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THE DETERMINATION OF INLAND VESSEL'S MANEUVERING AREA USING GPS

Abstract

The article discusses issues relating to the determination of a maneuvering area of an inland vessel. The author presents the methodology for defining the vessel's swept path width through simulation and field studies. The Global Positioning System has been characterized in view of possible use of GPS RTK to determine a safe maneuvering area of a ship sailing on inland waterway. The author also explains the procedure of measurements using GPS RTK and discusses problems that may be encountered during tests.

INTRODUCTION

The determination of inland vessel's manoeuvring area involves the determination of its positions in a water area during a manoeuvre. The vessel's position may be obtained by performing measurements using many different methods, e.g. radar, photogrammetric or GPS. The chosen measurement method used during field tests must provide position accuracy level of 0.95 (which represents from 1 to 3% of vessel's length). The operation of a selected device should be independent of the prevailing external conditions (including hydro-meteorological conditions) and should provide for maximum mobility of the device. Position accuracy also depends on the frequency of position determination [3].

1. DETERMINATION OF THE MANOEUVRING AREA OF AN INLAND VESSEL

The inland vessel can maneuver in a water area whose depth (H_A) and width (B_A) are sufficient to perform a given maneuver [8]. Parameters of the maneuvering area are variable and depend on the parameters of the moving vessel, type of maneuver performed and its duration, as well as the prevailing meteorological conditions. To determine the maneuvering area we use simulation methods (probabilistic model), analytical methods (deterministic model) as well as methods real time methods [5].

The methodology of determining safe maneuvering area by means of simulation methods consists in recording successive positions of a maneuvering vessel (its characteristic extreme points). Properly done simulation tests require several series of vessel passages to be performed. Test scenarios must take into account the vessel type and prevailing hydrometeorological conditions. Based on a series of passages the width of the swept path is defined. Maximum widths that the vessel occupied make up the outer limits of the maneuvering area.

To determine the distance from the fairway centre to the maneuvering area limit we use the following formulas:

$$d_l(y) = \frac{1}{\sigma_l\sqrt{2\pi}} e^{-\frac{(y-m_l)^2}{2\sigma_l^2}} \quad (1)$$

$$d_p(y) = \frac{1}{\sigma_p\sqrt{2\pi}} e^{-\frac{(y-m_p)^2}{2\sigma_p^2}} \quad (2)$$

Where:

- $d_l(y)$ – distance from the fairway centre to the left-hand limit of the manoeuvring area;
- $d_p(y)$ – distance from the fairway centre to the right-hand limit of the manoeuvring area;
- m_l – average distance from the fairway centre to the left-hand limit of the manoeuvring area;
- σ_l – standard deviation of the distance from the fairway centre to the left-hand limit of the manoeuvring area;
- m_p – average distance from the fairway centre to the right-hand limit of the manoeuvring area;
- σ_p – standard deviation of the distance from the fairway centre to the right-hand limit of the manoeuvring area;

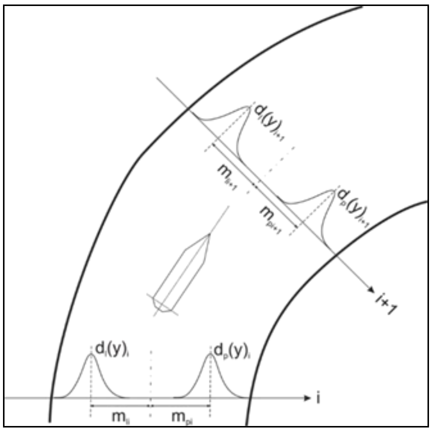

***Fig. 1** Distributions of distances of extreme points of ship's manoeuvring area on a waterway.* [5].

Analytical methods allow specifying the width of vessel's swept path based on known vessel's operating parameters, the parameters of the waterway (depth), hydro-meteorological conditions and aids to navigation. For such calculations vessel's position is not required.

