Specialized Navigational Systems Used in LNG Terminals

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ABSTRACT: Navigational systems employed at LNG terminals assist the navigation of gas carriers along approach channels and in port waters leading to LNG terminals. i.e. in restricted waters. The navigation in restricted waters is often referred to as pilot navigation. The term is derived from the fact, that a pilot assists in navigating through restricted areas, and the process of marine navigation the pilot participates is called pilotage.

1 INTRODUCTION

The navigation in restricted waters, due to fast changes in the ship's position relative to land-based objects, its fix and DR position is not determined on a navigational chart, as is the case when proceeding in open or offshore waters. The ship's position is established in the mental process of the pilot handling / conducting, and pilot navigation is based on good local knowledge of navigational conditions and their effect on ship's manoeuvres. At present several pilot navigation systems exist, featuring the ship position display on an electronic chart. This equipment enhances the accuracy of the determined position regarded as a point or the vessel's waterplane [S. Gucma 2004].

The ship can safely manoeuvre in an area that satisfies the conditions of the required depth. This area, called the **available / navigational area**, and the depth contour bounding it, called the **safe depth contour**, is defined by this relationship:

$$h_b = T + \Delta$$

where: h_b – safe depth, T – ship's maximum draught, Δ – underkeel clearance.

The determination of ship's position in open or offshore areas is identified as the determination of its coordinates (φ, λ), which in fact describe the point of observation. Depending on the method of observation, this point can be the location point of the observer or the antenna of the navigational system in use.

This manner of determining the ship's position is not sufficient in restricted waters navigation, as the information is not available on ship's linear parameters: length, breadth and position relative to navigational dangers (safe depth contour). Information on the linear parameters is included in ship's waterplane, but instead of actual / real waterplane position, the pilot is interested in its position relative to a danger (safe depth contour). Thus, the determination of ship's position comes down to establishing the position of the waterplane in reference to navigational dangers, such as: safe isobath, coast line or fairway centre line (Fig. 8.1). In order to devise and perform the right manoeuvre in a restricted area, the ship's pilot or captain should know:

- ship's position identified as the position of observation point,
- position of ship waterplane in relation to 'safe depth contour'.

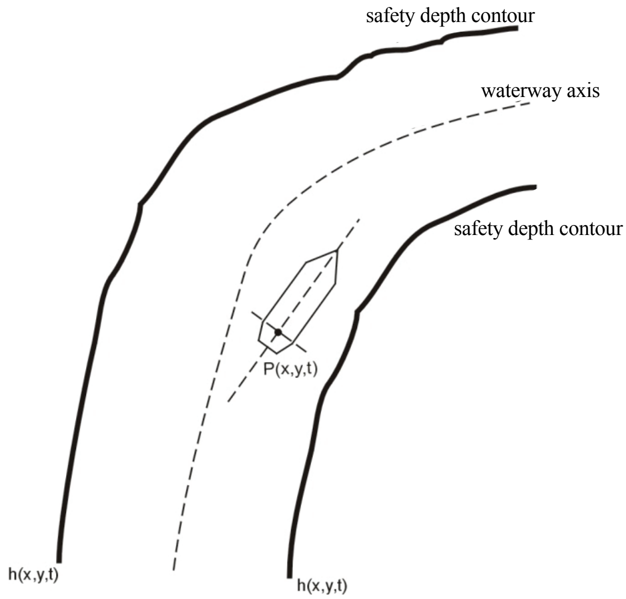

Figure 1. Ship's position in restricted waters.

Taking into consideration the above conditions, we can formulate characteristic features of the navigation in restricted waters, distinguishing it from the navigation in open or offshore waters.

The navigation in restricted areas consists of three tasks that have to be done:

1 Planning a safe manoeuvre.
2 Determination of ship's position in a given area with specified accuracy.
3 Controlling the ship movement assuring the performance of safe manoeuvre as planned.

