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A Basic Study on Implementing Optimal Function of Motion Sensor for Bridge Navigational Watch Alarm System

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Abstract : *A Bridge Navigational Watch Alarm System (hereafter 'BNWAS') is to monitor and detect if an officer of watch(hereafter 'OOW') keeps a sharp lookout on the bridge. The careless lookout of an OOW could lead to marine accidents. For this reason on June 5th, 2009, IMO decided that a ship is equipped with a BNWAS. However, an existing BNWAS gives the OOW a lot of inconvenience and stress in its operation. It requires that the OOW should press reset buttons to confirm their alert watch on the bridge at every three to twelve minute. Many OOWs have complained that at some circumstances they cannot focus on their bridge activities including watch-keeping due to a lots of resetting inputs of BNWAS. Accordingly, IMO has allowed the use of a motion sensor as a resetting device. The motion sensor detects the movements of human body on the bridge and subsequently sends reset signals directly to BNWAS automatically. As a result, OOWs can work uninterrupted. However, some of classification societies and flag authorities have a slightly different stance on the use of motion sensor as a resetting method for BNWAS. The reason is that the motion sensor may trigger false reset signals caused by the motion of objects on the bridge, especially a slight movement such as toss and turn of human body which can extend the period of careless watch. As a basic study to minimize the false reset signals, this paper proposes a simple configuration of BNWAS, which consists of only three motion sensors associated with 'AND' and 'OR' logic gates. Additionally, several considerations are also proposed for the implementation of motion sensors. This study found that the proposed configuration which consists of three motion sensors is better than an existing one by reducing false reset signals caused by a slight movement of human body in one's sleep. The proposed configuration in this paper filters false reset signals and is simple to be implemented on existing vessels. In addition, it can be easily installed just by a basic electrical knowledge.*

Key words : *motion sensor, Bridge Navigational Watch Alarm System, false reset signal, OOW, slight movement of human body*

1. Introduction

According to Korean Maritime Safety Tribunal's 2013 Report of the Latest 5 years Marine Accidents, over 80% of marine accidents are caused by operational negligence, which seems to be closely related with human error. More than 40% of the accidents by operational negligence resulted from carelessness and negligence during watch (KMST, 2014).

According to Japan Marine Accident Inquiry Agency's report presented in the 54^{th} session of Sub-Committee on Safety of Navigation of IMO, most of marine accidents are caused by human error and 10% of marine accidents result from OOW's sleepiness during watch. Almost 98% of the 10% accidents occur during solo watch (MOF, 2008).

IMO made an in-depth investigation into the risk of sleepiness or carelessness during solo watch in 3 shifts of 24 hours because of the increase of marine accident resulting from human error(Bae, 2009). As a result, on June 5th, 2009, IMO adopted MSC Res. 282(86), in which all new cargo ships over 150GT and all new passenger ships of any size constructed after July 1st, 2011 should be equipped with a BNWAS (IMO, 2009). Furthermore, all existing passenger ships and cargo vessels over 3,000GT should be equipped with a BNWAS not later than the first special survey after July 1st, 2012 and all existing cargo ships over 500GT by the first survey after July 1st, 2013. The final category of vessels, cargo ships over 150GT, will have to comply with the Resolution MSC. 282 the 86th session by July 1st, 2014.

At present, most of on-board BNWASs have used a manual reset method which is done by OOWs. For that reason OOWs are forced to lose their concentration on navigational watch because the resets should be done repeatedly every setting time. Japanese delegate's report in the 54th session of Sub-committee on Safety of Navigation

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says that in the shipping world sensor-based BNWASs using motion sensors are more preferable to BNWASs with manual reset only because they are more efficient and stable(MOF, 2008). IMO suggested in 55th session of NAV sub-committee that BNWAS will be able to use other reset methods as well as manual method. Accordingly, many manufacturers have applied passive infrared ray (PIR) motion sensors to their BNWASs, which detect the motion of human body as one of reset methods (MOF, 2009).

