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Position Control of Single link Underwater Robot Manipulator

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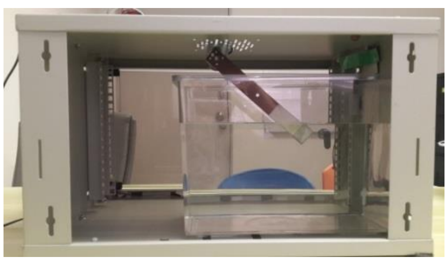
Graphical abstract



Abstract

This paper presents the responses of underwater manipulator control using conventional PID controller. Underwater manipulation tasks are difficult due to the presence of water as its environment. Many underwater vehicles invented incorporate underwater manipulators which could be used for underwater rescue, recovery or operations such as welding or ship repair. It is desired to investigate the position response of underwater manipulator using conventional PID control without modelling the dynamics which includes motion in water. For this purpose, a single link manipulator was experimented and compared between the response of the manipulator underwater and the manipulator without water to compare accuracy of the position tracking. Two different reference trajectories were given, namely step and varying frequency position control.

Keywords: Underwater manipulator, position control, PID control

Abstrak

Kertas kerja ini membentangkan respon kawalan pengolah bawah air menggunakan pengawal PID konvensional. Tugas-tugas pengolah bawah air adalah sukar kerana wujudnya air dalam persekitarannya. Banyak kenderaan bawah air yang dicipta menggunakan pengolah bawah air yang digunakan untuk operasi menyelamat bawah air, atau operasi seperti kimpalan atau pembaikan kapal. Adalah diinginkan untuk mengkaji respon kedudukan pengolah bawah air menggunakan kawalan PID konvensional tanpa memodelkan dinamik yang memasukkan gerakan dalam air. Untuk tujuan ini, eksperimen pautan tunggal pengolah bawah air dijalankan dan dibandingkan dengan respon pengolah bawah air tanpa persekitaran air untuk membandingkan ketepatan pengesanan kedudukan. Dua jenis trajektori rujukan digunakan, iaitu rujukan *step* dan kawalan kedudukan dengan frekuensi yang dipelbagaikan.

Kata kunci: Pengolah bawah air, kawalan gerakan, kawal PID

1.0 INTRODUCTION

Throughout the years, underwater systems have evolved rapidly due to the exponential progress of accessible technology which includes microcontrollers, sensors and actuators. This includes not only underwater vehicles, but also robot manipulators which are designed for use in underwater applications. Researchers in [1] developed a new underwater robot arm for underwater intervention in shallow waters. Of the eight commercially available underwater lightweight robot arms they compared, three are designed from electrical actuators, namely CSIP, Ansaldo and Mitsubishi (UNION project). The workspace, manipulability, mechanical design, control software architecture were explained. Researchers assembled a robot arm and tested the grasping capabilities by manipulating (operation of recovery) a flight data recorder (FDR) black box underwater. The position responses were recorded.

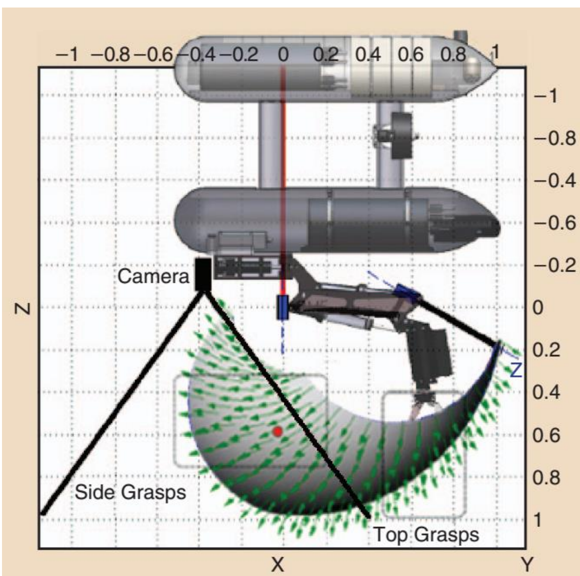


Figure 1 CSIP underwater robotic arm [1]

The idea of implementing the underwater robotic arm is by attaching it to an underwater vehicle and allowing a camera to see the movement of the manipulator to reach the target. While researchers in [1] investigated the attachable robot arm to an underwater vehicle, a Seabed mobile robot was proposed by researchers in [2]. They proposed the mobile robot with 2 arm-combined legs (weighing 44 kg each) and 4 dedicated legs (weighing 55 kg each) for locomotion underwater, CRABSTER200 (CR200). For the six-legged robot, the torques of each motors were determined and 10 kg weight lifting test was done by using one of its manipulators. Furthermore, investigations were done on the walking capabilities by testing posture change tests which includes sitting, standing and lifting postures. In more recent publications, the researchers tested CRABSTER200 in actual underwater environment.

