New Berthing Support System Using High Accuracy Differential GPS
- Application to Safety Navigation Management -

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The New Berthing Support System (NBSS) will enable position fix-accuracy to within 10cm. It is global and is an effective system to assist LNG tankers, VLCC and other dangerous goods carriers for their safe berthing and entering/leaving port. The system consists of an on-board, maritime mobile station and a base station shore-side. A major function of the mobile station is to record data, sound the alarm on such as course deviation, the monitoring of the velocity component and the position of an object vessel. The major function of the base station is in the management of safe navigation, and to transfer weather at sea information and alike to the mobile station.

1. Introduction
The operations of berthing have been the most difficult and delicate phases for operating vessels. The advent of huge vessels and change of decreasing crew have made berthing operations more difficult and complicated than ever. The most difficult aspect of berthing is the manipulation of various actuators, i.e. rudder, propeller, engines, side thrusters, utilization of tug boats. A berthing guidance system for large merchant vessels requires precise and reliable sensors of position, velocity, attitude and attitude rate. The estimates of state vectors are to be given into the controller of the berthing system (1). In recent years, marine traffic collisions have come into the important issues, because of running aground in narrow waterways, navigation watch in the congestion sea area, and constant vessel support on the arrival of the large tankers and LNG ships and the dangerous object conveyance vessels.

To meet such requirements of safety operation, the berthing support system with applied Global High Accuracy Differential GPS System (StarFire DGPS) is possible to offer the necessary and sufficient information such as distance, approach speed and recommendation route to the target ground, and simultaneously provides the same information to shipboard on the base station. This paper presents the importance of ship operation with StarFire DGPS system, a new berthing support system (NBSS) and full scale experiments.

2. Importance of ship operation system

2.1 Navigation management of ship

In the 21st century, the International Maritime Organization (IMO) adopted the revision of the International convention for the Safety of Life at Sea (SOLAS) and the preservation Code for the prevention of the terrorism. And IMO obliged all ships to be equipped with Automatic Identification System (AIS), and the security measures are prescribed. That was required, because, for examples, there are VLCC and LNG vessel berths only in Tokyo Bay and not only of large ships but also various fishing vessels navigation in the Tokyo Bay. From view point of marine traffic safety management, the ship’s navigation measurement
produces serious effect on the environmental problems and the international crisis control.

2.2 Navigation management of berthing

In the 21st century, Ministry of Land Infrastructure and Transport (MLIT) proposed the design of Intelligent Transport System (ITS). ①Weather routing system, ②Fleet support system, ③Collision/stranding evasion system, ④Vessel traffic control system, ⑤Berthing support system, ⑥Sea land consistency distribution system (2).

Purposes of berthing support system are support of steerage judgment and support of steerage execution of berthing. And a berthing support system provides the navigation routes at real-time, weather information, recommended route and mark of berthing point. However, it is the present condition that in the case of large vessel’s berthing, captains, pilots and berth master must operate ships to the berthing point controlling the tug boat and the caution ship. In particular, the captains of large vessels must maneuver the ships with high technological skill and the appropriate judgment of the circumstances under the low speed navigation in the bay, because the inertia of the hull is so big.

Approach speed of LNG vessel and large crude carrier must be a few cm per second that is slower than our walking speed. As the large ship’s berthing support, there are supersonic wave berthing speedometer and laser berthing speedometer on shore. However speedometers can offer the information of the distance and the speed only within the measurement range of themselves. Our new berthing support system using GPS can monitor the berthing ship’s approaching condition from the arrival route to the berthing point and the ship’s navigating routes to dolphin berth at real-time and provide all precise information of the approaching condition to the ship. So this system is very useful and efficient from view point of safety berthing navigation.

3. Safe navigation management of LNG carrier

As an example of the safety navigation management, this section introduces one of the examples that the standard of berthing navigation of LNG vessel based on the estimation from safety navigation management point of view. The outline of standard of berthing navigation is defined in the case that the berthing navigation and the route navigation when the ocean going LNG vessels of about 300m length of hull enter and leave port. The standard navigation is regulated to control that the captain, the pilot and the crew of tugboat maneuver safely and the berthing master appropriately guide the entering and leaving vessels. The followings are the example of the outline of standard navigation from the entering route to the berth (3).