However, if the motion sensors which are presently used for BNWAS adopt the same principle of detection and operation as used for the security system or fire alarm system, some problems impeding navigation safety can occur because monitoring a navigational watch aboard a ship is quite different from detecting in the security or fire alarm. Therefore in order to apply the motion sensors to BNWASs, the problems which will arise in the future should be investigated carefully. At the present time some classification societies and nations provide prerequisites for using motion sensors or prohibit their use, because they still wonder if using motion sensors will be efficient and safe (bnwas. com, 2013).

For related papers, Kim et al (2010) carried out the implementation of a FlexRay-based intelligent BNWAS and navigation bridge of NMEA Protocol. As a different researcher, Kim et al (2010) presented an NMEA-0183 based BNWAS to integrate NMEA-based navigational equipment. Choi (2009) developed a BNWAS with infra-red camera and image processing technique to give an alarm without any motion for a given time, which does not cover sleepiness during watch.

As a basic study this paper is to implement the optimal function of motion sensor in such a BNWAS covering sleepiness. That is, the paper investigates the problems which might occur when they are applied to the monitor of on-board navigation watch and suggests various measures to operate the BNWAS safely and efficiently.

This paper uses the motion sensors of UP370T model, which are approved by DNV and applied to real ships. They are located in such a place as navigational bridge. The paper investigates the frequency of wrong resets for typical motions which might happen in sleep, such as nodding, tossing and turning, lifting hands etc. and also validates the safety and efficiency of the configuration of motion sensors.

2. Outline of BNWAS

2.1 Configuration of a BNWAS

As shown in Fig.1, a BNWAS consists of manual reset unit, distribution unit, alarm unit, motion sensor unit, and main unit linked to an existing ECDIS or control display. The main unit is to reset an alarm automatically whenever the navigational equipment is used. The distribution unit is to provide interfaces for all other units and to supply electric power to all units. The manual reset unit is a reset button which OOWs can push by hand to confirm their alert watch on the bridge at every three to twelve minute and the alarm unit is to give a warning to OOW if the reset is not done for a given time. The existing ships are not equipped with motion sensor unit.

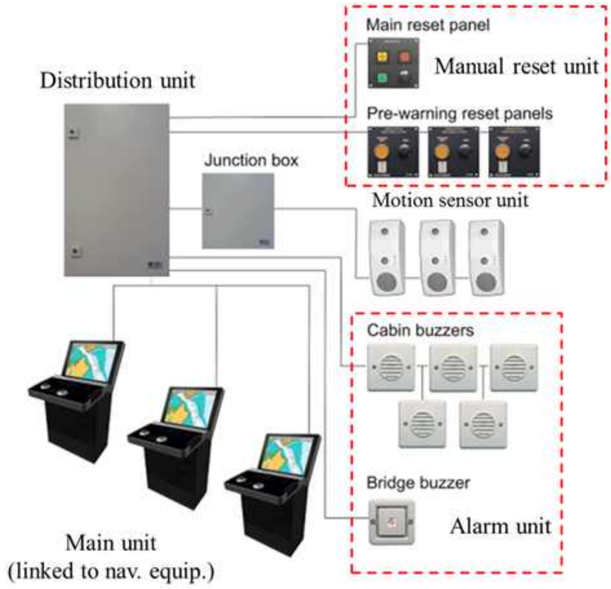

Fig.1 Configuration of BNWAS
(Source: Konsberg, 2013)

2.2 Operation of BNWAS

The BNWAS gives an alarm to master's room and crew room automatically in case that an OOW is not able to keep a lookout during navigation watch due to sleepiness, carelessness, or other reasons. In addition, it can call out other OOWs in case of emergency. The alarm signal should be going on without being reset by master.

The BNWAS supports the following three modes. The manual on-mode always activates the system, while the manual off-mode always deactivates it. The off-mode can be set only by master. The auto-mode actuates the system automatically, depending on the link of heading track or track control system. The BNWAS can set the dormant period from three to twelve minutes. The interval between the second and the third alarm can be adjusted from 90 seconds to 180 seconds. If the reset is not done during dormant period, for 15 seconds in the display the system activates the visual alarm of flickering which OOWs can see easily. If the reset is not done at all for the 15 seconds of flickering, the system also raises the first audible alarm loudly enough to give a warning to OOWs for 15 seconds. The first audible alarm can be reset manually by input button or automatically by motion sensor.

