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Merging of Satellite Remote Sensing and Environmental Stress Model for Ensuring Marine Safety

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Abstract : *A virtual vessel traffic control system is introduced to contribute to prevent a marine accident such as collision and stranding from happening. Existing VTS has its limit. The virtual vessel traffic control system consists of both data acquisition by satellite remote sensing and a simulation of traffic environment stress based on the satellite data, remotely sensed data. And it could be used to provide timely and detailed information about the marine safety, including the location, speed and direction of ships, and help us operate vessels safely and efficiently. If environmental stress values are simulated for the ship information derived from satellite data, proper actions can be taken to prevent accidents. Since optical sensor has a high spatial resolution, JERS satellite data are used to track ships and extract their information. We present an algorithm of automatic identification of ship size and velocity. It lastly is shown that based on ship information extracted from JERS data, a qualitative evaluation method of environmental stress is introduced.*

Key words : *satellite remote sensing, environmental stress model, virtual vessel traffic control system*

1. Introduction

The demand from politicians and maritime authorities to have control over movements of ships in their territorial waters in order to prevent accidents and marine disasters is rapidly growing. Coastal States demand compulsory compliance by those, who use these waters and have a need to monitor "the area to be avoided". With the increasing importance in monitoring ship traffic in both coastal and ocean waters, an automatic detection of ships, wakes, and ship velocity is very desirable. By using land-based radar, Vessel Traffic Service (VTS) has been developed and applied in waterways around ports.

The coverage of monitoring ships by traditional VTS is limited to the bay area or the approach from the sea to a harbour. There is a requirement for improving the VTS to be able to cover areas where radar coverage is almost impossible to achieve.

Satellite remote sensing technology has been applied in various fields because satellite data has become cheaper in the past decade. The cost of installing and maintaining a remote sensing-based vessel monitoring system (VMS) network may be minute compared to a VTS radar network.

In this research, remotely sensed data from satellites are adopted to detect ships and expand vessel-monitoring coverage to ocean waters. The Sub-Committee on Safety of Navigation (NAV), at its forty-ninth session held in 2003, have started work on a system for long-range tracking and identification of ships, taking into account the draft recommendation on the functional requirements. The Sub-Committee was of the opinion that a distance of 200 nautical miles was more logical than that of 100 nm for coastal States to identify and track ships because the distance 200 nm would better align with coastal responsibility in UNCLOS (United Nations Convention on the Law of the Sea) for a EEZ (Exclusive Economic Zone).

For a VTS, the Universal Ship-borne Automatic Identification System (Universal AIS) means a revolution in enhanced surveillance and control of ships, compared to what is possible with the traditional radar systems of today. However, since it is compulsory for 300 GT or larger ships to equip with the AIS from July 2002, we can get ship information from only AIS equipped ships(Shim, 2000).

It has been argued that accidents in coastal areas could be avoided, if the ship is identified. In this work, therefore, we introduce a concept that combined ship identification with prediction model of traffic stress. If a remote sensing-based VMS and an environmental stress model (hereby, ES model) are combined with each other, we can control ships besides those management in our territorial waters.

To build the base of the virtual marine traffic control (hereby, virtual MTC) system, a combination method of remotely sensed data and ES model is tested and a

