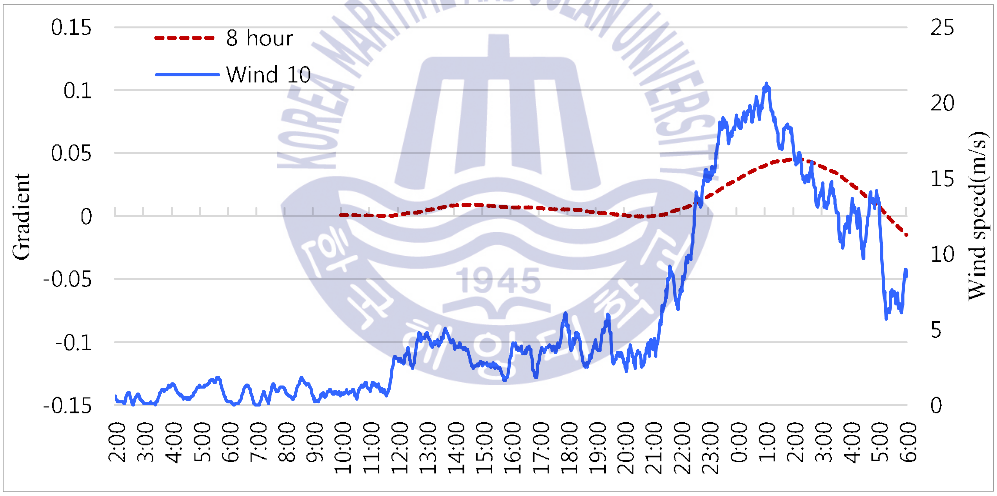

Figure 3.8 8 hours gradient and wind speed curve (OCEAN TANGO)

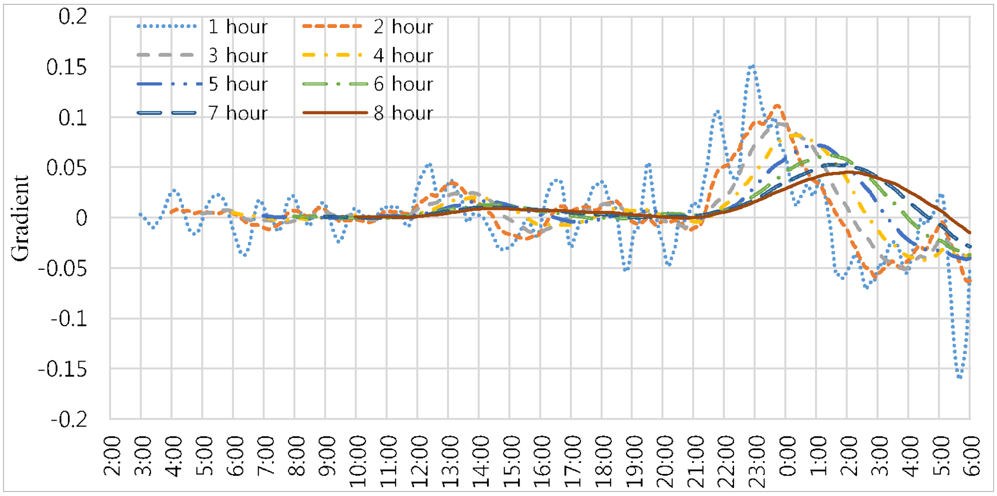

Figure 3.9 Gradient curve of least squares method (OCEAN TANGO)

Comparing the 9 figures plotted above, it can find the phenomenon that the fluctuation of the gradients becomes larger as the calculating unit becomes shorter. And as the calculating range becomes larger the time-delay of the gradient values is increasing. Applied the wind speed data of the other seven accidents into the 'llnest' function, it attains the same result. Therefore, this study takes an assumption that 6 hours is the most suitable computing unit.

Secondly, 6 hours gradient values curve and 10-minute average wind speed curve are displayed together to check out if the gradient values can effectively forecast the wind speed.

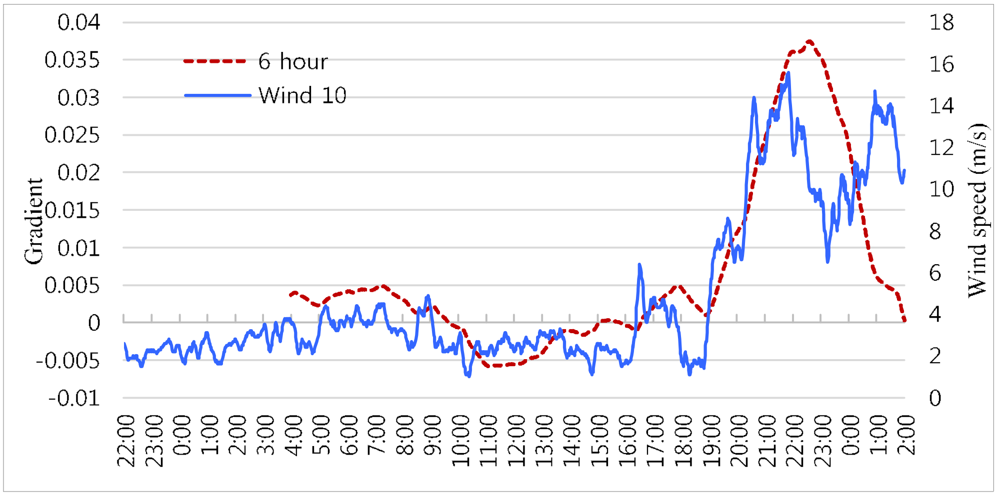

Figure 3.10 6 hours gradient and wind speed curve (TIAN HE)

Analyzing the gradient curve from the Figure 3.10, it is obvious that the 6 hours gradient values of the cargo ship 'TIAN HE' can indicate the changing trend of wind speed accurately. Especially from 19:00 to 23:00, during this period the wind speed velocity changes were rapidly and the gradient values can forecast it very efficiently. Therefore, for the cargo ship 'TIAN HE' accident the 6 hours gradient values is very practical in forecasting the wind speed changing trend.