As an example, the details of visual and audible alarms can be given as in Fig. 2.

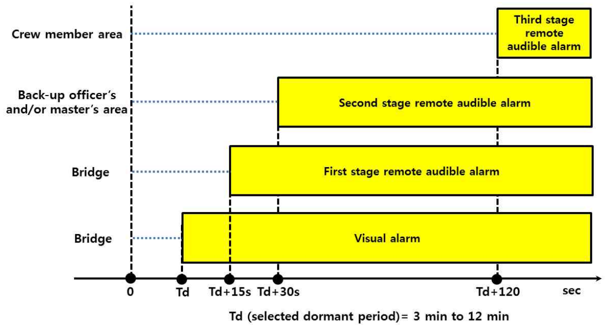

Fig. 2 Alarm sequence of BNWAS (Source: JRC, 2013)

3. Motion sensor for BNWAS

3.1 Introduction of motion sensor to BNWAS

The Danish Maritime Authority (DMA) who takes the lead in the research and development of BNWAS carried out a survey targeting 237 OOWs, who were experienced in using BNWASs aboard. It presented the result of the survey in the 53rd session of Sub-committee of Navigation, IMO(NAV, 2007).

93% of the OOWs surveyed answered that they are confident the BNWAS is essential equipment for protecting their ships and themselves. It shows that their recognition of BNWAS gets better and the BNWAS does not give additional jobs to OOWs or monitor them.

The 237 OOWs surveyed reset a total of 265,000 times manually. It shows that one OOW experienced about 1,120 times of manual reset. However some OOWs did not experience even a single reset while others about 5 times of reset every hour during navigational watch. 13% of the OOW who got on board ships equipped with sensors for detecting the motion of human body seldom experienced alarms.

28% of the OOWs surveyed took ships installed with manual reset only. They had so many experiences of alarms. 7% of the OOWs surveyed went on board ships with automatic reset linked to navigational equipment. Strangely enough, they also experienced much more alarms than we expected. It comes from less use of relevant navigational equipment because the ships make a long voyage in the ocean.

About 20% of the OOWs surveyed thought much occurrence of alarm is the key factor of disrupting their concentration on navigational watch. In particular, those who got on board ships equipped with manual reset only, thought that repeatedly resetting alarms is stressful work on duty.

On the contrary those who got on board ships equipped with motion sensors experienced alarms only few times and they thought that a BNWAS is a safe system which gets rid of risk and uneasy feeling during watch because they don't feel stressful or inconvenient by resetting alarms (Martek Marine, 2011).

On the basis of this study and investigation, IMO allowed a BNWAS to be equipped with motion sensors.

3.2 Operation principle of motion sensor for BNWAS

Human body radiates infrared rays with a wavelength of about $10\mu m$. A motion sensor is a passive infrared ray (PIR) sensor which detects a change in the radiation of infrared ray and the existence of human body. And it is used for most BNWASs as a basic sensor (Choi, 2008).

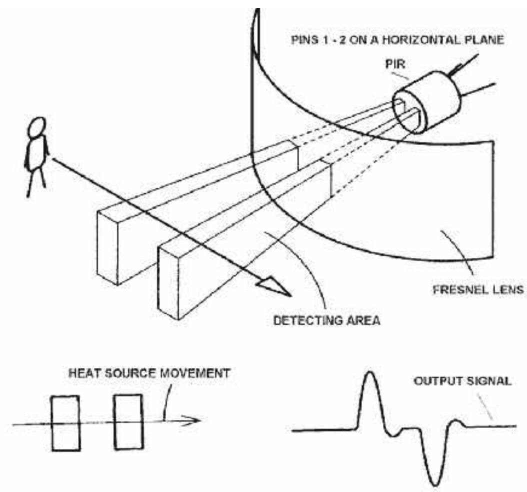

Fig. 3 Operation principle of PIR motion sensors (Source: Sensor workshop at ITP, http://itp.nyu.edu/physcomp/sensors/, 2014)