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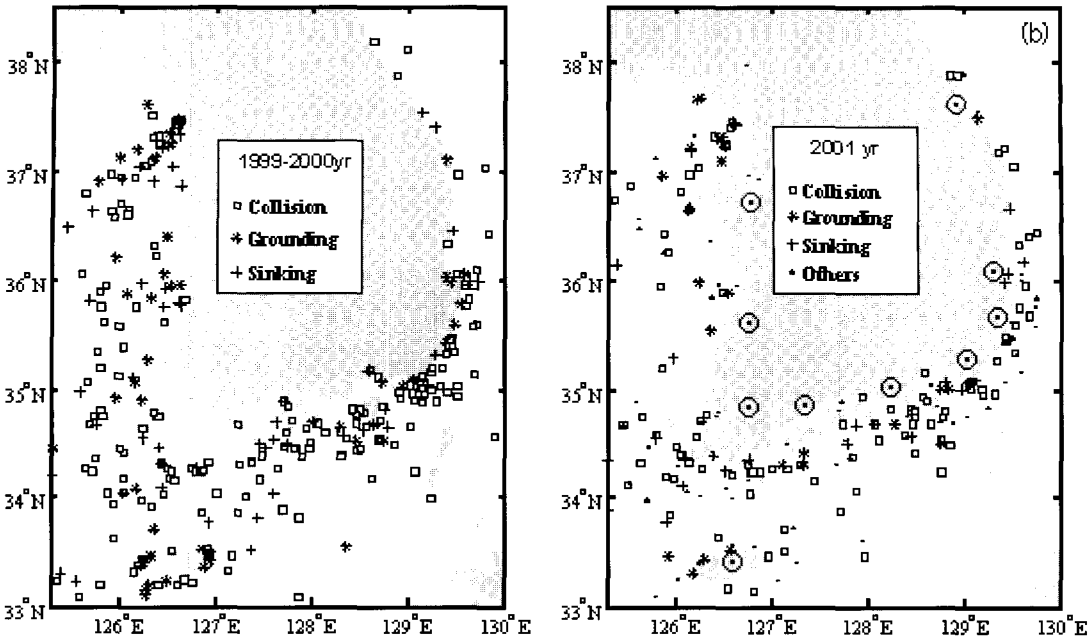

Fig. 1 Distributions of marine accidents during the period from 1999 to 2001 by inquired year. The double circle(⊙) denotes the site of PTMS. Note that the item 'others' is appeared in the figure(b).

possibility in application of satellite data to marine traffic is examined. Because an integrated ocean management including fishery information, coastal development, and marine safety may be introduced in the future, this work can be a preliminary study for the system.

The aim of this paper is to show an example of ship detection in satellite data and to suggest a virtual vessel traffic control system including a traffic simulation for natural feature and ship identification information that can be obtained from the data.

In the chapter 2, the present condition of marine accidents and traffic services in Korea waters is given and in a chapter 3 three different satellite data are used to give examples of ship detection and to examine why ship features vary according to sensor type of satellite. A combination of ES model with results of satellite data is shown in chapter 4 and finally, a summary of the results and the conclusions are given in chapter 5.

2. Present Status of Marine Casualties and New Technologies

A VTS which is operating in Korea, is introduced here and its limitations are shown through comparison with a trend in marine accidents.

2.1 Overview of VTS and marine accidents

Fig. 1 represents the locations of marine accidents according to type of accidents in the inquiry years from 1999 to 2001, that is obtained from Korean Maritime Safety Tribunal(Korean, 2000) (Korean, 2001) (Korean, 2002).

Left picture of the figure expresses collision, grounding and sinking only among 9 kinds of accident that Korean Maritime Safety Tribunal sorts, because those accidents are representative of marine accidents occurrence and it is possible to avoid lying one upon another. As shown in the figure, the distribution of marine accidents is comparatively constant in area except the East Sea. There is also a tendency that the number of accidents is likely to be proportional in length of surrounding coastline. In comparison of occurrence number for three sides of the territorial water of Korea, the number in the East Sea is 457, southern sea is 1376 and western sea is 896 during for 1997 to 2001. The number, that is, is higher in the water that coastline is complicated as in southern and western seas of the Korean Peninsula. It can be known that accident happens much in sea area that there are many islands.

The collision accident is approximately 40 % of the whole accident in the number. Collision is a dominating source of marine accidents and the tendency is similar every year as can be seen in Fig.1(b).

The locations (⊙) of VTS is shown in Fig.1(b). VTS system, which is to prevent ship accident at harbour and an approach from the sea to a harbour and to manage ship traffic efficiently, was established initially at Pohang port