Figure 2 CRABSTER 200 with 4 dedicated legs and 2 arms [2]

Authors in [3] developed a removable underwater manipulator equipped with a camera at the end effector of the manipulator. The manipulator is a 5 DOF, 2 kg payload and 20 m pressure resistant design, is attached to a main body which floats. Experiments were performed in two different environments, tap water and sea water at the beach. Data from the manipulator's camera and sensors were fed to the main body via wired Local Area Network (LAN) while data transmissions from the main body to the PC were done via wireless LAN.

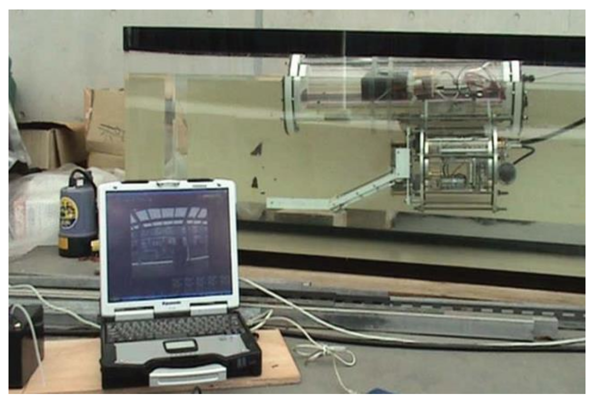


Figure 3 Underwater manipulator tap water experiment [3]

Several papers discussed different control methods for underwater manipulator fixed to an underwater vehicle [4], [5], [6], [7]. In [4], dynamic modelling, simulation and control were done on an underwater vehicle equipped with two degrees of freedom (DOF) planar underwater manipulator with all its joints revolute. Performance analysis and manipulator tracking control were performed in numerical simulations. PID controller feedback linearization was used and control was achieved in XYZ axis for the vehicle and XZ axis for the manipulator. Authors in [5] proposed a novel hybrid control method for a 7 function, 6 DOF, hydraulic underwater manipulator which can operate in a depth of 3000 m. Control was achieved via the CAN-bus structure and neural network was combined with the fuzzy CMAC structure. Simulation results show high precision trajectory tracking. In [6], time-optical control method was investigated for underwater manipulators based on iterative learning control and time-scale transformation. The input torque pattern that realizes the minimum-time motion can be formed from the basic torque patterns by using time-scale changing. For motion planning, it is not necessary to estimate any physical parameters such as hydrodynamic parameters. Researchers in [7] investigated coordinated control of multiple arm manipulators, although their experiments were done on one arm attached to an underwater vehicle.

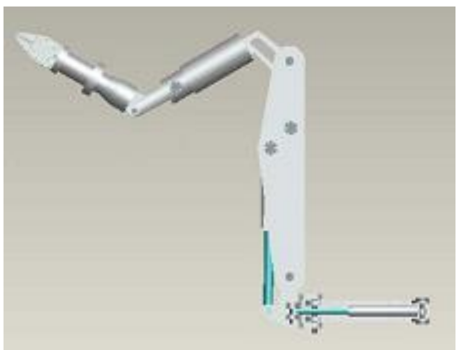


Figure 4 The underwater manipulator used for the hybrid control method [5]

The concern in underwater robotics is quite clear. Due to the manipulation environment which is underwater, accurate responses are needed for manipulation. This is to ensure rescue and recovery operations, ship repair could be run smoothly to avoid any casualties or fatalities to humans, as it is one of the significant points of using underwater manipulators.

2.0 SINGLE LINK UNDERWATER ROBOT MANIPULATOR

Although the previous researchers have done extensive investigations in underwater robot manipulators, our attempt is to investigate the position response of a single link underwater robot manipulator. The part which is submerged underwater is not the electrical motor but the link, as shown in Figure 5.

