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Basic Architecture of Navigation Safety Module in S2 Service of Korean e-Navigation System

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Abstract : *IMO introduced the concept of e-Navigation and proposed MSPs(Maritime Service Portfolios) concept to reduce marine accidents, to improve efficiency of ship operation, port operation, and ship operation technology. Korean e-Navigation defines S1 ~ S5 services, as the service concept focused on domestic e-Navigation service corresponding to IMO MSPs, and is constructing a system as an ongoing project. S2 service (onboard system remote monitoring service) among the concepts of Korean e-Navigation services, is a service concept that judges the emergency level according to risk if an abnormal condition occurs during navigation, and provides corresponding guidance to accident ships based on emergency level. The purpose of this paper is to provide a basic architecture proposal of Korean e-Navigation S2 service navigation safety module, based on the S2 service operation concept. To do this, we conducted a questionnaire survey to ask experts with experience with sailors, to respond to the subjective risk experienced by sailors considering effects of anomalies, including equipment failure relative to sailing and navigational safety. Risk level for each abnormal condition was classified. The basic algorithm design of the navigation safety module is composed of safety index (SI) calculation module based on results of questionnaire and expert opinions, safety level (SL) determination module according to safety index, and corresponding guidance generation module according to safety level. To conduct basic validation of basic architecture of the navigation safety module, simulation of the ship anomaly monitoring was performed, and results have been revealed.*

Key words : *e-Navigation, S2 Service, Navigation Safety Module, Basic Architecture, Anomaly Monitoring*

1. Introduction

The cause of ship collision, contact, and stranding, which accounted for the majority of all marine casualties, is operational error by human, accounting for 79% (KMST, 2017). IMO introduced the concept of e-Navigation in order to reduce marine accident, to improve the efficiency of ship operation, port operation and ship navigation technology. IMO also proposed maritime service portfolios (MSPs) which is the service concept of e-Navigation(IMO, 2011; IMO, 2013; IMO, 2014).

Korean e-Navigation has been proposed to enhance the maritime safety of marine navigation vessels in Korea and to improve the efficiency of marine vessel operation and port operation in keeping with IMO's introduction of e-Navigation(Jang and Kim, 2015; Jeong and Kim, 2008; Lee et al., 2012; Oh et al., 2012). Service targets include fishing vessels, small vessels and passenger ships that navigate the coastal area of the Korean peninsula, and the Korean e-Navigation service considers the characteristics of the marine environment in Korea(KMOF, 2016). Korean e-Navigation provides S1 ~ S5 service (S1 - Vulnerable ship monitoring service/ S2 - Onboard system remote monitoring service/ S3 - Weather information support service/ S4 - Small ship electronic chart support service/ S5.1 - Pilot tug and tugboat support system/ S5.2 - Maritime safety information support service), and among these services S2 service monitors the abnormal condition in case of a onboard system error and provides quick response guidance to prevent the spread of marine accidents due to shipboard system errors.

Korean e-Navigation S2 service has three sub modules: fire safety module, seakeeping performance safety module, and navigation safety module. The fire safety module calculates the fire safety index when a fire occurs and classifies the risk level according to the fire risk and generates corresponding guidance for each level(KMOF, 2016). The seakeeping performance safety module

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identifies the factors affecting the seakeeping performance of the ship and analyzes the dynamic data such as the loading status at the time of loading and unloading, the weather condition during the navigation and the ballasting operation. also provides the response guidance when an anomaly occurs. The navigation safety module identifies the factors that affect navigation safety including equipment failure when operating a ship, and monitors the ship's anomalies and provides guidance based on the emergency level by risk. The basic operating concept for implementing the S2 service has been proposed by Yoo et al.(Yoo, 2017).

This paper proposes the basic architecture of the navigation safety module which is one of the S2 service sub modules based on the previously proposed Korean Navigation S2 service operation concept. The basic architecture of the navigation safety module is designed based on the questionnaire survey on the navigator about the onboard system anomaly, and also suggests a concrete algorithm design based on the survey results. In addition, the basic validation for the navigation safety module in S2 service is carried out through the S2 service navigation safety module monitoring simulation in case of abnormal situation on the ship by each level according to the navigation safety module algorithm architecture.