Fig.3 shows the operation of a PIR sensor. It senses a change in the radiation of infrared ray and turns the change in the radiation into electrical signal of ampere or voltage. It does not work against a continuous and constant input signal but it works only on changing signals. According to Fig. 3, when human body comes into the detection area of PIR sensor, the radiation of infrared ray changes depending upon the difference of temperature between human body and the background surrounding it. And the sensor detects the existence of human body by sensing the change of infrared ray radiation.

3.3 Problems of application of motion sensor to BNWAS

A PIR sensor detects a change in radiation of infrared ray. It means that the sensor senses a variation of temperature. Therefore even if an object comes into the detection area, the sensor may not detect it. For example, it happens when the motion of the object is very fast or slow and a variation of temperature is very small. So it does when an obstacle between them exists.

The malfunction of a PIR sensor may occur in the detection area whose temperature is higher than that of human body, in the area of rapid change in temperature, in the place of air-conditioner or steam generator working, or in the area of strong sunlight or shadow.

When we apply a PIR motion sensor to navigation watch, we have to consider that the sensor detects even a slight motion of drowsing OOW during watch. It means that the introduction of motion sensor to BNWAS may impede the safety of crew and ship rather than securing it.

For such reasons some classification societies and nations prohibit the application of motion sensors to the BNWAS or do not recommend their application to it, either.

A survey carried out targeting Korean OOWs shows that about 45% of them answered ‘I am doing a vigilant watch-keeping through entire watch’ and the others ‘I feel sleepy or sleep slightly’. And about 55% of them surveyed answered they feel sleepy two or three times a week due to lack of sleep. This result shows OOWs feel sleepy frequently and repeatedly during navigational watch due to lack of sleep(Yang, 2009). Another report shows that persons of high tiredness tossed and turned more than two times than those of low tiredness(Shin, 2010).

Because a PIR motion sensor detects only the movement of human body, the sensor may sense a slight motion of nodding his or her head or of tossing and turning during sleep on watch and can send a false reset signal. Even if an OOW is in such a situation of being unable to be on watch, the BNWAS will be reset automatically and cannot detect if the OOW keeps a sharp lookout for a number of minutes or several tens of minutes. It may bring out a dangerous situation.

Therefore this paper is to mainly deal with slight movements of OOWs in their sleep such as head nodding or tossing and turning which are a high possibility of occurrence during sleepiness and can give a reset signal.

4. Experiment of application of motion sensor to BNWAS to obtain its optimal function

4.1 New configuration and design of BNWAS

As mentioned in the above the existing BNWASs equipped with PIR motion sensors detect a sight movement of head nodding or tossing and turning and can be reset, assuming that this sight motion of human body is a movement of normal navigation watch. As a result an unexpected risk of collision, grounding and so on may occur. The paper suggests a new configuration of BNWAS to prevent from such risk.

First of all, to carry out the experiment we used the three motion sensors. Their models are UP370T and manufactured at OOO Company, Ltd. Table 1 shows the technical data of one of the models.

Table 1 Technical data of UP370T motion sensor

Model	UP370T
Input Power	8 VDC - 16 VDC (12 VDC in normal)
Detection Scheme	PIR and Ultra-sonic
Detection Speed	0.1 m/s - 4 m/s
Detection Range	10 m
Alarm Output	Semi-conductor relay
Mounting Height	2.2 m at wall
Extra Functions	1. Compensate real temperature 2. Disarm detector (PIR or PIR/US) 3. Adjust sensitivity of detection 4. Reduce detection range 5. Apply pieces of the masking foil 6. Perform anti-masking

An existing BNWAS uses two motion sensors while a proposed one uses three sensors. The existing one uses an ‘OR’ logic gate as shown in Fig.4. If even one of the two sensors detects movement of human body, the BNWAS sends the reset signal and counts its dormant time.

