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ASSESSMENT OF SHIP'S MANOEUVRING AREA DIMENSIONS RECKONED BY MEANS OF GNSS MEASUREMENTS

ABSTRACT

The paper presents possible methods of dimensioning manoeuvring water area which take into account the GNSS accuracy factor. Based on real experiment measurements in Świnoujście harbour the comparison of manoeuvring areas' dimensions by methods with and without allowance for measurements' biases has been made. The precedence of these methods in respect of their reliability has been proposed.

Keywords:
manoeuvring area.

INTRODUCTION

As commonly known, a ship's movement path is an area obtained by a sequence of the consecutive ship's hull positions in the accessible water.

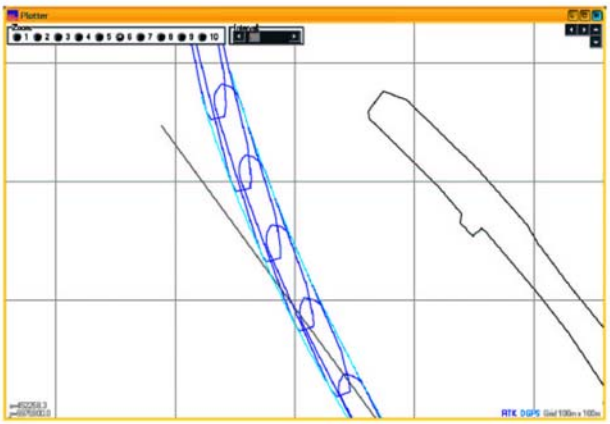

Fig. 1. A ship's movement path as a sequence of consecutive ship's hull positions (bird's eye view)

The ship's movement path is the parameter of a manoeuvring area, as it describes the area covered by a moving ship. Measuring of the manoeuvring area consists of the determination of its horizontal parameters in each point (x, y), at the every moment (t) of the manoeuvring in progress while the condition of safe depth (h) is met [4]

$$h(x, y, t) \geq T(x, y, t) + \Delta_T(x, y, t), \tag{1}$$

where: $T(x, y, t)$ — set of ship's draughts;
$\Delta T\,(x, y, t)$ — set of under-keel clearances.

The manoeuvring area determination process usually consists of simulation studies during which the researched ships' movement paths are registered. The reckoning of random variables of maximum distances between extreme points of the assumed ships' hull waterline outline and the reference line, for example: a fairway axis, leads to determination of the manoeuvring water area width. The manoeuvring water area width at a specified confidence level can finally lead to establishing of the safe manoeuvring area (and to proposal of the manoeuvring region) if this confidence level is resultant of accepted probability of accident (without consequences, confidence level usually equal or higher than 0.95) or accident risk level (including consequences).

The methods of the ship's movement path determination are based on position and heading information recorded during passages of the ships [1], [2], [3], [4], [5], [6], [7]. But usually these methods do not take into account accuracy of the above stated parameters which in reality can be more or less compromised by factors resulting from human assessment abilities and navigation systems capabilities. So the degree of conformance between the estimated or measured parameter of a craft at a given time and its true parameter at that time can be lower during real manoeuvres than in simulation studies if the allowance for real measurements' biases has not been made. Ultimately this leads to biased or wrong position of ship's hull outline in reference to the accessible water region. In this paper the comparison of manoeuvring area dimensions obtained by varying accuracy measurements and obtained by a method incorporating the idea of probabilistic GNSS ship's waterplane [10] will be presented.

ALGORITHMS OF RECKONING THE HORIZONTAL DIMENSIONS OF SHIP MANOEUVRING AREA

The algorithms for statistical reckoning of the manoeuvring area dimensions were thoroughly described in [2], [5], [7]. All of them are based on the idea of ships' movement path analysis as presented in the figures: fig. 2 and fig. 3. Analytical geometry procedures are used to calculate the most significant outer points of the assumed ship's waterplanes on the basis of synchronically recorded positions of the specified ship's point and its true heading (Ψ).