Real time field methods consist in measuring the movement of an inland vessel (registration of its positions) and the determination of the swept path width occupied by the vessel during a passage. The methodology for determining the swepth path width is the same as in the case of simulation methods. The only difference is that instead of data from simulated passages we use data from actual passages of the vessel. Real time methods give an accurate image of vessel's movements. The accuracy of calculations depends largely on the accuracy of the recorded position. GPS RTK is a widely used system of position determination.

2. GLOBAL POSITIONING SYSTEM (GPS) AS A TOOL FOR DETERMINING VESSEL'S POSITION.

The Global Positioning System is made up of three segments: space, control and user. The space segment is composed of satellites orbiting the Earth at a distance of 20,000 kilometers. The control segment consists of a master station and monitoring stations. The tasks of land-based stations, among others, are to monitor the operation of satellites, control the trajectory of their movement and synchronize the clock. The user segment consists of all kinds of GPS receivers.

The GPS system allows determining the location of a receiver installed on a vessel using earth-orbiting satellites. The determination of the three-dimensional position is possible if the receiver is within the coverage of four satellites. The distance to the satellites is determined based on the knowledge of the time difference between the signal transmission and reception. Calculations of pseudo ranges and the time deviation (the difference between the quartz standard installed in the receiver and the atomic clock) is sufficient to determine position coordinates. [10]

The accuracy of the Global Positioning System (accuracy of position determined by GPS) is about 10 m. This value is affected by receiver parameters and its siting, the constellation of satellites during the measurements, tropospheric refraction, tropospheric attenuation and signal jamming. In order to achieve the best accuracy differential corrections are used, e.g. RTK, DGPS, SBAS.

Real Time Kinematic (RTK) differential corrections guarantee less than a meter accuracy of a specific position. A position can be determined in the RTK mode using one of three methods [10]:

- One reference station: a method used when working with a mobile receiver, determining the position based on the reception of signals from the antenna (GPS antenna and modem).
- Many reference stations: antennas of receivers that use different GPS frequencies to transmit signals, mounted in two different places with known coordinates. The resultant position is an averaged position.
- A network of reference stations - a method that requires the use of at least three GPS receivers. There are two known methods to take into account the data from the reference network FKP (Flächen Korrectur Parameter) and VRS (Virtual Reference Station).

The accuracy of GPS RTK is so satisfactory that it can be used to determine the manoeuvring area of an inland vessel.

3. THEORETICAL BASIS OF USING GPS TO DETERMINE THE MANOEUVRING AREA OF AN INLAND VESSEL

The use of GPS to determine a safe manoeuvring area of a vessel is one of the research methods in real conditions. Such studies can be of passive and active nature. In passive studies there is no interference in the processes taking place in the studied system. That means a system and related processes are observed and analyzed. In case of active studies the processes taking place in the system are planned to suit the needs of the studies [2].

There are three possibilities for performing measurements using GPS receivers.

1. The measuring system consists of one receiver, where, additionally, vessel heading is recorded.
2. The measuring system composed of two receivers spaced along or across the centre line of the vessel. This allows determining the position relative to three degrees of freedom, as well as the size and changes in the vessel's trim and motions.
3. The measuring system consisting of three receivers. It enables determining the position in relation to all six degrees of freedom.

For the study, the most convenient on board site for the measuring system is near the wheelhouse. This location allows constant control of the inland vessel movement and a possibility of direct monitoring of measurements. In terms of measurement accuracy, the best measuring system is composed of receivers located both in the vicinity of the tug wheelhouse and the bow of the barge (if we consider the pusher tug-barge unit). Such arrangement of the receivers allows us to observe trim changes in the tug-barge unit. The choice of measurement system and its arrangement on the vessel depend on the purpose of the studies. When using GPS technologies for determining a safe manoeuvring area based on the vessel's position, a proper measuring system will consist of an RTK GPS receiver and separate recordings of the vessel's heading. Fig. 2a and Fig. 2b show the proposed site of installing the receiver on an inland vessel.