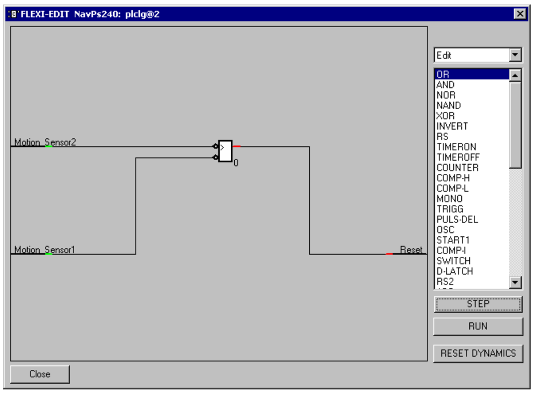

Fig.4 Circuit of existing configuration

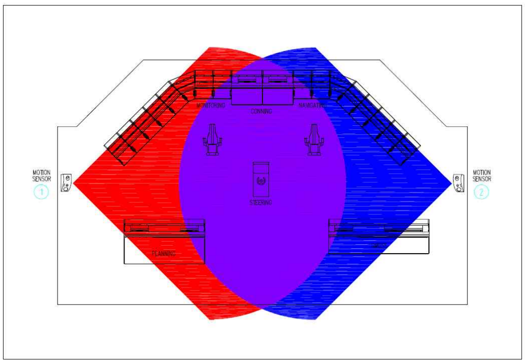

Fig.5 Detection area of existing BNWAS

Fig.5 indicates the detection area of the existing BNWAS with two motion sensors. No.1 motion sensor on the port side detects the red area, while No.2 sensor on the starboard side senses the blue area. The overlapped area of the two detection areas is covered with violet color.

This paper suggests a new BNWAS equipped with three motion sensors which are operated by ‘AND’ and ‘OR’ logic gates (Fig. 6). The inputs of AND gate 1 are the outputs of Motion Sensor 1 and 2. The inputs of AND gate 2 are the outputs of Motion Sensor 2 and 3. Finally the inputs of And gate 3 are the outputs of Motion Sensor 3 and 1. Meanwhile the inputs of OR gate are the outputs of three AND gates.

Fig.7 shows that additional third motion sensor is located behind the middle part in the bridge. Only if the two motion sensors of them detect the movement of OOW simultaneously, the input of reset is sent to the main unit and the dormant time starts the recount.

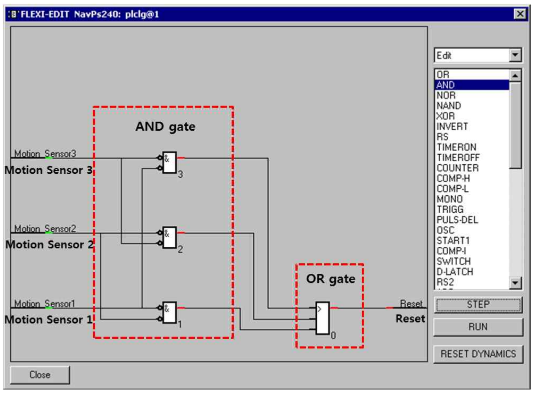

Fig.6 Circuit of proposed configuration

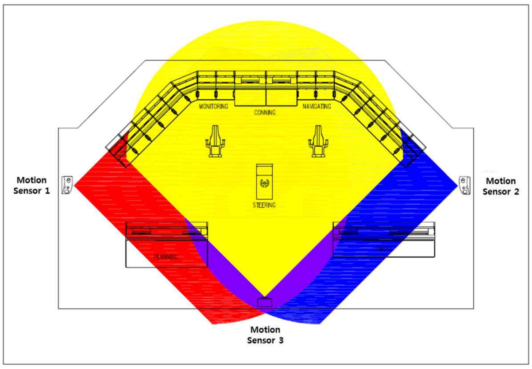

Fig.7 Detection area of proposed BNWAS

Human body in one’s sleep moves in a simple and repeated motion transversely or longitudinally. Or it moves one time in an irregular direction. Therefore because one of the two sensors detects a slight movement of OOWs in their drowsiness and the others sense it in different direction, the number of wrong reset can be reduced.

