Comparative study of Trajectory Control methodologies for Underwater Flexible Rayleigh Robot Manipulator using Bond Graph Approach

*Sumit Kumar, Sunil Kumar

*Department of Mechanical Engineering, Sant Longowal Institute of Engineering and Technology, Sangrur, Punjab, India

ABSTRACT- *The use of underwater robotic manipulator has widened the reachability of human being for the various tasks and thus requires the addressing of various issues related to the underwater robotic manipulators. The comparison of trajectory control of flexible robotic manipulator using various controller is prime focus of this research paper. The controllers like PID, Overwhelming and PI are used to control the flexible robotic manipulator modelled as Rayleigh beam using the bond graph approach. It has been founded that overwhelming control strategy has been the best control strategy among the others under the stipulated testing environment.*

Keywords: PID controller, PI controller, overwhelming controller, trajectory control, flexible manipulator, Bond graph.

I. INTRODUCTION

The manipulator control refers to the control of the manipulator arm by controlling the joint actuators so that the end-effector can reach the desired location. This is also known as trajectory control and it also includes environmental disturbances. Both direct and inverse kinematic can be used for trajectory planning. Due to the presence of non-linearity, transient behaviour and uncontrollable external factors the control of the manipulators becomes quite cumbersome. The widely used linear controllers are incompetent to address various issues of underwater system. [5] The authors have designed the controllers using sliding mode control technique, which works effectively due to decrease in model uncertainty causing more precise prediction of trajectory.

[16] The adaptive control strategy has been used for controlling the nonlinear dynamics industrial robots. [15] the authors studied the dynamic model of the ROV with adaptive control strategy. [13] The author deployed (ADOB) controller for underwater robots to counter the external disturbance. [9] The researchers have designed a trajectory controller for an underwater AUV and the analysis was done using bond graph modelling. [6] The author worked on both position and speed control of autonomous underwater vehicles (AUV). [10] The authors did the optimization of robust controller for an AUV manipulator system. They used the overwhelming concept. [15] The researchers worked with overwhelming controller to control a hydraulically driven 3 d.o.f parallel manipulator. The physical model based design of the controller is done with the help of bond graphs. [1] The author discussed the concept of overwhelming controller. He used the overwhelming control for the joint control of the manipulators. The authors [19] modelled the underwater robotic manipulator as Rayleigh beam and did the trajectory control of the same manipulator using overwhelming controller [18].

II. CONTROL STRATEGIES

There are various tailored control strategies available for the flexible manipulator, but this paper discusses the trajectory control issues of the flexible robotic manipulator considering the application of PI, PID and overwhelming controller. The PI controller refers to Proportional-Integral controller where controller applies force proportional to the error in position of the system as well as force proportional to integral of positional error. The PID controller is knows as Proportion-Integral-Derivative Controller

and in this case the controller applies the force in similar behavior to the PI controller with addition to a force proportional to the derivative of positional error i.e. velocity. The generation of force here is governed by the future position of the manipulator.
The overwhelming controller also known as robust controller treats the system in another way in manner that it does not determine the control inputs on the basis of inverse dynamics of the manipulator rather it assigns a ghost mass to the system in order to eliminates the effect of very small and difficult to estimate characteristics like friction, backlash, inertia etc. The ghost mass overwhelms any changes in the system and provide corresponding feedback resulting in robust control.

The bond graph models of the PI, PID and overwhelming controller are shown in following figures.

