JOURNAL OF MARITIME RESEARCH

Vol XII. No. II (2015) pp 95–101

ISSN: 1697-4040, www.jmr.unican.es

Real-time Navigation Monitoring System Research for LNG-Fuelled Ship in Inland water

J. Deng[1,2,*], J. Ma[1], L-S Xu [3] and S-X Luo[4]

ARTICLE INFO

Article history:
Received 03 April 2015;
in revised form 10 April 2015;
accepted 21 July 2015;

Keywords:
Inland Water, LNG-Fuelled Ship, AIS, Real-Time Monitoring.

ABSTRACT

With the implementation of "Gasification Yangtze River" strategy, as an economic, clean and safe energy, liquefied natural gas (LNG) is being gradually used in the inland vessels. However, as a special kind of hazardous substance, the risk of LNG application is Lack of effective assessment. As to ensure this kind of energy can be safety used by LNG fuelled ship in inland water, a set of on-line navigation safety monitoring system for LNG fuelled ship was developed, combining an update Automatic Identification System (AIS) device, some sensors and a software monitoring platform. It strengthens the risk control capacity by making alarm and enabling the management authority effective supervision at emergency situation.

1. Introduction

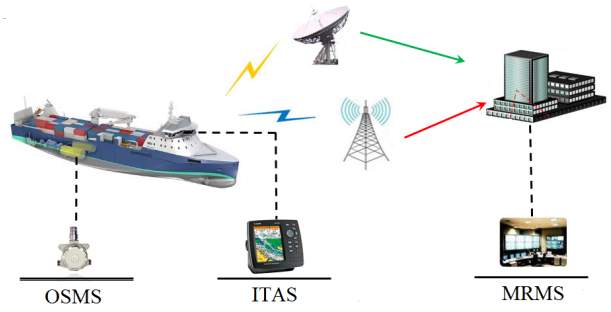
In recent years, with the rapid development of inland waterway transportation and increasingly stricter air emissions legislation, "Gasification Yangtze River Project" strategy is being implemented in China. As an economical and clean energy, Liquefied Natural Gas (LNG) is regarded as the best alternative energy for the ship. However, LNG application requirement for the vessel is different from it used on land. On the one hand, LNG fuelled ship hosts certain risks inherent in the process of navigating, mooring, operations and other operations. On the other hand, the main ingredient of LNG is hazardous fuel - methane, which may causes combustion, explosion, frostbite, suffocation and other accidents. So, when LNG is used as the fuel of the vessel, it will largely increase the risk of the vessel and surrounding ships and navigation infrastructures.

LNG has different hazards from traditional fuel oil. Also, the use of LNG as fuel for ships is relatively new concept. Therefor operators must clearly understand the risks. Some studies [1,2] were developed to assist LNG stakeholders in implementing the existing and planned regulatory framework for LNG fuelled vessel around the world. LNG fuelled ship should be equipped with some safety systems to monitor and protect against overfilling or leaking as required by some ship classification society, such as DNV, GR, ABS, Korean Register of shipping [3-5]. In recent years, China government conducted a lot of researches [6] on LNG fuelled ship and issued a series of rules and regulation, such as "Guidelines for Dual-fuel Engine System Design and Installation", "Rules for Natural Gas Fuelled ships" [7] and so on. Different from North American and Europe, most of LNG fuelled ships are transformed from used vessel and LNG storage tanks are always placed on the aft weather deck outside of the engine room. This situation will increase the risk in case of LNG leakage [6].

As to ensure the safety, the relevant regulations issued by Europe, North American (United State and Canada), make strict requirements for an alarm, monitoring, and control system installation of LNG fuelled ship and in particular to the specific requirements of the monitoring devices [3 5,7], such as pressure sensor, temperature sensor, combustible gas concentration sensor and liquid level sensor. These detectors and sensors should be fitted on the tanks, pipe ventilation duct and engine room. Also, this alarm, monitoring, and control system should be ac-

[1]Wuhan University of Technology, Wuhan, Hubei, China. E-mail Address: dengjian_whut@aliyun.com .
[2]National Engineering Research Center for Water Transport Safety, Wuhan, China.
[3]Waterborne Transportation Institute, Beijing, China.
[4]Changjiang Maritime Administration, Wuhan, Hubei, China .
[*]Corresponding author: E-mail address: dengjian_whut@aliyun.com.

