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CONCEPT OF FTS MODEL OF SHIP MOTION BASED ON EXPERT SHIPHANDLING KNOWLEDGE

ABSTRACT

The paper presents a concept of FTS model of ship motion reflecting navigator's decision process while entering a Świnoujscie harbour on specific ship type at given hydrometeorological conditions. The conceptual model has been based on the fuzzy logic controller with expert database formed by manoeuvres obtained from the real-time non-autonomous trials classified in relation to expert manoeuvre impact on ship's advance, lateral and rotation speed and her position in reference to the present ship status.

Keywords: Expert System, Ship Motion, Fuzzy Logic Controller.

INTRODUCTION

The autonomous model of ship motion allows to cut down the costs of navigators' employment as well as to shorten the entire time of studies and operating time of computer systems by the application of fast time simulation (FTS). The FTS method is increasingly used in predictions of manoeuvring characteristics of designed vessels (examination of vessel dynamic parameters at the designing stage). Moreover, attempts are made at assessing navigational situations or determining dimensions of navigational areas. Simulation studies give perfect opportunity to record the expert knowledge of pilots commanding vessels in the relevant area. An essential problem of the acquisition and representation of navigator's knowledge referring the conduct rules (procedural knowledge) and the analysis and evaluation of navigational situation (declarative knowledge) can be solved by gaining knowledge directly from electronic records made during such research [1]. Creation of a decision support system based on such knowledge can lead to ship's safety improvement following safer manoeuvring in confined waters and finally to the concept of autonomous ship control during FTS.

EXPERT DATABASE

In order to acquire expert decisions most relevant for current ship's situation the expert passage most close in the aspect of registered state vector parameters has to be found. This way the risk of wrong decision should be minimised. So, the problem should be reduced to finding the minimum difference between current ship's state vector and ship's state vector recorded in the files of expert passages. During the discussed studies performed on an accurate hydrodynamic ship model [2] the logged ship's passage parameters (or facts in expert systems' nomenclature stored in the form of time matrix files with 1s or 2s intervals) included:

- adjustments of ship's internal and external controls (main engine, helm, bow tug pull, bow tug line bearing, aft tug pull, aft tug line bearing, side tugs push forces in 6 predefined locations around the hull: bow, amidships and aft on port and starboard side), which actually were the expert decisions;
- ship's state vector parameters such as: waterline's gravity centre position: P_{xy} (x [m], y [m] given in Universal Transverse Mercator 2D projection), longitudinal velocity over ground (along the heading line): v_x [kn], transverse velocity over ground: v_y [kn], angular velocity over ground: ω [°/s] and ship's heading: ψ [°].

The resultant target function for the optimisation of a planned manoeuvre in the specific navigation conditions will be the function of the mentioned differences between both ship's state vectors' parameters:

$$u = f\left(\Delta P_{xy}, \Delta v_x, \Delta v_y, \Delta\omega, \Delta\psi\right) \rightarrow \min \tag{1}$$

where: ΔP_{xy} - difference between waterlines' positions [m],
Δv_x - difference between waterlines' longitudinal velocities [kts],
Δv_y - difference between waterlines' transverse velocities [kts],
$\Delta\omega$ - difference between waterlines' angular velocities [°/s],
$\Delta\psi$ - difference between waterlines' headings [°].

The following assumptions have been taken into account while defining the final form of this function:

a. the examined ship is manoeuvring in restricted area, where its accurate position is defined in the Cartesian coordinate system;
b. the examined area is also presented in the Cartesian coordinate system, where the coordinates: $x \in X$, $y \in Y$;
c. ships allowed to manoeuvre in the examined area belong to the countable, finished set J (this applies to size, type and loading conditions of vessels and other technical aspects affecting their manoeuvring characteristics);
d. characteristic navigational (hydrometeorological) conditions are contained in the countable, finished set K;

e. ship's state vector parameters are analysed in two dimensions only (three degrees of freedom), in the accepted coordinate system;

f. parameters of ship's state vectors' differences are normalized in some established ranges to the non dimensional values from the range of 0…1.