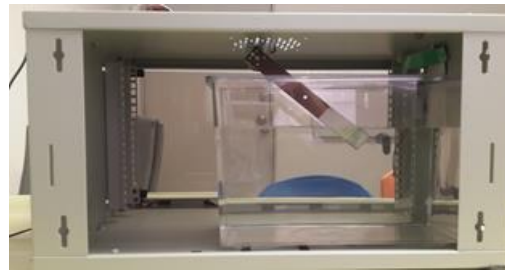


Figure 5 Single link underwater robot manipulator

In environment without water, the link is affected only by the load and gravitational effects. As seen in Figure 1, the control circuit and drivers are placed on the metal frame which has no contact with water; hence no waterproof seal is required. It is intended to investigate the link's position response with and without water for this setup.

The specifications of the DC motor are shown in Table 1.

Table 1 Specifications of the DC motor used in the experiments

Parameter	Value	Unit
Input Voltage	12	V
Speed	26	Rpm
Torque	588	mNm
Weight	160	G
Power	1.1	W
Diameter	37	mm
Length	27	mm

3.0 POSITION CONTROL

The position control of the single link manipulator uses PID controller with proportional (P), integral (I) and derivative (D) gains which are arbitrarily tuned according to critical damping characteristic equation. Two different experiments were performed, one with the medium of water and another without. No simulation modelling was done as the purpose of the experiment is to compare the position tracking with and without water. The flow of the experiments is shown as in Figure 6.

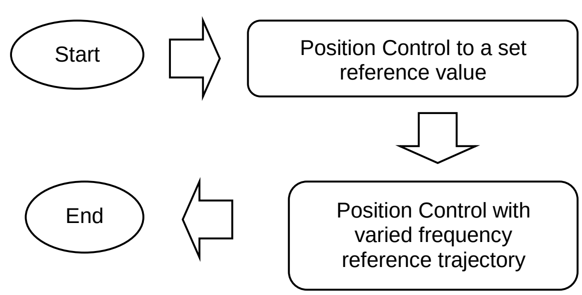


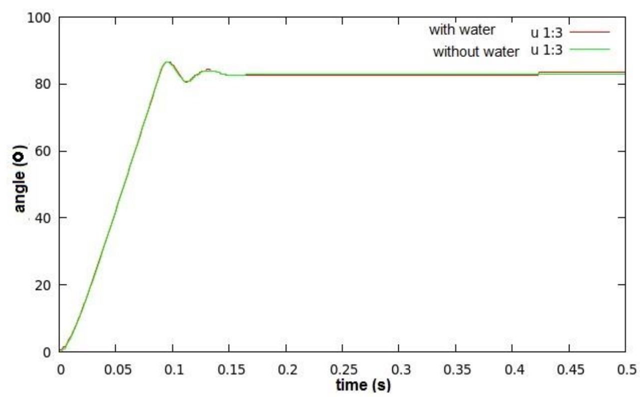
Figure 6 Flow of experiment for the single link underwater manipulator

At the initial position control to 83 degrees, a step reference trajectory was given, assuming the horizontal line as zero degrees. At this point, the link of the manipulator (at the end) is submerged underwater. Then the second phase of the experiment is performed by giving a varying frequency reference trajectory with amplitude of 30 degrees. The equation of the reference trajectory is given as in Equation (1).

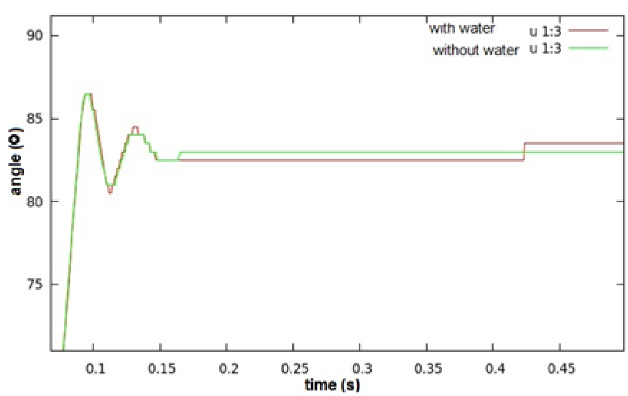
$$\theta_{ref} = -30\,(\sin(2\pi t^2)) \qquad (1)$$

4.0 RESULTS AND DISCUSSION

Position data are acquired from the incremental rotary encoder attached to the DC motor, which is read by the microcontroller which then sends the output via serial to the Serial Monitor on the PC at baud rate of 115200 bps. The data which has a sampling of 1ms are then plotted.