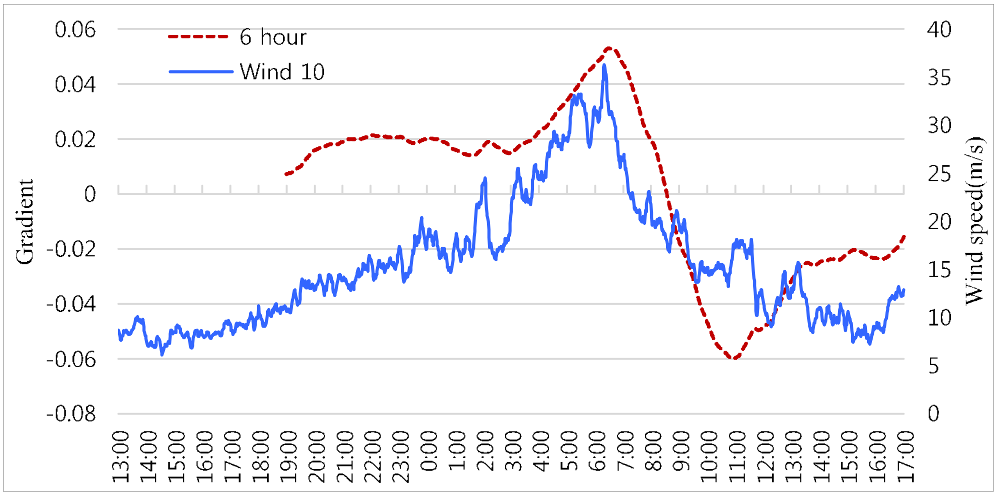

Figure 3.11 6 hours gradient and wind speed curve (CAI XIN)

As shown in Figure 3.11, within a certain range of wind speed, the gradient value is less fitted. However, on the whole, the gradient value can effectively predict the wind speed changing trend. The gradient values tend to be a certain of lager at the wind speed zone from 19:00 to 01:00, but it is still possible to predict the growth trend of wind speed. From 03:00 to 09:30, the wind speed changes rapidly, and the gradient values can be very practical in forecasting the changing trend for this period of time. Therefore, in terms of the cargo ship 'CAI XIN' accident, if this alarming system only uses the gradient values as the warning index, the predicting effect won't fit in with reality very well. For this grounding accident, the strong wind warning system needs to find a revision algorithm to improve its prediction accuracy.

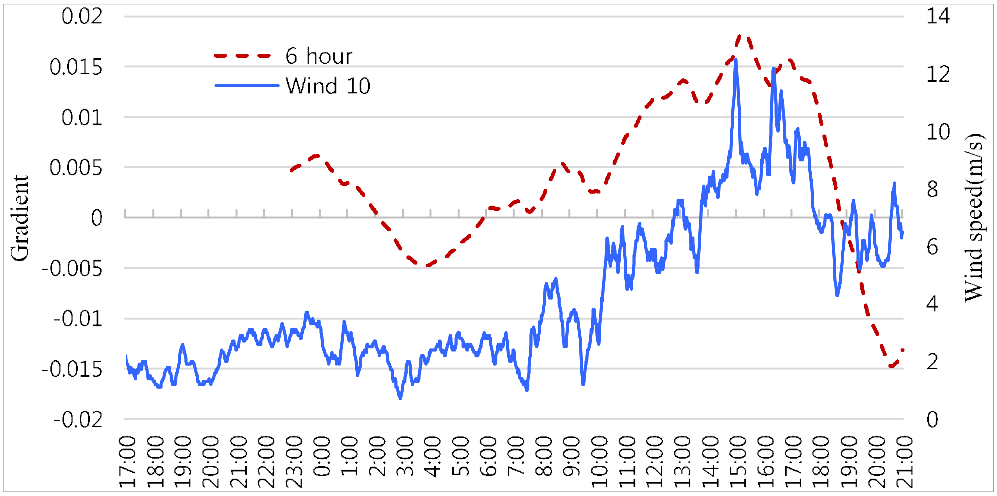

Figure 3.12 6 hours gradient and wind speed curve (JE HAE)

In general, the gradient values are conducive to predicting the wind speed changing trend for the cargo ship 'JE HAE' accident. However, from 23:00 to 10:00 at the low wind speed area, the gradient values are inclined to be somewhat larger, but still can predict the variation trends of wind speed. As a consequence, for the gradient values of this period of time, it's would be better to find a correction algorithm that can decrease the gradient values in the low wind speed area. As a result, the gradient values cannot be used to precisely forecast the variation trend of wind speed in 'JE HAE' grounding case.

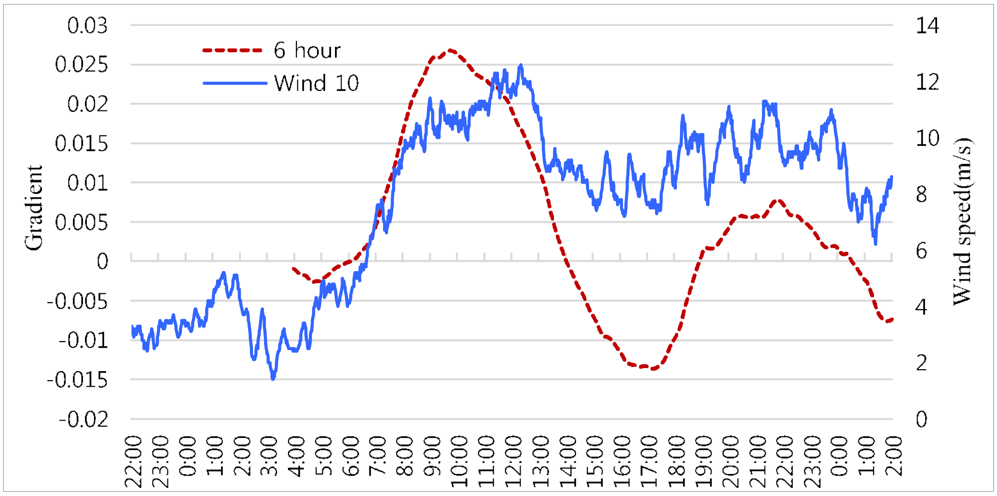

Figure 3.13 6 hours gradient and wind speed curve (FU SHENG HAI)

On the whole, the gradient values can reflect the variation tendency of wind speed curve pretty well as is shown in Figure 3.13. Whereas the gradient values appear to be somewhat smaller in the high wind speed zone of 7~10 m/s from 15:00 to 18:00, but it can still predict the wind speed changing trend. Hence, for the deviation of this wind speed region, it's better to find a way that can increase the gradient values.