Accepting the above assumptions the target function (1) can take the following form:

$$u_{jk} = \sum_{i=1}^{5} \Delta_{Njk} p_i \rightarrow \min \tag{2}$$

where $j \in J$, $k \in K$;

$$\Delta_{Njk} p_i = n_i \times \Delta\left(p_{Cjki}, p_{Ejki}\right) \tag{3}$$

$\Delta_{Njk}p_i$ - normalized absolute non dimensional difference or product of current ship's state vector i^{th} parameter and consecutively registered during expert passages i^{th} parameter of j^{th} ship type in k^{th} navigational conditions,

p_{Cjki} - i^{th} parameter of the current ship's state vector,

p_{Ejki} - i^{th} parameter of the registered expert ship's state vector,

n_i - normalization constant for i^{th} type of ship's state vector parameter:

n_1 - normalization constant for distance between waterline's present and expert position [1/m]:

$$\Delta_{Njk} p_1 = \Delta_{Njk} P_{xy} = n_1 \sqrt{\left(x_E - x_C\right)^2 + \left(y_E - y_C\right)^2} \tag{4}$$

where: (x_E, y_E) – Cartesian position gained from expert passage,
(x_C, y_C) – present position,
n_2 – normalization constant for difference between longitudinal velocities [1/kts]:

$$\Delta_{Njk} p_2 = \Delta_{Njk} v_x = n_2 \left| v_{Ex} - v_{Cx} \right| \tag{5}$$

where: v_{Ex} – longitudinal (advance) velocity gained from expert passage,
v_{Cx} – present longitudinal velocity,
n_3 – normalization constant for difference between transverse velocities [1/kts]:

$$\Delta_{Njk} p_3 = \Delta_{Njk} v_y = n_3 \left| v_{Ey} - v_{Cy} \right| \tag{6}$$

where: v_{Ey} – transverse (lateral) velocity gained from expert passage,
v_{Cy} – present transverse velocity,
n_4 – normalization constant for difference between angular velocities [s/°]:

$$\Delta_{Njk} p_4 = \Delta_{Njk} \omega = n_4 \left| \omega_E - \omega_C \right| \tag{7}$$

where: ω_E – angular (rotation) velocity gained from expert passage,
ω_C – present angular velocity,
n_5 – normalization constant for difference between waterline's headings [1/°]:

$$\begin{aligned} &\Delta\psi = \left|\psi_E - \psi_C\right|, \\ &\Delta\psi > 180° \Rightarrow \Delta\psi = 360° - \left|\psi_E - \psi_C\right| \\ &\Delta_{Njk} p_5 = \Delta_{Njk} \psi = n_5 \Delta\psi \end{aligned} \tag{8}$$

where: ψ_E – heading gained from expert passage,
ψ_C – present heading.

After several simulation trials with different numbers of expert passages included, the values of normalization constants have been accepted as presented in [2]. On the basis of the presented target function the decision tree for the expert system has been created and algorithm implemented in Delphi™ RAD environment (fig. 1). Basically it consists of 9 rules denoted as R0, R1, …, R8. Activation of rules R5, R6, R7 and R8 leads to creation of the matrix of $\Delta_{Njk}p_i$ components which are afterwards sorted from min to max value.

The results of this system work are expert decisions regarding ship's controls adjustments corresponding most closely to the current vector state. The adjustments (or commands) at this stage of system development has been restricted to main engine (propeller), helm and two tugs connected to bow, stern or six ship-side positions (10 possible adjustments). The system which evolved on the presented assumptions, even taking no account of its decision support qualities, appeared to be very useful from the educational point of view especially in terms of students' familiarization with manoeuvring tactics of big vessels [3]. Table 1 presents students' improvement in commanding simulated bulk carrier vessel entering Świnoujscie harbour measured by average probability of grounding parameter.

