ACTIVE VIBRATION CONTROL OF TWO FLEXIBLE LINK UNDERWATER MANIPULATOR

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ABSTRACT

In undersea conditions, there are unknown disturbances or vibrations, that are required to be taken care of. It is very difficult to achieve steady state once base of underwater manipulator (UM) vibrates in underwater condition. In this regard an attempt has been made to develop and implement active vibration control strategy for two link flexible UM. Information from base and joints through jacobian are fed to the controller. Controller, accordingly, actuates the force to makeup external disturbances to achieve steady state. A bond graph model has been created in SYMBOL sonata® software. Simulation output shows the efficacy of the developed active controller.

Keywords: Active vibration, Underwater Manipulator, Bond Graph, Control, Jacobian author's kit.

1 INTRODUCTION

Regular disturbances in oceans are major issues to be taken care for underwater vehicles and robots (UVR). There are number of control strategies for control of UVR but, to take care of vibrations due to regular disturbances need to be addressed for stability. In case of Underwater robot manipulator (URM) it becomes tedious to control end effector once base is unstable. Many researchers have developed or implemented some control strategies like adaptive control, PID control and many other for stability of UVR and URM trajectory or impedance control. Vibration control has been well taken care for on ground conditions through linear and nonlinear strategies (Ibrahim 2008 and Thomsen 2021). In these cases, vibrations are controlled by using passive or semi-active or active controllers. Innovative electronic micro components have played vital role for actuation, sensing and controlling through active control (Janocha 2007 and Brahms 1998). For on ground manipulator vibration control, integrated circuits with cantilever beams have been considered using different algorithms. Feedback system is one of the popular approaches to damp the oscillating base (Nenchev et al. 1996, Nenchev et al. 1997, and Lew and Moon 1999). Fuzzy logic based active damping is also one approach for control of vibration (Lew and Moon 2001, George and Book 2003, Lin et al. 2007, Zhilenkov et al. 2021 and Hongdu et al. 2020). The error in the trajectory can be revealed to diminish vibrations to achieve the desired path (Yoshida et al. 1999). To model and simulate vibration control, different modeling techniques are available. One of the techniques, Bond Graph has been implemented effectively for the modeling and control of robot manipulators (Pathak et al. 2008, Ghosh 1990 and Kumar and

ICBGM'2021 Nov 8-10, 2021- San Diego, California USA - ©2021 Society for Modeling & Simulation International (SCS)

Mukherjee 1989). Holterman 2002 has implemented passive based active control law using bond graph for vibration control of mechanical structures. Some authors have attained steady state condition of different systems in respect of active vibrations (Hassan et al. 2007, Tomac et al. 2010 and Gonzalez and Jorge 2010). Underwater command shape method is also a successful method to reduce vibration effect on the flexible rod used in underwater conditions (Shah et al. 2017). Biomimetic UVR has been controlled by one of the researchers using flow-aided navigation system by detection of hydrodynamic domain (Salumäe and Maarja 2013). Wang and Yang 2015 has developed model predictive control for reducing vibration of UVR by simplifying dynamic model. Ilya D. Ilya et al. 2018 has integrated pneumatic circuits as muscles fixed with UVR body robustly to reduce the external disturbance effect.

Present work is an extended research of the authors (Kumar et al. 2018) in which model of active vibration has been developed using bond graph and implemented on the base of single arm UMR. In present paper model of active vibration developed in bond graph has been discussed. Bond graph model of base, link and controller are modeled as capsules and further integrated. Capsule of arm modelled in bond graph is based on Euler Bernoulli methods. Simulation shows the efficacy of implementation of active vibration control model on two arm URM.