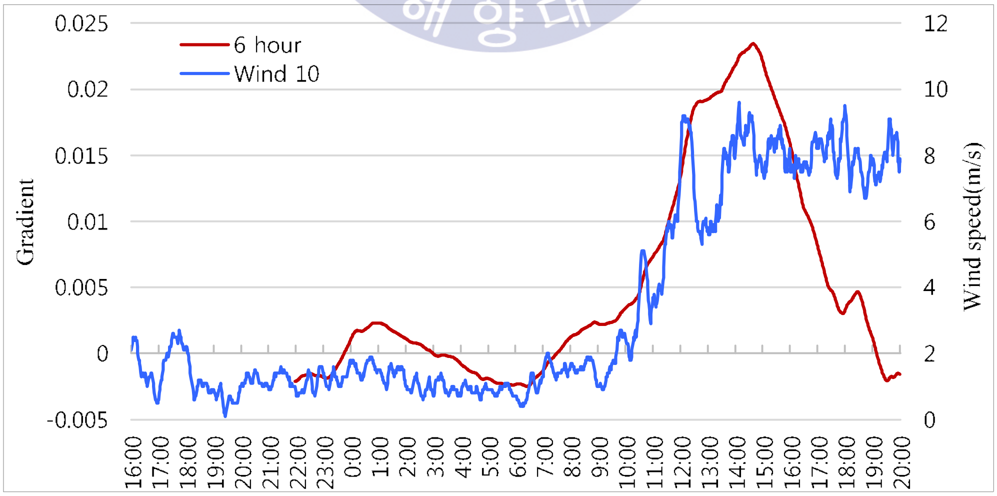

Figure 3.14 6 hours gradient and wind speed curve (CHENG LU 15)

As shown in Figure 3.14, the gradient values can forecast the changing trend of wind speed effectively. And more than one hour before the grounding accident, the gradient values reached its maximum number. Therefore, for this grounding case, the gradient values can be used to forecast the wind speed very well.

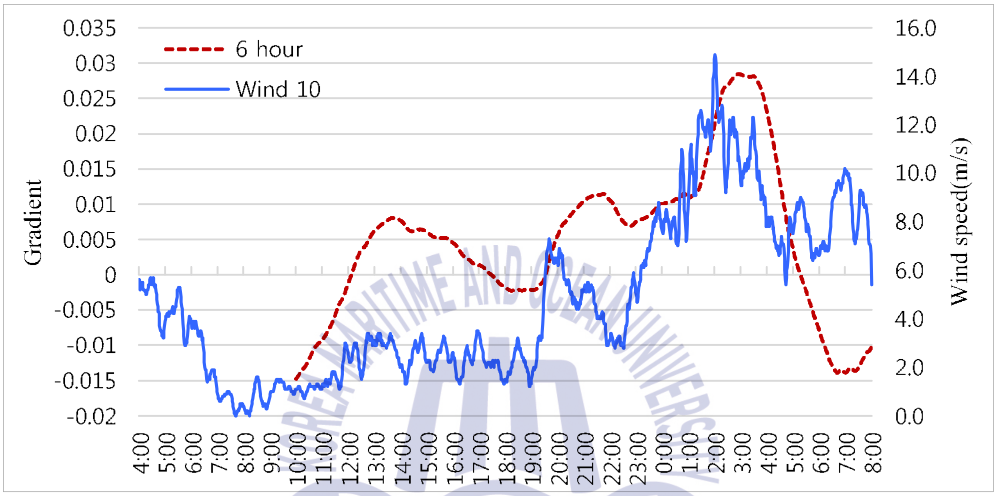

Figure 3.15 6 hours gradient and wind speed curve (BUM JIN)

In figure 3.15, although the gradient values can indicate the changing trend of wind speed well, the gradient values tend to be somewhat larger in the low wind speed zone which is under 4 m/s from 13:00 to 16:00. And in this period of time, the gradient values cannot reflect the wind speed changing trend. It means that if only use the gradient value to forecast the wind speed changing trend, it may not fit in with reality.

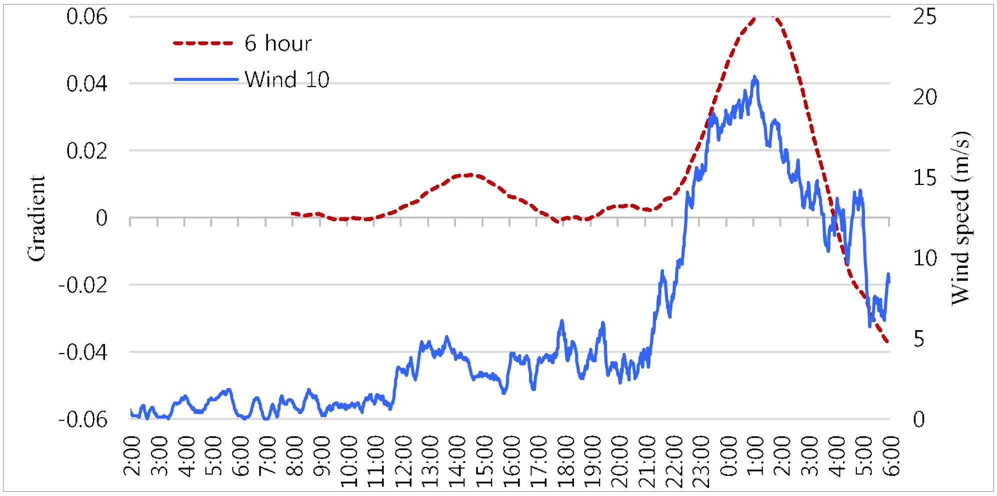

Figure 3.16 6 hours gradient and wind speed curve (OCEAN TANGO)

In the car carrier ‘OCEAN TANGO’ grounding case, the gradient values can indicate the changing trend of wind speed well. However, the gradient values tend to be too large in the low wind speed zone which is under 5 m/s from 8:00 to 18:00. As a result, only uses the gradient values, this system cannot accurately indicate the trend of wind speed of the car carrier ‘OCEAN TANGO’ accident.

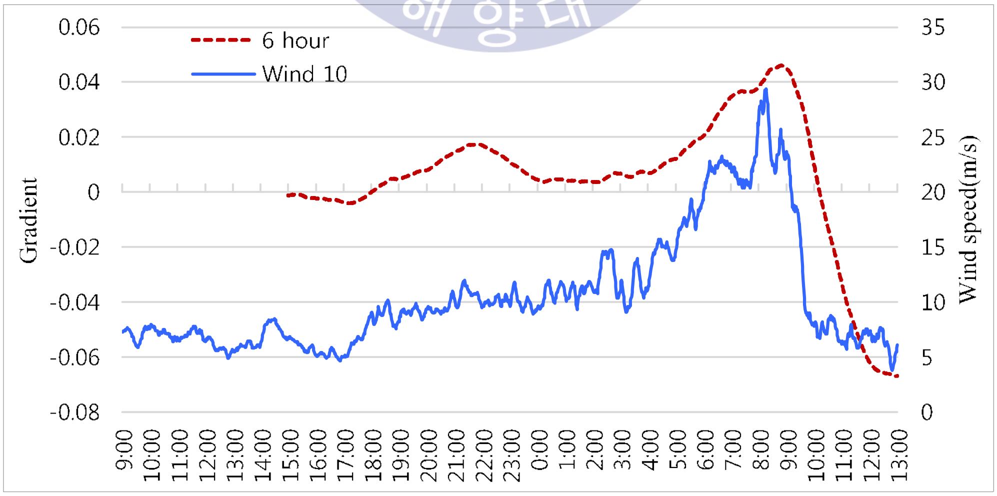

Figure 3.17 6 hours gradient and wind speed curve (MI NAM)

As shown in Figure 3.17, the gradient values can generally predict the changing tend of wind speed. Whereas, the gradient value tends to be too large from 15:00 to 02:00. Thus, if this study only uses the gradient values to forecast the wind speed changing trend, the accuracy of the prediction will be inaccurate.

