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PRESENT STATUS AND TENDENCIES IN DOCKING SYSTEMS' DEVELOPMENT

ABSTRACT

The process of the ships docking, especially very large ships, is an very risky operation in confined and busy port waters. The similar difficult is the task to pass along any channel, river, strait or similar water road. The basic difficulty causes maneuvering with the great mass of the ship in situation of small space to maneuvers, the large inertia of the object and poor maneuvering properties at small speeds occurring in such circumstances. An additional factor, which make this task more difficult is the influence of the wind and the sea current on the hull of the inert ship as well as consequences of the limited visibility. The bad weather can cause the necessity to delay the maneuver. However this joins with heavy costs. An alternative is usage of systems supporting this process.

In this paper nowadays accessible systems for augmentation the docking and harbor navigation are analysed. There are: shore based (active or passive) and ship based (active). This paper is prepared in the frame of Bonus project call 2012 'The Captain Assistant system for Navigation and Routing during Operations in Harbor'.

Keywords:
harbour navigation, harbor pilot, docking systems, efficient navigation.

INTRODUCTION

The process of the ship's docking, especially very large ship, is treated as an risky operation in port waters which are usually confined and busy. The similar difficult is the task to pass along any channel, which means the river, strait or similar water road. The basic difficulty causes maneuvering with the great mass of the ship in such situation as small reserve of the space to maneuvers, the large inertia of the object and poor maneuvering properties at small speeds occurring in such circumstances.

An additional factor, which make this task more difficult is the influence of the wind and the water current on the hull of the ship as well as consequences of the limited visibility. The bad weather can cause the necessity to delay the maneuver to the moment of the improvement of the weather, however this joins with heavy costs. An alternative is usage of some system for supporting this process.

Nowadays there are accessible different systems designed for specific ships, specific operations or specific area. All of them consists of different devices as well as based on different ideas, but in general there can be divided into three groups:

1. Situated on the shore:
   - active, shore based;
   - passive, shore based.
2. Situated on the ship, active.

SHORE BASED SYSTEMS

Shore based systems — active

Active, shore based systems are situated on chosen wharf and use laser or microwave transponders to measure distance to the ship, usually to two points on the ship's hull: the bow and the aft. Based on this measurements system counts the relative speed of designated points of the ship's body. The example is the Marimatech Berthing Aid System based on laser measurements. With the accuracy and reliability that laser technology offers it has become kind of standard. For many mariners this is an synonym of docking system with his big, visual tables (see fig. 1) on the warf.

Similar product — SmartDock®Laser is offered by Trelleborg Marine Systems, a world leader in the design and manufacture of advanced fender systems, docking, mooring and monitoring equipment and oil and gas transfer technology [www.trelleborg].

These systems consists usually of two (some time tree) laser sensors, with monitoring units located in a control room ashore. Vessel movement data can be displayed on a jetty-mounted monitor, and/or transmitted wirelessly to the dedicated ship's display or to pilot's device built on the basis of laptop or tablet. In the recent pass as the main defect of these systems its stationery was pointed. In the some nowadays products the laser units can be safely transported and mounted on tripods on the wharf when system is used occasionally.

Fig. 1. Characteristic great boards of the laser-system
[source: http://mampaey.com/i-moor/bas/large-led-display]

Docking Laser is the most accurate docking solution, but its range is limited (200–300 meters). So, in fact it can be used only during the mooring procedure, and then only when the vessel is immediately opposite the lasers. It can also be adversely affected by different paint coatings degrading the reflection possibilities. In fact extreme accuracy of measurements are true in laboratory conditions. Real ship's body has a lot of curvatures and in fact centimeter level accuracy is controversial. But these accuracy are important for precise counting the speed of the ship in relation to the wharf. Negative side of such solution is impossibility to measure speeds in any direction except at right angles to the berth. It only operates on a single berth and it does not perform any other functions, such as channel navigation for example. Producer's assurance is 1cm in distance and ± 1cm/sec for velocity.

The biggest disadvantages of laser systems are: the cost, as it is very expensive, short distances of work, limited places of installation and in addition problems with the dark-hulled ships which are non-reflective, so system may not work on full range. Some additional problems are from time to time with large jetty display which may be hard to see in some weather (fog, sunny) conditions.

