Motion Dynamics Analysis of a Floating Robot

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Abstract

Floating and underwater robot motion dynamics model with six DOFs is investigated. To simplify the problems associated with the objects interaction with the environment, water stream and wind flow, the models hull has been unified to a form of parallelepiped. In this case the robots translation motion can be easily described by the mass center motion equation, but the rotation around the center of mass – by the kinetic momentum exchange theorem.

Keywords

Motion control, floating robot, vibrations in fluid, floating interaction.

1 Introduction

The interaction forces along hull depend on the relative local speed components: the normal direction of the corresponding component squared, and the tangential direction like viscous interaction (in the first order of velocity component).

Robot's steering is done via three controls:

- control of propellers with variable propulsion force;
- control of steering (left or right) angle, which is controlled by the deviation from the desired vehicle heading;
- control of a bow thruster in front of the vessel pushing the bow to one or the other side.

Steering trajectories and control of the robot may be various, for example: straight line course, circular trajectory, PID controlled trajectories and others.

2 The mathematical model of the robot's body.

To best describe ship or submarine (the robots) motion dynamics, generally accepted denotations and coordinates of aircraft and ship movements [1, 2] are used. Explanation in English with references is given below.

Three critical flight dynamics parameters are the angles of rotation in three dimensions around vehicle's center of mass, known as pitch, roll and yaw [3, 4]. Ship motions are defined by the six degrees of freedom that a ship or boat can do – translation (heave, sway, surge) and rotation (roll, pitch, yaw) motion.

In this way, we will substitute vertical axis from ships center to the earth center direction. Axes, respectively, related to the ship (robot) in the center will be substituted with x, y and z.

Pursuant are the problems associated with the object interaction with the water, the water stream and wind flow around hull. For simplicity it will be described as a parallelepiped (Fig. 1.).

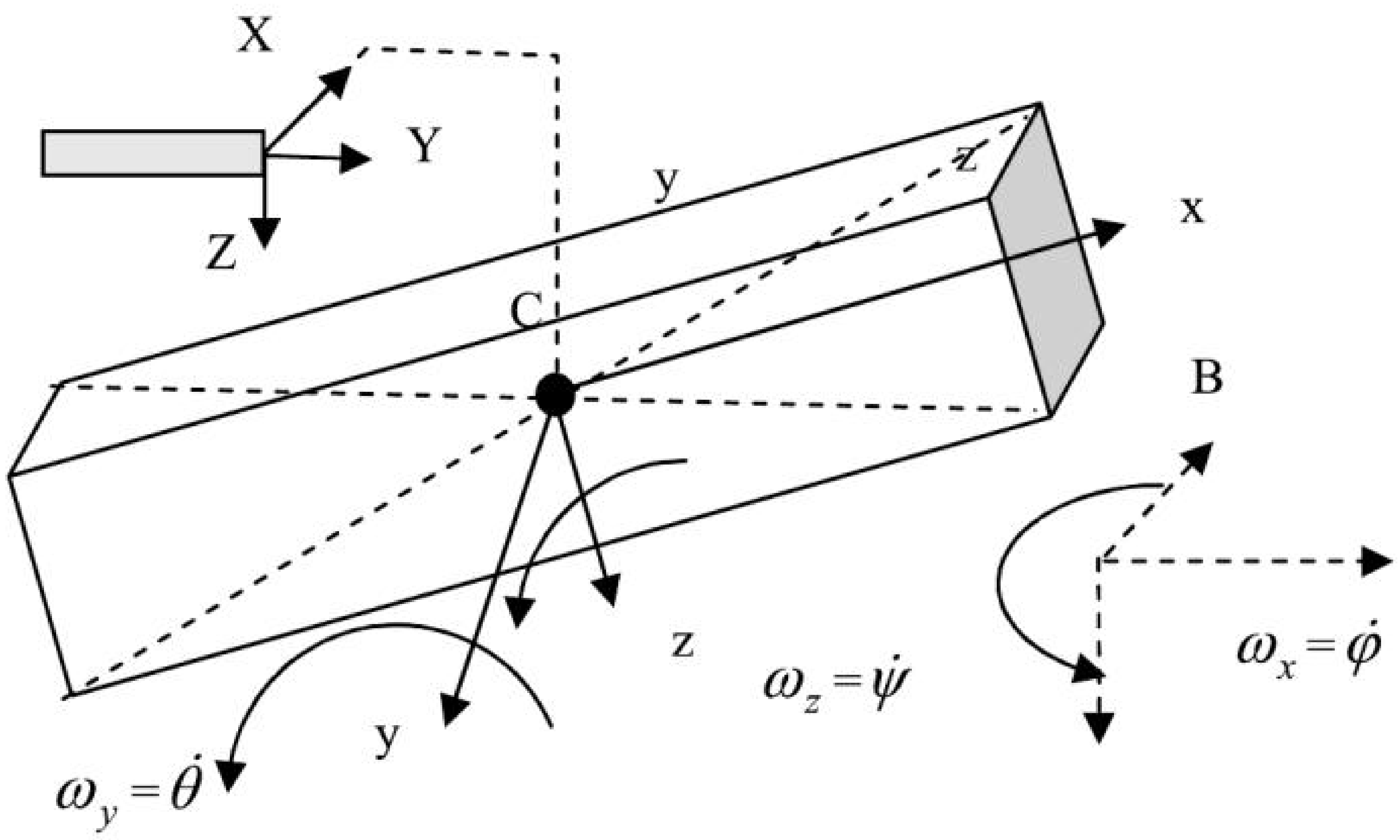

Fig. 1. Ship (a floating robot) body with x, y and z axes and angular speeds around them (ω with the indices x, y and z)