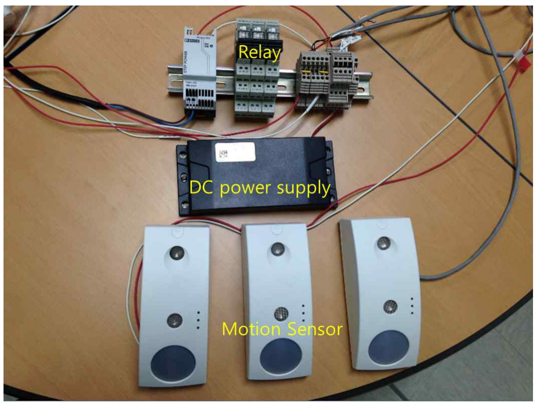

Fig.8 Components of motion sensor unit

In this paper the following are considered. First, the detection area of motion sensor can be the same as or less than the existing one, but it can include OOW's conning area and the place of watch. Second, the configuration is simple and the cost is inexpensive. In addition, it is easy to install a new BNWAS or update the existing one.

As a result the motion sensor unit we propose is composed of one DC power supply, three relays and three motion sensors (Fig.8).

4.2 Comparison of detection area between existing motion senor unit and proposed one

First, the experiment space of 15m x 9m, which is similar to that of ship's bridge, was established to improve the reliability of the experiment. The walking test of a test subject was carried out back and forth and right and left at an interval of 1m. A total of 5 walking tests were done respectively.

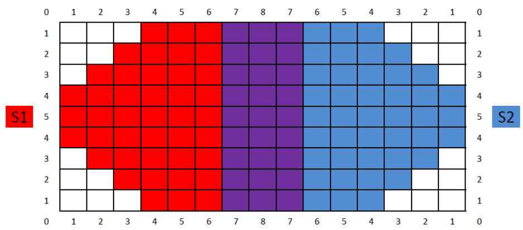

Fig.9 Detection area of existing BNWAS

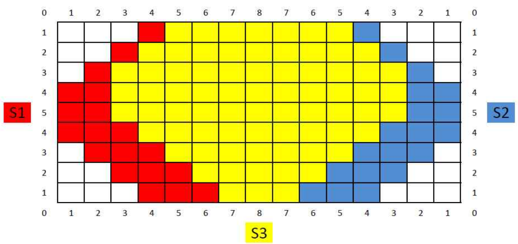

Fig.10 Detection area of proposed one

Fig. 9 shows the detection area of the existing BNWAS. The red area is to be responded by a motion sensor on the port side, while the blue area responded by that on the starboard side. The violet area is overlapped by the two sensors. The white area is not sensed by the sensors and can be called a blind sector or zone.

Fig. 10 denotes the detection area of the proposed BNWAS. The yellow area only is responded by the motion sensor unit. The detection area of the proposed BNWAS is smaller than that of the existing one. That is, the existing BNWAS detects 111 sectors of a total of 135, while the proposed one 73 sectors. In view of the result the proposed BNWAS may be less efficient than the existing one. However, if the detection area of yellow can include the conning area of bridge and the place of watch, it is not expected that the possible problems which may arise from less detection area occur.

4.3 Movement of human body during sleepiness

The experiment is to deal with two typical movements during sleepiness such as nodding head, tossing and turning, and to include two intentional movements of lifting left and right hand. The latter two movements are chosen to find out how much the sensors respond to a slight motion.

The experiment of each movement is repeated 20 times. And considering that the waiting time of reset input is 2 or 3 seconds, the time between consecutive movements or waiting time is given by 5 seconds.