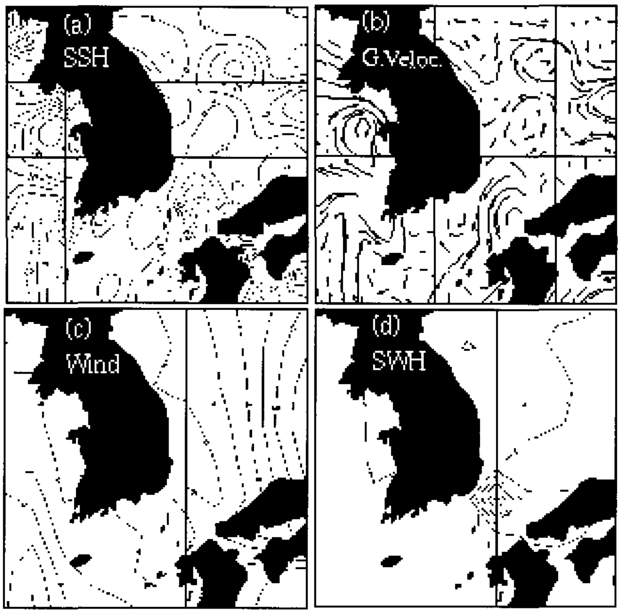

Fig. 2 Sea surface height (a), geostrophic velocity (b), wind speed (c), and significant wave height (d) on July 15, 2003.

(January, 1993). Yeosu/Kwangyang, Ulsan, Masan/Jinhae, Incheon/Pyeongtaek, Daesan, Busan, Mokpo, Gunsan, Donghae, and Jaeju ports is providing VTS now and the name VTS has been renamed in Port Traffic Management Service (PTMS) from 1999.

According to marine accident recording, port or harbour area that VTS is operating, displays a tendency that accident decreases. However, when compare accident ratio in accident location of each sea area, about 80.5 % of whole accidents occur in the coastal and open waters and about 19.5 % is in port and entry waterway. That is, marine accidents are much more many in the area that density of ship decreases remarkably than in the waters covered by VTS.

2.2 Automatic Identification System (AIS)

The AIS is new equipment for mutual communication system among ships and land stations by using a digital data link of VHF radio communication. A ship sends her data periodically to ships around and land stations such as a VTS through the AIS. It also receives the data from ships and land stations. It is compulsory for 300 GT or larger ships to equip with the AIS by international regulation from July 2002(Shim, 2000). Therefore, there are two problems to solve to apply AIS to ensure maritime safety: 1) we can detect only AIS equipped ships, 2) the effective distance for the AIS is measured as about 30 nm. It, therefore, can be said that AIS should be used with a long range VTS as an element that have supplementary function.

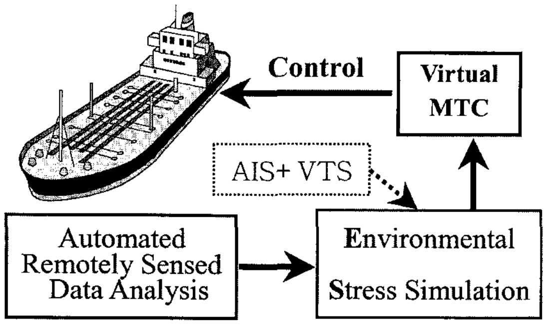

Fig. 3 Diagram of virtual marine traffic control

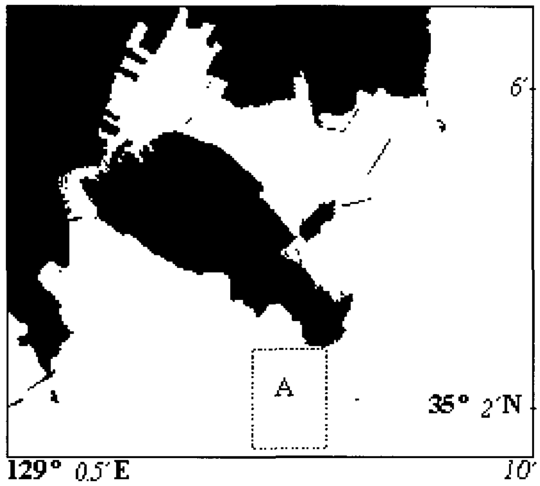

Fig. 4 Map of the study area with land mask produced by JERS-1(OPS)

2.3 Application of Satellite Data in Marine Safety

Satellite (or stratospheric platform) remote sensing is one of the principal means of gathering data about the sea state, weather and vessel traffic because it provides continuous acquisition of data, broad regional coverage, ability to combine satellite digital data with other digital data, and cost effective data. Remotely sensed data can be used to provide timely and detailed information about the marine safety, especially in tracking oil spills, waste pollution and ships, and monitoring coastal environment such as fogs, wave heights, currents and wind speeds, which must be considered in control of ships.