2 MODELING OF ACTIVE CONTROLLER

The active vibration control implemented is based on sensors and actuators in the system and is controlled due to the generation of the signal (Kumar et al. 2018). The resulting response is achieved by the connection of feedback to controller. The simulation is carried out on a straight-line graph, as shown in the Figure 1. The physical diagram shows the arm connected with the base through controller revealing that the controlled information from the arm is passed to the base. of one arm robot manipulator. The bond graph model shown in Figure 2 represents single arm robot manipulator (on-ground) in which lower part represents the base and upper part represents the link of robot manipulator. The flow information is measured through bond no 2 and 29 and feedback is given to the controller by source of flow SE 20 considering the moment of base and tip as shown in upper right part of figure.

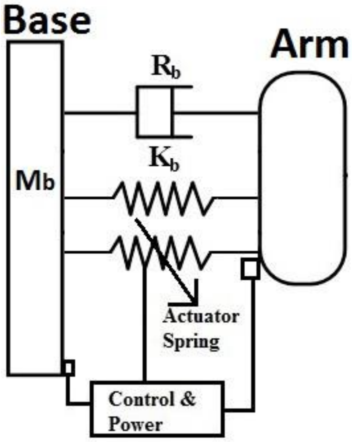

Figure 1. Schematic diagram of Active vibration control of two arm robot manipulator (Kumar et al. 2018)

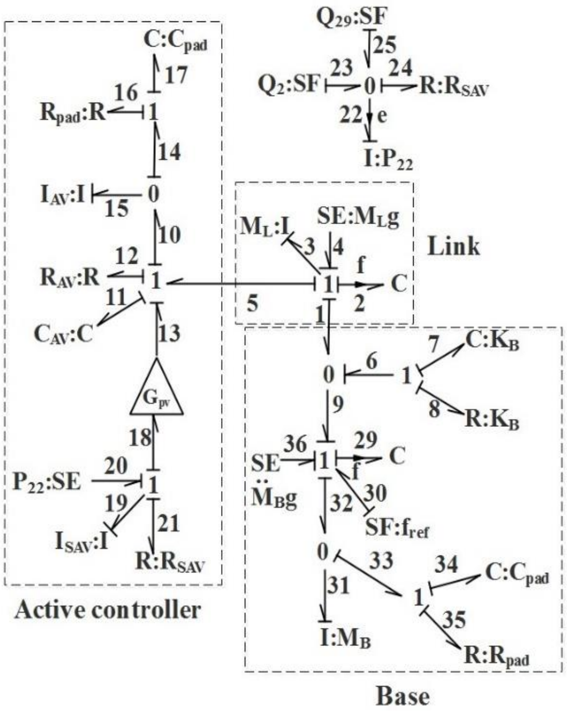

Figure 2. Bond graph of Active vibration control

Further, the information is sent to manipulator through gyrator Gpv. To remove the differential casuality, pads are attached by adding R and C element with bond 16, 35 and 17, 34. To reduce their effects on the system, high value of R and C are considered. IAV, RAV, KAV, ISAV and

RSAV are the parameters of active controller. Simulations are performed for different cases and initially these parameters are chosen by hit and trial method. To demonstrate the efficacy of active controller, it is applied on a single and two flexible link URM for welding, which is being discussed in next sections with simulation results.

3 ACTIVE VIBRATION CONTROL OF TWO ARM UNDERWATER ROBOT MANIPULATOR

An active vibration control strategy has been implemented for reducing end effector vibration. The modeling has been carried out by means of the establishment of the bond graph capsules of base, arm and active vibration controller and further integrating them for carrying out simulation.

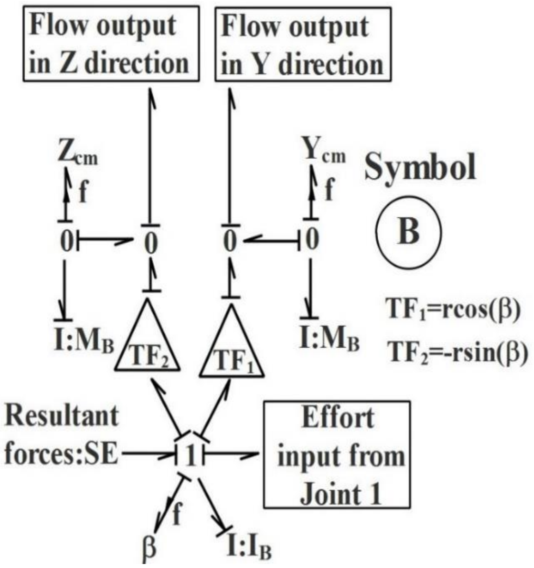

Figure 3. Bond graph model of base for URM.

