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Underwater capsubot controlled by motion of a single internal flywheel

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Abstract: An underwater capsubot with a single internal flywheel is studied. The robot performs plane-parallel motion. Thus, the system has four degrees of freedom and one control input. The mathematical model is constructed in the form of 5-order dynamical system. For this purpose, quasi-steady model of interaction with the fluid is applied. This model allows not only effective parametrical analysis, but also revealing features of motion associated with presence of lateral component of hydrodynamic force. Control strategy is constructed; parameters of the control law are adjusted. It is shown that the lateral force provides possibility of irreversible motion of the centre of mass in the desired direction. So, it is promising to design underwater capsule robots and control algorithms for them basing on exploitation of lateral force. Results of modelling are verified by experiments with a prototype of the capsubot. Qualitative agreement between model and experiments is confirmed.

Keywords: underwater robot, internal mass motion, quasi-steady model, underactuated system.

1. Introduction

Investigation of capsule water robots is one of the topical problems of the modern science. The detailed review can be found in [1]. Among classical results in this field, there are such works as [2-4]. Among the most recent results, there are e.g. [1, 5-8]. The corresponding mathematical models involve Kirchhoff equations, Navier-Stokes equations, added masses, vortexes and CFD simulation. However, there are only few examples where lateral force is intended for the propulsion e.g. [7, 8].

Plane-parallel motion is, in most cases, organized using two control inputs. Rear examples of plane-parallel motion with a single control input are given in [7, 8]. In [7], the robot has a shape of an airfoil and is controlled via an internal flywheel. Here, we study the scheme of the robot similar to [7], but the mathematical model is totally different, and the control law is essentially modified.

2. Description of the mechanical system and the control law

A rigid capsule with an inner flywheel can perform plane-parallel motion. The capsule has a shape of an airfoil (Fig. 1). A control torque is applied to a flywheel to organize a tacking-kind propulsion of the capsule. Hydrodynamic forces and torque acting on the capsule are described with a quasi-steady model using experimental data for NACA0015 airfoil. Added masses are taken into account. Equation of motion are derived in the form of dynamical system with the following variables: v_x, v_y – components of velocity of the centre of mass of the robot, φ, ω – angle and angular speed of the capsule, w – relative angular speed of the flywheel.

In the desired motion, v_x should be always positive periodic function, v_y, φ, ω and w should be periodic functions with zero mean.

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Two strategies of control were tested: 1) "mixed" control including parametric excitation and feedback: $U = a\sin(bt) + k\varphi + c\omega$, 2) purely feedback control: $U = -a\,\mathrm{signum}(\omega) + k\varphi + c\omega$. Here U is value of the control torque applied to the flywheel, a, k, c are positive parameters. The second approach to the control is inspired by problems of pumping of oscillations [9].

3. Main results

Numerical integration of the system with varied parameters and initial conditions was performed. It was shown that the both control strategies bring the system to the desired regime. The second strategy (pure feedback) provides faster increasing of the speed v_x and seems to be more energy effective.

Different stages of the desired periodic motion are qualitatively shown in Fig. 1: the velocity **V** of the centre of mass and lateral force **L** are shown qualitatively (drag force and torque are not depicted).

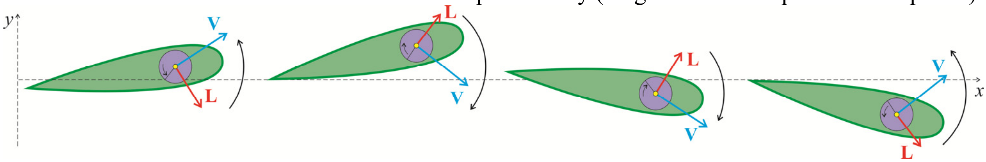

Fig. 1. The role of lateral force in robot propulsion (qualitative scheme; drag force and torque are not shown)

The essential conclusion obtained my means of a quasi-steady model is that the lateral force supports propulsion of the robot along the x axis. Moreover, the model allows parametrical analysis of the system. Parameters were adjusted numerically; and prototype of the capsubot was constructed and tested. Its motions qualitatively agree with the modelling.

4. Conclusion

The mathematical model of the capsule underwater robot with a single control input is developed in the form of dynamical system. Control laws were constructed that ensure transition of the system to the program motion. In this motion, robot performs irreversible propulsion in the desired direction. The crucial role in supporting of this motion belongs to the lateral hydrodynamic force.

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