Figure 1: Framework of online Monitoring System for Navigation Safety of Inland LNG Fuelled Ship.



Source: Authors.

tivated from on site, engine room and bridge.

Nowadays, the monitoring system is separated from other monitoring equipment and can not be effectively integrated into the vessel's overall alarms, monitoring and control system. It is a useful way to integrate the monitoring information with other vessel's operation information in the bridge and automatically transfer warning signals to surrounding vessels and local maritime authority in case of danger.

Automatic Identification System (AIS) plays an important role in ship navigation. At the same time, this system has a lot of interfaces to receive different of monitoring information. Nowadays, AIS provides a good scalability and is widely used in vessel emission monitoring [8], oil spill tracking[9] and so on [10]. China Maritime Safety Administration promulgated regulations requiring the vessels of 300 gross tonnage and upwards which sail in Yangtze River, the Pearl River, the Grand Canal should be equipped with AIS device. It provides an effective way to monitoring the LNG fuelled ship. Therefore, focusing on the requirement of LNG fuel ship risk control, this research makes use of original AIS device equipped in the ship and develops it into a LNG fuel ship navigation safety on-line monitoring system (LNSMS) in inland water by integrating other means of communication.

2. The Framework Design of the System

This system LNSMS consists of three subsystems as shown in Figure 1: onboard operation status monitoring subsystem (OSMS) based on multi-sensor, monitoring information transmission & alarm subsystem (ITAS), maritime remote monitoring software subsystem (MRMS) for LNG fuel ship.

Onboard operation status online monitoring subsystem (OSMS)based on multi-sensor: As to prevent the ship from danger, many sensors are fitted in suitable place to monitor the LNG equipment operation status. According to risk assessment, three different level hazardous area zones are defined in the regulation and gas sensor, temperature sensor, pressure sensor and level indicator are selected to monitor gas tank, gas compressor, gas engine area. Because leaking is the most dangerous situation, Combustible gas instrument and temperature sensor are used in OSMS. Combustible gas instrument is mainly used to monitor methane gas concentration and temperature sensor is to detect the gas temperature. These sensors are distributed in hazardous area zones and transmit the information to ITAS.

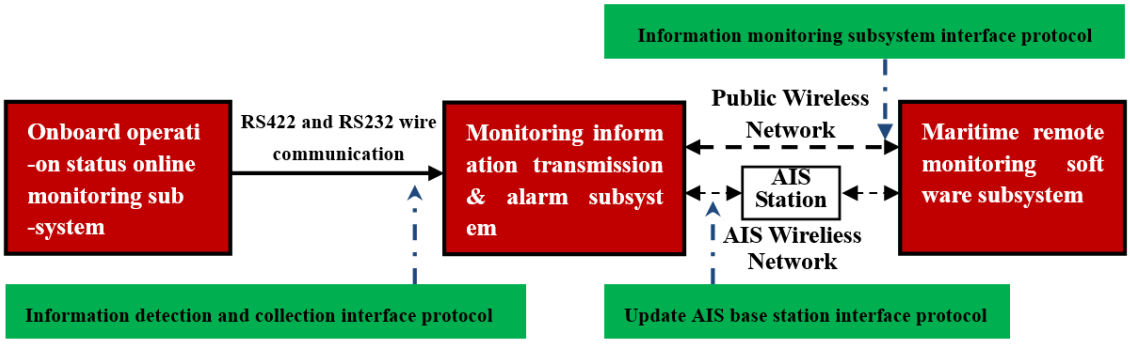
Monitoring information transmission & alarm subsystem (ITAS): the rules require that an audible and visual alarm should be activated in bridg, engine room and manned location [3-5,7]. In this research, Shipborne AIS device (AIS-B terminal) is used as prototype, while the information receive module is designed to receive the information from OSMS. This ITAS integrates the monitoring information with other ships navigation information, such as location and speed, to assess the risk of LNG fuel ship. If LNG fuel ship is in dangerous situation, the subsystem will make audible and visual alarm. At the same time, it will transmit the alarm message to MRMS by TD-SCDMA or VHF.

Maritime remote monitoring software subsystem (MRMS): It is an online monitoring software platform on shore based on GIS operated by MSA, which can obtain the emergency information from ITAS. As soon as the dangerous situation is confirmed by Maritime Safety Administration, emergency response measures will be took. Also, other vessels surrounding LNG fuelled ship will be informed by this subsystem. This subsystem is a complex one which is set up in the maritime agency and it can deal with the integrate messages, such as ship position, ship speed and navigation environment information, by combining electronic navigation charts and AIS base station. It can realize the remote monitor and control for LNG fuelled ship.

