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FUZZY CONTROL FOR SHIP MOTION

Abstract   In the article a fuzzy-logic based algorithm for ship motion control is presented. The system operates in an open-closed loop control system with set-point changes and wind action being compensated. a detailed description of the feedback loop controller is given. The controller has a hierarchical structure, in which independent coordinated fuzzy-logic controllers for vessel motion components are situated. The controllers perform in two modes: as velocity controllers and position controllers. The paper is completed with computer simulations.

INTRODUCTION

Among ship automation systems those dealing with ship motion are of particular importance, as being directly responsible for safety of navigation. The simplest of them are autopilots serving as ship course stabilizers. Much more complicated are Dynamic Ship Positioning (DSP) systems used to control all ship flat motion components, especially at drilling vessels [Fossen 1994]. Obviously, a vessel being in principle multidimensional, nonlinear and time-varying, represents a plant that is hard to control. DSP systems utilize both conventional PID algorithms to control surge, sway and yaw motions separately, and multidimensional controllers based, for example, on Kalman filtering [Lisowski 1991].

Recent trends are toward increased use of fuzzy-logic approach. It enables user's experience to be easily and qualitatively accounted for. As a result multidimensional control structures and control systems with disturbance compensation are obtained in a natural way. Applying the fuzzy-logic technique to autopilots results in a very good vessel course and velocity control performance, as well as in a resistance to operation condition changes [Broel-Plater 1998, 1999]. Tests carried out and described in the paper have shown that fuzzy-logic technique applied to DSP imparts high effectiveness to DSP control systems.

STRUCTURE OF THE CONTROL SYSTEM

To achieve the required control performance both an appropriate control algorithm, and control system structure is to be selected. As the vessel motion control is performed in the presence of strong disturbances (wind, waves), the DSP system has been based on the open-closed control structure with wind and set-point changes being compensated (see Fig. 1).
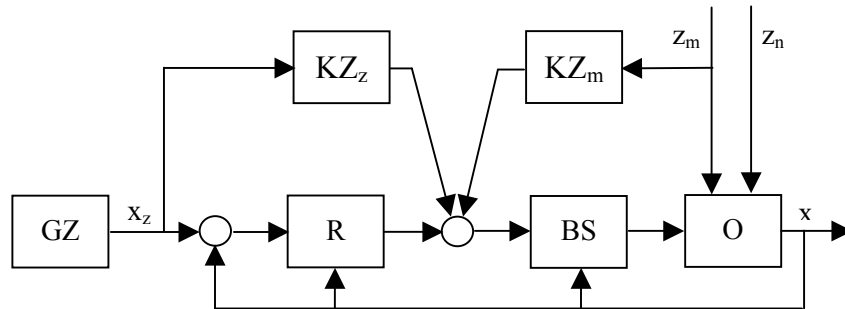
Fig. 1. Block diagram of the DSP system:
GZ – set-point device,
R – fuzzy-logic controller,
KZ_z – set-point changes compensation block,
KZ_m – wind compensation block,
BS – propellers control blocks,
O –ship,
x – controlled value,
x_z – set-point,
z_m – measurable disturbance,
z_n – non-measurable disturbance

Compensation of set-point changes results in an increased astatic order without sacrificing system stability margin. This circumstance is of particular importance when following up a movable underwater vehicle. Compensation algorithms are commonly known, and for this reason we will only dwell on the controller acting in the control loop.

For control system design it was assumed that only „accurate" information about vessel motion may be utilized, that is:

- „absolute" vessel position (x, y) related to a fixed „terrestrial" co-ordinate system;
- course angle (φ) related to a pre-set reference direction;
- velocity components for a linear absolute (terrestrial) vessel motion determined in a vessel-related co-ordinate system (u_x, u_y);
- speed of the vessel rotation (r_z) about its vertical axis passing through the vessel centre of gravity.

The relative velocity, however, is encumbered with too big errors to be utilized for control purposes. This applies especially to low velocities with arbitrary drift angles and working tunnel rudders, as well as main propulsion screws.