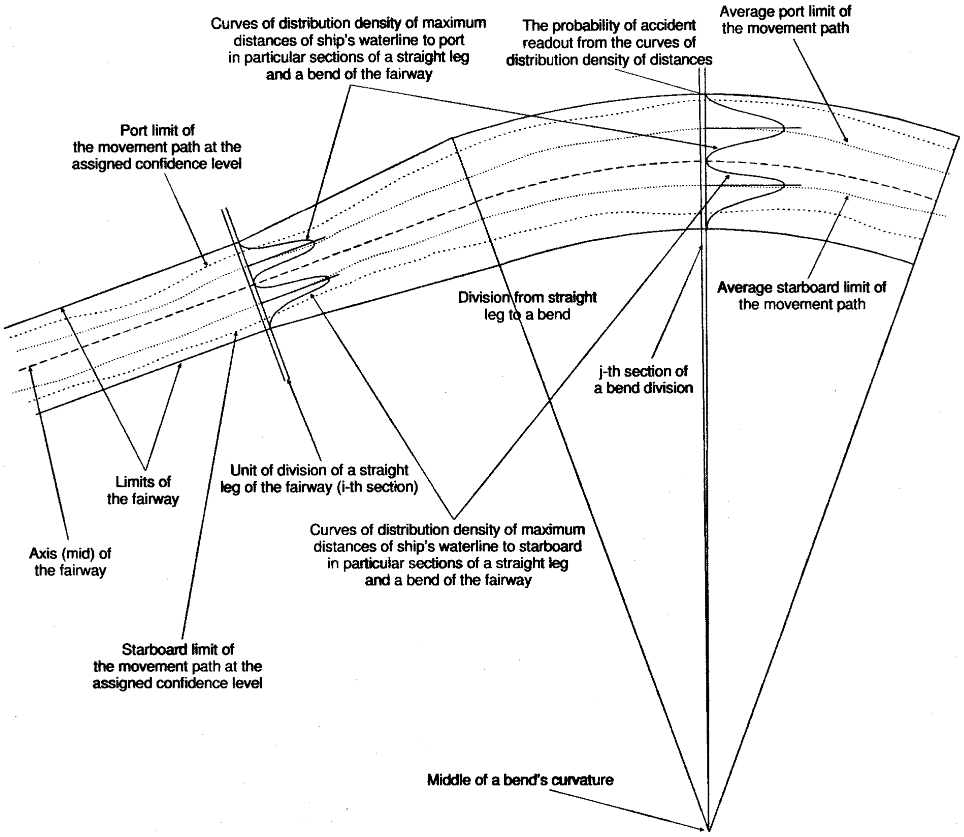

Fig. 2. Random variables of maximum port and starboard distances from the fairway axis and designation of the components of ship's motion path

Because all recorded and resultant variables describing ship's movement paths are therefore discrete (not continuous) by their nature so the studied harbour area has to be divided into the sections for statistics' categorization purposes (these sections should the best be perpendicular to the accepted fairway axis — mid of the fairway [7]). Then the width of the manoeuvring area in particular sections can be described by the sum of distances of extreme ship's waterplane outline points to the left and right of the reference fairway axis. Statistically, at the specified confidence level, it can be defined by the following formula:

$$d_{WS(C)} = (d_{slav} + k\sigma_{sl}) + (d_{srav} + k\sigma_{sr}), \tag{2}$$

where: $d_{ws(c)}$ — width of the manoeuvring area at c confidence level in reference to the s-section point of the fairway axis;

d_{slav}, d_{srav} — average distances of extreme ship's waterplane outline points to the left and right of the reference axis;

k — coefficient dependent on accepted confidence level and d_{sl}, d_{sr} variables' distribution (eg. $k \approx 2$ for normal distribution at confidence level 0.95);

σ_{sl}, σ_{sr} — standard deviations of distances to the left and right of the reference axis.