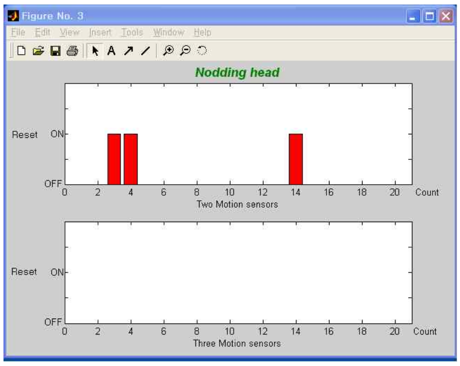

Fig.11 Comparison of nodding head
(Upper: existing, Lower: proposed)

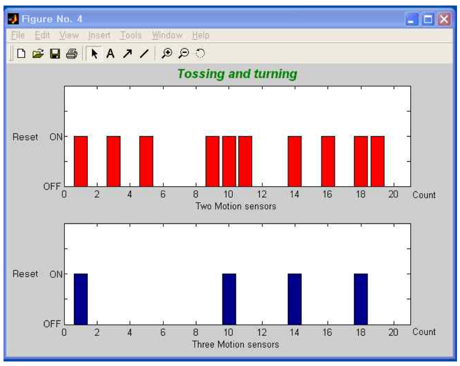

Fig.12 Comparison of tossing and turning
(Upper: existing, Lower: proposed)

Fig.11 shows the comparison of nodding head between the existing BNWAS and the proposed one. The upper graph is for the existing BNWAS and the lower graph for the proposed one. In the existing motion sensor unit the reset input occurs 3 times and in the proposed one no reset input comes out.

Fig.12 indicates the comparison of tossing and turning between them. In the existing one the reset input is repeated 10 times, while in the proposed one it happens 4 times.

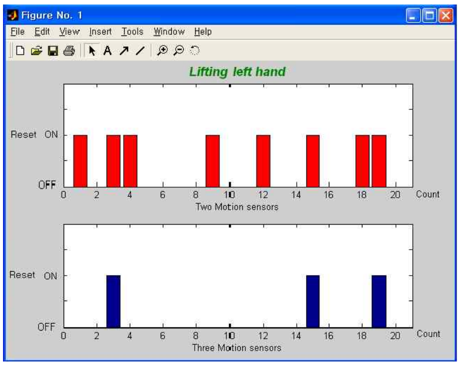

Fig.13 Comparison of lifting left hand (Upper: existing, Lower: proposed)

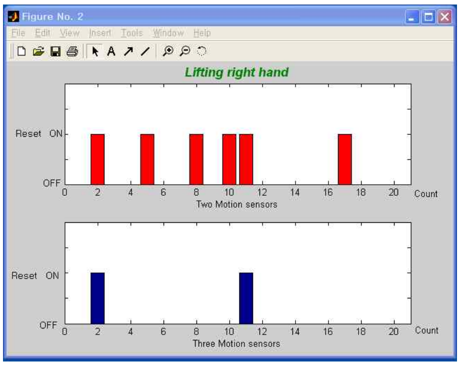

Fig.14 Comparison of lifting right hand (Upper: existing, Lower: proposed)

Fig.13 and Fig 14 show the comparison of lifting left and right hand respectively. In the existing unit lifting left and right hand causes the reset inputs of 8 times and 6 times respectively. On the contrary, in the proposed one the reset inputs of 3 times and twice occur respectively.

The following can be obtained from these results. If the configuration of BNWAS is made as the proposed one, the number of wrong reset input can be reduced considerably comparing with the existing BNWAS.

4.4 Additional measures or considerations for optimal function of BNWAS

4.4.1 Establishing the blind zone of detection area

An area at which an OOW mainly stays for drowsiness during navigational watch should be investigated for each ship. The area can be designated as a blind zone by using the mask function of motion sensors.

Mirrors of pumping optics surrounding a motion sensor are divided by each detection sector and are fixed as shown in Fig.15.