① Arrange four tugboats of 3,000HP according to the outline of standard navigation.
② Enter into the east route of Himeji Harbor at 7 knots, which is controllable speed by tugboat.
③ Set the speed at 7 knots during navigating in the east route of Himeji Harbor and maneuver the vessel in the center of the route considering the influence of the current and the wind.
④ Start turning to the right before entering the outer breakwater and controlling the speed at 6 knots or less than 6 knots, pass the outer breakwater and put on the brake by the tugboats on both sides of the bow.
⑤ Heading to course at 22 degrees aiming at the chimney of Kansai Electric Power Himeji the second power station. When the progress speed is big, stop the main engine.
⑥ After passing set course (the direction 91 degrees) of the south coast of the base, start slowly turning to the right and head to the chimney of 203m height on the east side of the power station.
⑦ Decelerate the speed to 2 knots when the center of hull reaches the port signal lamp for LNG vessel side (remaining distance is about 400m).
⑧ Turn left slowly to become parallel berth direction (the direction 14 degrees) when the hull parallels the second pier (the remaining distance is about 200m).
⑨ Stop the progress speed to make the remaining distance to the pier about 150m when the center of the hull parallels the center of the pier (unloading arm).
⑩ Make sure that the hull parallels the berth direction and the front and back positions of hull are set to the prearranged position noting the position of the pier by the pole. Then move the tugboat on the starboard bow to the port side to push the
center of the hull, taking the tub lines.

11. Stop the progress and back ward movement when the hull is set to the planned position. Then start the berthing operation to the pier by three tugboats.

12. When the remaining distance to the pier by reaches about 50m, stop the berthing operation once and take the spring line of the bow tail by the support boat.

13. After confirming that the spring line is fixed to the pier by hook, start again the berthing operation to the pier by three tugboats. Set the berthing speed about 20cm/sec.

14. During the berthing operation, adjust the front and back position of the hull by the tugboat on the stern, not using the main engine.

15. Berthing finally to the pier by less than 5cm/sec operating slowly to the front and backward.

16. After berthing to the pier, adjust the position of the front and the back by the hull lines or the tugboat.

17. After taking all mooring lines, release the tugboats.

4. Global differential GPS

4.1 GPS augmentation system

GPS (Global Positioning System) covers the whole world plural surroundings satellites, and, which has speed as a lot of means of transportation of land, sea and air forces as the system. Three dimension measurements are possible in the whole world. The GPS augmentation is shown in Table 1, and there are GPS independent, DGPS (Differential GPS) and RTK-GPS (Real Time Kinematics GPS). The most useful DGPS are the system used by the satellite.

<table>
<thead>
<tr>
<th>Table 1 GPS augmentation system</th>
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<tbody>
<tr>
<td><strong>Autonomous</strong></td>
</tr>
<tr>
<td>Beacon</td>
</tr>
<tr>
<td>Satellite use (MSAS)</td>
</tr>
<tr>
<td>Satellite use (StarFire)</td>
</tr>
<tr>
<td>Original station</td>
</tr>
<tr>
<td>Virtual station</td>
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</tbody>
</table>

4.2 StarFire wide area DGPS

The StarFire Wide Area DGPS (WADGPS) has been in progress from a set of regional DGPS networks which provided high accuracy service over independent continental areas to a robust unified global network offering unprecedented accuracy. This global network provides uniform sub-decimeter real time service over almost the entire Earth. It is based on technology developed by the Jet Propulsion Laboratory (JPL) for the National Aeronautics and Space Administration (NASA). There are several key characteristics which enable the extremely high accuracy and robustness of the StarFire system:

a. GPS measurement data from a global network of dual frequency reference receivers,
b. Very accurate orbit calculations using JPL’s technology,
c. Modeling of all significant error sources,
d. High quality dual frequency mobile receivers,
e. Highly redundant measurement data, processing structures, and communications links.

In combination, these characteristics offer a unified, robust, real time, global capability.
StarFire has been developed and operated by NavCom Technology, Inc. NavCom now broadcasts the correction stream over three INMARSAT satellites to provide global coverage. In addition to the JPL Hub software to generate the corrections, NavCom contracted with JPL to receive the data from the JPL/NASA global reference sites to augment the NavCom reference sites. The result is a global DGPS system which can supply high accuracy results almost anywhere in the world.