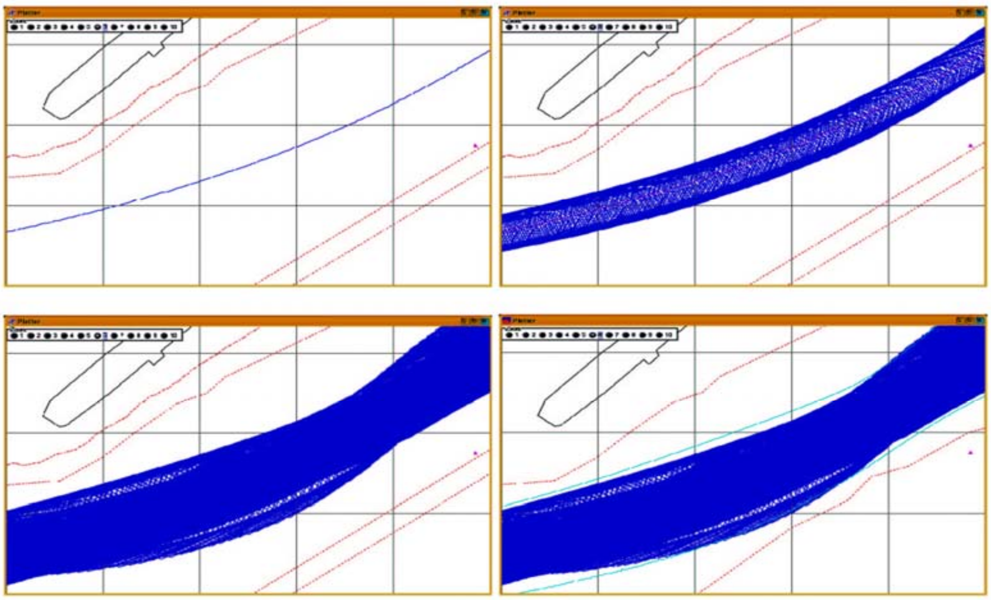

Fig. 3. Graphical presentation of ships' movement path analysis leading to safe manoeuvring area marked by light solid line at the last picture

As it was mentioned earlier in the introduction, the above presented algorithms do no take into account accuracy of the underlying positions of ships' assumed waterline contours. The navigators conducting simulation passages can lead their ships according to perfect ship's contour positioning and motion parameters — usually supported by the dedicated bird's eye view ENC or PNS presentation. In real navigation this means that the navigators' confidence to the established safe manoeuvring area must be limited if high accuracy and reliability measurement techniques — such as GPS RTK for instance — are not available. According to the minimum maritime user requirements for general navigation set for World Wide Radio-Navigation System in IMO Resolution A.915(22) [11] such techniques may be soon common in port areas, but they are quite expensive and not compulsory nowadays.

Taking the above into consideration the simulation method of determining of ship's manoeuvring area should incorporate means for degrading the position and heading accuracy. This can be done by ways described in [9] or preferably by incorporating the idea of probabilistic maximum waterline DGPS contour presented in [11]. The probabilistic dimensions of the waterline contour can be determined by transforming each DGPS waterplane relative to the assumed reference point on the basis of the values of random variables: distances between the reference point to the extreme points of waterplanes identified by the differential method (DGPS IALA or EGNOS position with DGPS compass or gyro heading) in the 360° range, taking the DGPS antenna position and heading simultaneously identified by RTK method as the reference (reference with negligibly small measurement error < 5 cm, < 0.1° — fig. 4).

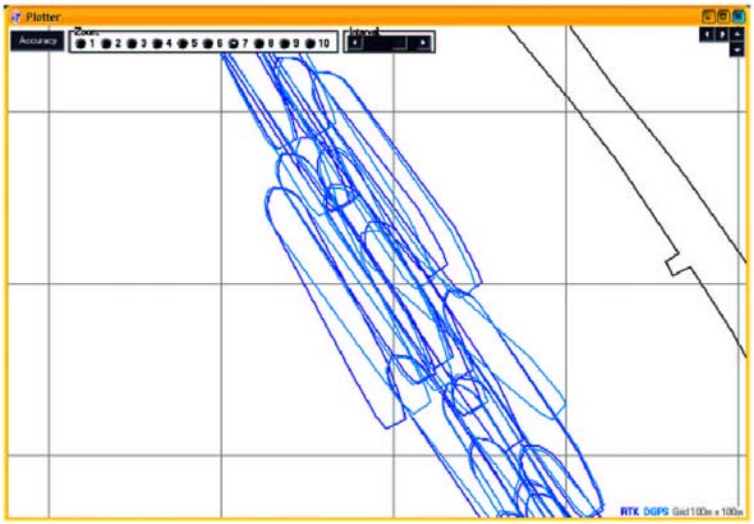

Fig. 4. Ship's waterline contours during several passages simultaneously recorded from DGPS and RTK position/compass receivers (darker colour — RTK equivalent)