The capsule bond graph of the base for URM is shown in Figure 3, in which the inertial element I attached to '1' junction represents the mass MB of the base for URM. The inertial element I attached to '1' junction in the lower part of bond graph represents the robot base inertia with respect to frame {B}. Source of effort SE attached to '1' junction in lower part of bond graph represents the resultant of dynamic forces acting on the base and link. This external force is applied for the stability of the robot. The symbol β attached through flow activated bond in lower part of bond graph provides the information about rotation of base. The flow information in Y and Z directions are passed over to link from lower '1' junction through transformers in respective directions. With lower '1' junction, bond is attached to take effort information form the first joint, which is related to torque given by the motor. Ycm and Zcm attached to '1' junctions represented by the half arrow with full arrow in center provide information about the position for CM of base.

The detectors of effort and flow are represented by the half arrow with full arrow in the center of bond as an activated bond. Capsule bond graph of base is symbolized with 'B', in integrated bond graph. The underwater conditions are imparted through SE in figure 3 which represents the resultant of different forces acting on the base in underwater conditions.

Total dynamic force of underwater manipulator is given by ((Kumar et al. 2014 and Kedar and Pathak 2007).

$$(P,\tau) = (m)\left(\dot{V},\dot{\omega}\right) + (m_C)(V,\omega) + B + G + H$$

Where, (P,τ): External input forces and torques, (m) : Mass and added mass-inertia matrices, (m_C) : Coriolis and centripetal matrices, B : Buoyancy force matrix, G: Gravity force matrix, H: hydrostatic pressure. Figure 4 shows the strengthening of the portion of the active vibration-feedback controller in the form of a capsule represented by the " AV " in integrated bond graphs as discussed by the author in earlier paper presented in ICBMG 18 (Kumar et al. 2018).

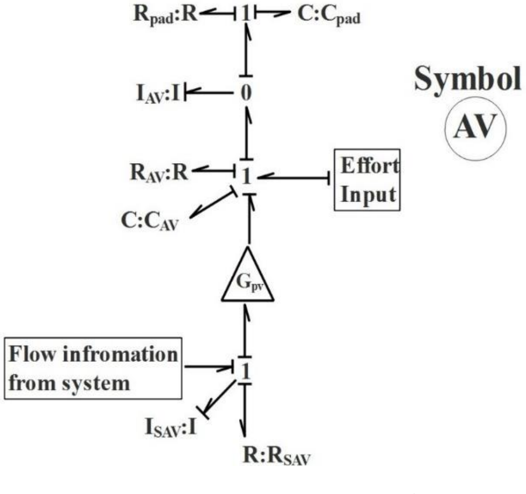

Figure 4. Bond-graph subsystem of an active vibration controller

It has been assumed that during the end effector movement the base of the URM is stationary, the added mass effect and coriolis due to arm moment is very less and thus first two terms of above equation are neglected.