There are many researches on how to obtain ocean-environment information (current, wind, wave height, the fog etc.), because most of observation satellite is designed to understand the changes of our planet, the Earth(Allan, 1983) (Ducet, 1999) (Yang, 2002) (Jones, 1993) (Yang, 2002). Fig. 2 shows examples of data gathering for surface condition by using Topex/Poseidon and ERS satellite. Geostrophic velocity (Fig. 2(b)) derived from surface height (Fig. 2(a)) is used to help mariners navigate around and through currents that can slow or speed a vessel's progress. Wind speed and significant wave height also can help mariner make a decision for ship navigation in both safe navigation and cost effectiveness.

There, however, is seldom research that detect ships by using satellite data(Vachon, 1997). A virtual vessel traffic control system consists of both data acquisition on ships and ocean environment by satellite remote sensing and a simulation of traffic environment stress based on the satellite data. This concept of this system is illustrated in Fig. 3.

3. Ship Detection Using Satellite Data

3.1 Data and method

Ship detection at a testing level were studied using three different satellite/sensor data: LANDSAT/TM, JERS-1/OPS and ERS-2/SAR.

LANDSAT-1 is the world first earth observation satellite launched by the United States in 1972 and in this study LANDSAT-5 equipped with thematic mapper was used to investigate details on ship detection.

JERS-1(Japanese Earth Resources Satellite) is equipped with high performance Synthetic Aperture Radar (SAR) and Optical Sensor (OPS) sensors. Here, OPS scenes were used, because it is capable of stereoscopic observation by forward look of 15.3° from nadir in near infrared band that has a ground resolution of 18m.

Radar remote sensing from space began with the launch of Seasat in 1978 and continued with the Shuttle Imaging Radar (SIR) and Soviet Cosmos experiments in 1980s. ERS-1 is the first remote sensing satellite of the European Space Agency (ESA). European Remote Sensing Satellite No.2 (ERS-2) is an Earth Observation Satellite to mainly observe ocean, sea ice distribution, sea surface wind, oceanic circulation, etc. and observes land areas with a high-resolution radar, too. Active Microwave Instrument (AMI) equipped with the satellite is also adopted for satellite image of this research, because the sensor is like SAR.

For remote sensing to extract separately two ship features that are close to each other, it is necessary for the reflected signals from the two objects to be received separately by the antenna. Any time overlap between the signals from two objects will cause their images to be blurred together. In general, a high-resolution satellite data is more suitable to detect ships and ,thus, the three satellite data sets used here are selected and preprocessed by radiometric correction.

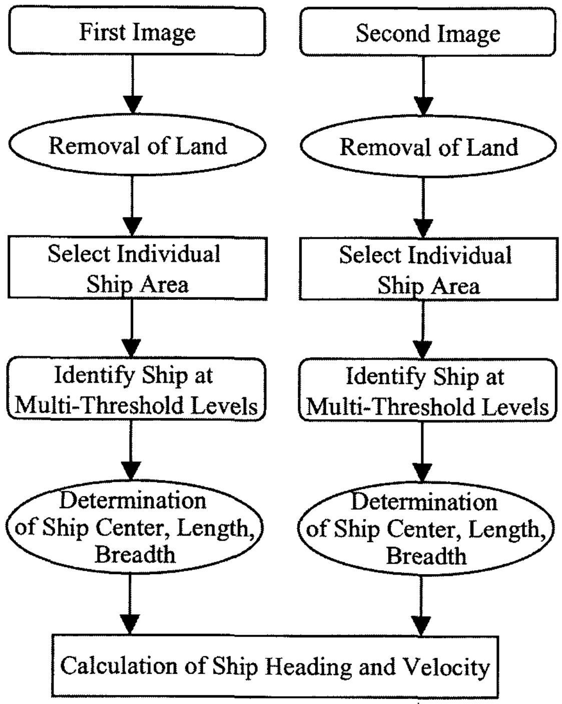

Fig. 5 Basic structure of the detection algorithm

Fig. 4 represents the study area in and around Busan Port which is masked for land using JERS-1 images. JERS data is used to detect ship positions and other satellite data simply are to show a typical imagery in which ships appear.