Shore based systems — passive

Passive, shore based systems use encoded ship data, mainly transmitted via AIS and presented to any permitted user via LAN, internet or Wi-Fi. The main question is the accuracy of this data, because standard ship's data are not sufficient for pilot operations. However in many cases it can be enough for channel operations. Generally speaking, today for the standard ship passive, shore based systems are not so good as active one, but at the moment only passive aids can provide data to any authorized users involved in the process out of extra communication devices. In many Vessel Traffic Services this kind of system is applied as an supporting one to shore radars. Nowadays accuracy can be estimated on 2–3 meters when DGPS or EGNOS is in use [Felski A. et al., 2011]. It can be enhanced with extra mathematical models of the ship, so accuracy of positioning process can be improved for 2–3 times. Unfortunately at the moment spatial orientation of the ship's hull and rate of turn (ROT) information is the biggest problem and not sufficient. Many ships has no ROT sensors at all and accuracy of the standard gyro compass is about 1° which is not sufficient to. In addition some troubles with accessibility of such information in AIS system is observed [Felski A., Jaskólski K., 2012]. Possibilities of changes in this range would demand more excellent measures of the angular orientation of the hulk, which is possible when MEMS technology or GPS compasses can be implemented. The easiest and most cheaper solution seems the common use of satellite compasses.

SHIP BASED SYSTEMS

Ship based systems are developed only as active one. As a rule are built with portable pilot's devices (PPU) supported with laptop or tablet and dedicated docking software. In many cases this kind of devices has option able to transmit data ashore via UHF. Typical portable pilot's system give pilots their own source of extremely accurate positioning data, heading and Rate of Turn. Usually implemented there special piloting software, is an overlaid on standard electronic charts (ECDIS). In some, the positions of surrounding ships can also be shown thanks to the use of AIS receiver.

At the moment the main source of positioning information in this kind of systems is GPS [Ward N., 2014]. In fact, at the moment in some areas of the earth, LORAN C signal is available, and probably in the near future e-Loran can be available however accuracy of this systems is still not acceptable for harbor operations [gpsworld.com/edloran-the-next-gen-loran].

There are several levels of accuracy for real-time position whether bases on pure GPS or supported (augmented) one, which mean differential version (DGPS, EGNOS) or Real-Time Kinematic one (RTK). Each method uses signals from satellites and/or ground stations to provide additional data to the user's (pilot's) device.

However accurate position is not sufficient in this case, although better accuracy of position is increasingly smooth velocities and course over the ground, calculated from one second to the next, which is the most significant benefit to the pilot. In addition, heading of the ship is very important, as usually big ships are long so small error in heading take effect of important enlargement of the width of the ship's moving path. This is especially important, when GPS antenna is situated on the aft of the ship.

In real conditions of ordinary harbor it is no sense to use pure GPS, because it's accuracy (up to 10 m) is 2–4 times bigger than required one. Differential GPS applies a secondary source of correction data to raw GPS signals. This improves the accuracy of the position by about three times (2–3 meters). Differential corrections are freely available through the EGNOS satellite system covering all European waters or via MF beacons (DGPS) operating in the 300 kHz band, distributed on the shore of many countries. For example on Polish waters there are two stations situated in Rozewie and Dziwnów. For very accurate measurements the extra reference station for real-time GPS phase measurements should be used (RTK), but this version is not commonly use in marine technology. What is more, usually has limited (horizontal) range, as it works on VHF or GPRS technology. However where neither is available, it is possible to set up a dedicated base station at the harbor.

DGPS — based Portable Pilot's Units (PPUs) have proved accurate enough for many pilotage situations, especially for transition along the canals or route. In most cases, no shore-based infrastructure is required, the technology is commonly known and can be operated almost anywhere. Differential GPS systems are the most flexible, as well as the cheapest accurate option. At the moment on European waters a lot of DGPS reference stations are accessible but probably the better solution is EGNOS — the same all over the Europe system with the constant accuracy, even on inland waters, particularly on big European rivers. In fact both option offers the same accuracy, about 2 meters in horizontal plane.

However DGPS/EGNOS technology is not capable support all pilotage requirements when less than 1m of position accuracy or 2cm/sec (0.05 Kn) for velocity is needed. Additionally DGPS/EGNOS cannot offer heading measurements itself, so it need extra equipment or special kind of receiver called usually GPS Compass [Felski A., 2011]. This is two or more antennas system happily now offered in reasonable prices, so becomes more and more spread used. This technology in fact merging two receivers in one: first for positioning and the second one, usually with two antennas system for heading measurements by phase analysis (so called moving-base RTK-GPS system). This second one receiver is not dependent on differential corrections, as it determine direction from one antenna to second on the base of phase measurements.