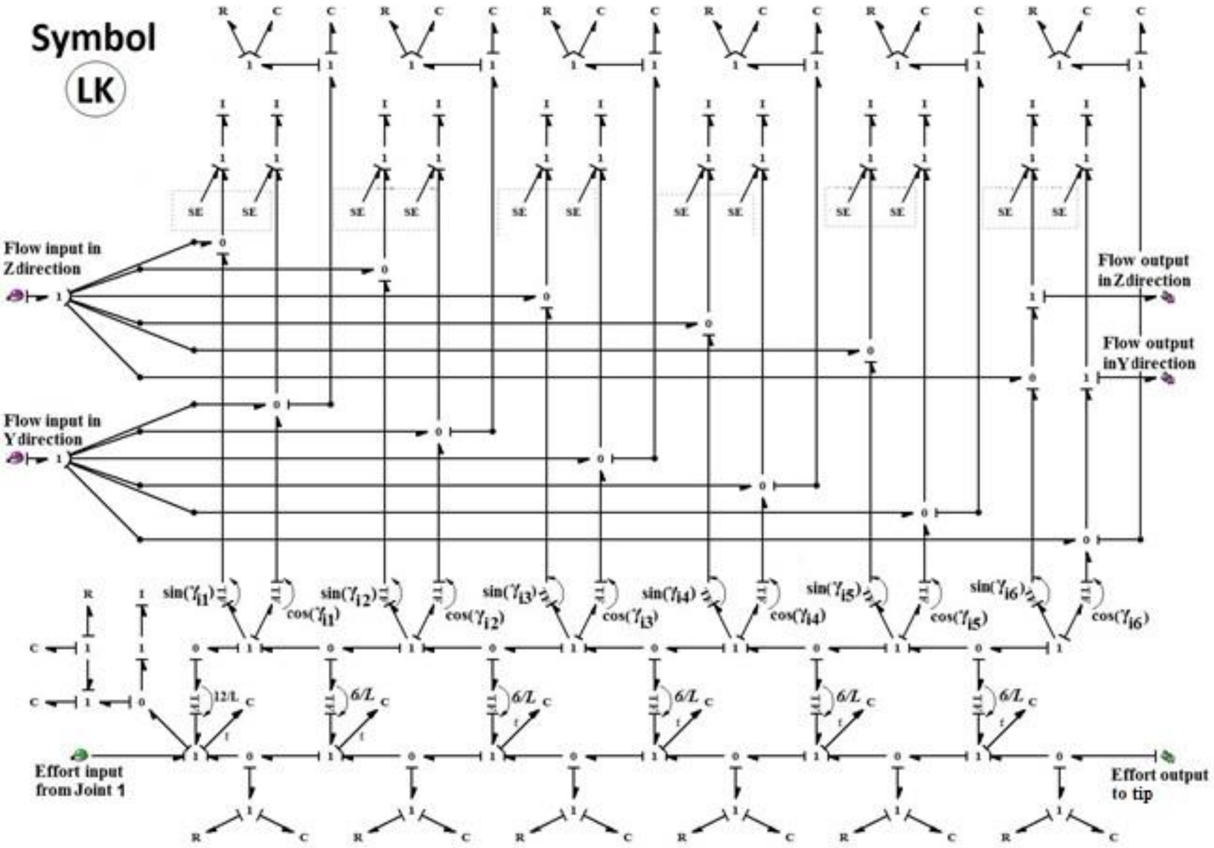

Figure 5. A capsule bond graph model of the flexible arm

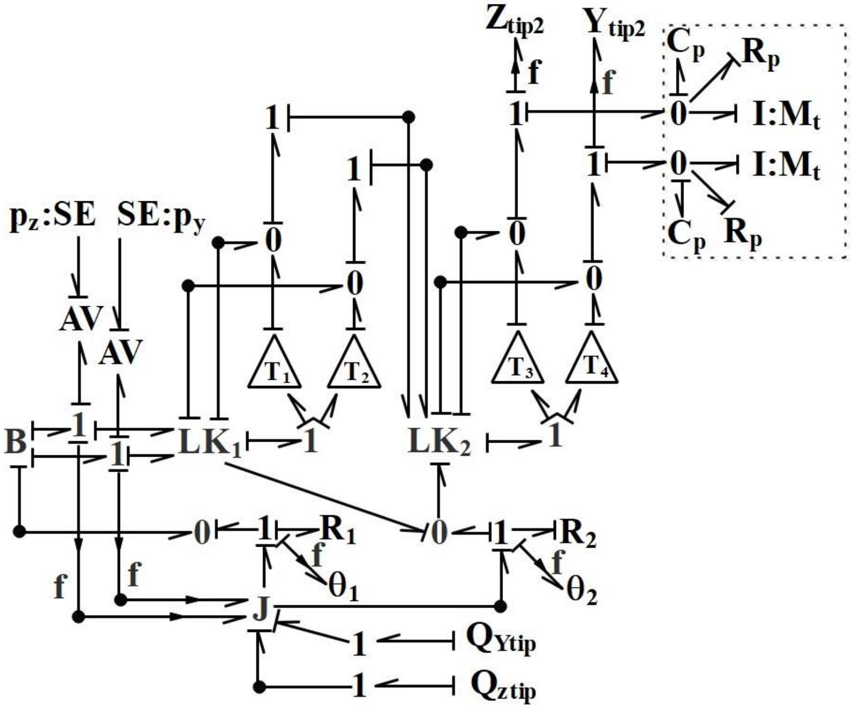

Figure 6: Integrated Bond graph model of two flexible arm UM with active vibration controller.

Figure 5 shows the sub system of flexible single arm bond graph capsule modelled according to the Euler Bernoulli beam model. Beam is discretized in six segments, as discussed by the author in earlier paper presented in ICBMG 14 (Kumar et al. 2014). The effect of underwater conditions on arm is imparted through the SE effort attached at the upper part of the capsule bond graph of arm. Figure 6 is the integrated bond graph model for two arm UM with active vibration controller. The effort signal pz and py are sent to 'AV' (active controller) in respective directions after considering the flow signal of end effector, which is attached to second link and also to center of base. Rp and Cp are pads attached to the sub system for computational simplicity i.e., to avoid the differential casuality and values of pad coefficient are kept high to reduce the effects of the model. The transformer moduli T1, T2, T3 and T4 convert rotational velocities of link in Z and Y components (Kumar et al. 2014).

4 SIMULATION AND RESULTS

To validate the steady state behaviour and effectiveness of active vibration controller, simulation study is carried out. It is assumed that the base of UM is to be in static condition. Initially, the vibration in the underwater robot manipulator is produced by exerting an external force on the base in Z direction. The input parameters for simulation are presented in Table 1Table. The simulation run is carried for 10 seconds so that steady state behaviour is achieved.