3.2 JERS/OPS : stereoscopic sensors

JERS-1/OPS imagery was acquired on March 2, 1998 and gives a nominal 75 km swath width. Since data acquisition intervals between two bands is almost 20 seconds, the imagery is useful in detecting a moving object.

In order to estimate ship information such as length, breadth, course, and speed with JERS-1/OPS data, we assume the following: maximum speed of ship supposed by 30kts, search area of 300 m based on the observation time of satellite data, and search direction by ±30 degrees to the bow of a ship.

The basic structure of the detection algorithm is summarized in Fig. 5. Each step of the detection is introduced. Ship features can be identified using the thresholding technique. The detection starts with the identification of individual ships that are selected by hand, and is repeated to until done. The ship information on the satellite data are identified as following 6 steps.

Step 1 getting intensity of ship and its wake in 0.76-0.86μm

Step 2 calculating a mixel value between ship and sea surface

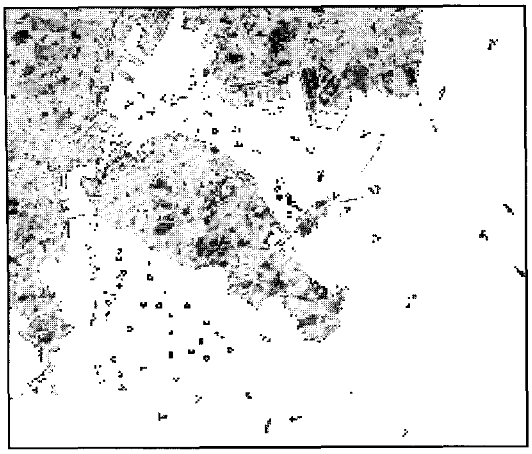

Fig. 6 An example of Ship detection

Step 3 masking of land

Step 4 identification of ship in ch.4 image

- using simple thresholding technique
- searching for each ship from left to right
- making a ship dimension from obtained ship pixel
- heading determined by ship wake

Step 5 same procedure as in the step 4 for ch.3 image

Step 6 pattern matching of steps 4 and 5 : calculation of ship speed

The detection starts with the identification of ship. As mentioned, ships have very bright features thus can be identified using simple thresholding method. Figure 6 shows a vector plot of individual ships. In the figure, the symbol of open circle denotes mooring ships and the length of the vector represents a distance that ship sailed for about 20 seconds.

3.3 LANDSAT/TM and ERS-2/AMI-image

When single band data with the same incident angle is used, we have to compare satellite data with in-situ ship information because ship wake is the one source to decide ship heading and speed. Also, in case of SAR data (Fig. 7 (left)), wakes do not appear and ship detection is affected by wind condition(Vachon, 1997).

Because albedo difference between ship and the sea is big in LANDSAT/TM(right of Fig. 7), discernment of ship is easy, and wake of ship clearly appears.

As can be seen in Fig. 7, ship detection is controlled by two independent sensing system parameters: ground resolution cell size and multi-band number. This multiband is referred to as the spectral characteristics which is scheduled to investigate the Korean waters.

In general, the minimum detectable ship size by using optical sensors is lower than that of SAR because the former has a higher resolution than the latter. In addition, a ship itself is a strong reflector since it is made of metal and has structures with right-angled corners. Therefore, a ship usually appears as a bright dot in a SAR image. However, the wake of ships that is a method to get ship direction, shows occurrence frequencies with 1/6 of all cases(Vachon, 1997). In OPS images, the ship and the foam and white water around and directly behind the ship is often noticeably bright, but the image is affected by the weather condition. Since OPS and SAR supplement mutually merits and demerits of each other, the two sensors are indispensable to detect ship more exactly.

