RESEARCH ON NEW OBSTACLE AVOIDANCE ALGORITHMS FOR SHIPS

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Abstract. The contribution reports the progress of a research project for Young Academic Staff in FY2018. The project is dedicated to the development of a path planning module, constituting a part of an intelligent control system for ships - a Guidance, Navigation and Control (GNC) system. The paper describes the stages of the project, including already carried out research tasks and tasks planned to be performed. Preliminary simulation and real experiments results are presented in the paper. The outcome of the research will contribute to the development of new solutions for safer and more efficient shipping.

1 INTRODUCTION

Ensuring the safety of ship navigation is one of the fundamental issues in marine transport. Technological development enables application of systems aimed at ship's collision avoidance. Recent trends include decision support, remote control of a ship and finally autonomous navigation. The objective of new collision avoidance solutions development is the achievement of more efficient, safer and greener shipping. The aim of a research presented in this paper is the development of new, original, effective algorithms for the determination of a safe, optimal path for a ship in a collision situation at sea. The algorithms will be tested by carrying out simulation and experimental studies. Ship's trajectory planning methods have been recently revised in [1,2,3]. The aim of the carried out research is to develop a method for ship's trajectory planning, characterized by low run time, repeatability of solution, consideration of both static and dynamic obstacles and the International Regulations for Preventing Collisions at Sea (COLREGs), and therefore applicable in a commercial Decision Support System.

2 INTELLIGENT SHIP CONTROL SYSTEM

Modern ship control systems have a structure show in Fig. 1. They are known as Guidance, Navigation and Control (GNC) systems [4]. The GNC system is composed of three main subsystems: the Guidance System, responsible for path planning, the Control System, responsible for motion control and the Navigation System, responsible for measurement of motion parameters (ship's position, course and speed). The basic component of the path planning module (the Guidance System) is called the Trajectory Generator (TG). An

advanced optimization algorithm, constituting the core of the TG, calculates a safe, optimal path for a ship.
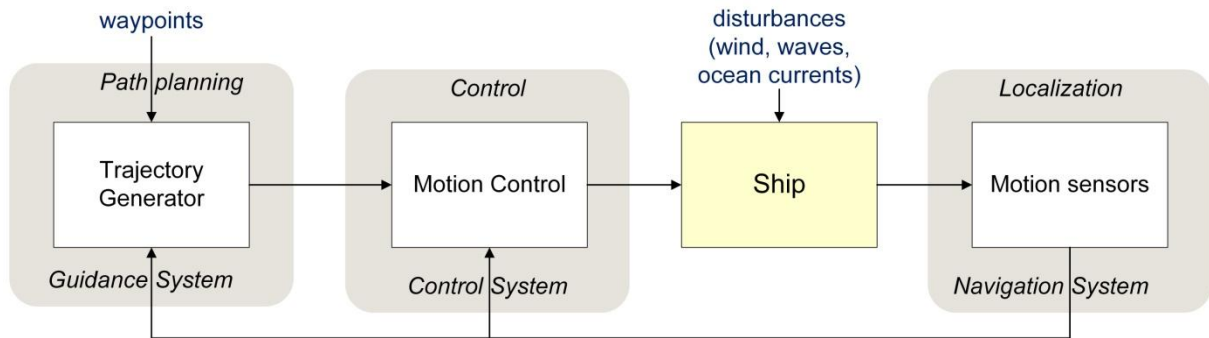

Figure 1: Guidance, Navigation and Control system

3 SHIP TRAJECTORY CALCULATION

Ship collision avoidance is a complex optimization problem with various restrictions and requirements to be considered. The ship's trajectory planning algorithm has to fulfil the following assumptions:

- availability of navigational data describing the current situation at sea;
- the International Regulations for Preventing Collisions at Sea (COLREGs) compliance of the calculated trajectory [5];
- static (lands, shallows) and dynamic (target ships - TSs) obstacles taken into account;
- safe distance (D_S) taken into account;
- trajectory calculated between the current own ship (OS) position and the defined final waypoint of the trajectory;
- dynamic properties of the OS considered;
- TSs maintain their motion parameters;
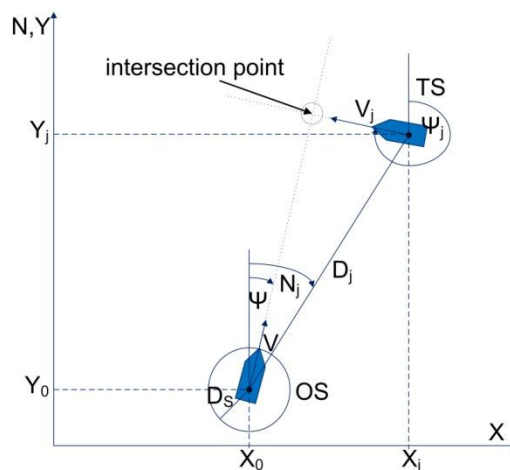- weather conditions (visibility) taken into account.