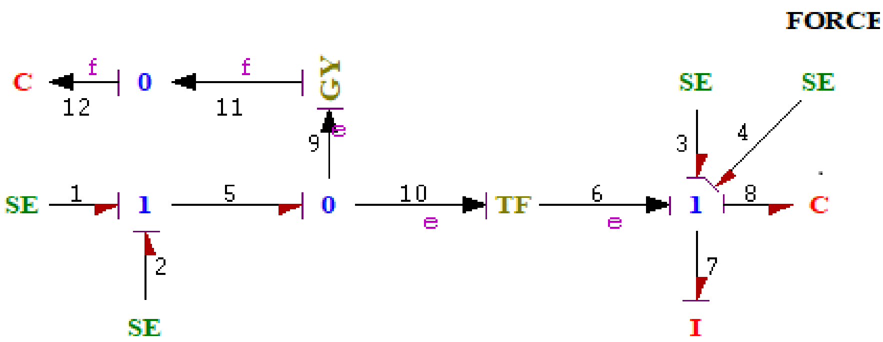

Figure 1: PI controller a BG model

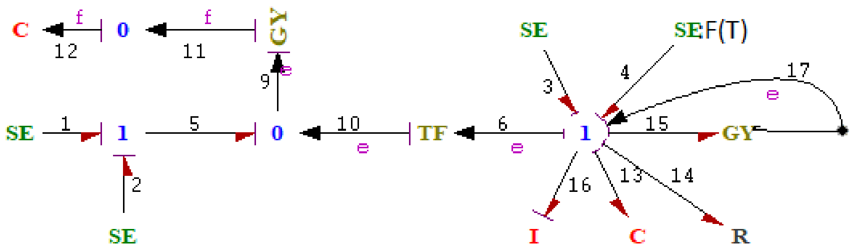

Figure 2: PID controller a BG model

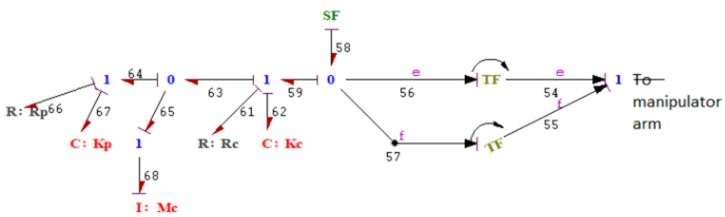

Figure 3: Overwhelming controller a BG model

III. UNDERWATER FLEXIBLE MANIPULATOR

The flexible manipulator for the underwater application is modeled as a Rayleigh beam. The dynamics of underwater environment is considered to have buoyancy force, gravity force and hydrostatic force. The surface waves do not affect the robot maneuvering at the depth of 30m or more. The following equation presents the total dynamic model of the underwater manipulator vehicle

$$(F,\tau) = (M+\bar{M})(\dot{V},\dot{\omega}) + (M_C+\overline{M_C})(V,\omega) + B + W + (D)(V,V^2)$$

where,

ω: Angular velocity matrix

D: Damping forces

(F,τ): External input forces and torques.

W: Gravity force matrix

$(M_C+\overline{M_C})$: Coriolis and centripetal matrices

V: Linear velocity matrix

$(M+\bar{M})$: Mass and added mass-inertia matrices.

B: Buoyancy force matrix.

The physical description of underwater flexible manipulator is shown in the figure 4. The position and orientation of the arm is given by the absolute frame {A}. Frame {2} is located at the tip of the manipulator and r is the distance between CM of the vehicle and robot base. The rotation of the vehicle frame with respect to absolute frame is given by Angle (φ) and the rotation of joint with respect to absolute frame is given by angle (θ). The base incorporates the joint motor. The mass of the joint motor is m_1 and (τ) is the torque applied by it on the link.

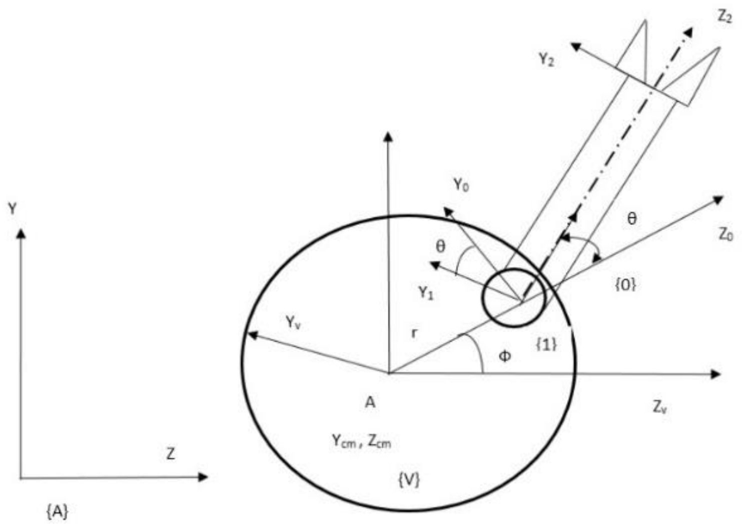

Figure 4: Representation of 1 DOF manipulator

The bond graph [2]-[4], [7], [8], [11], [12], [14] of the flexible manipulator modeled as Rayleigh beam in underwater situation and is coupled with PI, PID and overwhelming controller. In present work modeling of flexible link of underwater robot is done by considering the arm as Rayleigh beam and mass lumping is done along with the consideration of both lumped inertia of the beam as well as rotary inertia. In addition to this buoyant force, gravity and hydrostatic force is taken into consideration acting in Z-direction. The initially developed model of the reticulated flexible Rayleigh beam is used here.

IV. SIMULATION AND RESULTS

The bond graph methodology is used to simulate the behavior of flexible manipulator in the underwater environment and the trajectory is controlled by using the PI, PID and overwhelming controller. The simulation time is 5 seconds and various input parameters used in simulation are given in Table 1.