Task 1, i.e. planning a manoeuvre that will satisfy all conditions (criteria) of safe navigation in restricted waters. The general condition of navigational safety in these waters can be written in this form:

$$\left.\begin{array}{l} \widehat{p(x,y) \in \mathbf{D}(t) \quad \mathbf{d}_{ijk} \subset \mathbf{D}(t)} \\ h(x,y,t) \geq T(x,y,t) + \Delta(x,y,t) \end{array}\right\}$$

where: $\mathbf{D}(t)$ – available navigable area (meeting the condition of available depth at the moment t), $\mathbf{d}_{ijk}$ – safe manoeuvring area (swept path) of the i-th ship performing the j-th manoeuvre in the k-th navigational condiions, $h(x, y, t)$ – depth at the point with coordinates (x, y) at the moment t, $T(x, y, t)$ – draught at the point with coordinates (x, y) at the moment t, $\Delta(x, y, t)$ – underkeel clearance at the point (x, y) at the moment t.

It implies / means that in order to satisfy the condition of navigational safety, the ship's swepth path (safe manoeuvring area) has to be comprised / contained within the available navigable area which meets the condition of safe depth.

In practice this task consists in:

– setting a safe ship's speed,
– assuming a safe underkeel clearance,
– establishing the safe manoeuvring area accounting for the distance of passing navigational dangers swept path traffic lane in fairways,
– planning tactics of particular manoeuvres in a restricted area,
– planning approaching or leaving restricted waters.

Task 2, i.e. determination of the ship's position consists in establishing the position of the waterplane in relation to the safe isobath, shoreline or the fairway centre line. The waterplane position determination relative to the safe isobath takes place in the mind of the navigator, and can be said to have three stages:

– good familiarization of local knowledge, including the contents of the relevant navigational chart covering the area the ship is proceeding in,
– determination of ship's position identified as the point of observation,
– determination of the position of ship's conventional waterplane in relation to the safe isobath, after taking account of the ship's parameters and course.

Modern navigational pilot systems based on accurate positioning devices and the display of observation point or ship's waterplane on electronic charts may assist the navigator's thinking process aimed at establishing the waterplane position in relation to the safe isobath.

Task 3, i.e. ship movement control enabling the safe performance of a planned manoeuvre consists in deciding on the settings of the rudder, engine(s), thrusters and the required tugs. The navigator makes the decision concerning these settings in a few stages:

– determination of the current position of the waterplane in the manoeuvring area and of ship movement parameters,
– determination of the projected position of ship's waterplane in the manoeuvring area and the ship movement parameters,
– establishing the parameters of the manoeuvre to be made, accounting for the prevailing navigational conditions (hydrometeorological and bathymetric conditions),
– coming to a decision concerning the settings of the rudder, engines, thrusters and tugs.

Modern systems of manoeuvre prediction based on the display of future ship movement trajectory or the ship dynamic domain on electronic charts may also assist the navigator in his decision making process leading to the determination of rudder, engine and thruster settings and the tugs involved.

The navigational systems employed on gas carriers entering LNG terminals support the process of pilot navigation during the manoeuvres:

1. fairway passage.
2. port entry.
3. turning.
4. berthing and unberthing.

Navigation during the first three types of manoeuvring is supported by Pilot Navigation Systems (PNS), whereas Docking Systems are used to facilitate berthing and unberthing operations. Attempts are being made to integrate the two systems by designing a navigational pilot-docking system.

2 PILOT NAVIGATION SYSTEMS (PNS)

The idea behind the construction of a pilot navigation system is to enhance mental process of the pilot conducting the ship by providing him with information enabling safe performance of a planned manoeuvre in specific navigational conditions in a set time. This information has to be [S. Gucma, M. Gucma 2006]:

- sufficient for the manoeuvre to be performed safely;
- redundant, as pilots tend to reject information excess as it hinders current observation and ship conduct;
- presented in a form that that does not distract the pilot from his continuous observation and ship conduct.

These requirements are satisfied by:

- minimization of information needed for a safe manoeuvre in specific navigational conditions;
- proper visualization of the required minimum information that will enable the pilot to translate it into relevant settings of the ship's machinery executing safe manoeuvre performance without distracting him from observation and ship conduct.

Pilot navigation systems practically assure safe navigation in restricted waters at all times, regardless of hydrometeorological conditions, other systems in operation and aids to navigation.

The existing PNS systems utilize the image of ship's position displayed on an electronic navigational chart. The ship's 'conventional waterline' is usually presented in relation to navigational dangers such as a safe depth and shore line or the fairway centre line (Fig.1).

Portable PNS systems are used at LNG terminals. Those currently operated usually based on GPS and other systems based on it, such as GPS, DGPS, RTK, EGNOS, WAAS. The majority of systems utilize the existing electronic charts (ECDIS and ENC), which substantially simplifies the distribution of amendments.