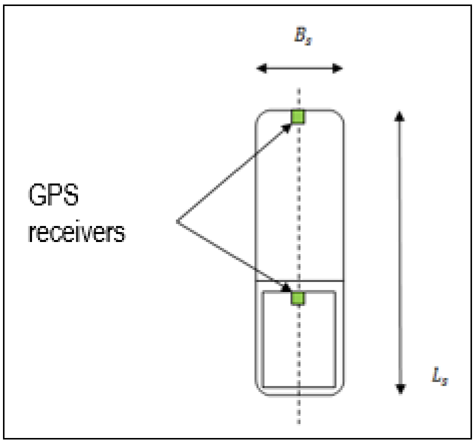

Fig. 2a *A measuring system consisting of two GPS receivers installed near the wheelhouse and on the bow of the barge.*
Source: author's own work.

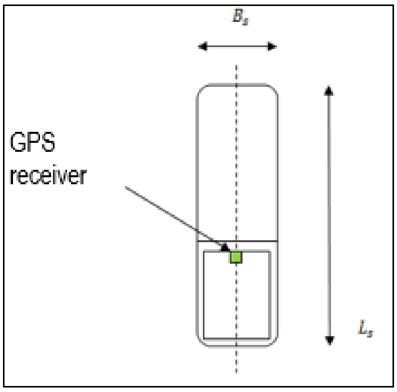

Fig. 2b *A measuring system consisting of one GPS receiver installed near the wheelhouse, with independent heading recordings.*
Source: author's own work.

To determine the manoeuvring area of an inland vessel by means of GPS RTK we should:

- install a GPS RTK receiver on the vessel;
- determine the distance of GPS RTK position from characteristic points (distance measurement);
- record the vessel's position and heading when negotiating the bend and on a rectilinear section;

- determine the position of the vessel's characteristic points utilizing the known position of the receiver on the vessel (including the distances to starboard and port sides);
- determine the vessel envelope based on the location of characteristic points;
- determine the width of the swept path during the manoeuvre (position of the envelope of the vessel when passing the waterway);
- divide the examined part of fairway into sections;
- determine the level of confidence (for manoeuvring area - 0.95);
- determine the manoeuvring area at a specified confidence level.

Prevailing hydrometeorological conditions and water level are two important factors of the tests. Depending on the prevailing conditions and the level of water, the manner of manoeuvring will change. This can affect the width of the path swept by the vessel during the successive series of passages [6]. Fig. 3 shows the position of the GPS RTK receiver on an inland vessel and the distribution of the proposed characteristic points.

Characteristic points specified on the vessel (while the position from GPS RTK is known) are to help determine the envelope of a manoeuvring vessel. Fig. 3 shows the proposed locations of characteristic points. Depending on the purpose of the research, their location can be arbitrary. When selecting the characteristic points one should remember to choose points where the distance from the receiver can be easily and correctly determined. The correctness of the characteristic point positions affects the accuracy of the determined vessel envelope. It is advisable to assume the characteristic points to be the extreme points on vessel's sides and the extreme points on the bow and stern of the vessel. To correctly define the envelope of the vessel we should assume that the GPS RTK receiver's position is the origin of the coordinate system fixed to the vessel.

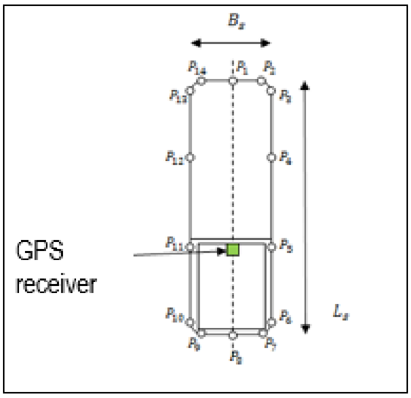

Fig. 3 *The position of a GPS RTK receiver on an inland vessel and positions of the proposed characteristic points.*
Source: author's own work.

