CONTROL SYSTEMS FOR AUTOMATED VESSEL PILOTING THROUGH LOCAL STATIONARY OBSTACLES

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Abstract: To reduce the "human factor" component in the causes of accidents during pilot age of vessels along areas of fairways with local stationary obstacles we propose a device which provides: a) real-time presentation on a graphical display of information on current and predicted positions of a vessel with regard to a stationary obstacle; b) automated or semi-automated piloting of a vessel in to a straight path for safe passage of an obstacle. Specified device will allow reducing the risk of accidents while piloting a vessel along difficult parts of fairways.

Key words: control systems, navigation, microcontroller.

Each year, in Saint-Petersburg a number of vessel collision events with bridge piers takes place during the passage of cargo ship caravans along the Neva [1]. In order to reduce the "human factor" component in the causes of accidents during pilot age of vessels along areas of the fairways with local stationary obstacles a device for vessel piloting (DVP) has been developed in OJSC "CSRI "Kurs". DVP is designed for:

a. Delivery of information to navigator on current and predicted positions of a vessel with regard to a local stationary obstacle (for example, piers of a bridge);
b. Automated or semi-automated piloting of a vessel into a straight path for safe passage of an obstacle.

STRUCTURAL DIAGRAM OF A DEVICE FOR VESSEL PILOTING (DVP)

The following designations are used below:

D_v – a tuple of a vessel geometrical parameters D_v - {d, l_b, l_{st}} where *d* is a vessel hull beam, l_b, l_{st} are distances from bow and stern to a vessel center of mass respectively.

T_{pr} - one-dimensional (linear) array of tuples of parameters of preset straight-line motion paths in the vicinity of a j-th obstacle $T_{prj}= \{\phi_{pr}, \lambda_{pr}, \phi_{pr}, l_{pr}, L,\}_j$, where ϕ_{pr}, λ_{pr} are the latitude and the longitude of an initial point, l_{pr} is the length of a preset path, L is the length of a maneuvering area in front of an obstacle.

Structural diagram of a DVP is presented in Figure 1. Connections shown dashed may be absent in a simplified version of a device. Units of a DVP gear are designed to fulfill the following functions. *Graphical screen* 1 displays on a screen in visual form symbolic representations of current and projected positions of a vessel with regard to an obstacle. *Control unit* 2 is used to control DVP operation. *Angular speed sensor* (ASS) 3 measures angular speed of a vessel hull turning rate in horizontal plane w. *Heading sensor* 4 measures the current heading of a vessel ϕ_h. *Global positioning system* (GPS) *receiver* 5 measures current velocity vector of longitudinal vessel movement V_v

and the vessel current coordinates f_v, l_v. *Microcontroller* 6 performs calculations of the following values with period τ (See Figure 2): x_{vl}, x_{vr} coordinates of the current projection of a vessel hull and of its center of mass x_{cm} on oX axis in the local coordinates system XOY, x_l^p, x_r^p coordinates of predicted over time Dt position of a vessel hull projection and of its center of mass onto OX axis, the current distance to an obstacle L, obstacle approach speed $V_{ap.}$. It displays on a graphical screen in a visual form current and predicted geometric parameters of the mutual position of the vessel and the obstacle X_v, X_v^p, L, V_{ap}. It stores the vessel motion actual parameters T_{ac} in permanent memory. It estimates V_v, f_v, lv in case of short-term signals from SNS receiver drop out. *Rudder feedback 7* measures the current rudder position δ. *Digital interface 8* is used to enter the coordinates of the obstacles S_{ob}, of preset motion paths in the vicinity of obstacles T_{pr}, of vessel geometric parameters D_v, of prediction time Dt, and to feed the actual path and other vessel motion parameters T_{ac} into a PC for further analysis. *Interface with the steering gear actuator* 9 is used to transfer rudder deflection calculated value d_{pr} into the actuator. *Permanent memory* 10 is used for storage of: coordinates of obstacles S_{ob}, preset motion paths in the vicinity of obstacles T_{pr}, vessel geometric parameters D_v, prediction time Dt, actual path and other vessel motion parameters $T_{ac.}$

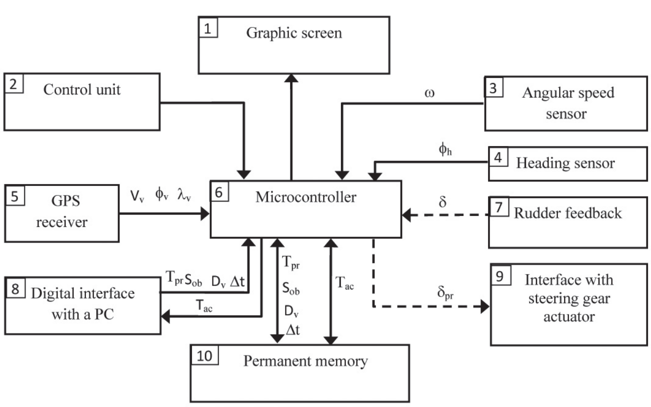

Figure 1. Structural diagram of a vessel piloting device

DVP OPERATION DESCRIPTION

Let us consider geometric layout of a vessel entering a preset path for passing an obstacle presented in Figure 2. XOY is a local system of coordinates connected with definite stationary obstacle. OY axis has a direction of a preset motion path in the vicinity of an obstacle. OX axis is perpendicular to OY axis. The origin of coordinates "O" lies at the initial point of a preset path for passing through an obstacle $\{f_{pr}, l_{pr}\}$.