2. Basic architecture of navigation safety module in S2 service

The basic architecture of navigation safety module in S2 service of Korean e-Navigation system consists of survey questionnaire which is a cognitive survey on shipboard navigational equipment, a safety index calculation and a safety level determination based on the survey results to generate risk level specific guidance in case of anomaly. The basic architecture of navigation safety module is divided into survey design and algorithm design.

2.1 Survey design

The questionnaire survey was conducted from September in 2017 to August in 2017, for a group of maritime crews working on cruise ships, merchant vessels, and Korea Maritime Ocean and University training vessels, VTS operators, and experts in related organizations with sailing experience. A total of 56 respondents were in the effective questionnaire.

In addition, the expert group opinion gathering for KJ method consisted of specialists of professional training institute of maritime agencies, and composed of about 30 experts with experience of navigator and engineer(Kawakita, 1985). Table 1 shows the overview of survey and expert opinions gathering.

Table 1 Survey and expert feedback overview

Item	Details
Survey period	2017. 09 ~ 2018. 08
Subject to questionnaire	Current navigators and expert group with sailing experience
Number of effective questionnaires and expert feedback	56/ 15
Subject to expert group	Experts from professional education institute with experience of navigators and engineers

Table 2 Emergency level classification of navigation safety module in S2 service

Display	Meaning	Description
LL (Low-Low)	Attention	Navigational attention needed
L (Low)	Warning	Navigational warning occurred
M (Middle)	Alert	Navigation restricted
H (High)	Critical	NUC (Not Under Command)
HH (High-High)	Accident	Dead-ship

The questionnaire survey of the sailors 'awareness of the ship' s navigational equipment is divided into five stages which are classified into LL(Low-Low)/ L(Low)/ M(Middle)/ H(High)/ HH(High-High). The list of equipment is based on the SOLAS ship equipments, and the level of risk for each level is listed in Table 2 and presented in the questionnaire.

1 point was given to the ship equipment failure with the least impact on the navigation safety of the ship, and 5 points to the equipment failure with the greatest impact when the shipboard system was damaged. The risk level

is classified as shown in Table 3 based on the results of questionnaire survey on navigational equipment and expert group opinions.

Table 3 Anomaly classification of navigation safety module in S2 service according to emergency level when anomaly occurred during navigation

Level	Anomaly classification
LL (1)	• LOG failure • AIS failure • NO.1 GPS failure • ECDIS failure
L (2)	• NO.1 RADAR failure • ECHO-SOUNDER failure • GYRO-COMPASS failure • NO.1 STEERING-GEAR failure • NO.1 GENERATOR failure
M (3)	• AUTO-PILOT failure • NO.1 & NO.2 RADAR simultaneous failure • NO.1 & NO.2 GPS simultaneous failure • ENGINE. SLOW-DOWN occurred
H (4)	• NO.1 & NO.2 STEERING-GEAR simultaneous failure • ENGINE SHUT-DOWN occurred • EMERGENCY-GENERATOR turned on
HH (5)	• EMERGENCY-GENERATOR failure

2.2 Algorithm design

The basic algorithm of the navigation safety module for onboard system anomaly monitoring is to calculate the safety index(SI) for the determination of the safety level(SL) expressed as Eq. (1).

$$SI = \sum_{j=1}^{M} \sum_{i=1}^{N} e_j (w_i \cdot x_i) \tag{1}$$

where

M, N is the number of emergency level and anomaly condition, respectively;
e is the emergency level of LL ~ HH;
w is an weighting factor when anomaly condition occurred;
x is machine identifier by sensor.

The LL ~ HH emergency level determination generates a safety level flag SL_{flag} in accordance with the safety index SI result value. SL_{flag} generates 'ATTENTION' for LL level, 'WARNING' for L level, 'ALERT' for M level, 'CRITICAL' for H level and 'ACCIDENT' for HH level. Because the service priority ship is a passenger ship navigating the designated route near the coastal area of the peninsula, do not consider HH level (dead-ship condition). The safety level SL determination is expressed by Eq. (2) based on the SI value.