So, similarly to ship's path width determination, one has to transform the recorded data to one joint reference point and then classify them in conformity with the adopted sector width (α_p at fig. 5).

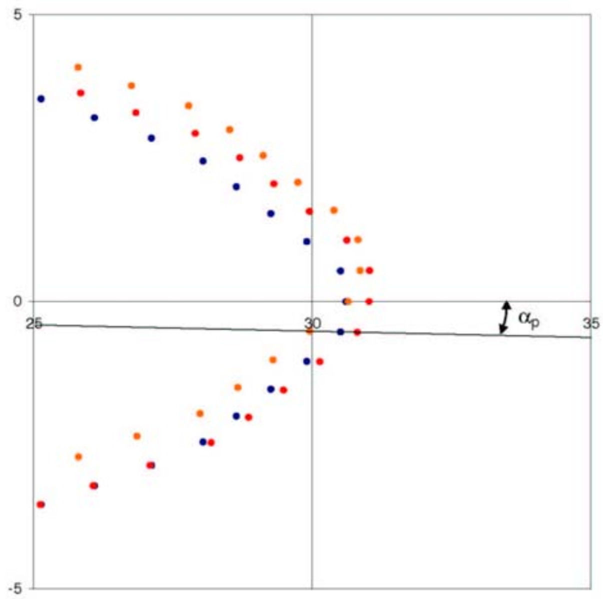

Fig. 5. Statistical samples of the waterline contours' extreme points at αp intervals

The above process finally leads to statistically calculated probabilistic shape of ship's waterline contour formed by discrete points at, say, 1° angular intervals (fig. 6 and fig. 7).

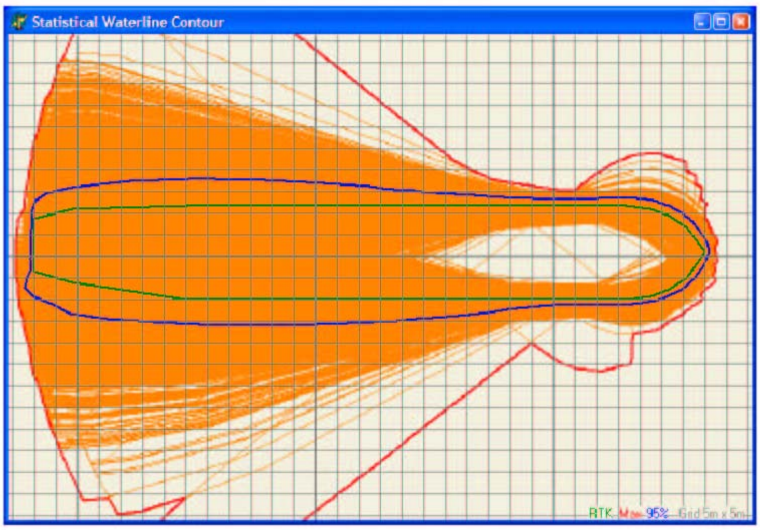

Fig. 6. Graphical presentation of the process of reckoning probabilistic waterplane's dimensions (headings from two simultaneously recording receivers [8])