DSP SYSTEM CONTROLLER ALGORITHMS

The structure of the DSP system arouse as a result of a number of simulations carried out on simple structures. Increased complexity is aimed at eliminating adverse phenomena, such as:

- steady state error arising either during leading the vessel to a specified point on the sea area where a sea current occurs or during following up a slowly moving „target";
- vessel overaccelerating when being too distant from the point of destination.

The structure of the DSP system is hierarchical and complicated. Its algorithms will be described in turn beginning from the direct control level. The designations used are explained in Fig. 2.
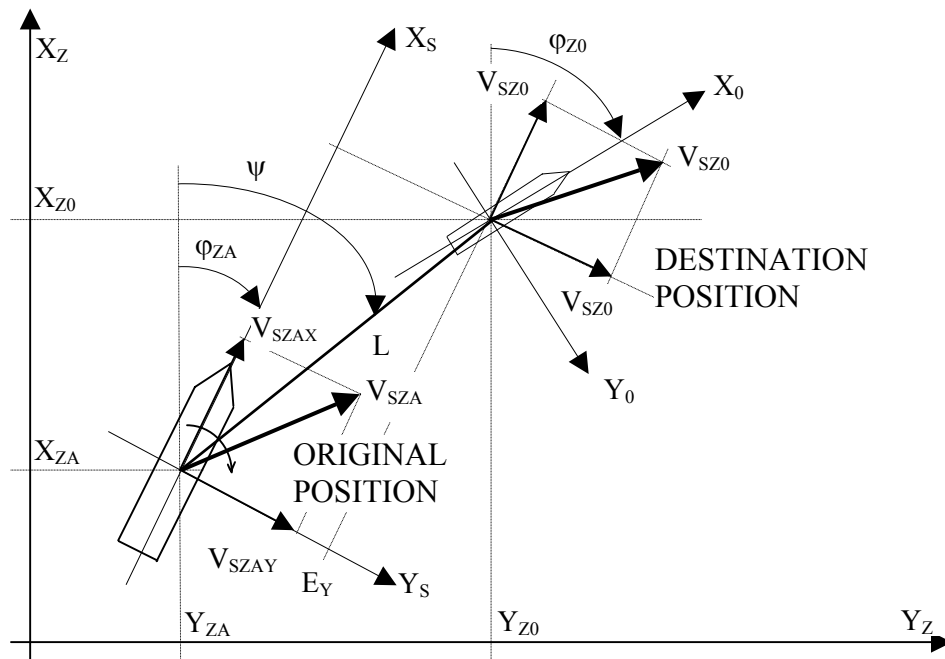

Fig. 2. Navigational situation during DSP system operation

The main control algorithm used for DSP is the fuzzy PD one, denoted further as PD-FL (see Fig. 3). The PD-FL algorithm has been realized using classical fuzzy control techniques. A min-max algorithm has been employed in which products and sums have been determined according to Zadeh, the control surfaces have been created by means of the so-called scaling approach, and fuzzyfication have been realized utilizing the control surface gravity centre technique [Piegat 2001]. The variables have been fuzzyficated up to 7 sets.
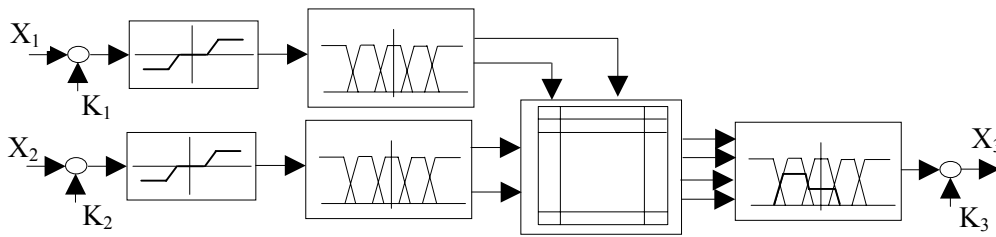
Fig. 3. PD-FL controller algorithm

Two PD-FL algorithms accordingly connected form a PID-like controller denoted further as PDPI-FL (see Fig. 4).