RTK — based PPUs need a shore RTK-base station. This GPS variant gives few cm accuracy, making them the highest-accuracy available. Velocity in this case can be measured with accuracy of ± 1cm/sec. This is very accurate system, can be used at every berth in the port and for channel navigation. In addition this variant can deliver real-time heading with good accuracy, however it need two antennas distributed on the ship, extra base station and unfortunately is limited by range from his base station.

Nowadays in the Europe unified net of reference stations EUPOS is developed (in Poland ASG-EUPOS) as well as many producers offer his own nets (Leica, Topcon etc.). These nets can deliver corrections via GSM so there is no need to establish own base station in the harbor. Some problem can appear with the range, but usually in the harbor range of GSM signal is good.

Fig. 2. An example of Portable Pilot Unit RTK type [source: www.navicomdynamics.com]

Pilots' Portable Systems are produced in many version by some producers. Usually it is the set of laptop equipped with special software and specialized receiver with two distributed antennas and some additional elements installed in the receiver box. There are power sources, MEMS gyros and WiFi elements and typically system is autonomous and self-synchronized with pilot laptop. Some examples of producers are: Navicom Dynamics, Transas, Trelleborg Marine Systems, Atlantasmarine etc. As an standard example of such device can be shown Navicom Dynamics' Harbor Pilot Lightweight. This is portable and compact system just only 5 kg in total. It working with RTK variant of GPS and consists of two GPS antennas, main device and laptop packed in the carry bag. Components of the system are: shock-proof and waterproof polycarbonate/polyester blend electronics box consists of DGPS receiver, WiFi or Bluetooth transmitter, master and secondary GPS antenna, integrated gyro, laptop, backpack. Optionally AIS and UHF receiver can be included. System is fully wireless and very easy and fast (2 minutes) to installation. Pilot's interface works on the ECDIS basis, so it is marine-oriented and easy to go.

Fig. 3. Harbor Pilot Lightweight [source: www.navicomdynamics.com]

Main performance specifications:

Weight 5–8 kg (depends on laptop type)
Battery life 15 hrs
Start-up: fast start-up (normally < 2 min)

Accuracy with raw GPS:	position 2.5 m (95%)
	heading ± 0.2°
	rate of turn ± 0.5°/min
Accuracy with DGPS:	position 50 cm (95%)
	heading ± 0.2°
	rate of turn ± 0.5°/min
Accuracy with RTK:	position: 2 cm
	heading: ± 0.2°
	rate of turn: ± 0.5°/min

Very similar are problems of maneuvering/mooring in relation to different objects in offshore activity, so it is proper to take into account practical solutions made in this field. This becoming accomplished on the ground of Kongsberg Seatex solutions, the commonly known producer of systems for wide spectrum of offshore technology: positioning systems, reference systems, Dynamic Positioning systems as well as position mooring systems. However all this systems are stationary in relation to the ship (not portable), some solutions are very interesting and would be able to become adapted.

As an example of this technology Seatex Seatrack 220 can be shown. It is high performance GPS transponder system for marine tracking operations. It mean it is the relative GPS tracking system and is tailored to applications demanding extremes in reliability and accuracy. System is designed to accurately track the position of distributed objects relative to a vessel in real time and consists of group of transponders and vessel control unit equipped with Seadiff RNAV software. Each transponder captures GPS carrier and phase code and transmits it to the host vessel via UHF radio signals (or via cable) for accurately processing the data and calculates relative positions. Data transmitted allows either pseudorange or RTK processing onboard the vessel, providing meter to centimeter level position accuracy. Probably distributed on the wharf Seatex Seatrack transponders allows the pilot equipped with Seadiff RNAV software to use it as pilot's assist.

The Seatrack 220 is self-contained with all electronics and antennas integrated in the polyethylene unit, operation starts automatically upon power up. A low power UHF radio and a TDMA (Time Division Multiple Access) protocol provide efficient communication between the vessel and the transponder. The built in 12-channel GPS receiver has a sophisticated anti-multipath feature for maximum accuracy and minimum signal degradation. The UHF radio in the Seatrack 220 transponder has a typical range of 15–20 km. Erroneous data is detected and removed by utilizing a reliable data protocol, protecting the RGPS processing against invalid results. The TDMA technique makes it possible to allocate time slots for 24 transponders, however it is not clear how many vessels can operate in the range.

According to the source there are other options for gaining information transmitted via AIS. There are devices which can be plugged-in with vessel's AIS receiver. An example of these group is E-Sea Fix CAT ROT produced by Atlantasmarine (www.atlantasmarine.com). This is a small and compact pilot unit primarily designed to connect to a ship AIS pilot plug and transmit data via Wi-Fi to the Pilots laptop, iPad or iPhone.