As shown in Figure 3.10-3.17 above, the situation can be divided into three categories, the first kind is the gradient values can predict the wind speed changing trend accurately: 'TIAN HE', 'CHENG LU 15'; the second type is the gradient values tend to be too large in the low wind speed zone: 'CAI XIN', 'JE HAE', 'BUM JIN', 'MI NAM', for these four stranded accidents, the gradient values in the low wind speed zone need to be decreased; the third kind is the gradient values tend to be too small in the high wind speed zone: 'FU SHENG HAI'. The gradient values in the high wind speed zone need to be increased for this grounding accident. It means that if this paper only uses the gradient values as the warning index, it may not fit in with reality. And the gradient values need to be revised.

3.2.2 Exponential Function Method

In terms of the wind strength, the strong wind speed is one of the main causes of the grounding accidents, and the low wind speed has little significance in the grounding accidents. Meanwhile, the gradient values tend to be somewhat larger at the low wind speed zone, and tend to be somewhat smaller in the high wind speed area. Therefore, if this paper manages to design an effective strong wind alarming system, it would be better for this paper to decrease the gradient values in the low wind speed zone and increase the gradient values in the high wind speed zone. This paper process the gradient values and wind speed data using the exponential function to further emphasize the large values. Table 3.2 shows the calculation method of the exponential function for gradient index, wind speed index, warning index (in this table 'G' is the column of 6 hours gradient). And each base of the exponential function was so calculated that wind speed 20m/s was set to index 30 and gradient 0.02 was set to index 20.

Gradient index

$$G = a^{m*1000} \qquad (3-6)$$

Where G is gradient index, a is about 1.122, m is 6 hours gradient values.

Wind speed index

$$Q = b^{V*1.5} \qquad (3-7)$$

Where Q is Wind speed index , b is about 1.08 , V is wind speed.

Warning index

$$W = G * Q \qquad (3-8)$$

Table 3.3 Exponential function method

Wind speed	G (6 hours)	Gradient index	Wind speed index	Warning index	Time
V1					8:00
V2					7:59
…					…
V360	Index(Linest(V1:V360))	Power(1.122, G360*1000)	Power(1.079, V360*1.5)	Gradient index*Wind speed index	2:00
V361	Index(Linest(V2:V361))	Power(1.122, G361*1000)	Power(1.079, V361*1.5)	Gradient index*Wind speed index	1:59
V362	Index(Linest(V3:V362))	Power(1.122, G362*1000)	Power(1.079, V362*1.5)	Gradient index*Wind speed index	1:58
…	…	…	…	…	…
V1680	Index(Linest(V1320:V1680))	Power(1.122, V1680*1000)	Power(1.079,V1680*1.5)	Gradient index*Wind speed index	4:01
V1681	Index(Linest(V1321:V1680))	Power(1.122, V1681*1000)	Power(1.079,V1681*1.5)	Gradient index*Wind speed index	4:00

3.3 Strong Wind Warning System Concepts

Applied the computational process to all the grounding cases in Table 2.1. Figure 3.18 – 3.25 show the calculation result of the gradient index, wind speed index and wind warning index for the eight grounding accidents. This paper divided the wind warning level into 4 stages which are namely warning index 5 as the limit of level 1 (attention), 10 as level 2 (warning), 15 as level 3 (alert), 20 as level 4 (critical). Actually, the wind warnings must be issued a few hours before the upcoming strong wind, this paper takes 2 hours as the basic pre-warning time. And the different ship can use the different warning level information based on the condition of the ship itself. Because there are too many factors which can affect the ship's grounding accident such as the ship's shape, the quantity of loading cargo, holding power of anchor and cable, depth of water area, and the geographical features of the coast, and others. And because the warning index numbers does not necessarily equate to an integer, that is why the warning level does not necessarily appears at integer points.

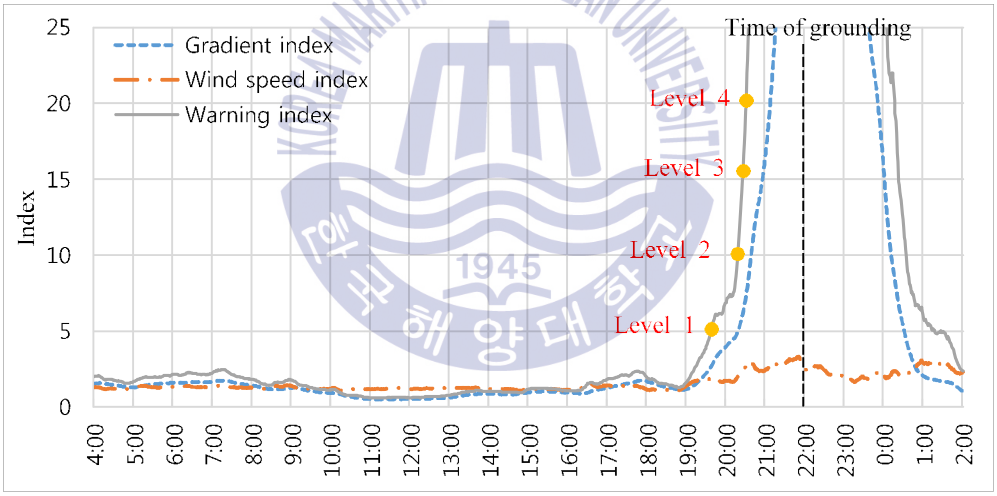

Figure 3.18 Calculation results curve of 3 indexes (TIAN HE)

As shown in Figure 3.18, the warning 'level 4' can be indicated at 20:23, and the accident happened at 22:00. It means that the cargo ship 'TIAN HE' would be alerted more than one and a half hours before the accident. Therefore, by using this warning system, the mariner can have sufficient to do the preparation work for the coming strong wind.