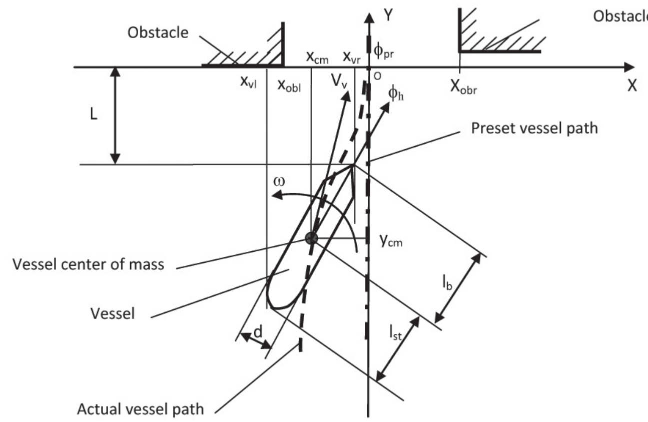

Figure 2. Geometric layout of a vessel entering a preset path of passing through an obstacle

Along the entire length of a ship fairway serviced by DVP when a vessel is in motion DVP operates in one of the two modes: a) next obstacle approach state and b) piloting state. In the state of next obstacle approach DVP monitors the current distance from a vessel to the next obstacle and when a vessel enters the vicinity of an obstacle passes into "piloting state" mode. By "the vicinity of an obstacle" we mean a part of water area near an obstacle sufficient for entering a preset path for passing an obstacle. After the state of piloting has set in a navigator may choose one of the three modes to pilot a vessel into a preset path to pass obstacles and to move along this path:

3. Manual control without an advisor.
4. Manual control with an advisor.
5. Automatic control.

In manual control modes a navigator uses displayed on a screen information on a preset path, on current and predicted vessel position, on an obstacle position and pilots a vessel into a preset path to pass an obstacle. In manual control mode with an advisor the screen displays a recommended value of rudder deflection. In this case to control a vessel motion it is enough for a navigator to match the images of the current rudder position with a recommended one with the help of rudder control gear. When passing an obstacle a navigator uses information presented on the screen in order to counteract vessel deviation from a preset path in manual control modes and to control the process of motion in automatic mode. After piloting a vessel through an obstacle DVP passes into the state of "next obstacle approach".

Model view of a screen with information on the state of vessel piloting is shown in Figure 3 [2]. Symbolic presentations of a vessel hull edge lines are accomplished in a form of a vessel hull schematic drawings halves in plan view. When the angle of drift is equal to zero vessel hull halves are joined into a complete view of a vessel hull. When the angle of drift is not equal to zero vessel hull halves are pushed apart at a distance proportionate to the angle of drift. The position of the vessel hull projection edge lines x_{vr}, x_{vl} onto OX axis and the projections of the left and the right obstacles onto OX axis are displayed on a screen in the scale of OX axis.

In case of ideal current state of the vessel piloting process the vessel center of mass should lie on a preset motion path, a current speed vector of the vessel longitudinal motion should coincide with a preset vessel motion path and the vessel boards should be ultimately removed from the obstacles. Model screen view with information on ideal vessel piloting state is shown in Figure 4. Points O, $x_{cm,}$ X_{cm}^{p} coincide; halves of a vessel hull joins into a complete image of a vessel hull projection onto a horizontal plane.

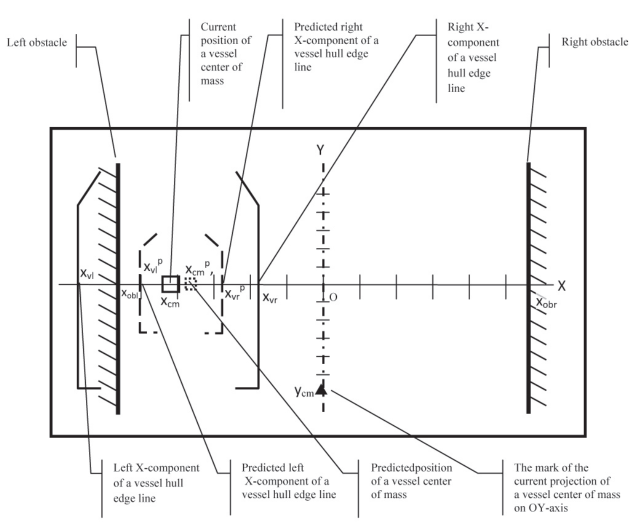

Figure 3. Model screen view with information on the state of vessel piloting process