A portable PNS system is composed of a laptop computer, electronic navigational chart and a positioning system supplying ship's position and course data. Figure 2 presents the configuration / architecture of such system.

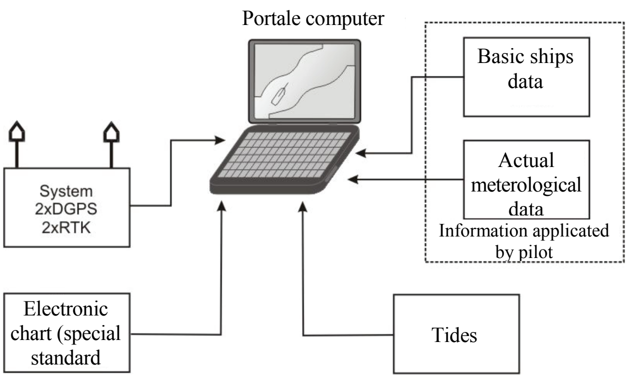

Figure 2. Configuration of a portable PNS system.

Following is a description of three portable PNS systems that may be used on LNG carriers LNG.

2.1 *IPPA System*

The IPPA project executed within the 5-th EU Framework Project is headed by Holland and involves almost all EU nations. It assumes that certain information will be delivered directly to the pilot so that a VTS operator's work will be reduced.

The system consists of:

- ground segment (data base VTS – via GPRS);
- portable segment (DGPSx2, AIS, ENC, GPRS).

The pilot embarking a vessel carries equipment in a suitcase - portable pilot unit (PPU). The PPU includes: PMU (portable mobile unit), featuring a laptop with an electronic navigational chart and a communications module, PEU (portable external unit) – a nodule installed outside with two DGPS receivers, an AIS receiver, GPRS module and a module for communications with the PMU (see Fig. 3). The communications between the PMU and the PEU runs via a WLAN 802.11 protocol at 2.4 GHz. The pilot can freely move around the bridge carrying the laptop. The ENC used is one produced by the C-Map company.

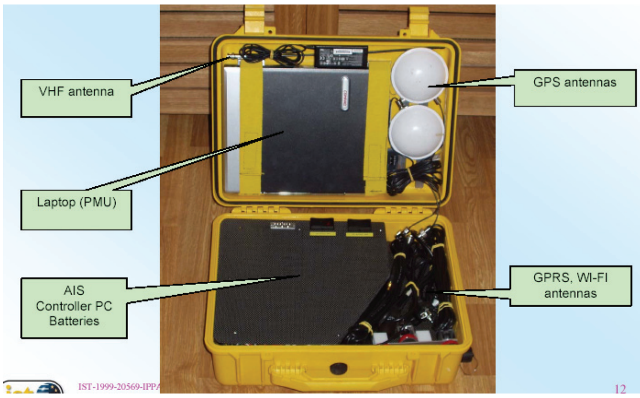

Figure 3. IPPA system.

2.2 *E-Sea Fix System*

Made by Aarhus-based Danish firm Marimatech, this system uses the positioning GPS/GLONASS system in its standard version, differential (DGPS) and RTK (Real Time Kinematic). The accuracy quoted by the maker is 3 to 4 m in the standard version, about 1 m for DGPS, while the RTK yields less than 10 centimeters. There are two types of the system: E-Sea Fix Pilot (DGPS) and E-Sea Fix Docking (DGPS + RTK). The complete unit weighs, respectively, 3 kg (Pilot) and 4 kg (Docking). Both units feature a laptop for the pilot (Fig. 4) with a touch XGA 10.4" screen in a watertight casing. The system ECDIS chart made by SevenCs meets the IHO 57 standard. It has an option of downloading amendments on request via a GSM module.

Like in the IPPA system, the pilot can easily move on the bridge. The E-Sea Docking version has two GPS receivers that are mounted on the antenna deck with magnetic clip-ons). In addition, the unit has an electronic heading sensor. Its two receivers provide information on the position as well as the course. The respective accuracies are as follows: course - 0.01°, rate of turn - 0.02°/s, speed - 0.02 knot. The RTK version has a range of about 15 Nm.

Figure 4. The E-Sea system.

The operating system features numerous functions making the navigation easier for the pilot, such as: calculating and displaying the safe isobath depending on the height of the tide, collision avoidance and voyage planning.