$$SL_{flag} = \begin{pmatrix} ATTENTION \\ WARNING \\ ALERT \\ CRITICAL \\ ACCIDENT \end{pmatrix}, \text{ if } \begin{cases} 0.0 < SI \leq 0.25 \\ 0.25 < SI \leq 0.5 \\ 0.5 < SI \leq 0.75 \\ 0.75 < SI \leq 1.0 \\ 1.0 < SI \end{cases} \tag{2}$$

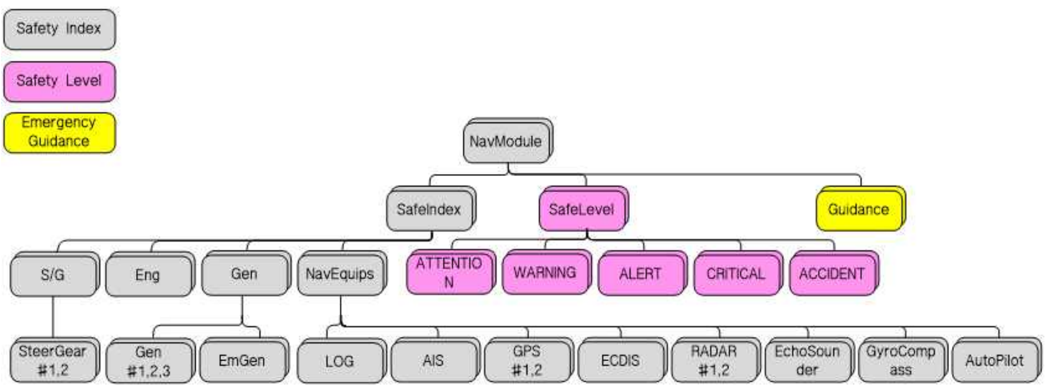

Fig. 1 Algorithm architecture of navigation safety module in S2 service of Korean e-Navigation system

The navigation safety module algorithm of Fig. 1 is divided into a sub-module for calculating the safety index SI, a sub-module for determining the emergency level according to the calculated safety index, and a sub-module for generating the corresponding guidance for each risk level.

3. Navigation safety module simulation

In this section, simulation validation for onboard system failure monitoring algorithm based on the basic architecture of S2 service navigation safety module is performed. The simulation algorithm calculates the safety index from the input parameters such as the ship equipment ID(Sen_ID), the shipboard system anomaly alarm information(Sen_Alarm), the total number of risk level(M), the total number of navigational equipment(N). A safety level is determined according to SI value, and a emergency response guidance is generated according to the determined safety level.

Algorithm 1 Navigation safety module simulation

```
Ini_Set: e, ω, χ
Input: Sen_ID, Sen_Alarm, Simul_time, M, N
Output: SI, SL_flag
t = 0; SI = 0;
while t <= Simul_time
        t = t + 1;
        if Sensor_Alarm == 1
            for j = 1 : M
                for i = 1 : N
                    SI = SI + e_j × ω_i × χ_i;
                end
            end
            if 0 < SI ≤ 0.25
                SL_flag = 'ATTENTION'
            elseif 0.25 < SI ≤ 0.5
                SL_flag = 'WARNING'
            elseif 0.5 < SI ≤ 0.75
                SL_flag = 'ALERT'
            elseif 0.75 < SI ≤ 1.0
                SL_flag = 'CRITICAL'
            else 1.0 < SI
                SL_flag = 'ACCIDENT'
            end
        else Sensor_Alarm == 0
            SI = SI;
        end
end
```

The sensor alarm returns a value of '0' when normal, and a value of '1' when it is abnormal. The SL flag generates 'ATTENTION' if the SI output value is between 0 <SI ≤ 0.25, and 'WARNING' if it is between 0.25 <SI ≤ 0.5. Also, a flag 'ALERT' is generated when 0.5 <SI ≤ 0.75, and a 'CRITICAL' is generated when 0.75 <SI ≤ 1.0. If 1.0 < SI, it is considered as an accident and generates 'ACCIDENT'.

The basic flow of the navigation safety module simulation applying Eq. (1) and Eq. (2) is the same as Algorithm (1).