In this case the ships (the robots) mass center motion is described by the mass center motion equation (1), but the rotation around the center of mass is described by the kinetic momentum interception theorem (2) [1]:

$$m \cdot \overline{a}_c = \sum \overline{F}_k^{(e)}; \tag{1}$$

$$\frac{d\overline{L}_c}{dt} = \sum \overline{M}_k^{(e)}, \tag{2}$$

with the following variables: mass, center of mass acceleration, the geometric sum of forces of the external k-forces i.e. gravity and interaction of the displaced water, Archimedes force, air (wind) and water (current) influence, ship management (generated by propellers and thrusters) forces, the ships kinetic moment against the mass center, the derivative of the kinetic moment at time, the geometric sum of moments of external forces against the mass center.

Choosing axes as principal axes of inertia, the centrifugal moments of inertia equal to zero. In case of small vessel movements like pitching and rolling, the components are equal to the corresponding angle first order derivatives (see Fig. 2.). The kinetic momentum derivative is found as derivative against structure axes x, y, z

In such way these expressions (1) and (2) let us obtain six differential equation left hand sides (3) and (4).

$$\begin{aligned} m \cdot \ddot{X}_c &= \sum F_{kx}^{(e)}; \\ m \cdot \ddot{X}_c &= \sum F_{kx}^{(e)}; \\ m \cdot \ddot{X}_c &= \sum F_{kx}^{(e)}; \end{aligned} \quad (3)$$

$$\begin{aligned} J_x \cdot \ddot{\varphi} + (J_z - J_y) \cdot \dot{\theta} \cdot \dot{\psi} &= \sum M_{kx}^{(e)}, \\ J_y \cdot \ddot{\theta} + (J_x - J_z) \cdot \dot{\varphi} \cdot \dot{\psi} &= \sum M_{ky}^{(e)}, \\ J_z \cdot \ddot{\psi} + (J_y - J_x) \cdot \dot{\varphi} \cdot \dot{\theta} &= \sum M_{kz}^{(e)}, \end{aligned} \quad (4)$$

It is important to note that the mass center of the movement is described in the absolute coordinates, but the rotation around the center of mass – in the relative angle intercept coordinates.

3 Force Reduction of the mass center C

3.1 Reduction of wind interaction forces

Let's divide forces in two parts: the lateral forces are acting on two surfaces: the side length A1 of the ship and front part length B1 of the ship.

The forces depend on the projection of the relative speed (on the normal of the area) **squared**. In this way we obtain the following projection of the wind torque against the vertical axis (5).

$$\begin{aligned} NA1_x &= -k1 \cdot A1 \cdot C1 \cdot \cdot \left(\dot{X} \cdot \sin(\alpha+\psi) - \dot{Y} \cdot \cos(\alpha+\psi) + Vv \cdot \sin(\psi+\beta)\right)^2 \cdot \sin(\alpha+\psi) \\ NB1_x &= -k2 \cdot B2 \cdot C2 \cdot \left(\dot{X} \cdot \cos(\alpha+\psi) + \dot{Y} \cdot \sin(\alpha+\psi) + Vv \cdot \cos(\psi+\beta)\right)^2 \cdot \cos(\alpha+\psi) \\ Mv_z &= -k1 \cdot A1 \cdot C1 \cdot \left(\dot{X} \cdot \sin(\alpha+\psi) - \dot{Y} \cdot \cos(\alpha+\psi) + Vv \cdot \sin(\psi+\beta)\right)^2 \cdot e1, \end{aligned} \quad (5)$$

Here we use the following inputs: drag force proportionality coefficients, the height of the wind interaction edge of the side and end; the absolute wind speed; wind force outlets to the mass center, eccentricity. Angles are shown in Fig. 2.