Table No.1 Parameters used in simulation

S.NO.	PARAMETER	NOMENCLATURE	VALUES
1	Modulus of Elasticity	E	$70 \times 10^9 N/m^2$
2	Link Length	L	0.45m
3	Moment of inertia of cross-section of link	I	$4.525 \times 10^{-7} m^4$
4	Density of Aluminium(alloy)	Rho	$2700\ kg/m^3$
5	Cross section area of link	A	$1.6 \times 10^{-3} m^2$
6	Gain value	Meuh	10
7	Acceleration due to gravity	G	$10\ m/s^2$
8	Mass of link	Mlink	1kg
9	Volume of link	Vlink	$08\ X\ 10^{-4} m^3$
10	Mass of base	Mv	20kg
11	Moment of Inertia of space vehicle	Iv	5kg-m²
12	Volume of base	Volbase	0.216m³
13	Radius of base	r	0.9m
14	Pad sub model parameters	Cpad, Rpad	cpad=100rpad=1
15	Controller parameters	Kc, Rc,Mc	Kc=0.001,Rc=0.01, Mc=0.5 kg

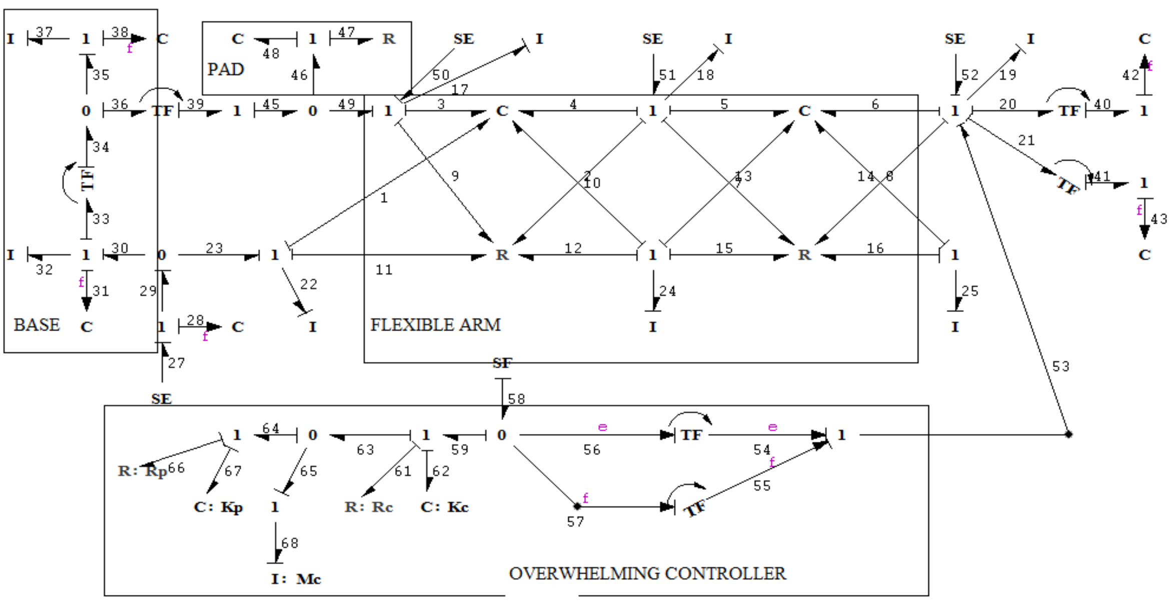

Figure 5: one arm flexible underwater robot with overwhelming controller a BG model

Figure 5 shows the robotic manipulator coupled with overwhelming controller. Figure 6, 7 and 8 shows the change in joint angle with respect to time when the manipulator is used with overwhelming PID and PI controller and the graphs shows that in case of overwhelming controller joint angle decreases exponentially to a maximum value of -1.6 rad. and the trend line is smooth compared to joint angle variation with the use of PID and PI controller. The trend line is much more accurate and smooth in overwhelming, PID and PI controller.The amplitude variation has been reduced with the use of overwhelming controller.