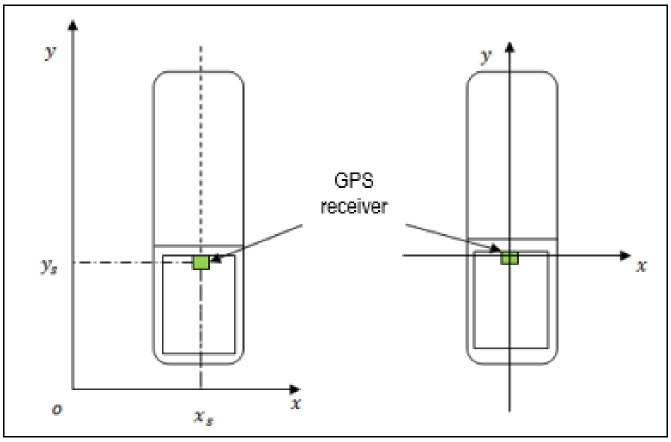

Fig. 4 *The transformation of a coordinate system to the position of GPS RTK receiver on the vessel*
Source: own study.

4. PRELIMINARY REAL TIME STUDIES DETERMINING THE MANOEUVERING AREA OF AN INLAND VESSEL

Preliminary field studies were carried out on a section of the central Odra River between its 514.0 km (Krosno) and 429.8 km. (Nowa Sól). It is a free-flowing stretch of the Odra, whose width at the bottom ranges from 44 m to 58 m, while its width on the surface varies from 63.5 m to 98.4 m. In this section the Odra is regulated by under-current stone-fascine groynes, whose condition is rather poor. The groynes play a regulatory function by affecting the flow of water in the river and its transit depths. The central section of the free-flowing Odra contains a total of 5250 groynes. Apart from the groynes, the river banks are protected by fascine bands and other regulatory structures. Most of the groynes along the navigable waterway are overgrown. Their state is presented in Fig. 4.

Fig. 4. *A groyne on the central Odra River, at 440 km.*
Source: own study.

Insufficient water levels create a problem for navigation on the Odra River. Insufficient depths disturb smooth cargo transport, and carriers are at times forced to wait for higher water with the vessel aground, at anchor or at berth. Table 1 presents indications of water level gauges at the central section of the Odra recorded on 3 August 2016.

Table 1 shows the current level of water on the day of field tests. The water level gauge Krosno Odrzańskie indicated the current water level of 78 cm. On 3 August 2016 an inland ship left Krosno Odrzańskie with a draft 0.68 m (unladen). Despite a low underkeel clearance the navigation along the waterway was possi

Tab. 1 Indications of water level gauges at the examined section of the Odra River on 3 August 2016, at 0600 UTC.

Water level gauge	Km of waterway	Current level of water [cm]	Alarm level [cm]	High navigable water [cm]
Nowa Sól	429.8	143	400	450/480
Cigacice	470.7	147	400	440/470
Nietków	490.5	166	400	-
Krosno	514.1	78	350	390/420

Source: [8].

Tab. 2 Indications of water level gauges at the examined section of the Odra River on 4 August 2016, at 0600 UTC.

Water level gauge	Km of waterway	Current level of water [cm]	Alarm level [cm]	High navigable water [cm]
Nowa Sól	429.8	209	400	450/480
Cigacice	470.7	152	400	440/470
Nietków	490.5	161	400	-
Krosno	514.1	67	350	390/420

Source: [8].

ble. A rocky bottom was dangerous, however, as it could damage the barge's hull. The vessel sailed slowly at a speed of 2 to 3 knots. Table 2 presents indications of water level gauges at the central section of the Odra recorded on 4 August 2016.

The tested vessel was a pusher tug proceeding without cargo. The vessel was equipped with a mobile floating thruster, having the dimensions: length - 4 m., breadth 9 m., draft - 2.5 m. The thruster was powered by a 300 HP engine. This device facilitates manoeuvring of the vessel, especially during the transport of oversize cargo. Table 3 shows the parameters of the pusher tug on which the field tests were performed.

Tab. 3. Parameters of the vessel that was unit used for field tests.