This device, as well as many similar has an integrated rate sensor thus providing decimal degrees to the heading information, a valid Rate-Of-Turn (ROT) and reliable predictions. As a backup solution the CAT ROT has an integrated GPS receiver, so system can act independently if pilot take it to the bridge wing to acquire a GPS signal. It must be mentioned, that the majority of AIS receivers do not provide decimal degrees as well as ROT to the pilot plug, however these parameters are vital for the pilot when maneuvering. Proposed device, through build-in integrated rate sensor, in combination with the ships' gyro data taken from the AIS output and with the advanced Kalman filtering, can generate accurate ROT and decimal readings to the gyro output. This kind of equipment does not require any dedicated software and can support the most common pilot software on the market. Positive details of this option are:

- low cost; easily affordable;
- light weight and small size (easily carried in the Pilot's pocket);
- 11 hour battery life.

Fig. 4. E-Sea Fix CAT ROT [source: www.atlantasmarine.com]

Mentioned before Navicom Dynamics also offer very similar system Channel Pilot Mk2, according the company system is dedicated especially for channel and river pilotage, however it can be useful in all ports as well. As contrasted with previous this solution possess independent AIS receiver. Works with a wide variety of navigation software, including Rose Point ECS, Qastor, Euronav, etc implemented on pilot's laptop and deliver position, heading, ROT for own ship, as well as independent (additional) AIS signal for other ships in the vicinity.

CONCLUSIONS

There are three, at the moment, solutions in the field of harbor pilot supporting systems. Passive shore based systems — positive is the option of broadcasting information to many users, however its accuracy is poor.

Active shore based systems based on laser devices — are the most expensive, has limited range of work and can work only on dedicated wharf, however its accuracy is the best.

The most flexible seems to be active ship's systems which can deliver adequate accuracy on rather spacious harbor parts on the rationale prices.

As the most important conclusion from the analysis and comparison of accessible systems seems desirable, so that the proposed system possess the possibility broadcasting the information to many users. The system should not only present the current position and information about the movement of the ship, but should play the role of advisory means. For this purpose it need to deliver to the pilot:

- vectors showing instantaneous direction of ship's movement, advisable separately of bow and stern;
- athwartships component of velocity at bow and stern;
- fore/aft component of velocity at midpoint, as well as angle of approach to wharf;
- distances off wharf at shoulder and quarter.

In addition, when lock approach system should present distances to both sides of the lock alike at bow and stern and distance to end of lock. Desirable is the showing cross-track error in relation to the centerline of the lock.

In turn of relative positioning mode (in relation to other ship, tug or to the buy) important are:

- heading, rate of turn (ROT), course and speed over ground (COG and SOG);
- true and relative bearing, and distance from bow of the vessel to stern of other vessel;
- relative speed between both vessels;
- vectors showing direction and speed of bow and stern of vessel;
- alarms when distance closes the user-defined limit.

Mentioned above features demand uses of positioning system, in fact it should be DGPS or EGNOS, preferably RTK. On Gdanska Bay all of this option are available (Reference DGPS station Rozewie with the range of 250 km or RTK base station in Hel according Gdynia Marine Board offered permanent service of RTK via VHF and GPRS). On the all Gdanska Bay GPRS signals are available, and ASG-EUPOS corrections are available also.