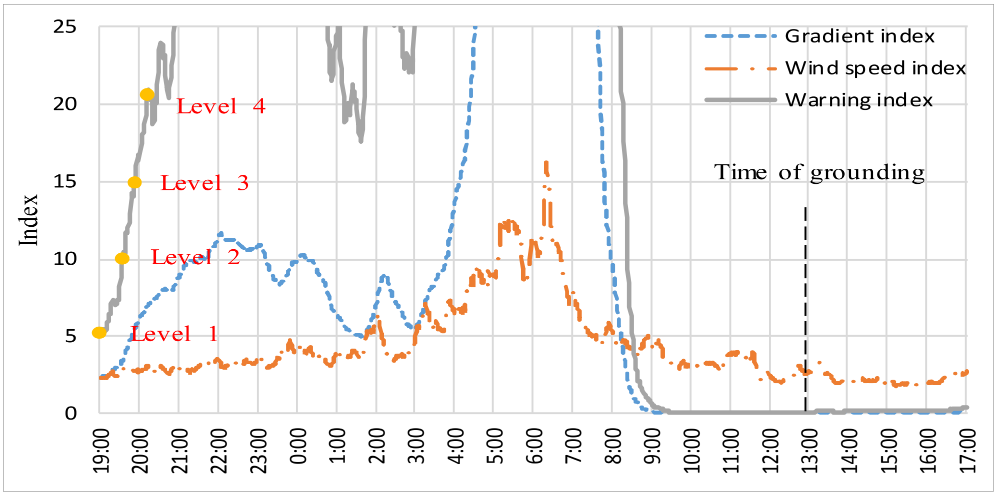

Figure 3.19 Calculation results curve of 3 indexes (CAI XIN)

As shown in Figure 3.19, the warning 'level 4' can be indicated at 20:10 22nd, and the grounding accident happened at 13:00 23rd. Therefore, for the cargo ship 'CAI XIN' accident, the warning 'level 4' can be notified almost 17 hours in advance.

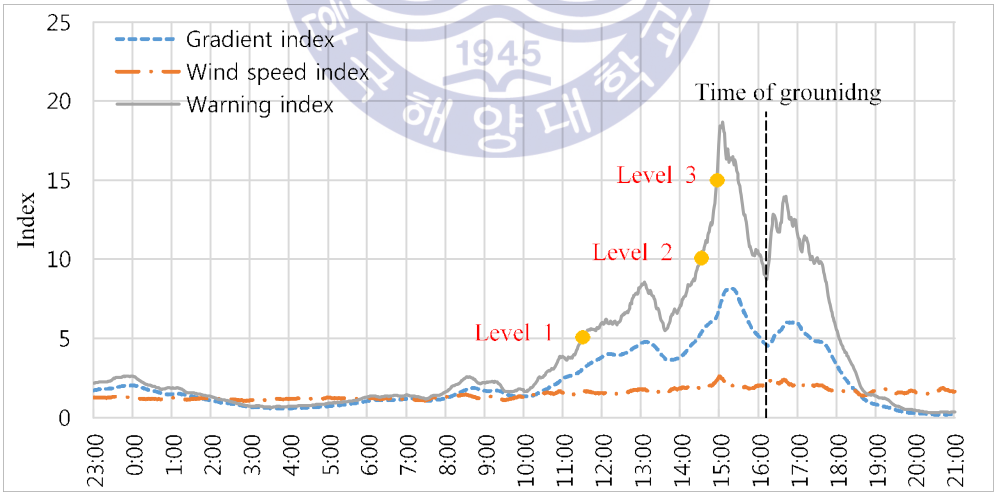

Figure 3.20 Calculation results curve of 3 indexes (JAE HAI)

From Figure 3.20 it can attain the information that the warning 'level 4' cannot be issued, and the warning 'level 3' can be notified at 14:55.

The cargo ship ‘JAE HAI’ accident happened at 16:17. Therefore, cargo ship ‘JE HAE’ has almost one and a half hours to do enough preparation after the ‘level 3’ alarming signal occurred.

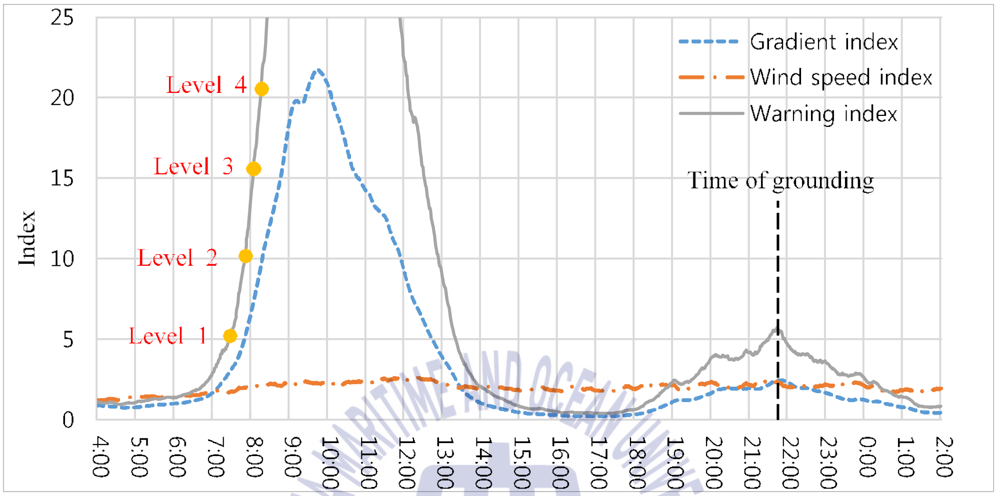

Figure 3.21 Calculation results curve of 3 indexes (FU SHENG HAI)

As shown in the Figure 3.21, the warning ‘level 4’ can be issued at 08:16 and the accident happened at 21:40. Hence, the bulk carrier would be informed the warning ‘level 4’ nearly 14 hours before her grounding accident. This warning system can provide enough pre-warning time for the ship’s crews to do sufficient work for the coming strong wind.

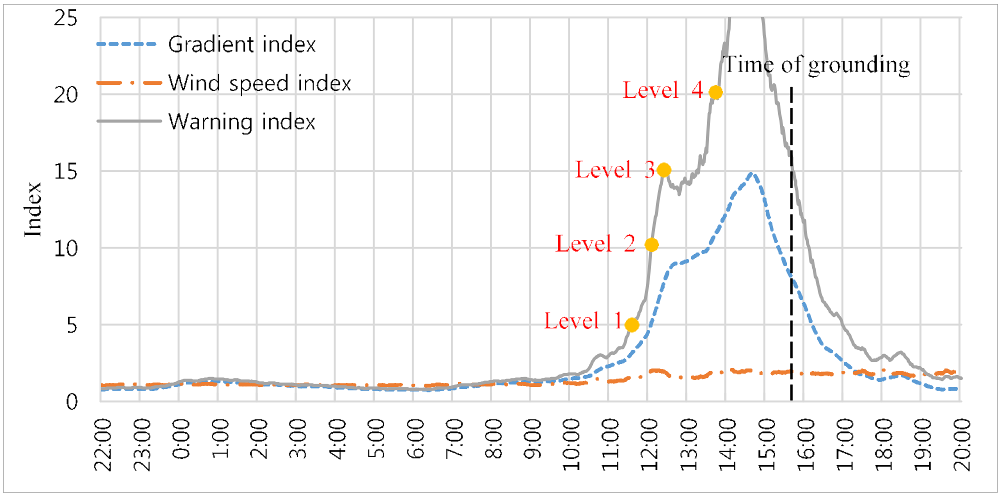

Figure 3.22 Calculation results curve of 3 indexes (CHENG LU 15)

From Figure 3.22, it can attain the information that the warning 'level 4' can be notified at 08:16 and the grounding time was at 15:40. It means that for the crews on freighter 'CHENG LU 15', they would have nearly 2 hours pre-warning time to do preparative works before the strong wind arrive.