To calculate a predicted position of the vessel hull projections edge lines (x_{vl}^{p}, x_{vr}^{p}) onto OX axis for time value t+Dt one can accept that V_v and ω are constant for time interval Dt. To calculate a predicted position of a vessel center of mass one can use vector expression (1) where symbol «T» stands for transposition operation.

$$(x_{cm}^{p}, y_{cm}^{p})^{T} = (x_{cm}, y_{cm})^{T} + V_{v}^{T}*\Delta t \tag{1}$$

For proximate calculation of predicted position of the most jutting out vessel hull points expressions (2) are used. In the expressions (2) it is accepted that a vessel hull projection onto a horizontal plane is approximated by a rectangle with adjacent to it semicircles corresponding to bow and stern. For proximate calculation of the current position of the most jutting out vessel hull points expressions similar to expression (2) are used.

$$(x_{std}^{p}, y_{std}^{p})^{T} = (x_{cm}^{p}, y_{cm}^{p})^{T} - (l_{st} - d/2)*(\sin(\phi_h - \phi_{pr} + \omega*\Delta t), \cos(\phi_h - \phi_{pr} + \omega*\Delta t))^{T}$$

$$(x_{bd}^{p}, y_{bd}^{p})^{T} = (x_{cm}^{p}, y_{cm}^{p})^{T} + (l_{b} - d/2)*(\sin(\phi_h - \phi_{pr} + \omega*Dt), \cos(\phi_h - \phi_{pr} + \omega*\Delta t))^{T}, \tag{2}$$

$$x_{vl}^{p} = \min(x_{std}^{p} - d/2, x_{bd}^{p} - d/2)$$
$$x_{vr}^{\text{п}} = \max(x_{std}^{p} + d/2, x_{bd}^{p} + d/2)$$

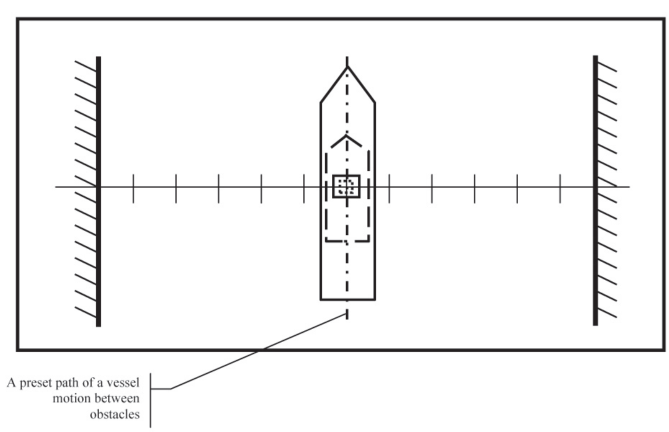

Figure 4. Model screen view with information on ideal state of a vessel piloting process

The process of vessel piloting along a part of the fairway with a local stationary obstacle consists from two stages:

- Piloting a vessel into a safe path to pass an obstacle.
- Keeping a vessel on a safe path for passing an obstacle.

A navigator's task for the case of manual control consists in keeping minimal distance between points O, x_{cm}, x_{cm}^{P} with the aid of vessel steering and propulsive thrust control gear, and in controlling that symbolic presentations of the vessel hull projection edge lines onto OX axis preset by points x_{vl}, x_{vr}, x_{vl}^{P}, x_{vr}^{P} do not overlap on a screen the images of obstacles preset by points x_{obl}, $x_{odr.}$

In the capacity of an operating path for piloting a vessel into the path to pass an obstacle Bernstein basis fifth-degree polynomial curves are applied [3]. Specified operating paths are physically realizable.

In manual control modes with an advisor and in automatic control mode the calculation of control signal is accomplished with the use of nonlinear control law described in article [4].

Summary

DVP will permit a navigator to pilot a vessel in advance into a preset path for safe passing of a stationary obstacle. When piloting a vessel through an area with stationary obstacles with the appliance of DVP a navigator may use not only eye estimations of a vessel position in relation to an obstacle but also objective estimations of current and predicted mutual position of a vessel and an obstacle. Additional objective data will provide a rise of accuracy of vessel motion control in the vicinity of an obstacle and thereafter lead to reduction in the number of accidents. Navigator's control of the vessel motion using data displayed on a screen will allow to accurately pilot a vessel in the vicinity of obstacles at night-time and at adverse weather conditions.

Actual path and other vessel motion parameters (T_{ac}) storage in permanent memory will permit to fulfill objective accident-incident analysis.

The device may be manufactured as a separate element for installation in a pilot room or as a self-contained portable device with no connection to rudder translator and steering gear actuator and there after without automatic control mode. DVP operation algorithm may be realized as a separate task within bridge vessel motion control system.

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