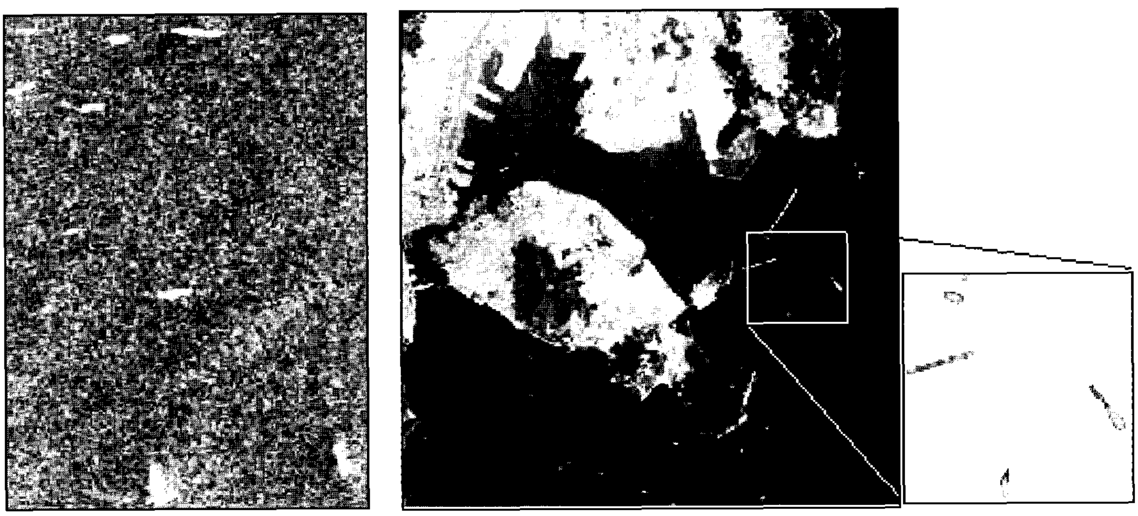

Fig. 7 ERS-2/AMI-image mode(refer the area 'A' of Fig. 4) (Left) and LANDSAT/TM True color composite of bands 3, 2 and 1 (Right)

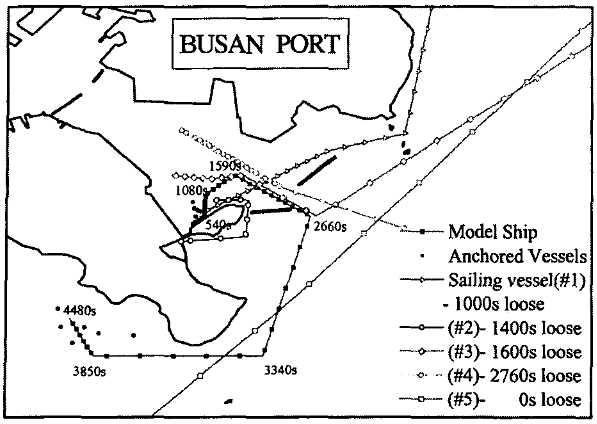

Fig. 8 Simulation of environmental stress under the traffic condition partly obtained from ship traffic information of Fig. 6.

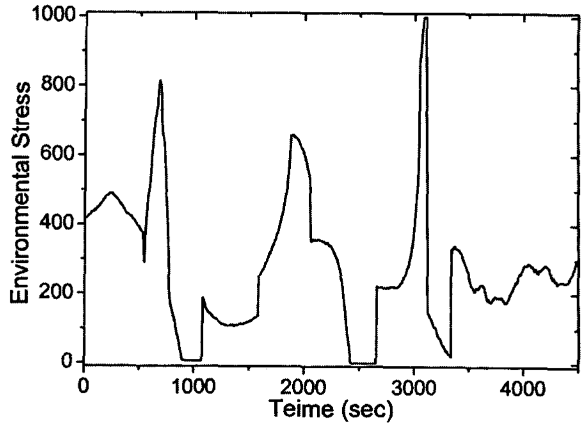

Fig. 9 Environmental stress for a model ship

4. Merging of Satellite Remote Sensing and Environmental Stress Model

4.1 Environmental Stress Model

Inoue (2000) proposed a quantitative model, called the ES model, for evaluating the difficulty of ship handling arising from restrictions in maneuvering water areas and arising from traffic congestion(Inoue, 2000). This model, also clarifies the acceptance criteria of the stress value based on mariners' perception of safety.

The ES model is composed of the following three parts:

(1) Evaluation of ship handling difficulty arising from restrictions on the water area available for maneuvering. A quantitative index expressing the degree of stress forced on the mariner by topographical restrictions (ES_L value, that is, Environmental Stress value for Land) is calculated on the basis of the time to collision (TTC) with any obstacles.