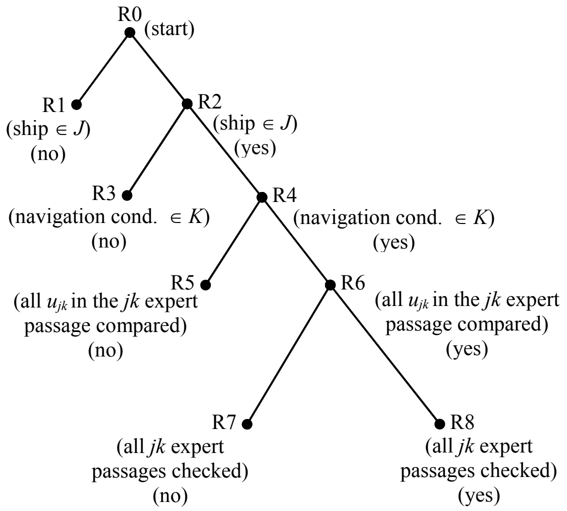

Fig. 1. Decision tree for the discussed expert system

Table 1. Probabilities of grounding obtained from experts' passages, students' passages and students' passages supported by the decision system

Reference axis range [km] / Type of passage	2.10	2.15	2.20	2.25	2.30	Average path width [m]	Average probability of grounding to E 14.5m isobath
95% ship's path widths gained by experts [m]	127	127	128	122	123	**125**	**0.00000906**
95% ship's path widths without decision support system [m]	151	150	149	149	146	**149**	**0.00078943**
95% ship's path widths with decision support system used [m]	126	125	125	120	115	**122**	**0.00000885**

FUZZY LOGIC CONTROLLER

In autonomous FTS the manoeuvring decision finding should follow the procedure described in chapter 1. However if any of the present ship state vector parameters comes outside the scope of expert database it is assumed that the optimum manoeuvre should lead the ship to regain safe values of state vector parameters as logged in expert passages.

This requirement led to the concept of fuzzy logic controller utilizing solution of the target function (2). The controller's task is to work out ship controls adjustments based on fuzzy sets, fuzzy rules, inference and defuzzification methods implemented for each control adjustment in relation to their impact on ship's advance, lateral and rotation speed in reference to the offsets of the closest expert vector state parameters and present ship status parameters. At this conceptual phase of FTS model development the research on the most suitable fuzzy sets, fuzzy rules, inference and defuzzification methods is still ongoing so the general structure of fuzzy controller has been accepted utilizing most popular methods found in literature [4,5] (fig. 2).

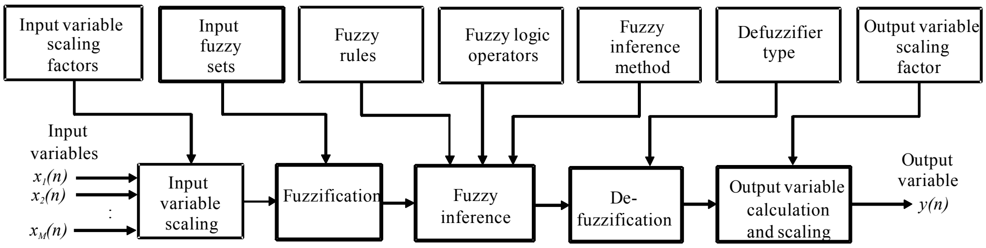

Fig. 2. Structure of a typical MISO Mamdani fuzzy controller

The 5 input variables are ΔP_{xy}, Δv_x, Δv_y, $\Delta\omega$, $\Delta\psi$ and one of the output variables can be main engine order (MISO – multiple input, single output).

As an example of how input variables are fuzzified by commonly used input fuzzy sets the fuzzification process of non-absolute difference between advance speeds Δv_x (modified formula (5)) is presented at fig 3.