Figure 2: Description of navigational situation

Navigational data needed for the algorithm include an OS course (Ψ) and speed (V), TSs courses (Ψ_j), speeds (V_j), bearings (N_j) and distances from an OS (D_j), information concerning position of static constraints (lands, islands, buoys, fairways, canals, shallows) and visibility/weather conditions. The navigational data describing actual situation at sea are marked in Fig. 2. These data are registered from navigational equipment such as a radar with an Automatic Radar Plotting Aid (ARPA), an Automatic Identification System (AIS), an Electronic Chart Display and Information System (ECDIS), a gyrocompass, a speed log, an echo sounder, a Global Positioning System (GPS) or a Differential Global Positioning System (DGPS), wind speed and direction sensors.

The COLREGs compliance means determining adequately large course alteration manoeuvres (rule 8b) and a manoeuvre on the relevant side of the ship (rules 14, 15). A safe distance is assured by the application of a ship domain around TSs. Weather conditions such as visibility (poor or good) are taken into account by an application of a proper size of the TSs domain. It is assumed that the TSs maintain their course and speed. The solution is recalculated if changes in motion parameters of TSs and/or new TSs are detected.

4   OBSTACLE AVOIDANCE ALGORITHMS

The project has been divided into several stages as shown in Fig. 3.
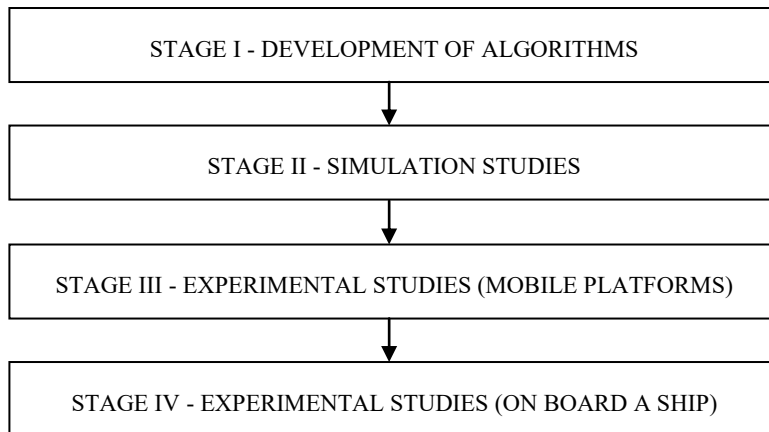
Figure 3: Stages of the project

Two different algorithms, one deterministic and one heuristic, have already been developed for application to ship's trajectory calculation problem.

The Trajectory Base Algorithm (TBA) is a deterministic method using a simple concept of searching a predefined set of trajectories in order to find the shortest safe trajectory for the considered situation. A detailed description of the approach is presented in [6]. The method is very fast and effective for simpler scenarios. The computational time might increase for complicated situations.

$$P_{wp_{ij}}^{ant}(t) = \frac{\left[\tau_{wp_j}(t)\right]^{\alpha} \cdot \left[\eta_{wp_{ij}}\right]^{\beta}}{\sum_{l \in wp_i^{ant}}\left[\tau_{wp_l}(t)\right]^{\alpha} \cdot \left[\eta_{wp_{il}}\right]^{\beta}} \tag{1}$$

A different algorithm for ship's safe trajectory calculation is based upon a heuristic method called the Ant Colony Optimization (ACO) [7]. The method was inspired by an observation of an ant colony foraging behaviour. It was discovered that ants, when searching for food, use a special mechanism to find the shortest path between the food source and their nest. This mechanism constituted an inspiration for the development of the Ant Colony Optimization. This algorithm is applied to solve the ship's safe trajectory calculation problem and is particularly suitable for complex navigational situations. In this approach an artificial ant chooses the next OS position (the vertex on the graph) with the use of Equation (1), expressing the probability of choosing the next vertex. The choice of the next vertex depends on the value of the pheromone trail ($\tau_{wpj}(t)$) on the neighboring vertex and the heuristic information called visibility (η_{wpij}). The heuristic information is the inverse of the distance between the current vertex (i) and the neighboring vertex (j). A detailed explanation of the algorithm is given in [8].