To obtain appropriate PDPI-FL properties different rule tables for both controller channels have been employed (see Fig. 5).
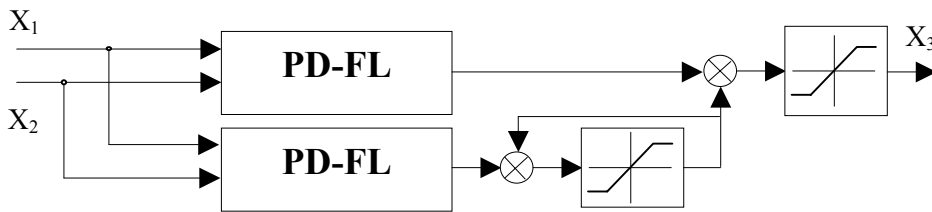

Fig. 4. PDPI-FL controller algorithm

E/dE	BM	MM	SM	Z	SP	MP	BP
BM	BM	BM	MM	MM	SM	SM	Z
MM	BM	MM	MM	SM	SM	Z	SP
SM	MM	MM	SM	SM	Z	SP	SP
Z	MM	SM	SM	Z	SP	SP	MP
SP	SM	SM	Z	SP	SP	MP	MP
MP	SM	Z	SP	SP	MP	MP	BP
BP	Z	SP	SP	MP	MP	BP	BP

Rule table - channel PD-FL

E/dE	BM	MM	SM	Z	SP	MP	BP
BM	BM	BM	MM	SM	Z	Z	BP
MM	BM	MM	MM	SM	Z	Z	BP
SM	MM	MM	SM	SM	Z	BP	BP
Z	MM	MM	MM	Z	MP	MP	MP
SP	BM	BM	Z	SP	SP	MP	MP
MP	BM	Z	Z	SP	MP	MP	BP
BP	BM	Z	Z	SP	MP	BP	BP

Rule table - channel PI-FL

Fig. 5. Rule tables for the PDPI-FL controller: E – error, B - big, M - medium, S - small, Z - neutral, N - negative, P - positive.

In the control channel two PDPI-FL controllers have been used. One of them is for position control, and the second one is for velocity control. The controller of a component motion is shown in Fig. 6.

As vessel motions are interactive, the controllers of component motions have been connected in a structure shown in Fig. 7. Auxiliary blocks have been included to co-ordinate individual motions depending on the vessel position in relation to a specified point.

SIMULATION RESULTS

The effectiveness of the described DSP system has been tested by means of computer simulations on a vessel with following parameters:
- length L_{pp} = 64.2 m,
- breadth B = 11.6 m,
- displacement D = 1540 T - 1730 T (depending on loading),
- draft T = 3.5m - 3.9 m (depending on loading).
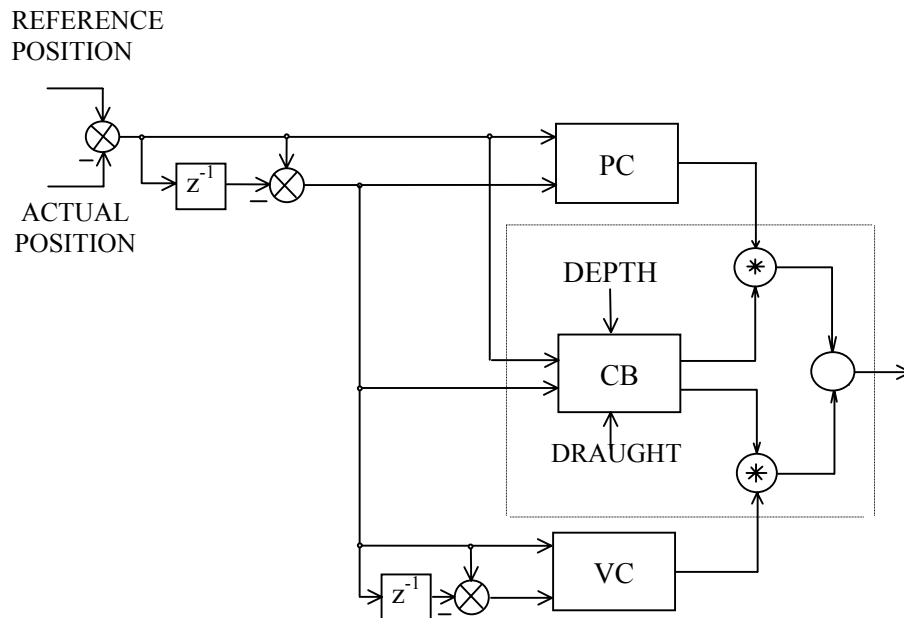
Fig. 6. Controller of a component motion: PC – position controller, VC – velocity controller, CB – co-ordination block