3. Work Principle of the System

Gas sensor is always used to detect combustible gas concentration which can judge whether the LNG gas (methane) is leaking. Therefore, online monitoring for combustible gas concentration procedure is described to introduce the working principle of this system. The gas sensors of OSMS will monitor the combustible concentration of gas. Because these sensors are distributed around hazardous area zones onboard, a procession module is designed to collect and integrate these signals. These analog signals will be transferred to digital signal through A/D transmission. Also, the module will converse, amplify and post-process the concentration value signal in accordance with the "Information collection & detection interface protocol". After that, these update signals are sent into ITAS device to calculated and judged. If the concentration value exceeds the threshold value, ITAS will make audible and visual alarm in the bridge and on the operation site. When the value exceeds 20% Lower Explosive Limit (LEL), the situation will become more dangerous and the warn signal will be transmitted to MRMS operated by Maritime Safety Administration through VHF and public communication network TD-SCDMA in real time. Maritime Safety Administration will confirm this situation by VHF and give response instructions to the ship in danger. Also, the warning message will be posed to surrounding ships through AIS to guide them response.

Figure 2: Work principle of the system.



Source: Authors.

In this part, the hardware structure of the system will be discussed. It consists of Information Collection Hardware and Information Integration Hardware.

3.1. Information Collection Hardware

Information collection is done by onboard operation status online monitoring subsystem (OSMS) which composes of some different kinds of sensors and data collection module. The detection equipment, such as combustible gas sensor, temperature sensor, liquid level sensor and pressure sensor, should be located where gas may accumulate and/or in the ventilation outlets. Permanently installed gas detectors should be fitted in the tank room, in all ducts around gas pipes, in machinery spaces of the ESD-protected type, compressor rooms and other enclosed spaces containing gas piping or other gas equipment without ducting. Liquid level sensors and pressure sensors are always installed in the tank. Temperature sensors are always fitted in the sewage tank of connection area of different LNG tanks. The number of detectors installed in different space depends on the risk.

Combustible gas concentration sensor (Fig.3) use sensitive probe, which measuring range is from 0 to 100% LEL. The sensitive probe is enclosed in an explosion-proof metal shell covered by glass. It detects catalytic flameless combustion to determine LNG concentration value. LNG concentration sensor value is converted into 4-20 ma electric current signals and directly displayed on the screen of the device. Also, the value can be read by data acquisition instrument converted to a standard protocol packets reported to the upper computer.

Temperature sensors (Fig.4) use of thermocouple technology to detect the environment temperature and the detection range is from -50 to 100 ^{o}C represented by 4-20ma electric current signal. Detector is enclosed by water-proof metal cover and can be widely used in different place, such as tanks, radiator area and engine room.

Data collection module is designed to gather all analog signals, convert to digital signals and transmit them to ITAS. The core of data collection modules is a 32 bit low RISC MCU (STM32F103RCT6) with power consumption. The integrated circuit plate consists of MCU core module, Digital Input/Output

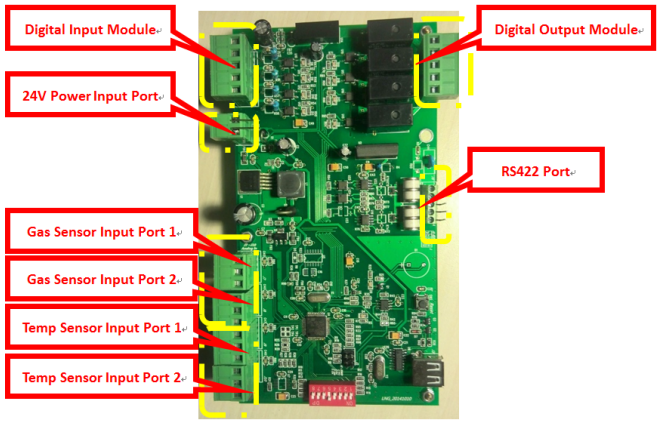
Figure 3: Gas sensor for combustible gas concentration.

Source: Authors.

Figure 4: Temperature sensor.

Source: Authors.

Figure 5: Diagram of the data collection module.



Source: Authors.