5   SIMULATION STUDIES

The simulation studies will be carried out with the use of the MATLAB environment. Simulation studies will include both simple (1-3 TSs) and more complex (up to 10 TSs) navigational situations and situation with both static and dynamic obstacles in the environment. Exemplary results for an encounter situation with eight target ships are presented in Fig. 4. The same OS trajectory was received for both algorithms - ACO and TBA, but the run time of the algorithms was different. The run time of ACO, for calculations conducted with the use of a PC with an Intel Core 2 Duo E7500 2.93 GHz processor, 4GB RAM, 64-bit Windows 7 Professional, reached about 20 - 30 seconds, while for TBA it was 2 seconds.

Input data to the algorithm for this situation are listed in Table 1.
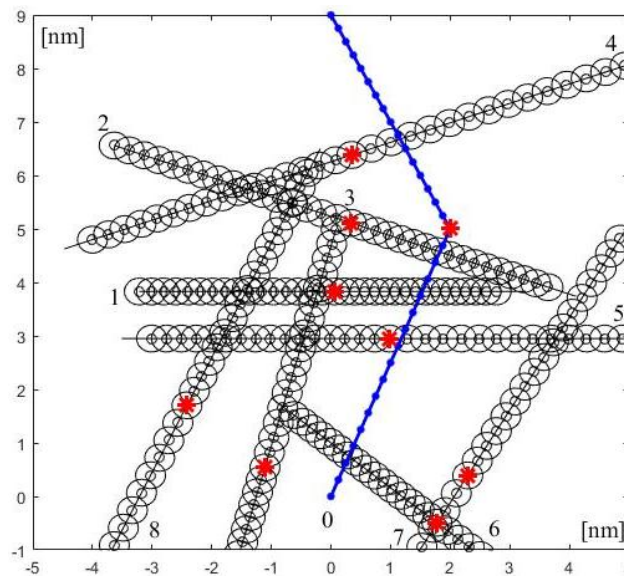
Figure 4: Encounter situation with eight target ships solved by the TBA and ACO algorithms (OS trajectory marked by blue line), OS course: 22º, 333º (red stars mark the positions of all ships at the moment, when an OS is changing its course)

**Table 1**: Data describing an exemplary navigational situation

Ship	Course [°]	Speed [kn]	Distance [nm]	Bearing [°]
0	0	14	-	-
1	90	8.5	5	320
2	110	11	7.5	331
3	195	12	5	1
4	250	14.5	10	34
5	270	12.5	6.5	63
6	310	9.8	5.5	122
7	30	16	5	189
8	25	15	6	234

6   EXPERIMENTAL STUDIES

Experimental studies will include two stages. At stage III of the project the developed ship's path planning algorithms will be tested with the use of a system composed of a group of mobile platforms and an Indoor Positioning System (IPS) for localization of the moving objects.

The IPS from Pozyx labs [9] is composed of tags placed on mobile platforms, providing information about their position and direction of movement, and four nodes (anchors) with known positions. The tag contains an ultra-wideband transceiver and an inertial measurement unit DWM1000 from DecaWave for measuring the orientation of an object, including accelerometers, gyroscopes and magnetometers.

The mobile platforms DFRobot Pirate-4WD [10] with the dimensions of 200 x 170 x 105 mm (length x width x height) and a speed of up to 0.9 m/s, equipped with 4 DC motors and characterized by differential-drive steering will be used in experiments. The results of experimental studies for situation with one dynamic obstacle in the environment are shown in Fig. 5. The mobile platform is marked as 0x6973, an obstacle is marked as 0x6e42. Objects marked by 0x697b, 0x6924, 0x6929 and 0x6909 are the anchors of the IPS.
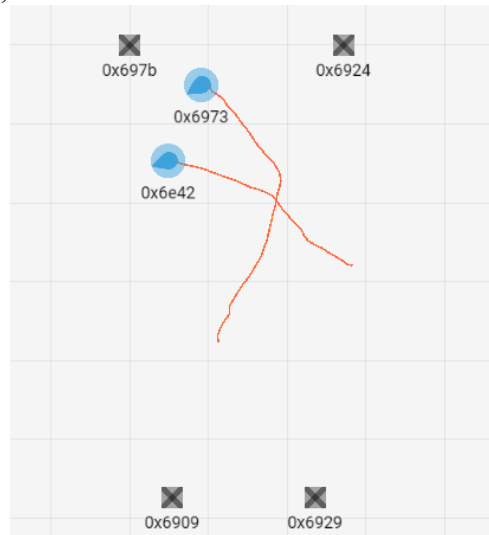
Figure 5: Results of experimental studies for an encounter situation with one dynamic obstacle registered with the use of an Indoor Positioning System