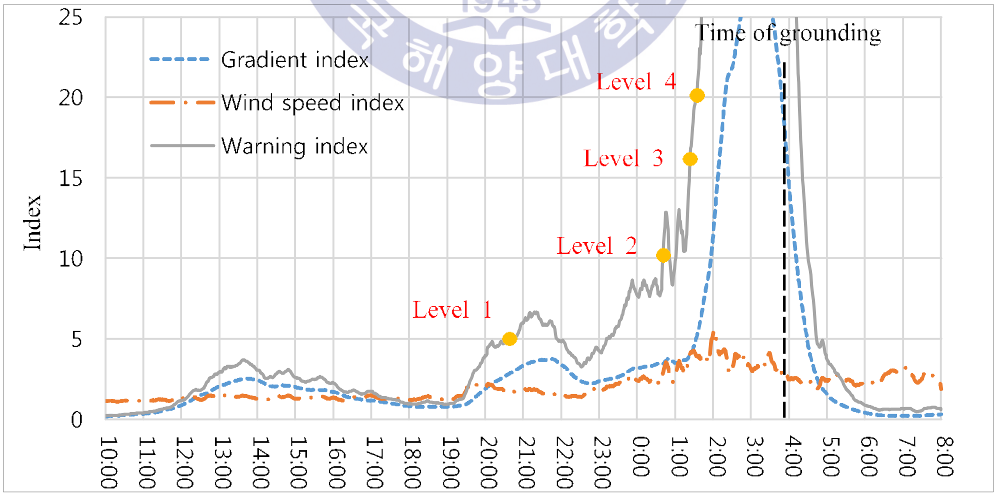

Figure 3.23 Calculation results curve of 3 indexes (BUN JIN)

Figure 3.23 shows the three kinds of warning indexes of the oil tanker ‘BUM JIN’ accident, the warning ‘level 4’ can be indicated at 01:34 and the grounding accident happened at 03:55. Therefore, for the mariners on ‘BUM JIN’, they would have more than 2 hours early warning time before the strong wind arrive. During this period of time, the sailors could carry out some reasonable coping strategies for the coming strong wind.

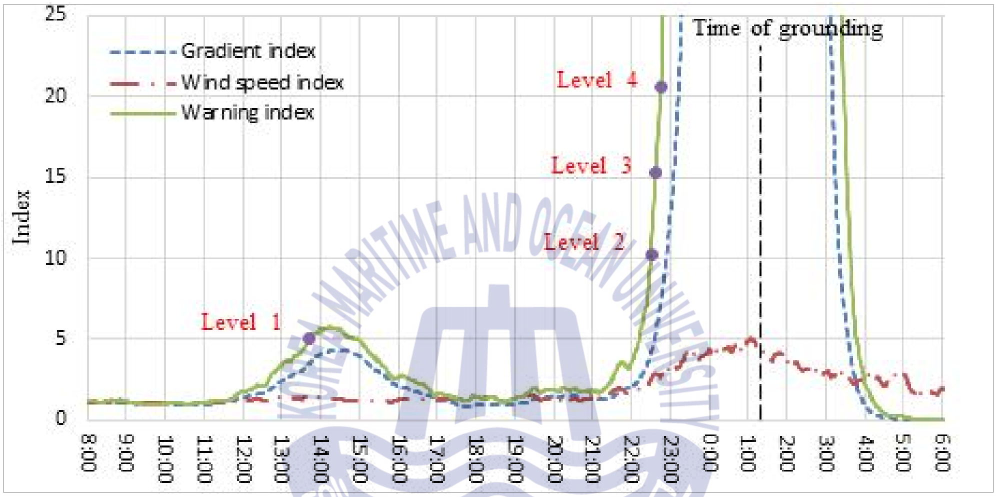

Figure 3.24 Calculation results curve of 3 indexes (OCEAN TANGO)

As is demonstrated in Figure 3.24, for the car carrier ‘OCEAN TANGO’, the ‘level 4’ could be notified at 22:45 16th and the grounding time was at 01:02 17th. Hence, the car carrier ‘OCEAN TANGO’ could obtain the warning ‘level 4’ more than 2 hours before her stranding accident. And because ‘OCEAN TANGO’ berthed at the port in light ship condition, the mariner can adjust the ballast water to increase the ship’s draught and reduce the windward area, finally improve the ship’s stability to resist the strong wind.

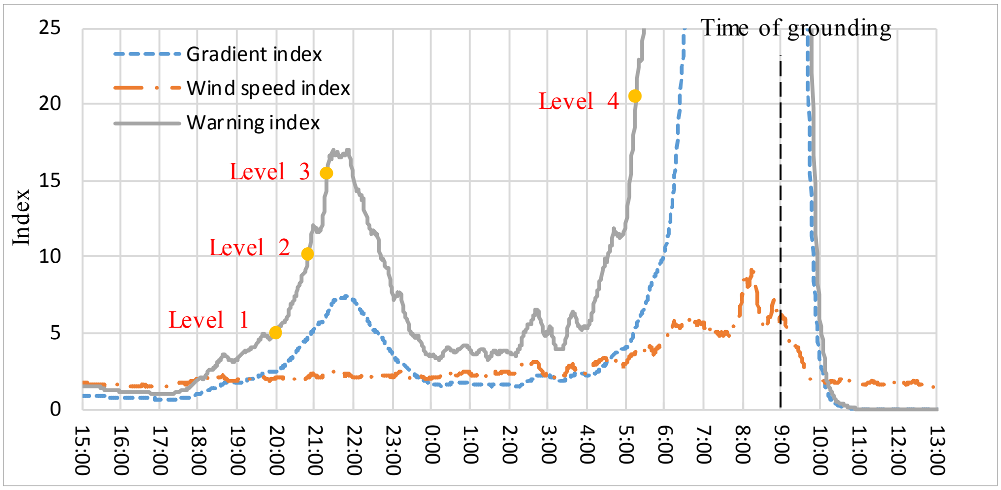

Figure 3.25 Calculation results curve of 3 indexes (MI NAM)

As shown in Figure 3.25, the warning 'Level 4' can be indicated at 05:15 and the accident happened at 09:00 for the passenger ship 'MI NAM'. It means that the warning 'level 4' can be indicated three and 45 minutes before the strong wind reach. This warning system can let the mariners on 'MI NAM' have enough time to do sufficient strong wind preventive work for the coming typhoon 'CHABA'.

