

# **Analysis on Dynamics of Underwater Robot Manipulators based on Iterative Learning Control and Time-Scale Transformation**

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Currently, underwater robots are not sufficient to replace divers. The manipulator operations are limited to simple tasks because the manipulators are relatively much smaller than the body of the underwater robots. The development of multidegree-of-freedom underwater manipulators instead of the diver's arms is an important challenge from now on.

Dynamics analysis is very important for motion control. In the case of the underwater robot manipulators, fluid dynamics should be considered. One of the conventional methods to analyze the dynamics is the computational fluid dynamics. However, it is difficult to analyze the dynamics by the computational fluid dynamics in terms of real-time control or calculation accuracy. Another method combines fluid dynamics with robot dynamics for control and planning. In those methods, however, the dynamic models are briefly expressed by the joint angle, angular velocity, and angular acceleration. It is difficult to treat the complicated fluid dynamics by using those models, when the manipulators move unsteadily in the water.

In this paper, a new method is proposed to analyze dynamics of the underwater robot manipulators for control and planning. The method is based on time-scale transformation. Using time-scale transformation, we can realize the analysis on the complicated nonlinear dynamics of the multidegree-of-freedom manipulators in the water. The reason is that the dynamics can be easily treated by changing scalar quantity "time-scale". In this method, several time-scale functions are used to the analysis. Input torque patterns of the underwater manipulators corresponding to a time-scale function are necessary in the process of the analysis. In this paper, iterative learning control is utilized to obtain the input torque patterns. It is not clear so far that time-scale transformation and iterative learning control are valid for the underwater robot manipulators. Therefore, this research demonstrates the effectiveness of time-scale transformation and iterative learning control for the underwater robot manipulators.

In this paper, at first, iterative learning control for the underwater robot manipulators is theoretically discussed and the effectiveness of the control method in the water is shown through experimental results in which an underwater 1-DOF arm and a 3-DOF manipulator are utilized. Next, the proposed method of analysis on dynamics of the underwater robot manipulators is theoretically explained and the availability of the method is confirmed by the experimental results.