

Theoretical and Experimental Studies on Iterative Learning Control for Underwater Robots

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ABSTRACT

On underwater robot manipulators, high speed and high precision are basic requirements in order to improve efficiency of operations. To satisfy these requirements, feedforward control inputs are crucial. For making feedforward inputs, one method is to estimate all parameters of the robot dynamics, including hydrodynamic terms such as added-mass, drag force and buoyancy. However, the parameter estimation of hydrodynamic coefficients is not suitable for forming the feedforward control inputs of underwater robot manipulators, because it is difficult to model and estimate the hydrodynamic terms. To overcome such a difficulty, we apply iterative learning control to underwater robots. In this paper, we theoretically and experimentally investigate the performance of iterative learning control for underwater robot manipulators. The effectiveness of iterative learning control is demonstrated through several experimental results.

INTRODUCTION

Underwater human operations involve high risks because currents, waves, water pressure and fluid resistance make the operations dangerous, hard and inefficient. For these reasons, many underwater robot vehicles have been studied and developed (e.g. Fossen, 1994; Yoerger, 1985; and George Lee, 2001). Further, underwater manipulators mounted on the vehicles that work in water instead of human arms have been studied, and many papers on manipulators have been published (e.g. Scholberg, 1994; Kato, 1996; Shintaku, 1999; Canudas-de-Wit, 2000; Chung, 2001; and Sarkar, 2001). These papers confirmed the validity of the work through simulation results with some assumptions, not through experimental results. The main reason is that the actual dynamics of underwater robot manipulators with multi-degrees of freedom is very complicated. For example, if we consider 3-D flow velocity into dynamics, it is extremely difficult to treat the direction and magnitude of flow velocity that act on each part of a manipulator's links. In other words, most of the previous works ignored the hydrodynamic factors which cannot be easily modeled.

On the underwater robot manipulators, high speed and high precision are basic requirements in order to improve the operations' efficiency. To satisfy these requirements, feedforward control inputs are crucial. For making feedforward inputs, one method is to estimate all parameters of the robot dynamics, including hydrodynamic terms such as added-mass, drag force and buoyancy. The papers by Rock and his colleagues (McLain, 1995; McLain, 1996; and Leabourne, 1998) have addressed feedforward control based on estimating the added-mass and the drag coefficients through experimental tests. In particular, in Leabourne's 1998 paper, a 2-DOF manipulator was used to estimate the drag coefficients. However, they investigated only those cases where the second joint of the manipulator was fixed at some joint angles, because it is extremely complicated to consider the dynamics of

general motions where the first and second joints move simultaneously. In consequence, it may be concluded that the parameter estimation of hydrodynamic coefficients is not suitable for forming the feedforward control inputs of underwater robot manipulators, or conventional modeling technique is not useful for forming the feedforward input of underwater robot manipulators.

To overcome such a difficulty, we apply iterative learning control to underwater robots. In this control, feedforward inputs are obtained by repeated trials. To be more precise, feedforward inputs are modified by velocity or acceleration errors of the motion at the previous trial. This iterative learning control had been proposed for robots in the air. The effectiveness of the control was theoretically and experimentally demonstrated. In the learning control, it is not necessary to estimate the parameters of object dynamics, because only the relation between inputs and outputs is required. Moreover, even though there are some disturbances which cannot be easily modeled, the desired motion is realized if the disturbances are repeated. Instead of parameter estimation, the output dissipativity condition of systems is crucial for learning desired motions. If robot manipulators move in the air, the output dissipativity of systems is theoretically proven. In practice, robots can learn desired motions after several trials in the air.

In applying learning control to underwater robot manipulators, we should note that there are repeated disturbances and unrepeated disturbances in dynamics, and the influences from repeated disturbances can be eliminated by learning control even though the repeated disturbances cannot be easily modeled. Of course, in the case that unrepeated disturbances are significantly large, learning control cannot attain sufficient performance. In our previous work (Kawamura, 2002), we experimentally demonstrated the usefulness of iterative learning control. However, it was not theoretically clear whether or not the learning control is effective for underwater robot manipulators.

In this paper, we theoretically and experimentally investigate the performance of iterative learning control for underwater robot manipulators. At first, an assumption is theoretically given to satisfy the output dissipativity condition for underwater robot manipulators. Then, the effectiveness of iterative learning control is demonstrated through experiments, in which 1-DOF and

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