Table 1 Parameters used for modeling of two flexible arm UM with active vibration controller

S. No.	Parameter	Nomen-clature	Values
1	Modulus of Elasticity	E	$7 \times 10^{10} N/m^2$
2	Link Length	L	0.5m
3	Moment of inertia of cross-section of link	I	$2.13 \times 10^{-7} m^4$
4	Density of Aluminum (alloy)	ρ	$2700\ kg/m^3$
5	Cross section area of link	A	$1.6 \times 10^{-3} m^2$
6	Joint resistance	R_1 R_2	0.001Nm/(rad/s) 0.01Nm/(rad/s)
7	Acceleration due to gravity	g	$10\ m/s^2$
8	Mass of link	m_L	0.5kg
9	Volume of link	V_L	$8 \times 10^{-4} m^3$
10	Mass of base	M_B	50kg
11	Moment of Inertia of space vehicle	I_B	10kg-m²
12	Volume of base	V_B	0.216m³
13	Distance between base CM to first link joint	r	0.1m
14	Gain value	G_{pv}	2
15	Controller parameters	C_{AV} R_{AV} I_{AV} I_{SAV} R_{SAV}	4.17e-5 0.8 0.021 1 1
16	Surface Area of link	A_s	0.02
17	Fluid density	ρ_L	1000kg/m3
18	Depth	H	10m
19	Mass of welding torch	M_t	1kg
20	Torque	τ	1.0 Nm

The vibration due to injected external force in Z direction is balanced by using an active vibration controller until steady state behavior is achieved, which is exhibited by simulation results. Figure 7 (a) shows the deflection of base in Z direction, which depicts that steady state of the base is achieved within 6 seconds and the maximum deflection is approximately 0.002 m produced initially during simulation.