Fig. 1 shows an overview of the StarFire WADGPS architecture. At a conceptual level, it is similar to other wide area DGPS systems that are the Federal Aviation Administration’s Wide Area Augmentation System (WAAS), Europe’s EGNOS, and Japan’s MSAS. It is important to note that StarFire is designed to have as few single points of failure as possible. Its architecture is highly redundant, which is essential to its reliable operation.

4.3 StarFire DGPS service

The StarFire global subscription service provides real-time accuracy typically better than 10cm (4 inches). Its globally corrected signal is available virtually anywhere on the Earth’s surface on land or sea, from 76ºN to 76ºS latitude. To accomplish this, StarFire utilizes a network of more than 60 GPS reference stations around the world to compute GPS satellite orbit and clock corrections. Two completely redundant processing centers and multiple communication links ensure the continuous availability of StarFire GPS corrections. These corrections are broadcast via three geostationary satellites, providing worldwide coverage and enabling precise real-time navigation without the need for local ground base stations.

5. Berthing support system

With the significant development of GPS technology is now an essential tool in almost all forms of modern position referencing and tracking systems. NBSS has adapted this technology to produce a flexible and cost-efficient means of supporting and monitoring the position of a large vessel during berth. The system provides two basic functions, the first as a berthing aid providing precise information on approach distance, position, and speed. The second is for use as a berthing aid providing audible and visual alarms on collision danger, and more importantly a difference in heading alarm, giving a vital early warning of tanker fishtailing. NBSS could provide a precious database with users for not only supporting the vessel’s safety operation but also the vessels managing system providing the proper information.

To meet such requirements of safety operation, the berthing support system with StarFire is possible to offer the necessary and sufficient information such as distance, approach speed and recommendation route to the target ground, and simultaneously provides the save information to shipboard on the base station.
5.1 System configuration

NBSS is completely self contained and consists of the base station permanently installed in terminal control room and the mobile station of lightweight portable unit to be hand carried onto the approaching vessel. NBSS consists of the base station and the mobile station shown in Fig.2. The two units communicate via integral radio transceivers or cellular phone and provide a real time graphical display of the berthing process with sub meter portion accuracy. In addition to the positional information wind, wave and sea current speed/direction data may be displayed on the system from terminal control system.

The base station is a self contained device suitable for either desk or rack mounting. The base station contains a desk top computer, a radio transceiver for communication with target vessel. The basis behind the operation of StarFire DGPS system is the requirement of an absolute reference for a non moving base station. The requirement of an absolute reference of NBSS is receives the corrections broadcast from the communications satellite (INMARSAT).

The mobile station consists of a portable computer, StarFire DGPS receiver, cellular phone for communication to the base station, wireless LAN for communication to another monitor and fiber optical gyro to determine the vessel heading. The unit includes all necessary cable and antenna for operation and once on board the vessel the unit can be deployed on the bridge quickly. The mobile station of NBSS is shown in Fig.3.

![Configuration of New Berthing Support System](image1)

![Mobile station of New Berthing Support System](image2)
5.2 Function and performance

The base station and the mobile station of the system mainly function as GPS reception, communication between both stations. At the base station, information about wave and current information are transmitted to the mobile station, and simultaneously, the data has been recorded. At both stations, it is possible to switch three modes i.e. approaching mode, berthing mode and mooring mode from one to another on the screen. The functions of base station and mobile station are shown in Table 3.

NBSS provides the following information:
- a. Relative distance between vessel and user defined way point,
- b. Final berthing position and recommendation route,
- c. Dangerous line and alarm,
- d. Absolute vessel heading, speed, direction,
- e. Wind, wave and sea current.

Performances of this system are follows;
- a. High accuracy in sub meter order,
- b. Vessel position and speed can be monitored at real time,
- c. The object vessel data has been recorded and reproduce it in the off-line,
- d. The object vessel data can be monitored by using wireless LAN PC at the wing.