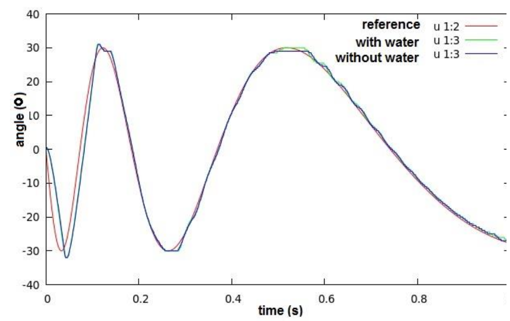
(a)



(b)

Figure 7 Step response of single link manipulator (a) and zoomed-in view (b)

The step response shown in Figure 7 shows the change of position from a horizontal position to a position less than 90 degrees. Although the responses seem similar, there is a slight difference visible in the right side of Figure 7(b) which shows that the step response with the water as a medium is more accurate than without. Next the responses of the varying frequency sine wave reference trajectory are shown.



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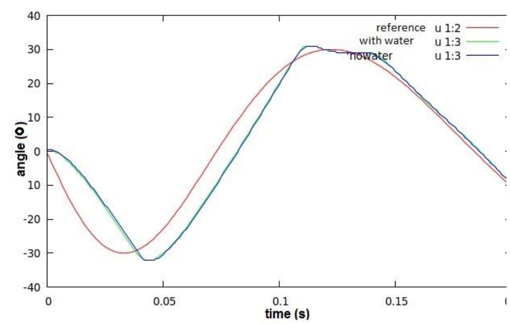
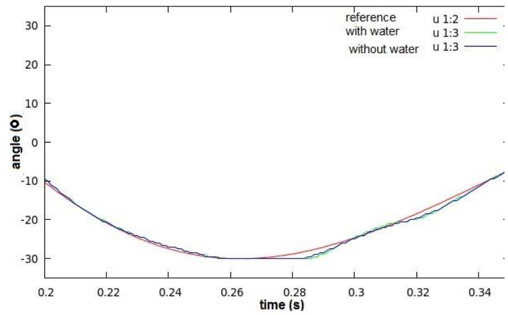
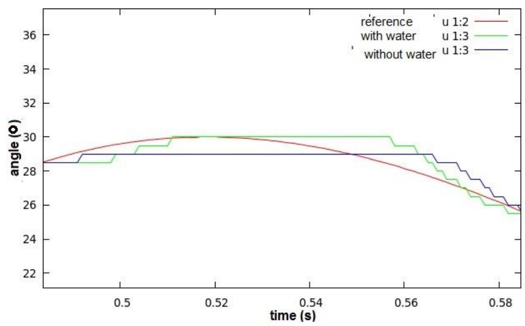


Figure 8 Varying frequency sine wave response (a) and zoomed-in view (b)

Figure 8 shows the varying frequency sine wave response, with the red line as the reference trajectory, green line as the response with water and the blue line is the response without water. The magnified view of the response (right side of Figure 8(b)) shows almost similar results between green and blue line. If zoomed in closely (Figure 9(a) and (b)), the response with water shows a better response.



(a)



(b)

Figure 9 Varying frequency sine wave response (a) and zoomed-in view (b) between 0.2 s and 0.6 s

5.0 CONCLUSION

To summarize the results, that position tracking with PID controller can be achieved underwater by using the same gains without the medium of water. Experiments tested step reference and varying frequency sine wave reference trajectories. In both trajectories, tracking was achieved and showed that better response was shown in the case when the link is submerged underwater. The reason behind this is because without water, the experimental setup is affected by gravity due to the pendulum-like setting of the apparatus. With the presence of water, gravity is different due to the presence of buoyancy. It is intended in future work, to investigate the responses of the position control in different motions, in which buoyancy will help reduce the control effort and increase accuracy.

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