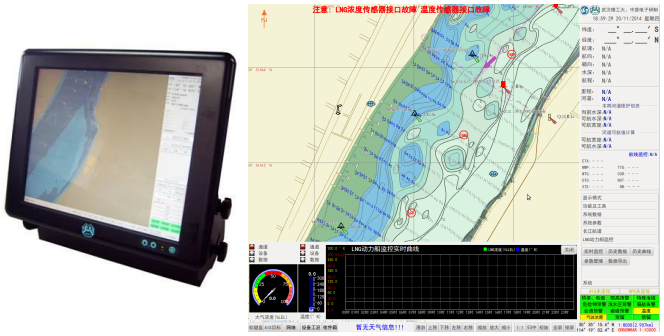
Module, Sensor Input Ports, RS 422 Output port, etc, as shown in fig.3. Analog signals will input from sensor input ports and Digital signals will output through RS422 port after digital signal processing. The rule of Digital signal processing will be discussed in 4.1.

3.2. Information Integration Hardware

Information integration and transmission is mainly implemented by an update shipborne AIS device. AIS (Automatic Identification System) technology is very essential and originally conceived for collision avoidance. This technology provides a vast amount of near-real time information, calling for an ever increasing degree of automation in transforming data into meaningful information to support operational decision makers. Static and voyage related information transmitted are strictly defined by IMO regulation [11]. At present there are 27 message types, which are specified by the International Telecommunications Union (ITU). Nowadays, some researches of expanded use of AIS have been done. Physical Oceanographic Real-Time System Data has been integrated into USCG AIS[12]. The implementation of a Tide and Weather station transmitting live data over standard AIS has been carried out [13]. Furthermore, AIS provide a meaningful method to transmit the LNG fuel ship information without investing any additional hardware or even any additional software.

An updated AIS device is developed in this research (fig.4), which consists of five parts: VHF digital communication channels, TD-SCDMA digital communication channels, information processing and control module, GPS receivers, RS232 and RS422 device interface. Firstly, this updated AIS device will receive the digital signals from OSMS, such as combustible gas concentration, temperature, level, pressure and so on. GPS receiver gathers other information, such as ship position. Secondly, the microprocessor will control information transmission and exchange via VHF according to AIS network protocol. According ICE61162 agreement, AIS can receive and send messages by two different VHF channels. Meanwhile, VHF contains a DSC module that can receive calls from shore station. Also, other ships or navigation monitoring center can

Figure 6: The update AIS device.



Source: Authors.

call the ship when the ship is found abnormal. Due to limit of VHF channel bandwidth, the basic parameters of the LNG fuel ship safety status (“1” means “normal”, “0” means “abnormal”) data is inputted into controller after TDMA, DSC decoding. The updated AIS Binary Messages rule is discussed in 4.1. After that, the controller will packed all data received according to VDM or VDO statement ICE61162 agreement. The data will be transmitted via the serial port or broadcasted in packaged form agree with BBM statements of “AIS base station interface interaction protocol”. Because just the principal safety status information is not enough for the maritime safety administration to make response decision, the detail value of monitoring information will be transmitted to by TD-SCDMA digital communication channel at the same time. The Binary Messages Rule is discussed in 4.1.

This update AIS can record and inquire LNG gas leak-related information through the real-time message transmitted by AIS. During the monitoring period, the subsystem can record the time, ship position, sensor status, monitoring value and warning signal. Prompt investigation and evaluation of the danger will be activated as soon as the accident occurs, to achieve real-time monitoring information related to the danger. The subsystem will automatically alert when the following happens: combustible gas concentration range exceeding the alarm threshold combustible gas concentration sensor failure, temperature sensor exceeding the alarm threshold, the temperature sensor failure, checksum failure. When an emergency situation occurs, the device will make audible and visual alarm. Both audible and visible alarm in the bridge and engine room will be activated as soon as the gas concentration reaches 20 % of the lower explosion limit (LEL). After concentration is above 50% LEL, the signal will be sent to MRMS on shore.

4. Design and Realization of Software System

4.1. Communication Protocol and Binary Messages Rule

As to achieve these functions of subsystem, a set of suitable interface protocols is designed as shown in fig.2. This communication protocol agreement consists of three independent protocols.

Information Detection and Collection Interface Protocol

This protocol defines the transmission rule for signal from sensor to AIS device. Onboard operation status online monitoring subsystem connects with Monitoring information transmission & alarm subsystem via RS232 or RS422 ports. The monitoring signals are organized as 61162 standard and output by serial communication. There are three kinds of message report method:

1) Report the message at a regular time interval when monitoring signal is normal condition.