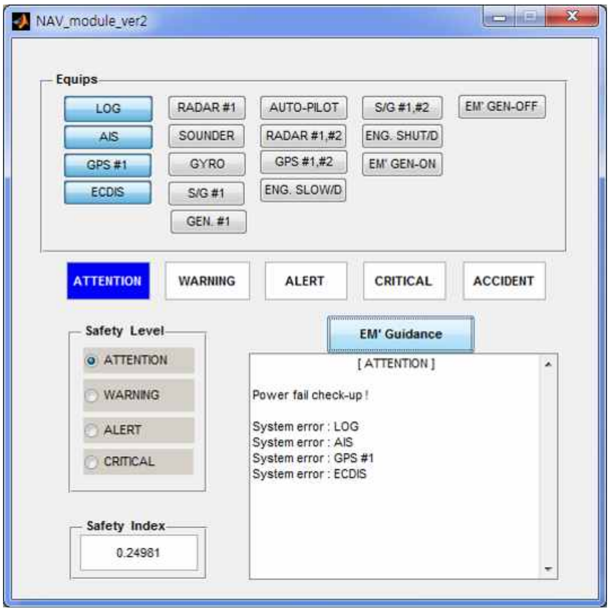

Fig. 2 Navigation safety module simulation result when emergency level-1 occurred

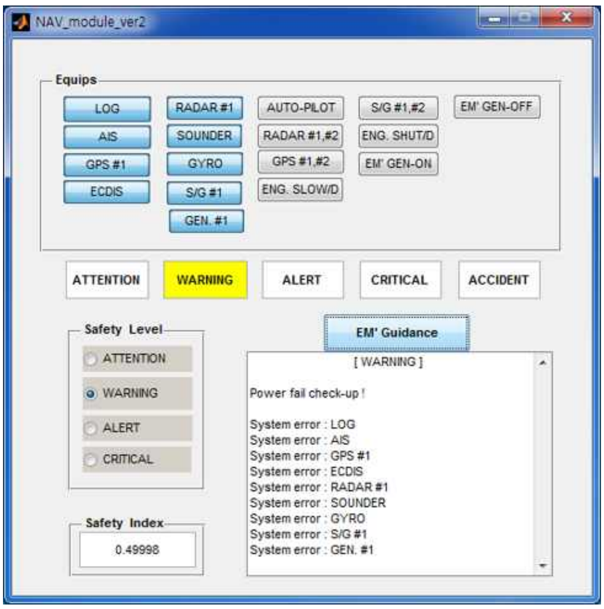

Fig. 3 Navigation safety module simulation result when emergency level-2 occurred

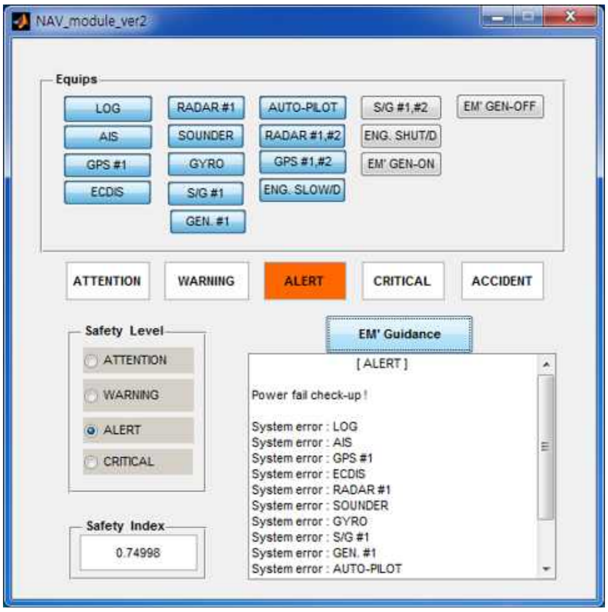

Fig. 4 Navigation safety module simulation result when emergency level-3 occurred