The vessel has been equipped with:
- two man propulsion screws, each producing a thrust ranging from -40 kN to +80 kN with change-over time of 20 s and positioning accuracy of 5%'
- two tunnel rudders, each producing a thrust ranging from -26 kN to +26 kN with change-over time of 14 s and positioning accuracy of 1%.

Arrangement of final-control devices is shown in Fig. 8.

The following phenomena have been accounted for during the tests:
- average sea current forces action,
- hydrodynamic forces of vessel inertia,
- hydrodynamic damping forces,
- aerodynamic forces action.

The following measurement errors have been assumed during the simulation tests:
- linear position +/- 2 m,
- angular velocity +/- 2 deg,
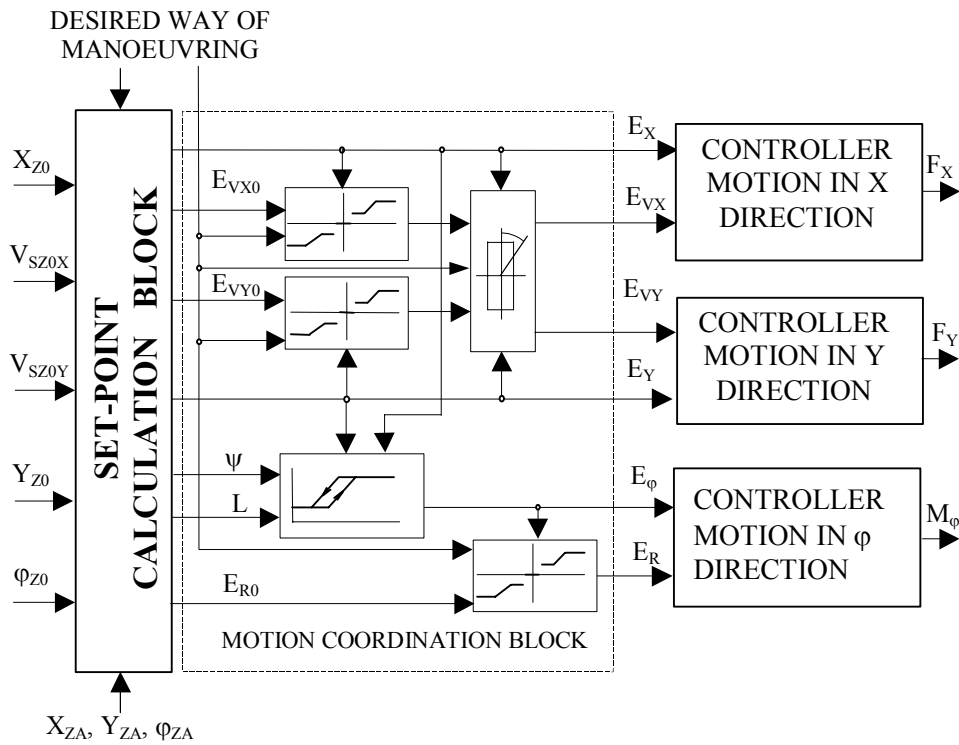- linear velocity +/- 0.1 m/s,
- angular velocity +/- 0.1 deg/s.