Pusher tug parameters	Value
Length (without thruster)	29.60 m
Breadth	7.30 cm
Maximum draft	1.0 m
Airdraft	3.94 m
Displacement	124 m^3

Source: [7]

Preliminary field tests involved the vessel position recording using a receiver S82-T SOUTH GPS for RTK GNSS for measurements. The test setup was placed at the stern of the vessel, on its centre line. The receiver was located at a height of 2.40 m., providing good signal quality. The main features of this type of receiver are as follows [9]:

– Robust and handy housing made of of polycarbonate and ABS materials;
– **Control panel with two** function keys and six bright LEDs to inspect the status and mode of the device;
– **Module GNSS - BD970**. Enhanced MAXWELL 6 technology from PacificCrest;
– **Antenna working on two frequencies,** eliminating the effect of multipath signal and increasing the quality of satellite tracking;
– **Integrated dual-channel Bluetooth; s**imultaneous wireless connection with the controller and a mobile phone;
– **Integrated transmission package; a**dvanced data transfer with built-in modems: radio (receiver) and GPRS / CDMA; freely configurable communication - radio or GSM;
– **5-pin communication port;** LEMO socket for connection to an external radio modem and the external power supply;
– **Serial RS-232 port** ensuring connection to a computer in order to import data from static measurements and to the field controller;
– *Lithium-ion battery with a capacity of 2500 mAh providing up to 8 hours of continuous operation.*
– ***SIM card slot** providing a direct connection to mobile networks to download corrections from a network of reference stations;*
– ***Software used for testing: Carlson SurvCE**;*
– *The measurement of differential GNSS code: H: 25 cm + 1 ppm RMS, Vertical: 50 cm + 1 ppm RMS. Thye accuracy of SBAS differential measurement is typically <5m 3D RMS.*

The recorded positions have been mapped using the ArcGis program. The results are presented in Fig. 5

***Fig. 5** The position of the GPS RTK receiver placed on the inland vessel when negotiating a bend in the central part of the Odra. Source: [own study using ArcGis].*

At a later stage, the positions of the characteristic points and the envelope of the vessel will be determined on the basis of the positions of the GPS RTK receiver. Widths of the vessel's swept path during the manoeuvre will be determined (positions of the vessel envelope when proceeding along the waterway) and the vessel's manoeuvring area will be defined at 95% confidence level.

SUMMARY

The performance of real time tests on inland waterways faces many limitations. Proper measurements should be executed on the same section of the river in the same hydrometeorological conditions. These requirements are often difficult to meet, since inland shipping is largely irregular. Cargo carriage is performed as a single transport task: carriage from the starting point to a destination. In Poland, regular cargo transport voyages seem to be decreasing, which reduces opportunities for real time tests [1]. One of the many reasons for the lack of regular shipping (especially on the Odra

River) is low water level. The problem of determining the safe manoeuvring area in inland navigation mainly refers to water depths. Navigability of inland waterways depends on the water level. Too low water levels in rivers hamper cargo transport.

Another difficulty is the problem of determining a position using GPS, refers mainly to the visibility of satellites. Correct position determination requires that 4 or 5 satellites should be visible simultaneously, which may be prevented by terrain features along the river (forests, bridges). If a signal is lost, the position will not be defined. This means that the frequency of the determined position may be lower. The tests performed proved that interruptions in data recording were mainly due to absence of GSM coverage.

CONCLUSIONS

The article presents the concepts of real time field studies conducted with the use of GPS RTK. The analysis of research problems shows that the use of GPS RTK to determine safe manoeuvring area is justified. The device is characterized by appropriate parameters and accuracy that allows to carry out measurements. It has been shown that vessel's positions obtained using GPS RTK receiver can be utilized to create the envelope of the vessel on the basis of determined positions of the vessel's characteristic points. The presented problems and research methodology will be used in further field tests.

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WYZNACZANIE OBSZARU MANEWROWEGO JEDNOSTKI ŚRÓDLĄDOWEJ ZA POMOCĄ GPS

W artykule omówiona została problematyka określania obszaru manewrowego statku śródlądowego. Przedstawiono metodologię określania szerokości pasa ruchu jednostki za pomocą badań symulacyjnych oraz rzeczywistych. Scharakteryzowano Globalny System Pozycjonowania i zaprezentowano możliwość wykorzystania GPS RTK do określania bezpiecznego obszaru manewrowego statku w żegludze śródlądowej. Omówiono procedurę wykonywania pomiarów za pomocą GPS RTK oraz problemy jakie można napotkać podczas przeprowadzania badań.

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