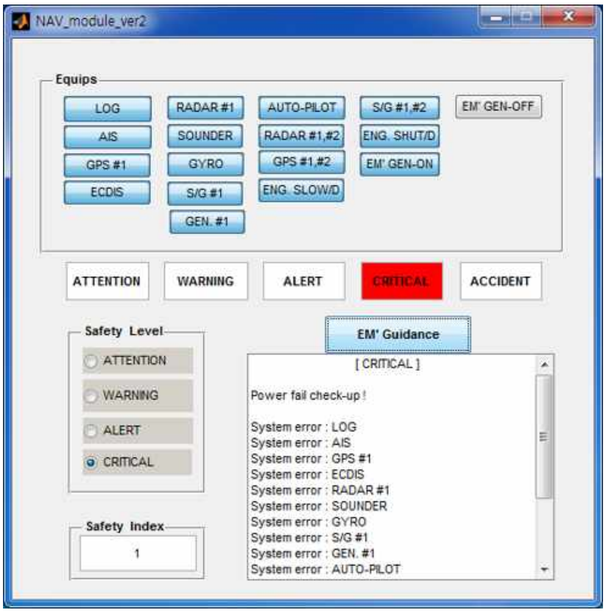

Fig. 5 Navigation safety module simulation result when emergency level-4 occurred

Figs (2) ~ (5) show the simulation results of the navigation safety module anomaly monitoring according to the emergency level in the case of an onboard system failure.

The simulation result for the abnormal condition monitoring of navigation safety module is configured to provide information such as the abnormal equipment ID, the safety level flag, the safety index and the guidance. Especially, the color information about the emergency level(ATTENTION: Blue, WARNING: Yellow, ALERT : Orange, CRITICAL: Red) is added to allow navigators to intuitively recognize the level of danger using visible information. Emergency response guidance by level is composed only at the initial level, and correction and augmentation work is needed to provide customized guidance for each vessel.

4. Conclusion

The Korean government defines five service concepts S1 ~ S5 similar to the concept of Maritime Service Portfolios (MSPs) proposed by IMO e-Navigation service concept, and is under construction for the Korean e-Navigation system. Once the Korean e-Navigation system is established, S1 ~ S5 services will be provided to vessels navigating the coastal area in Korea.

Among the five service concepts, the S2 service that is the onboard system remote monitoring service consists of three sub modules, fire safety module, seakeeping performance safety module and navigation safety module. The S2 service navigation safety module calculates the safety index(SI) when an anomaly occurs on the ship during navigation, and determines the safety level(SL) according to the calculated SI index, and generates corresponding guidance for each level.

In this paper, the basic architecture of the navigation safety module is proposed based on the concept of S2 service operation. S2 service for the basic architecture of the navigation safety module, we collected questionnaire survey on the ship 's navigational equipment on the basis of SOLAS ship mandatory equipments and opinions of expert group who have experienced navigation.

First, the questionnaire design was designed to respond to the importance of the equipment considering the effect of the equipment failure on the safety navigation during navigation. As a result of survey and expert opinions, the importance of equipment failure to safety voyage was divided into five stages, which was classified into LL(Low-Low)/ L(Low)/ M(Middle)/ H(High)/ HH(High-High).

Second, the basic algorithm design S2 Service navigation safety module calculates safety index SI when an anomaly occurs in the ship based on the equipment grouped from the risk level LL ~ HH. It is a structure that determines the risk level for the abnormal state according to the SI value and generates the corresponding guidance for each level.

Third, we have performed the anomaly monitoring simulation of the navigation safety module in order to carry out the basic validation of the S2 service navigation safety module and showed the simulation result. The scenarios for the shipboard abnormal situation are four stages from LL ~ H, and we did not carry out the dead-ship condition situation(HH level) considering that Korean e-Navigation service vessels were navigating the domestic coast. S2 service navigation safety module anomaly monitoring simulation results show that the risk index for each abnormal condition has been calculated and ATTENTION/ WARNING/ ALERT/ CRITICAL/ ACCIDENT flag has been generated for the risk level. In addition, it was possible to provide risk information for each risk level as visual information(ATTENTION: Blue, WARNING: Yellow, ALERT: Orange, CRITICAL: Red).

In summary, we proposed the basic architecture of the navigation safety module in S2 service, which is an onboard system remote monitoring service among the five service concepts provided by the Korean navigation system. The navigation safety module basic design suggested the basic design of algorithm based on the result of survey by ship user. The basic architecture of S2 service navigation safety module suggested the algorithm architecture based on the result of survey by ship user. In addition, the availability of the module was evaluated through the simulation results of the navigation safety module.

For the further study, it is necessary to design a system architecture considering communication, ship and ship type differences in order to implement Korean e-Navigation service, also the usability test is required for the validation.

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