Table 3 Functions of New Berthing Support System

<table>
<thead>
<tr>
<th>Installation</th>
<th>Equipment</th>
<th>Amount</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Station</td>
<td>Monitoring</td>
<td>1 set</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Communication (Ship ~ Land)</td>
<td>1 set</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>GPS</td>
<td>1 set</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Heading gyro</td>
<td>1 set</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Monitoring</td>
<td>1 set</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Communication (Ship ~ Land)</td>
<td>1 set</td>
<td>0.2</td>
</tr>
<tr>
<td>Mobile station</td>
<td>Communication (Wireless LAN)</td>
<td>1 set</td>
<td>0.7</td>
</tr>
<tr>
<td>Augmentation</td>
<td>INMARSAT</td>
<td>3 sets</td>
<td>(world wide)</td>
</tr>
</tbody>
</table>

5.3 Monitoring

Both vessel and base station operates NBSS application system. It is quite simple for novice users to work this new berthing support system with the interface. All options are accessible via menus which allow the operator to call up any parameter in a small data window at a moment notice. NBSS has two typical screens. The first screen details the tanker on approach to a berth. The approach distance, speed, and bearing are displayed in movable station. With additional instruments at the terminal the wind speed and direction and sea current speed and direction may also be displayed. The second screen details a berthing tanker on its final approach. The difference in heading can be set to generate an audible alarm at an operator defined limit.

To assist the pilot who uses this NBSS, the system makes use of vessel profiles to record the dimensions of the vessel and the previous position of the GPS antenna. The ultimate accuracy of the system depends on how accurately the GPS antenna is placed on the vessel. The configuration screen attempts to assist to operator by asking for the length and breadth of the vessel and then the position of the GPS antenna.
6. Full scale experiments

6.1 Berthing monitoring

Fig. 4 shows the approach mode, on which numeric data of vessel speed and course and other information and some graphics. This mode shows calculated speed from GPS, alarm of navigation and sensing (GPS, gyro, communication) and object vessel in the area of set route in the approach mode. The recommendation line and zone set up in advance, and trajectory of the applicable vessel are sometimes indicated in 5sec. to 60 sec. with sight information corresponding to the tide and wind conditions and the depth of water. Information of a monitoring is made in the base office and on board at the same time as a bird's-eye view.

![Fig. 4 Typical screens of approach mode](image)

![Fig. 5 Typical screens of berthing mode](image)
Fig. 5 shows berthing mode, on which bow and stern speed and distances, etc. are displayed in order to obtain the information of the vessel hull in detail. In berthing mode, the final berthing speed of large tanker is limited under 10 cm/second. Loading and unloading position of tanker in berth is indicated on the screen in advance because the loading arm on the terminal should be connected with ship’s manifold within the allowance of a few meters. The corner of the movement speed of the bow, stern required at the time of berthing and displacement of the bow, stern and the bow direction are indicated by the numerical value and the graphical vector.

### 6.2 Approach speed

Approach speed of VLCC and LNG vessel crude carrier must be a few cm per second at berthing mode. The time series in Fig. 6 are one of the results of NBSS and Laser Docking Systems (speedometer). In this figure, blue (thick) line is the results of using NBSS and purple (thin) line is the results of using laser speedometer. From these results, both approach speed and distance between the berth and vessel of NBSS and Laser Docking system fit well.

![Approach speed](image1)

![Distance between the berth and vessel](image2)

**Fig.6 Approach speed and distance from berth**
7. Conclusions

NBSS aims at going safety operation under the disturbance environment by watching vessel’s motion with dangerous load about the large tanker and LNG vessel. This system provides a precious database with users for not only supporting the vessel’s safety operation but also the vessels managing system. StarFire is to be improved more than ever to promote the safety operation for the vessel’s operator and manager. Though the base station is permanent establishment, a mobile station has developed as acceptable type with the excellent simple operation installed with the vessel which becomes a monitoring object as man-machine interface of light weight. This system provides a precious database with users for not only supporting the vessel’s safety operation but also the vessels managing system providing the proper information. Authors wish this system would widely be equipped with various types of vessel, from small, medium to large vessels. Also authors hope, if this system could be of more effective usage for operation of the tanker and the dangerous object conveyance vessel and also the control of ship’s operation (7).

Acknowledgment

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