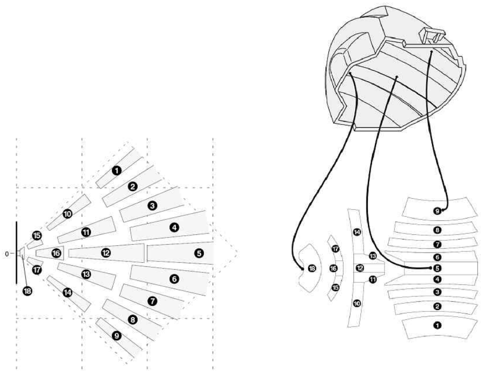

Fig. 15 Detection sectors and corresponding pieces of masking foil (Source: Konsberg, 2013)

A place where the detection is unnecessary can be set into a blind zone, by attaching a masking foil to a corresponding detection sector. In doing so the area where the possibility of an OOW's drowsiness is high can be excluded. By reducing wrong reset inputs in advance safe navigation will be improved.

4.4.2 Use of motion sensor together with other sensor

As an example an ultrasonic sensor can be used together with motion sensors. In this paper walking test was done by using motion sensor and ultrasonic sensor simultaneously. The results did not show any significant difference from that of motion sensor alone. This paper confirmed the motion sensor alone is sufficient to detect OOW's navigation watch. However, it did not confirm how minutely the sensor detects and how many times it excludes wrong detections.

4.4.3 Implementation of overriding function of automatic reset input

By investigating the time zone prone to drowsiness, the overriding function of automatic reset input can be added during the period. Yang(2012) reported the drowsiest time zone of OOWs is between 0000 and 0400 hours. And also according to the report on marine accidents for recent 5 years, marine accidents in Korea occur the most in the time slot of 0400 to 0800 hours (MOF, 2013).

Overriding the automatic reset input during time slot of being sleepy will be a method to promote the safe navigation.

4.4.4 Establishment and operation test by expert

There can be many experts who have an experience of installing and testing motion sensors or are approved by the authority concerned. It is necessary for them to select which motion sensor is proper and to decide the place of installation and the number of sensor considering ship's structure and environment. And also, after installation, it is necessary for them to decide if the detection area is proper and to confirm if the sensibility of the sensor is set appropriately. In short, considering all the things mentioned above, the standardized procedure of installation and operation is needed.

4.4.5 Additional use of compressed pad or voice recognition sensor

In addition, as a reset input the compressed pad or voice recognition sensor will be needed in the future. At the present time no manufacturer applies it to a BNWAS together with motion sensor. Such additional sensor will be able to reduce the vulnerability of BNWAS resulting from the use of motion sensor only.

5. Conclusion

According to IMO Resolution a BNWAS became the requisite equipment on board. To reduce the inconvenience in its use the motion sensors were applied to the BNWAS. However the motion sensor may work on a slight movement of human body during sleepiness and give a wrong reset. Finally, it can bring out the risk of marine accident.

As a basic study, this paper suggested a new configuration of three motion sensors which are applied to the BNWAS to decrease the number of wrong reset input. The circuit consists of 'AND' and 'OR' logic gates. The comparison experiment between the existing BNWAS with two motion sensors and the proposed one with three motion sensors was carried out. The results are the following.

(1) The detection area of the proposed BNWAS is smaller than that of the existing one. However, if the detection area of the proposed one can include the conning area of bridge and the place of watch, it is not expected that the possible problems resulting from less detection area occur.

(2) Regarding a slight movement of human body during sleepiness such as nodding head, tossing and turning, including lifting left and right hand, if the configuration of BNWAS is made as the proposed one, the number of wrong reset input can be reduced considerably comparing with the existing BNWAS.

(3) Additional methods or considerations were suggested for the purpose of improving navigation safety in using motion sensor. For example, they can be the establishment of the blind zone within detection area, use of motion sensor together with ultrasonic sensor, overriding function of automatic reset input and so on.

However, this study was carried out in the laboratory, not on the bridge of a real ship. The test object was only selected actions such as nodding head, tossing and turning, and lifting left and right hand. The experiment was done by one test subject. The number of observation remained insufficient to enhance a statistical reliability. These are the limits of the paper.

In the future study of making up for the limits, the methods for enhancing navigation safety in connection with various sensors will be dealt with.

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