At stage IV of the project the problem solving capability of the developed solution will be proven by its implementation in the GNC system and performed tests on board the Research/Training ship M/V Horyzont II under operating conditions.

Horyzont II is a Research/Training ship owned by Gdynia Maritime University. It performs a research function, a training function for students and a transport function for Polish Academy of Sciences – transporting equipment to the Polish scientific bases on Spitsbergen. Table 2 shows the main technical parameters of the vessel.

Figure 6: Research/Training ship M/V Horyzont II

Table 2: Technical specification of M/V Research/Training Ship Horyzont II

Length	56.34 m
Breadth	11.36 m
Designed draft	3.90 m (5.33 m together with the keel)
Deadweight	288 t
Gross Tonnage	1321 BRT
Speed	12 knots
Main engine power	1280 kW
Controllable Pitch Propeller CPP	CP 65 WARTSILA , D = 2.1 m
Bow thruster	STT 10 LK SCHOTTEL - power: 125 kW
Build year and place	2000, Gdańsk
IMO Number	9231925

Input data for the algorithm are transmitted from an ARPA with the use of the NMEA standard. It is a serial asynchronous data transmission protocol used for communication between marine electronic equipment and external devices. The standard defines the data frame structure: one start bit, eight data bits, no parity bit and one stop bit, and the transmission speed: 4800 bits per second. It also defines the transmitted sentences structures. The sentences needed for the algorithm are marked as OSD (Own Ship Data) and TTM (Tracked Target Message). The standard repetition time of OSD sentence is 1 second and of TTM sentence is 10 seconds. The sentence structures concerning Own Ship Data and Tracked Target Message are as follows:

$RAOSD,a.a,A,c.c,X,x.x,Y,y.y,z.z,N*hh<CR><LF>
RA - talker identifier: RA - radar
OSD - sentence formatter: OSD - own ship data
a.a - heading, degrees true
A - heading status: a - valid, V - invalid
c.c - vessel course, degrees true
X - course reference: W - water-referenced
x.x - vessel speed
Y - speed reference: W - water-referenced
y.y - vessel set, degrees true
z.z - vessel drift (speed)
N - speed units: N - knots

$RATTM,aa,b.b,c.c,T,t.t,x.x,T,y.y,z.z,X,n,Y,R,hhmmss. ss,M*hh<CR><LF>
RA - talker identifier: RA - radar
TTM - sentence formatter: TTM - tracked target message
aa - target number: 00 to 99
b.b - target distance from own ship
c.c - bearing from own ship
T - degrees true
t.t - target speed
x.x - target course
y.y - DCPA - distance at closest point of approach
z.z - TCPA - time to the closest point of approach [min]
X - speed, distance units
n - user data (e.g. target name)
Y - target status: L - lost, Q - query (target in the process of acquisition), T - tracking
R - reference target (used to determine own ship speed)
hhmmss.ss - time of data (UTC) M - type of acquisition: a - automatic, M - manual,
R - reported (eg.AIS)

The real navigational data describing the current situation at sea will be registered during the Horyzont II voyages. After that the algorithm will be tested whether it is capable of finding solutions for real navigational situations.

Figure 7: The interior of the bridge of the Research/Training ship M/V Horyzont II

7 CONCLUSIONS

The research presented in this paper deals with the problem of ship's safe trajectory calculation in a collision situation at sea. The paper presents the progress of a research project for Young Academic Staff in FY2018. The main goal of the presented research is the development of new path planning solutions for ships, which will contribute to achieve safer shipping and progress in autonomous navigation.

Preliminary research results lead to the following conclusions:
- the TBA and ACO algorithms are capable of finding a ship's safe trajectory in collision situations at sea with both static and dynamic obstacles;
- the run time of both algorithms does not exceed 1 minute, therefore the algorithms are suitable for use in commercial systems;
- the results of real experiments with navigational situations registered on board the ship will be used to further validate the presented methods.

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