The pilot can choose a chart option (chart of the passage or docking screen). Figure 5 shows a chart in this system.

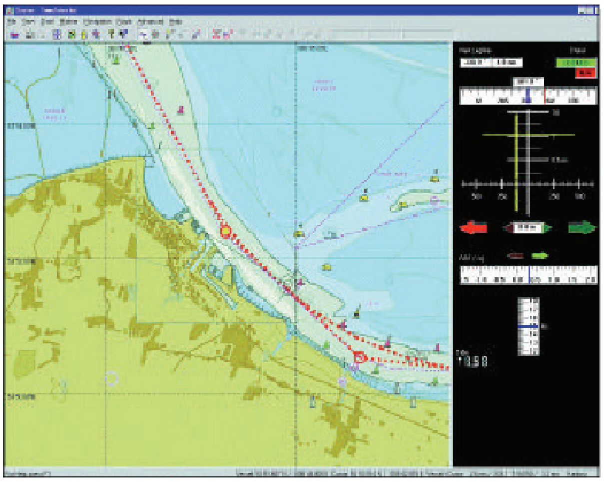

Figure 5. Chart display in the EPDIS system.

2.3 *PNS developed at MUS*

The system devised at the Maritime University of Szczecin within an applied project of the Ministry of Science and Higher Education.

This dedicated system is designed for navigation in confined waters (pilot navigation). Its main features include:

– integration with the area,
– integration with the vessel,
– optimal information,
– optimal user interface,
– prediction and manoeuvring support.

The system, apart from standard images, offers special form of presentation for specific manoeuvres in restricted areas, i.e.:

– shore visualization for mooring,
– fairway visualization for fairway passage manoeuvres.

The information presented on displays is optimal. The optimal user interface is specially built for pilots of large ships and ferry captains. The interface design has been based on simulation studies involving ship pilots and field tests conducted on the Świnoujście-Szczecin fairway. The system has a purpose-modified chart in its own format containing elements needed in pilot navigation, e.g. a feature of constructing an accurate, safe dynamical isobath. The system can also make use of IHO-57 standard charts or other electronic charts.

The pilot arrives onboard with a suitcase weighing about 5 kg. The pilot uses a laptop with a touch 15′ screen that can be freely carried across the bridge. The system uses DGPS positioning carried out by two correlated receivers with antennas mounted 0,5 m apart. They are mounted on magnets in an open space of the LNG carrier (e.g. bulwark). The accuracy of each waterplane point oscilates around ± 1.5 m.

The function of manoeuvre prediction in a 3-minute time span has a 15% accuracy of track covered. The portable version of the pilot navigation system built at the maritime University of Szczecin is shown below (Fig. 6).

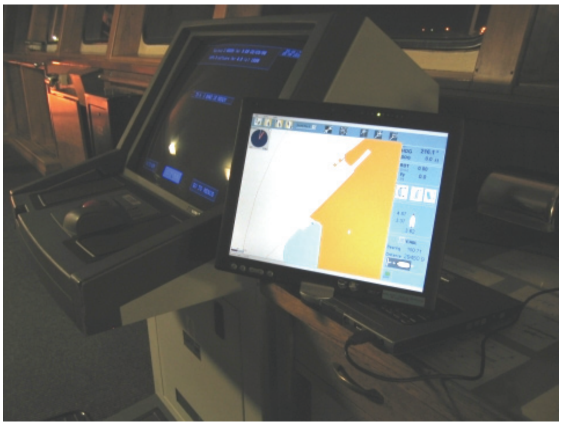

Figure 6. Pilot navigation system (portable version) built at the Maritime University of Szczecin.

3 NAVIGATIONAL SYSTEMS SUPPORTING BERTHING MANOEUVRES (DOCKING SYSTEM)

The idea behind the construction of a docking system is to facilitate berthing and unberthing of an LNG carrier by an accurate determination of ship hull position relative to the berth and equally accurate relative speed of the ship. Its main advantage is the identification / determination of ship's distance to the quay independent of ship positioning systems as well as the measurement of hull transverse speed relative to the quay.

SIGGTO and OCIMF organizations recommend the use of docking systems as a support for LNG carrier berthing. The IMO in the A.915 document sets out the following accuracy levels for each type of navigation.