Table 3.4 Warning time of the cases at each level (6 hours calculation unit)

No	Ship's name	Accident time	Warning time				
			Level 1 (Attention)	Level 2 (Warning)	Level 3 (Alert)	Level 4 (Critical)	Pre-warning time
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	14:55	No	1h 22mins
4	FU SHENG HAI	2013.07.02 21:40	07:28	07:52	08:04	08:16	13h 24mins
5	CHENG LU 15	2013.10.15 15:40	11:36	12:06	12:25	13:36	2h 4mins
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	2016.10.05 09:00	19:58	20:50	21:18	05:15	3h 45mins

Table 3.3 is the calculation result of the warning time at each warning level of the grounding accidents. For the eight cases analyzed in this paper, all vessel except JE HAE can issue the 'Level 4', the other six ships can be notified the warning 'level 4' more than two hours, for 'TIAN HE' ship the 'Level 4' can be warned about one and a half

hours.

Table 3.5 Warning time of the cases at each level (5 hours calculation unit)

No	Ship's name	Accident time	Warning time				
			Level 1 (Attention)	Level 2 (Warning)	Level 3 (Alert)	Level 4 (Critical)	Pre-warning time
1	TIAN HE	2007.03.04 22:00	19:31	20:14	20:21	20:26	1h 34mins
2	CAI XIN	2012.08.23 13:00	18:32	19:10	19:32	19:56	17h 4mins
3	JE HAE	2013.02.01 16:17	10:54	13:59	14:21	No	
4	FU SHENG HAI	2013.07.02 21:40	06:53	07:13	07:40	07:49	13h 51mins
5	CHENG LU 15	2013.10.15 15:40	11:29	11:59	12:06	12:13	3h 27mins
6	BUM JIN	2013.11.25 03:55	19:59	21:03	01:02	01:05	2h 50mins
7	OCEAN TANGO	2016.01.17 01:02	13:06	22:25	22:30	22:33	2h 29mins
8	MI NAM	2016.10.5 09:00	19:17	19:43	20:19	05:15	3h 45mins

Table 3.6 Warning time of the cases at each level (7 hours calculation unit)

No	Ship's name	Accident time	Warning time				
			Level 1 (Attention)	Level 2 (Warning)	Level 3 (Alert)	Level 4 (Critical)	Pre-warning time
1	TIAN HE	2007.03.04 22:00	20:05	20:25	20:33	20:42	1h 18mins
2	CAI XIN	2012.08.23 13:00	18:59	20:02	20:30	20:51	16h 9mins
3	JE HAE	2013.02.01 16:17	12:28	14:53	16:18	No	
4	FU SHENG HAI	2013.07.02 21:40	07:49	08:22	08:39	08:53	12h 47mins
5	CHENG LU 15	2013.10.15 15:40	11:05	12:17	13:50	14:21	1h 19mins
6	BUM JIN	2013.11.25 03:55	23:24	00:26	01:04	01:23	2h 32mins
7	OCEAN TANGO	2016.01.17 01:02	22:11	22:32	22:46	22:52	2h 10mins
8	MI NAM	2016.10.5 09:00	20:20	21:32	05:15	05:30	3h 30mins

Table 3.7 Warning time of the cases at each level (8 hours calculation unit)

No	Ship's name	Accident time	Warning time				
			Level 1 (Attention)	Level 2 (Warning)	Level 3 (Alert)	Level 4 (Critical)	Pre-warning time
1	TIAN HE	2007.03.04 22:00	20:17	20:33	20:59	21:07	53mins
2	CAI XIN	2012.08.23 13:00	//	//	21:25	21:42	15h 18mins
3	JE HAE	2013.02.01 16:17	12:48	14:50	16:37	No	
4	FU SHENG HAI	2013.07.02 21:40	07:59	08:52	09:21	09:40	12h
5	CHENG LU 15	2013.10.15 15:40	11:59	13:32	14:08	No	1h 32mins
6	BUM JIN	2013.11.25 03:55	23:27	00:40	01:04	01:23	2h 32mins
7	OCEAN TANG O	2016.01.17 01:02	22:16	22:30	22:50	23:01	2h 1mins
8	MI NAM	2016.10.5 09:00	20:39	23:06	05:29	05:48	3h 12mins

This study applies the 5 hours, 7 hours and 8 hours calculation unit into the warning algorithm to verify the hypothesis proposed in section 3.2.2, and obtains the warning time at each warning level of the grounding cases which are shown in the Table 3.4, Table 3.5 and Table 3.6.

Table 3.4 shows that 'JE HAE' cannot issue the warning 'level 3', the cargo ship 'TIAN HE' can be informed the warning 'level 4' more than one and a half hours, and the other six vessels can be notified the warning ‘level 4’ more than two hours before the coming strong wind. Compared to the alarming system based on 6 hours calculation unit, the early warning time of the wind warning system do not changed too much. Therefore, the alarm system that based on 6 hours computing unit is effective enough.

Table 3.5 shows that ‘JE HAE’ cannot issue the warning ‘level 3’, ‘TIAN HE’ and ‘CHENG LU 15’ can be indicated the warning ‘level 4’ less than one and a half hours, and the other five vessels can be notified more than two hours before the strong wind reach. Compared to the 6 hours computing unit, the alarming system which is based on 7 hours calculation unit has a poor early warning time. Therefore, the alarm system based on 7 hours calculation unit is not efficient as the alarm system based on 6 hours computing unit.

Table 3.6 shows that ‘JE HAE’ cannot issue the warning ‘level 3’, ‘CHENG LU 15’ cannot issue the warning ‘level 4’, ‘TIAN HE’ can be informed the warning ‘level 4’ 53 minutes in advance, and the other five vessels can be notified the warning ‘level 4’ more than two hours before the strong wind arrive. And it compared to the alert system which is based on 6 hours calculation unit, the time-effectiveness of the wind alert system is poor, the predication quality of the alert system based on 8 hours calculation unit is not good as the alert system that based on 6 hours computing unit.

As mentioned above, the hypothesis proposed in chapter 3.2.2 (on the page of 33) turned out to be right. Therefore, the 6 hours calculation unit is proved to be the most suitable computing unit.

3.4 Simulation

In order to verify the feasibility of this strong wind warning system, this study carries out a simulation test by a grounding tug ship which was stranded by the strong wind in the coast of Wallhang port Yeosu-si at 10:20 on May 3, 2016. For this grounding accident the wind observations place is Sinbok-ri, Dolsan-eup, Yeosu-si, the nearest wind speed observation station to the accident.