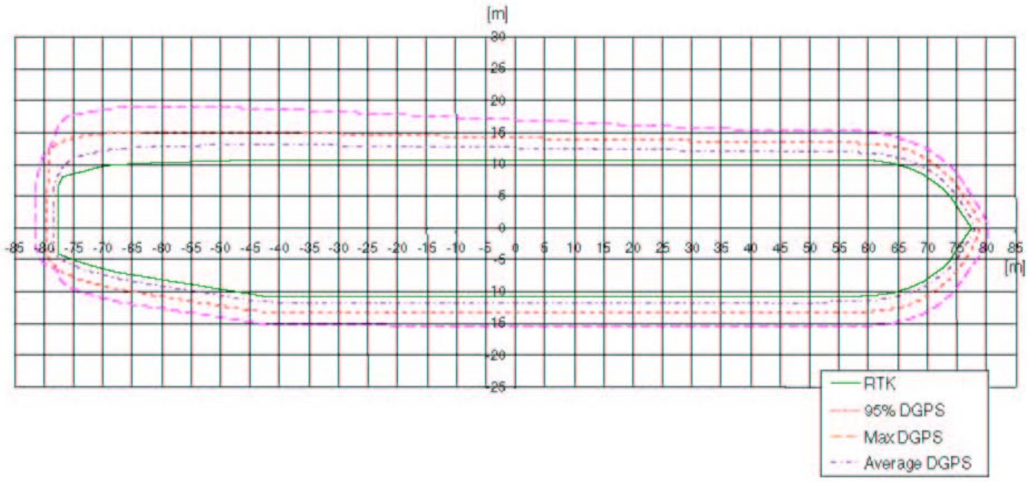

Fig. 7. The probabilistic maximum contour of the m/f Jan Śniadecki hull obtained by DGPS EGNOS measurements (headings from DGPS compass) in Świnoujście harbour

After implementing this new — allowing for measurement biases — ship's waterline contour to the algorithm for statistical reckoning of the manoeuvring area dimensions we will get the resultant area with additional safety margin for positioning errors.

COMPARISON OF MANOEUVRING AREA'S DIMENSIONS RECKONED WITH AND WITHOUT ALLOWANCE FOR MEASUREMENTS' BIASES

The experiment performed in Swinoujscie harbour onboard m/f Jan Śniadecki (data recorded from two synchronically working RTK receivers and DGPS PNS) led to the comparison of manoeuvring area's dimensions reckoned with and without allowance for measurement biases (fig. 8). The research area has been established near the East breakwater head as to cover the straight and turning ship's motion during exiting and entering the harbour. 22 ships passages of ship exiting and entering the harbour has been evaluated for manoeuvring area and ship's probabilistic water-plane determination.

The manoeuvring area dimensions presented at fig. 8 can be interpreted as follows:

— 95% RTK is equivalent to simulation obtained area with no real measurement errors prediction;

— 95% DGPS is equivalent to real measurements' area with errors intrinsically included in consecutive ships' waterplanes positions;
— 95% RTK with DGPS errors is equivalent to simulation obtained area with prediction of real measurement errors — in this case DGPS errors included in probabilistic waterplane.