Table 1. Accuracy standards developed by IMO

IMO navigation requirements	Accuracy	Integrity			Continuity	Availability
		Alert limit	Time to alert	Integrity risk	over 3 hours	per 30 days
	[m]	[m]	[s]	$[^{-5}]$	[%]	[%]
Ocean and coastal	10	25	10	10	N/A	99.8
Port approach	10	25	10	10	99.97	99.8
Port navigation	1	2.5	10	10	99.97	99.8
Automatic docking	0.1	0.25	10	10	99.97	99.8

The accuracy of 0.1 m can be ensured by satellite positioning receivers working with an external system source, such as the RTK system. Similar accuracy is yielded by a laser system operating on the quay, which, to its advantage, is independent of external factors affecting the position received via a satellite system.

The laser docking system for LNG vessels consists of the following components:

– external sensors – at least two per quay – laser or radar sensors;
– control system located at the operator's room on the quay;
– readout system, which may have different options, based on:
  - large display located on the quay
  - light on the quay signaling that safe movement parameters have been exceeded,
  - remote transmission, using portable receivers, mainly laptops or dedicated palmtops.

The systems which present information on mobile displays turn out to be better than boards in poor visibility. Such systems replace systems based on large display located on the quay, and additionally can be integrated with pilot navigation systems. Besides, remote systems can be used by skippers of tugs participating in un/berthing manoeuvres.

One example of a docking system is SmartDock made by the Trelleborg Harbour Marine. This laser system is based on remote data transmission. Its external sensors are shown in Fig. 7, while Fig. 8 depicts its portable display.

Figure 7. External sensors of the SmartDock Harbour Marine-made system.

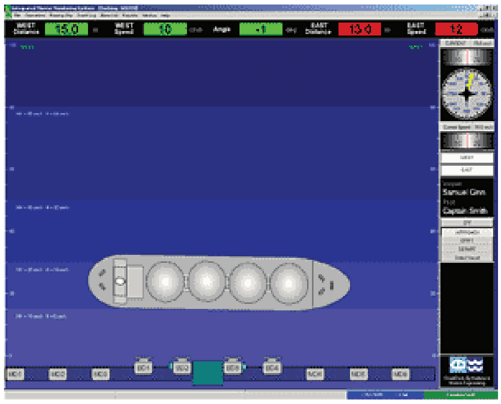

Figure 8. Portable display of the SmartDock system.

A similar solution is offered by Marimatech, a company that produces docking systems with a large display mounted on the quay and mobile displays. Figure 9 shows three different displays of the docking system BAS (berthing aid system) made by Marimatech.

Figure 9. A large display and mobile displays of the BAS system by Marimatech.

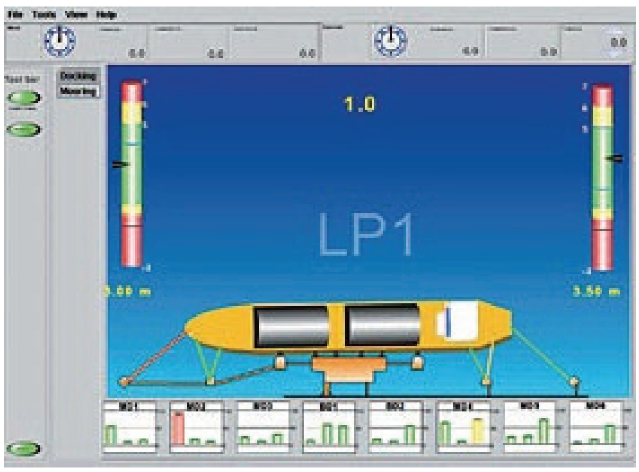

Figure 10. Portable display of the BAS Marimatech system.

The docking BAS Marimatech system, with a range of 300 m from the quay, delivers data on the distance to the quay and transverse speed. The visualization on a portable display takes account of the ship type and terminal design (Fig. 10).

4 CONCLUSIONS

Nowadays there are two types of navigation support systems that becoming more important in LNG terminals i.e:

- pilot navigation system (PNS) supporting process of navigation during maneuvers of transit and entering port as well as turning inside basin,
- docking system for supporting maneuvers of berthing and unberthing.

Researches for combining both systems and presenting information over synthetic portable display are running. It will be display of PNS over which two types of coordinates could be used:

- either fairway or north related (pilot navigation system)
- berth coordinates (docking system)

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