2) Report the message at a shorter time interval when monitoring signal is abnormal condition.

3) Report the message as soon as monitoring signal is changing from normal to abnormal condition.

There is a binary message example as (1) and the meaning of this binary message was explained in Tab.1:

$$\$--G01,xxx.x,a\ *hh\langle CR\rangle\langle LF\rangle \tag{1}$$

This protocol defines the message transmission rule from shipborne AIS device to AIS base station.

The aim of AIS is to improve ship safety by assisting target tracking and simplifying information exchange. The VHF radio frequencies used in AIS data transmission have limited capacity, and therefore there is no special binary messages field defined in standard message of AIS now. Whereas the other messages have a fixed structure, there are two message types, Binary addressed message (Message ID 6) and Binary broadcast message (Message ID 8), for which multiple content structures can be defined[14]. The potential offered by the flexibility of the Application-Specific Messages has not been fully exploited. In this research, Binary addressed message (Message ID 6) was used. Since the data content of this binary message is defined by the LNG fuelled ship application, Message 6 is an Application Specific Message. The Binary data field is variable according application and it's defined as Tab.2 shown.

As to enable this technology to be used in other inland area where there is no AIS base station, the public wireless channel also be used to transmit the monitoring signal. This protocol defines the transmission rule for signal from shipborne AIS device to monitoring software platform through TD-SCDMA channel. According to TCP message format,the message format for monitoring signal is designed as shown in Tab.3 and Tab.4.

4.2. Maritime Remote Monitoring Software

Maritime remote monitoring software subsystem is developed by Microsoft visual C + + 6. 0 combined with ArcGIS software platform. Software achieves a friendly interactive interface and can dynamically display LNG fuelled ship sailing condition, monitor signal, working status of sensor. The subsystem software can achieve the following features:

1) Basic ENC function: This software can show the electric navigation chart (ENC) of Yangtze river. Some information, such as geographical and navigational mark, water depth, is shown in different layer of ENC. At the same time, ENC also can be overviewed, enlarged, narrowed in this subsystem.

2) Information transmission function: the software can receive the message from Monitoring information transmission & alarm subsystem stalled on board real-time by VHF and TD-SCDMA channel. Also, when the emergency situation is confirmed, the warning signal will be sent to other ship around the LNG fuel ship automatically by this subsystem.

3) Combustible gas concentration monitoring function: it can deal with the monitoring information of combustible gas concentration, such as storage, judgment, inquiry, statistics and warning.

4) Air temperature monitoring function: it can deal with the monitoring information of air temperature, such as storage, judgment, inquiry, statistics and warning.

5) Decision-making support for Emergency response function: according to the amount of leaked LNG and environment condition, the software can plot the dangerous area circle around the LNG fuelled ship and broadcast the warning message to the ships which are in dangerous circle. At the same time, the database of this software can provide emergency response procedures to command officer and staff.

6) Maritime safety management function: Maritime Safety Administration can analyze the monitoring information and detect the potential high risk ships.

7) System management function: Parameters of communication, warning threshold and root user information can be set in this system.

5. Conclusion

As a new trend, LNG is regarded as a clean energy and being gradually used in inland water. Meanwhile, the risk of this application has attracted extensive attention worldwide. In this research, LNG fuelled ship real-time navigation monitoring system is developed consisting of three subsystems: onboard operation status monitoring subsystem (OSMS) based on multi-sensor, monitoring information transmission & alarm subsystem (ITAS), maritime remote monitoring software subsystem (MRMS) for LNG fuel ship. Especially, LNSMS is set up based on an upgrade AIS device, combing with the LNG fuelled ship monitoring sensors and public wireless communication module. It can transmit the real-time information to the bridge and maritime safety administration on shore. On one hand, because this method makes use of the message exchange of existing AIS system, it can be widely used with low costs. On the other hand, combining the public wireless network enable

Table 1. The explanation of binary message

Message	Field name	Field length	Data type	Description
$--	address 1	2 bit	Text	The symbol of sensor： temperature sensor: W0～WF Gas Sensor: L0～LF
G01	address 2	3 bit	Text	Message Identifiers： S01：Report period setting S02：Alarm threshold setting G01：Data report
xxx.x	data 1	variable	Float	Monitoring value
a	data 2	1 bit	Text	Sensor situation 0: abnormal 1: normal
***hh**	check	2 bit	Text	

Source: AIS base station interface protocol.