Fig. 7. Full structure of the DSP system controller
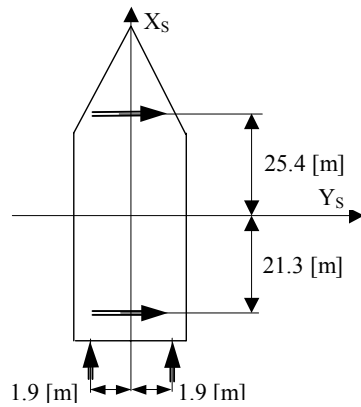
Fig. 8. Arrangement of final-control devices

The algorithm of control distribution among the propellers has been based on numerical minimizing the „distance" between the pre-set vector and the actual one. As minimizing criterion a sum of weighted absolute error values related to individual action components has been employed.

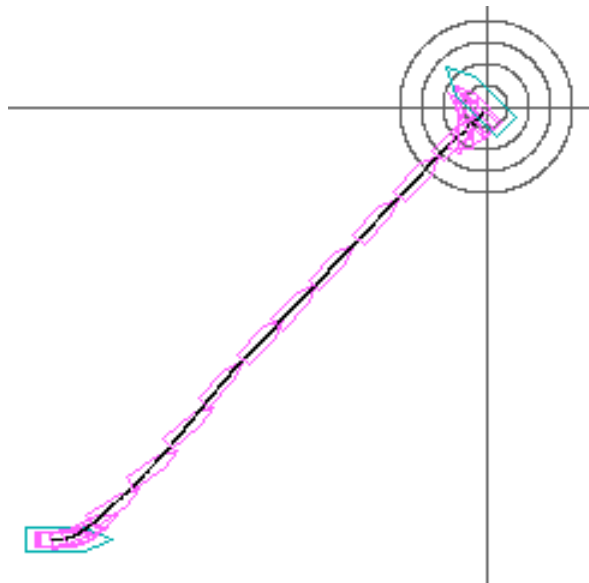Figs. 9, 10 and 11 exemplify some simulation results for different navigational situation.
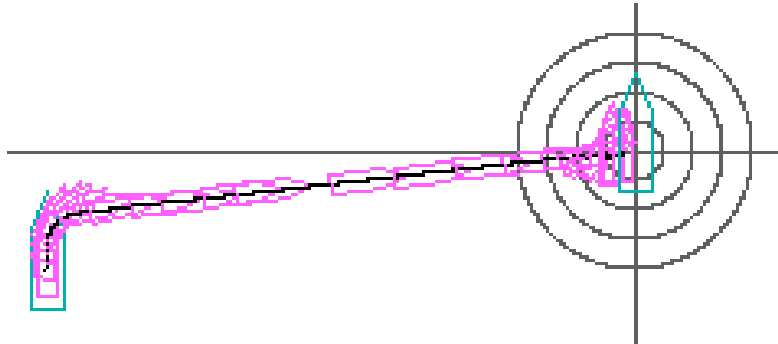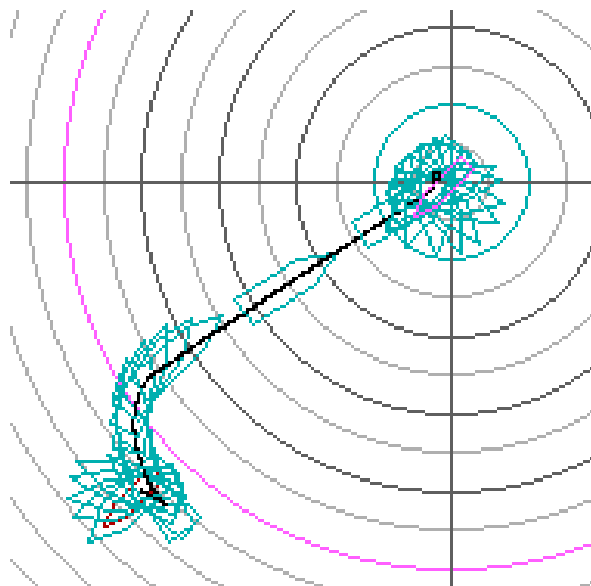

Fig. 9.

Fig. 10.

Fig.11.

The simulations comprised approaching a pre-set stationary destination position from different distances and course positions:

- with keeping constant a pre-set course angle,
- aiming at the „target" while being far from the destination, and course stabilization while being near the destination point.