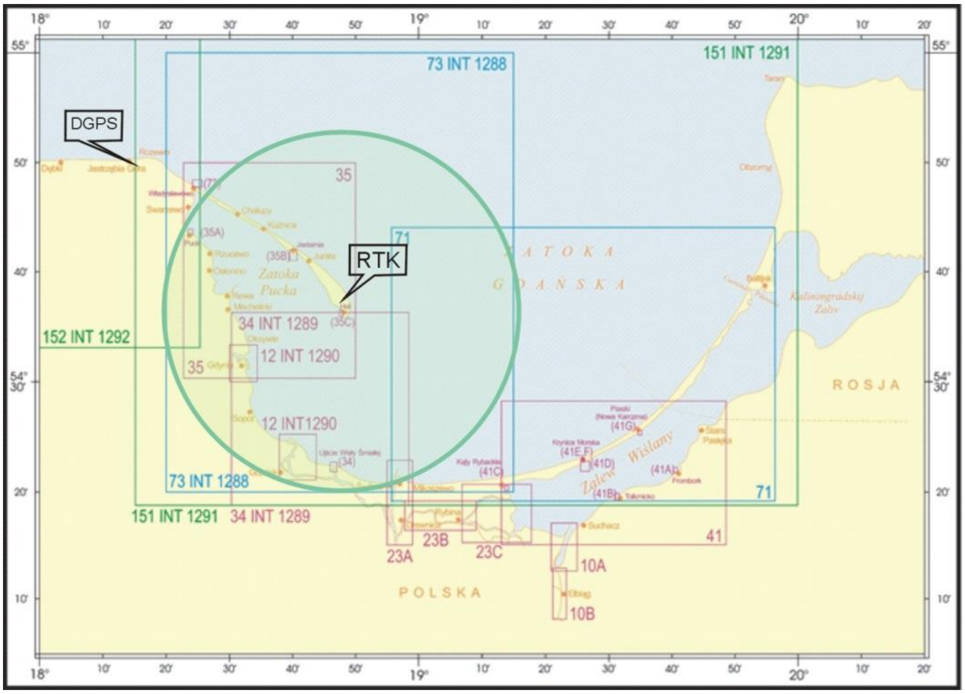

Fig. 5. Range of RTK permanent service and the place of Rozewie DGPS monitoring station

Important question, especially on big vessel, is information about Course and Heading. Standard equipment of ordinary vessel has poor accuracy of Heading information (about 1°) so it should be upgraded. This is the reason why usually two antennae system is recommended. This solution, so called Moving Base RTK solution, offer the ability to compute the direction from main antenna to slave, which can be interpreted as heading of the ship. However this mode in the pure form has defect in periodically poor accuracy, with the big errors (up to 20° errors or more during some seconds) which is impermissible. This is the reason of inertial (more often MEMS) sensors utilization as an additional. Optionally inertial (6 degree) solution can be used, more often build on fiberoptic, sometimes MEMS type.

Another great advantage is that when GPS signal or corrections signals are lost, the system reverts to GPS accuracy, but thanks MEMS supporting, it is usually good enough to continue the berthing operation.

Desirable is, so that the system be able to perform following functions:

- route creation;
- fully record and replay the process;

— operate with AIS for display information about the ships in the vicinity and recognition of other vessels' maneuvers (speed, course, turns) and predict Closest Point Approaches';
— curved path prediction for monitoring turns.

All this functions are as well important as the information about the position of the ship. Mentioned function can be implemented only on the basis of dedicated software with some models of the ship and extra information about some weather parameters around. From this it results that the system should consists of three main parts:

— pilot device;
— harbor infrastructure (net of weather/oceanographic sensors, harbor server equipped with special software and short range communication system);
— radio-communication system with the range of some teen miles (horizontal range).

Individual pilot's unit cannot act without cooperation with harbor infrastructure. It should take into account the net of environmental sensors, mainly wind, sea current and sea level as well as system of communication between vessel and land (server and pilot) with the regard of internet technology.

Discussed system can improved communication between pilots and masters — because information displayed on the easily understood ECDIS chart reduces language barriers, pilot has a reliable source of information even if the ship's systems fail, but in the same time he has a system that he is familiar on every ship. If the pilot possesses its own tool, he is able to fine-tune their abilities by comparing Pilot's terminal information with the view out of the window, and he has recording and playback capability which allows other pilots to analyze their performance afterwards. This capability is also excellent for training, testing and debriefing new pilots.

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STRESZCZENIE

Proces wprowadzania statków do portów, zwłaszcza statków bardzo dużych, to ryzykowna operacja, szczególnie na wodach ograniczonych i zatłoczonych. Podobnie trudne jest zadanie przeprowadzenia statku przez jakikolwiek kanał, rzekę, cieśninę lub podobną drogę wodną. Podstawowa trudność wynika z wielkiej masy statku w sytuacji małej przestrzeni, wielkiej

bezwładności obiektu i złych własności manewrowych przy małych szybkościach, typowych dla takich okoliczności. Dodatkowym czynnikiem utrudniającym to zadanie jest wpływ wiatru i prądu morskiego na kadłub bezwładnego statku, jak również konsekwencje ograniczonej widoczności. Zła pogoda może spowodować potrzebę odłożenia manewru na później, jednak łączy się to z dużymi kosztami. Alternatywą może być zastosowanie systemów wspierających ten proces.

W artykule przedstawiono analizę dostępnych obecnie systemów dedykowanych dla wspierania takich operacji w portach oraz żeglugi w akwenach ograniczonych. Systemy te występują w wariantach brzegowych (aktywne lub pasywne) oraz okrętowych (aktywne). Artykuł został przygotowany w ramach projektu BONUS 2012 „System wspomagania kapitana w procesie nawigacji w trakcie operacji portowych".