(2) Evaluation of ship handling difficulty arising from restrictions on the freedom to make collision-avoidance manoeuvres. A quantitative index expressing the degree of stress forced on the mariner by traffic congestion (ES_S value, that is, Environmental Stress value for Ship) is calculated on the basis of the time to collision (TTC) with ships.

(3) Aggregate evaluation of ship handling difficulty forced by both topographical and traffic environments, in which the stress value (ES_A Value(Environmental Stress value for Aggregation)) is derived by superimposing the value ES_L and the value ES_S.

In the respective calculations of the values ES_L and ES_S, a common index was used and the same algorithm was introduced to perform simultaneous aggregate evaluations of ship handling difficulty as experienced in encounters with other ships in ports and narrow waterways.

4.2 Calculation of Stress Value

The value ES_L and value ES_S are calculated under the common procedure shown below.

(1) Consider the ships course in the range of 180°.

(2) Calculate the TTC for each one degree gradation in the range of ±90° centered on the present course.

(3) Convert the TTC into the mariners perception of safety for each one degree.

The conversion formulae shown in Eq.(1) are given by regression equations found through ship handling simulator experiments (31-subjects) and questionnaire (573-answers) (Inoue, 1998).

$$SJL,\ SJS = \alpha \cdot TTC + \beta \tag{1}$$

where SJL is the subjective judgment of mariners in relation to TTC with obstacles and SJS is the subjective judgment of mariners in relation to TTC with ships. The scales of the subjective judgment consist of numeric values with seven steps from 0 (extremely safe) to 6 (extremely dangerous). α and β are coefficients determined by the size of own ship (in case of SJL value) or by the combination of the size of own ship and target ship (in case of SJS value).

The values SJL, SJS within the range of courses ±90° are summed to find the stress values as follows:

$$ES_L = \Sigma(SJL)_i \tag{2}$$

where $i = -90° \sim +90°$.

$$ES_S = \Sigma(SJS)_i \tag{3}$$

where $i = -90° \sim +90°$.

This ES model can be used as a useful index in subject with the marine traffic safety and Park *et al.* (2003) used the ES model to assess a TSS (Traffic Separation Scheme) by focusing on vessel traffic flow.

4.3 ES model Prediction Model based on ship detection data

Future marine traffic stress for satellite-derived ships can be predicted by using ES model. Purpose of this combination of satellite data and ES model is to expand vessel monitoring area and to make a virtual traffic control system by predicting a future traffic stress that ships are received on voyage.

Fig. 8 is a scenario of traffic environment assessment on a model ship that is also a reference ship to start a simulation. As shown as a line with a closed circle in the figure, the model ship leave a port of Korea Maritime University and move to anchoring area west of Young-Do as meeting other ships. the track of model ship, Note that in the index from No. 1 to No. 5 ships are released at different time to each other (*e.g.* in this simulation #1 ship was started 1000 seconds after).

The environmental stress that the model ship may encounter on a voyage is plotted in Fig. 9, with the total stress value for land and ship stress. In the figure, a high ES value was recorded around time 3000 sec, because the model ship is under collision danger with No. 5 ship.

Remote sensing based virtual MTC (refer to Fig. 3) consists of data acquisition such as ship's position, course and speed, and traffic flow simulation. It will have to be integrated with AIS and Electronic Chart Display and Information System (ECDIS) in future to make ship operators obtain direct and visible benefits from the system. In addition to that, remote sensing technology will be able to give shore and mariners a much-needed leg up in reacting weather events because it can deliver 2-dimensional sea condition.

5. Conclusions

This work investigated and showed the possibility in detecting ships and their wakes in the Korean waters from satellite data as a method of information collection on marine traffic environment.

Since monitoring of ship traffic is a routine exercise, it is thus desirable to develop computer-based algorithm to get ship information. In this paper, a processing technique for identification of individual ships is introduced and the results are presented. In addition to that, examples of vessel features produced in other satellite data are presented. Lastly, a combination of environmental stress model and satellite data is evaluated to predict a imposed risk in future and it can be concluded that a satellite data-based ES model will be useful to control marine traffic safely and effectively.

Further development is on the way to improve the applicability of the algorithm in as many different ambient sea condition as possible and to reduce the computational time.

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