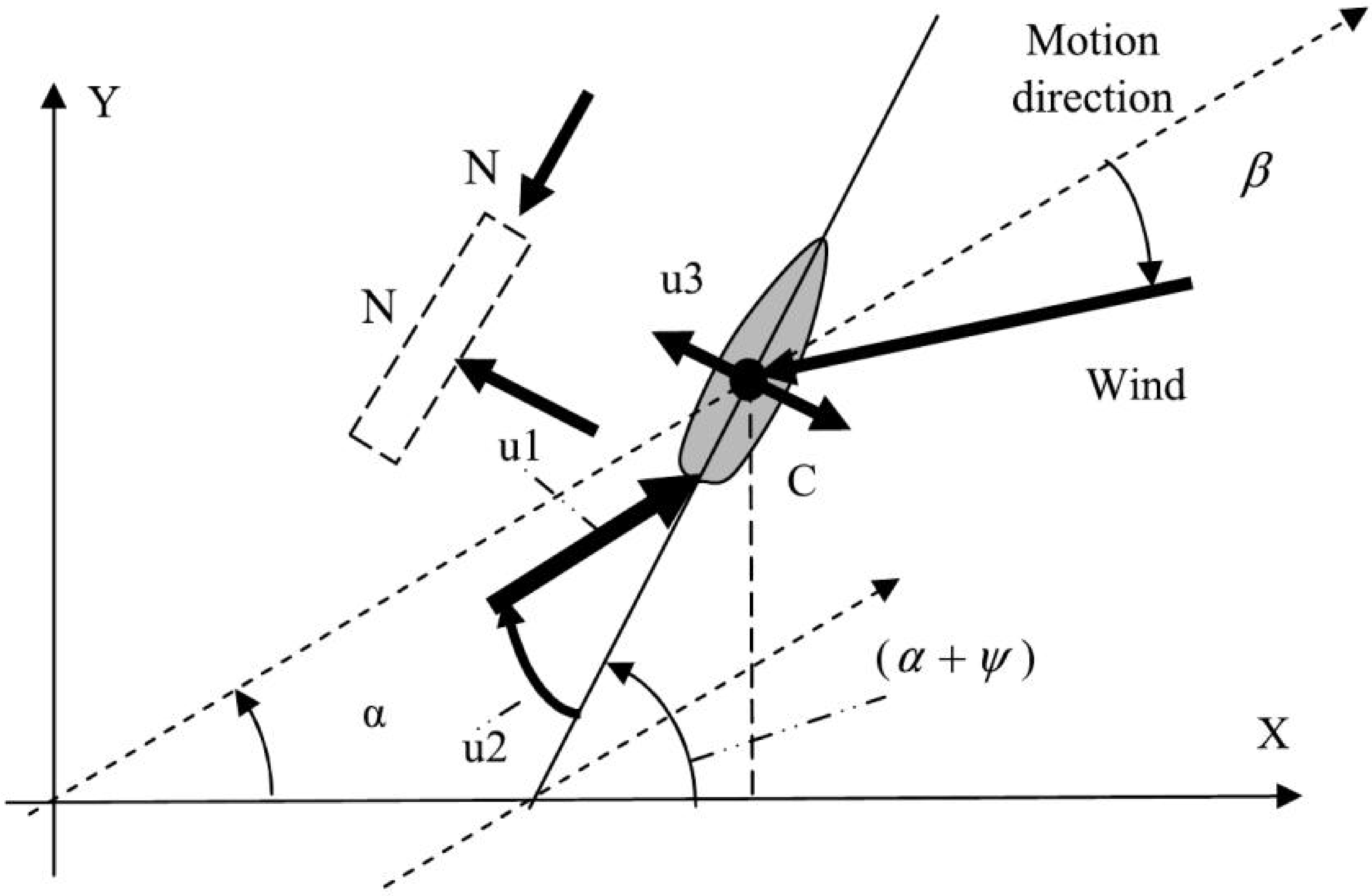

Fig. 2. Ship's direction of movement, currents and wind direction, robots control U1, U2 and U3

3.2 Reduction of the water current interaction forces

As before (at wind interaction), the forces are divided in two parts: the lateral forces acting on the two sides: the side part of the robot, and the front part of the robot. The forces (6) depend on the relative speed projection (on the normal of the corresponding area) squared.

$$NA3_x = -k3 \cdot A3 \cdot C3 \cdot \sin(a+\psi) \cdot (\dot{X} \cdot \sin(a+\psi) - \dot{Y} \cdot \cos(a+\psi) + Vs \cdot \sin(\psi - \gamma))^2$$
$$NB4_x = -k4 \cdot B4 \cdot C4 \cdot \cos(a+\psi) \cdot (\dot{X} \cdot \cos(a+\psi) - \dot{Y} \cdot \sin(a+\psi) + Vs \cdot \sin(\psi - \gamma))^2 \quad (6)$$
$$Ms_z = k3 \cdot A3 \cdot C3 \cdot l \cdot \left(\dot{X} \cdot \sin(\alpha+\psi) - \dot{Y} \cdot \cos(\alpha+\psi) + Vs \cdot \sin(\psi - \gamma)\right)^2 \cdot e1,$$

In addition, there are viscous interactions to the robot's **side** (7), such as water sliding force, which depend on the relative slip velocity in the **first order**.

$$NA0_x = -2k0 \cdot [\cos(a+\psi) \cdot (\dot{X} \cdot \cos(a+\psi) + \dot{Y} \cdot \sin(a+\psi) + Vs \cdot \cos(\psi - \gamma))] \quad (7)$$

3.3 Interaction of the waves

The complex interactions of the waves are adopted as follows:

- Waves spread accurately to the direction of the wind with given angle;
- Wave interactions are considered only from the lateral side;
- The wave propagation velocity is not greater than the wind speed;
- Periodic wave length is given or determined from the wave period and the velocity;
- Wave interaction strength depends on the vessel mass or weight;

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