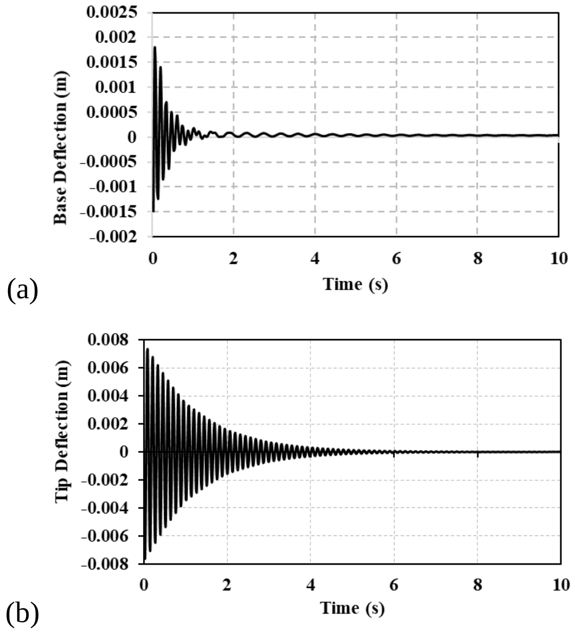

Figure 7: a) Plot for the deflection of base and b) Plot for the deflection of tip.

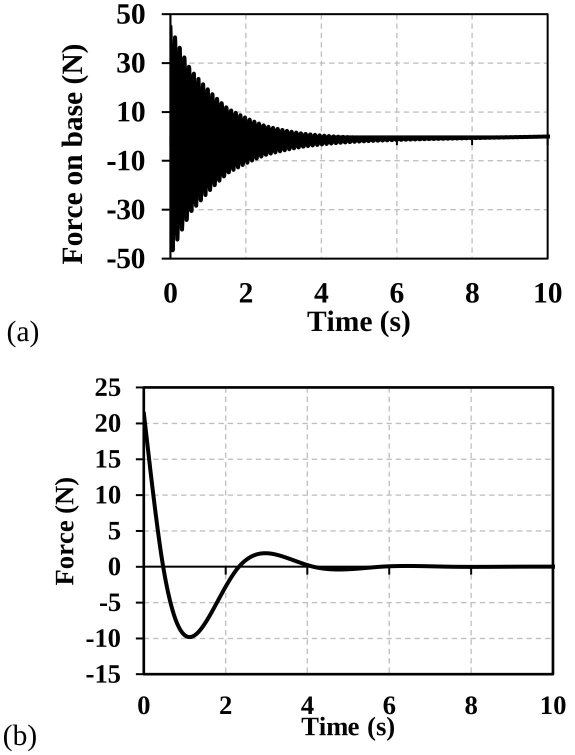

Figure 8: a) Plot for the force acting on base and b) Plot for the force sent by controller.

The deflection of welding tip of the robot manipulator is shown in Figure 7 (b). The maximum deflection observed is 0.006 m initially and it reduces further in sinusoidal manner achieving the steady state within 8 sec. Figure 8 (a) illustrates the sinusoidal reduction in the force acting on the base of underwater robot manipulator. Figure 8 (b) exhibits the available force provided by active controllers to the base to balance the injective external force.

5 CONCLUSIONS

Active vibration controller implemented is novel in modeling using bong graph technique for the control of vibration in underwater conditions and demonstrated by considering two arm UM. The developed controller is unique in its application to robotic manipulator and achieves a steady state behaviour. The controller implemented, has considered the vibration of both the base and the tip of the URM and it controls the system effectively and the steady state has been achieved. The bond graph model of vibration controller for single flexible link URM for welding has been created. Simulation has depicted that; steady state of base and tip has been achieved within 4 seconds and 6 seconds respectively. It is also observed that active controlled URMs have a negligible steady state error at the base and at the tip. They have performed effectively in presence of external disturbance, which has been injected through an external force. Thus, the proposed active control strategy is successfully validated by simulation results.

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