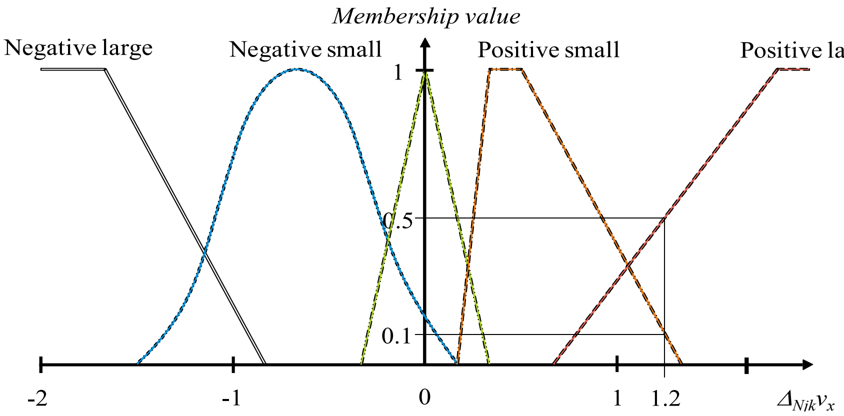

Fig. 3. Illustration of input variables fuzzification

The controller's design process is further complicated by its multidimensional output reaching up to 10 output variables. The possible solution of this problem has been presented in [6] by utilizing coupled controllers. Also usage of independent fuzzy controllers in the control of a MIMO system (multiple input, multiple output) can give good results.

Figure 4 presents exemplary structure of a coupled fuzzy controller for 5 input variables and 2 output variables (engine and helm order). Each controller utilizes its own fuzzy sets membership functions and fuzzy rules.

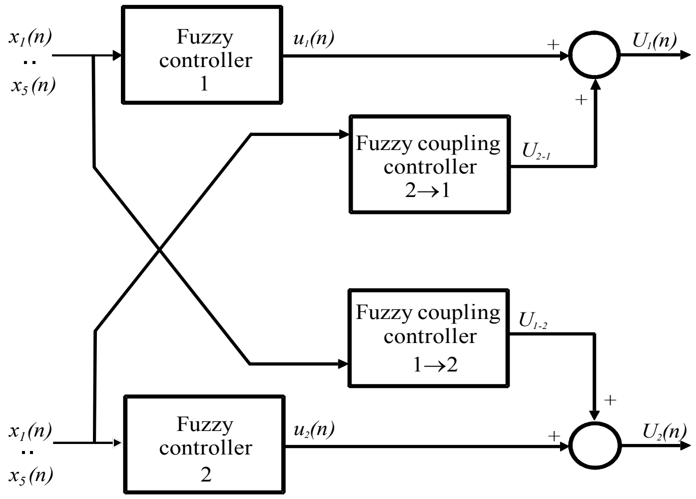

Fig. 4. MIMO coupled fuzzy controller

CONCLUSIONS

The adjustments of ship controls generated by an expert commanding a real or simulated vessel can be used for creation of expert database later utilized in autonomous ship control in confined waters. The number of expert ship passages in the area of interest is practically limited and does not cover all possible manoeuvring situations. If any of the present ship state vector parameters comes outside the scope of the expert database the human modelling expertise and knowledge can still be captured and utilized in the form of fuzzy sets, fuzzy logic and fuzzy rules. The expertise and knowledge are actually nonlinear structures of physical systems which are represented in an implicit and linguistic form rather than an explicit and analytical form, as dealt with by the conventional system modelling methodology. That is why fuzzy controllers can be suitably implemented into nonlinear dynamic model of ship control. Fast time simulation based on such model should give satisfactory results even after logging only one or few expert passages in relevant area and conditions. Afterwards the FTS model can run totally autonomously provided that the proper ship safety limits are achieved by designed fuzzification (membership functions) and inference (fuzzy if-then rules and operators) processes.

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