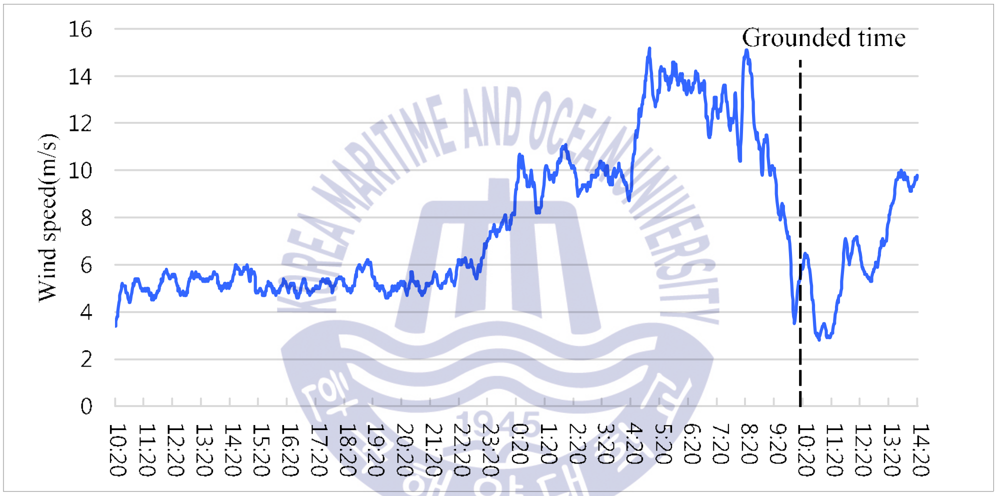

Figure 3.26 10-minute average wind speed before and after the 'TUG' accident

Figure 3.26 shows the wind speed before and after the grounding accident, for this grounding case the accident occurred almost two hours after the maximum wind speed appeared. From 10:20 to 22:20 the wind speed was under 6 m/s and the wind speed changes smoothly, but from 22:20 to 14:20 the wind speed changes rapidly. Especially, during this periods of time, the wind varies dramatically.

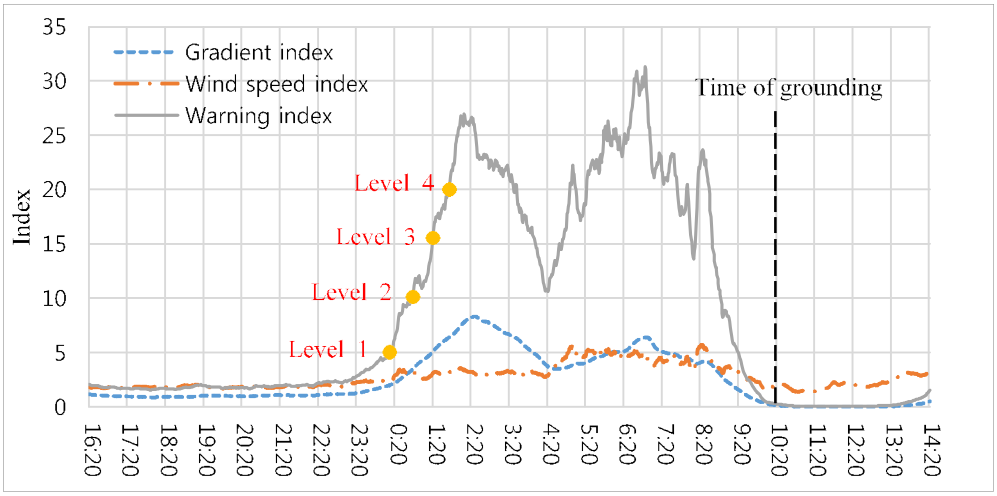

Figure 3.27 Calculation result curve of 3 indexes (TUG)

Bring the wind speed data into the strong wind warning algorithm, this study acquires the different warning time at each warning level. For this grounding accident the warning 'level 4' can be indicated more than 8 hours before the grounding time.

Table 3.8 Warning time of the cases at each level (TUG)

Warning time					
Level 1 (Attention)	Level 2 (Warning)	Level 3 (Alert)	Level 4 (Critical)	Accident time	Pre-warning time
00:11 a.m.	00:48 a.m.	01:19 a.m.	01:45 a.m.	10:20 a.m.	8h 35mins

As mentioned above, this strong wind warning system will be very practical in predicting the coming strong wind, saving human life and property at sea, protect the marine environment and marine ecological balance.

Chapter 4. Conclusion and Future Prospects

This study aims to develop a strong wind warning system. Normally, the seafarers on watch in the bridge have to check and record the change of wind speed or atmospheric pressure to estimate the coming bad weather condition around their water area. But these precaution activities mainly depend on the knowledge and past experience of watch-keeping which needs years of working experience and there is always the human error exists in forecasting the coming bad weather.

This study analyzes 10-minute average wind speed data of eight grounding accidents that happened in Korean coast and anchorages. Firstly, this study analyzes the wind speed before and after the grounding accidents to carry out the correlation analysis of strong wind and grounding accidents, and attains the conclusion that it cannot make the warning level based on the wind speed; secondly, this study uses the least squares method to obtain the wind speed changing rate by changing the calculation unit from 1 hour to 8 hours (the computing unit is 1 hour, 2 hous, 3 hours, 4 hours, 5 hours, 6 hours, 7 hours and 8 hours) . And make an assumption that 6 hours is the most effective and appropriate calculating unit in forecasting the changing trend of wind speed. Nevertheless, the gradient values tend to be somewhat larger in the low wind speed zone. In terms of the wind strength, the low wind speed doesn't have too much impact on the grounding accident, and the high wind speed are the main cause of the grounding accidents; thirdly, in order to develop a more efficacious wind speed alert system, this study uses an exponential function to process wind speed data and gradient values to decrease the low wind speed and increase the high wind speed, and then gets the wind speed index and gradient index; lastly, this study multiplies the wind speed index by the gradient index for calculating the warning index, and then classifies the warning level into 4 stages, takes the warning index 5 as the lower limit of ‘level 1’ (attention), the warning index 10 as the lower limit of ‘level 2’ (warning), the warning index 15 as the lower limit of ‘level 3’ (alert), the warning index 20 as the lower limit of ‘level 4’ (critical).

In order to verify the feasibility of this strong wind warning system, this study takes a grounding accident for simulation. After simulating it is confirmed that this strong wind alarming system will be very helpful in predicting the coming strong wind, and this system will provide the effective and timely alarming signal to the watch-keepers on board. By this warning system the sailors on board could have sufficient time to make adequate preparative work for coming strong wind.

As is well known that the wind speed has a deep relation to the change of air pressure, and the angle between the wind and the ship is a very important factor that cannot be ignored when predicting the effect of wind on the ship. Therefore, in order to get a more efficient warning system, in the future studies the atmospheric pressure at sea level and wind direction would be applied to the warning system.

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