Table 2. The message format of Binary data field in AIS Message ID 6

Name	Type	Length	Description
MMSI	Numeric	30	
Report Time	Time	14	Example: 20040304112311 (year+month+day+hour+minute+second)
LNG Concentration value	Numeric	6	%LEL
Situation of concentration sensor	Logical	1	"1"：normal；"0"：abnormal
Temperature value	Numeric	6	K
Situation of temperature sensor	Logical	1	"1"：normal；"0"：abnormal

Source: Information monitoring subsystem interface protocol.

Table 3. The message format for Transmission Signal

0	4	10	16	24	31
source port				destination	
send sequence number（32bit）					
acknowledged sequence number（32bit）					
Beginning length	reserve		bit elements	window	
Checksum				URGent	
Choice（if have）					filling
DATA					
……					

Source: Authors.

Table 4. The message format of DATA FIELD

Name	Type	Length	Description
MMSI	Numeric	30	
Message ID	Numeric	6	
precision	Numeric	1	1=high (<10m) ; 0=low (>10m)
Longitude	Numeric	28	0° ~180°
Latitude	Numeric	27	-90° ~90°
Report Time	Time	14	Example: 20040304112311 (year+month+day+hour+minute+second)
LNG Concentration value	Numeric	6	%LEL
Exceed the threshold?	Numeric	1	"1" : No ; "0" : Yes
Situation of concentration sensor	Logical	1	"1" : normal ; "0" : abnormal
Temperature value	Numeric	6	K
Exceed the threshold	Numeric	1	"1" : No ; "0" : Yes
Situation of temperature sensor	Logical	1	"1" : normal ; "0" : abnormal

Source: Authors.

this system can also be applied to other inland water area without AIS base station. The system fully meets the requirements of relevant standard and rule of ship classification society.

This system has been installed on two LNG fuelled ship - "Haichuan 2" and "Haichuan 3" sailing along Yangtze river for two month field experiment. Changjiang Maritime Administration tests this system via AIS base station network. Preliminary experiments showed that the system is reliable and effective.

Acknowledgement

This work was supported by the Transportation Construction Science Foundation of China (grant number 2013 328 811 530).

References

International Council on Clean Transportation. (2013). *Assessment of the fuel cycle impact of liquefied natural gas as used in international shipping.*

American Bureau of Shipping.(2014).*Bunkering of liquefied natural gas-fuelled marine vessels in North American.*

Det Norske Veritas (DNV). (2010). *Gas fuelled engine installations*.

Germanischer Lloyd (GL). (2010). *Guidelines for the use of gas as fuel for ships.*

Korean Register of shipping(KR). (2013). *Guidance for Gas-fuelled Ships.*

Wuhan University of Technology. (2014). *Research report of navigation risk prevention for LNG fuelled ship and bunkering station*. Wuhan. CHN.

China Classification Society(CCS). (2013). *Rules for Natural Gas Fuelled Ships*.

Heather M.Perez, Roger, Chan, Richard Billings, Theodore L. Kosub. *Automatic Identification Systems (AIS) Data Use in Marine Vessel Emission Estimation*. Available from: `www.epa.gov/ttnchie1/conference/ei18/session6/perez.pdf`

Kurt D. Schwehr, Philip A. McGillivary. *Marine Ship Automatic Identification System (AIS) for Enhanced Coastal Security Capabilities: An Oil Spill Tracking Application.*

Information Center of Changjiang Maritime Administration. (2013). *Research report of shipborne AIS device function extension and it's application in maritime management*. Wuhan. CHN.

International Maritime Organization (IMO). (2010). *Guidance for the presentation and display of AIS application-specific messages information.*

Darren Wright, CDR. Brian Tetreault.(2007). *Integrating PORTS Data into the USCG AIS*. Available from: http://www. nauticalcharts. noaa.gov/ocs/hsrp/archive/ mar2007/PORTS_AIS_3-07.pdf

E.F.Read, W.S.Heaps. *Tide and Metrological data over AIS*. Available from: `http://www.ohmex.com/AtoNpaper.pdf`

Finland. (2009). *Remarks on the use of AIS based on experience from the Baltic AIS trial (AISBALTIC) project*. 55th session of IMO Sub-Committee on Safety of Navigation .