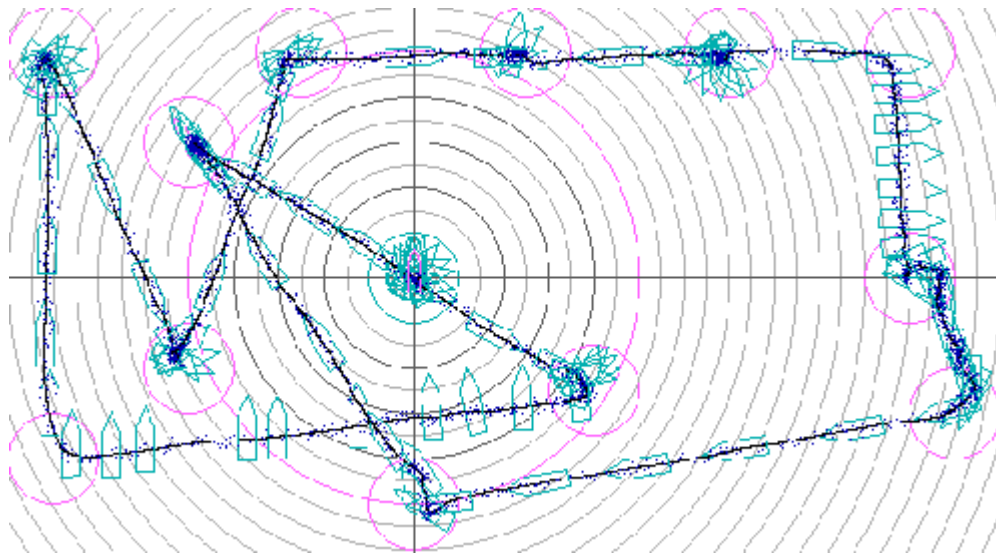In Fig. 12 and 13 results of a simulation carried out for a ship steered along a given trajectory is depicted.
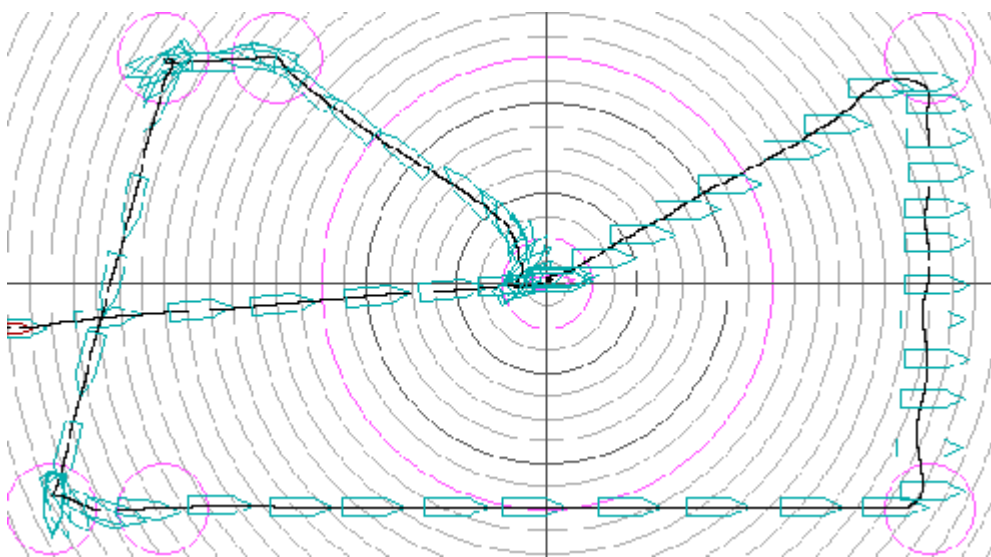
Fig. 12.

Fig. 13.

CONCLUSIONS

The presented DSP system controller structure is characterized by a high control effectiveness. Its tuning is simple, and may be accomplished on the basis of typical manoeuvring quality test results. The proposed algorithm is resistant to changes both in vessel loading, and in hydrometeorological conditions.

Acknowledgements

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