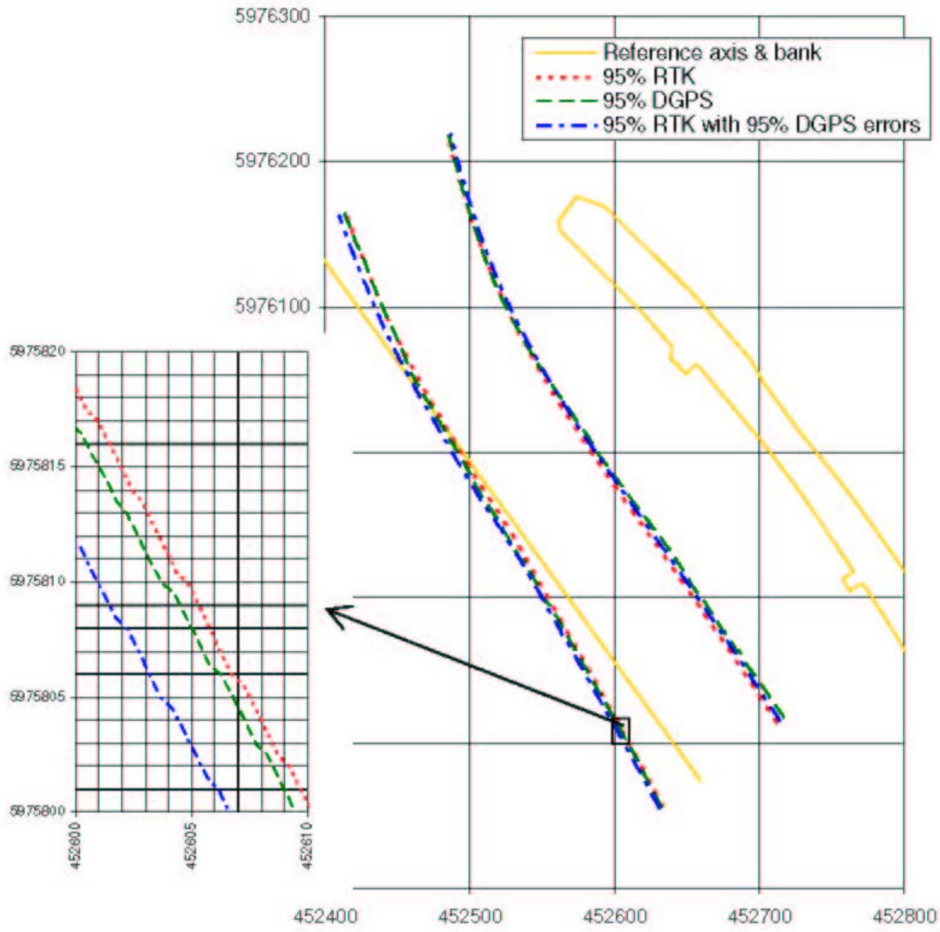

Fig. 8. Manoeuvring area dimensions obtained by means of: RTK (negligible errors), DGPS, and RTK with DGPS probabilistic waterplane incorporated

The resultant manoeuvring area dimensions, presented as maximum ship's path widths for straight leg and bend of the fairway, are shown at table 1.

Table 1. Comparison of ship's path width obtained by means of: RTK (negligible errors), DGPS, and RTK with DGPS probabilistic waterplane incorporated

Max. ship's path width at 95% conf. level [m]	Straight leg	Bend	Difference relative to RTK [%]
RTK	97.84	115.85	
DGPS	104.44	117.05	6.75–1.04
RTK with DGPS errors	105.01	122.53	7.33–5.77

The conclusion is that maximum difference between safe manoeuvring areas obtained from studies without allowance for measurement biases and studies with such allowance can reach approximately 7% in Świnoujście harbour area for the DGPS system used. table 1 and fig. 8 shows similarities between real DGPS data measurements and errorless measurements (RTK were regarded as such) degraded by probabilistic shape of DGPS waterplane. The maximum ship's path width reckoned from these two measurement methods differs less than 0.6% for straight motion leg of the fairway and less than 4.8% for bend of the fairway. The much wider area reckoned with probabilistic waterplane at the bend is caused by the differences between samples of random variables used from real DGPS measurements for ship's path determination and probabilistic shape of waterplane determination. The data used for probabilistic waterplane determination was much larger in quantity (several thousand recorded waterplanes' positions from 22 ship passages) and gathered from the whole researched area without discrimination to sections of manoeuvring area width reckoning, which gave the extra safety margin. Any offsets of DGPS measured area are covered by RTK measured area with DGPS probabilistic waterplane incorporated.

CONCLUSIONS

The experiment performed has proved the necessity of real measurements' biases allowance in simulation studies leading to determination of safety manoeuvring areas. There are statistically significant differences in the manoeuvring area dimensions obtained by almost perfect accuracy measurements and measurements from common navigation devices. That's why the method incorporating the idea of probabilistic ship's waterline contour is suggested to take precedence in the process of manoeuvring area determination. This method always requires preliminary research of the navigation system used or recommended in the studied area, but the resultant safety measures are more reliable.

In the carried experiment the approx. 7% difference in safety criterion was noted between errorless measurement (RTK) method and error inclusive measurement (DGPS) method. The same difference has been obtained between errorless method and method based on errorless measurements but with probabilistic waterplane incorporated.

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Received September 2006
Reviewed October 2007