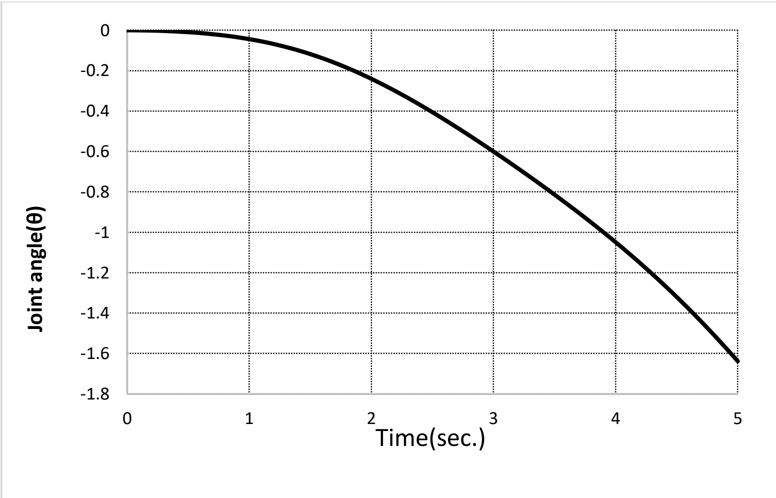

Figure 6: Plot showing joint angle (ϑ) with respect to Time with overwhelming controller

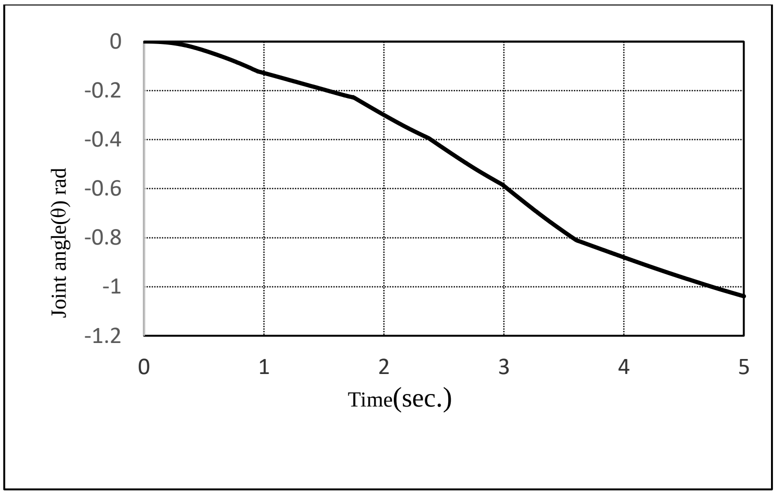

Figure 7: Plot showing joint angle (ϑ) with respect to Time with PID controller

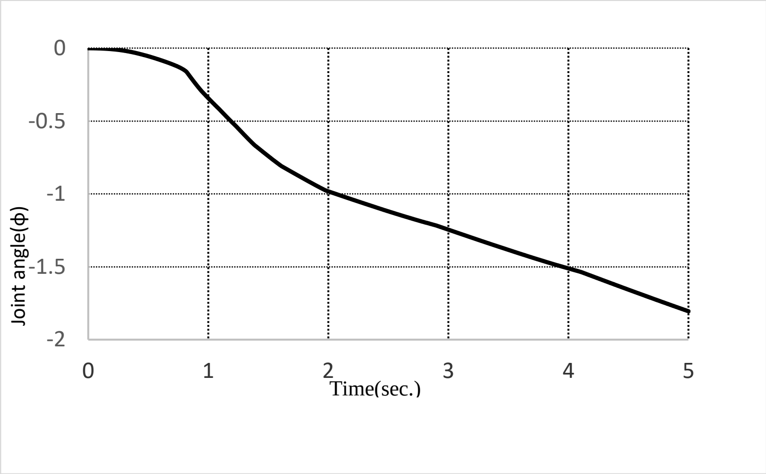

Figure 8:Plot showing joint angle (ϑ) with respect to Time with PI controller

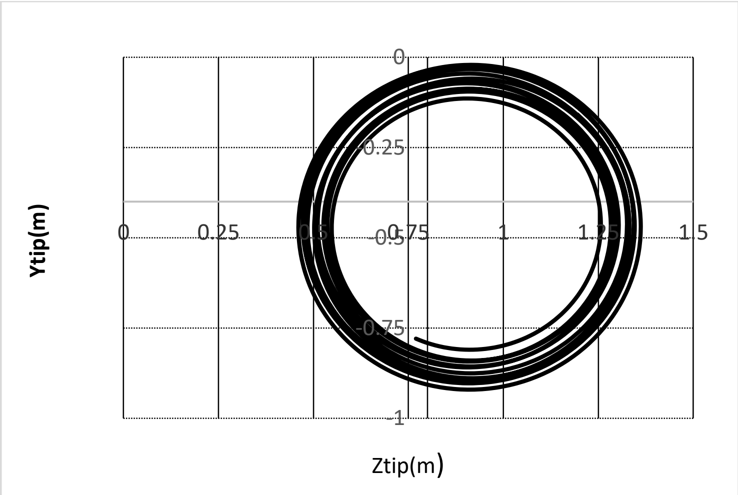

Figure 9:Tip trajectory of one arm flexible underwater robot with overwhelming controller

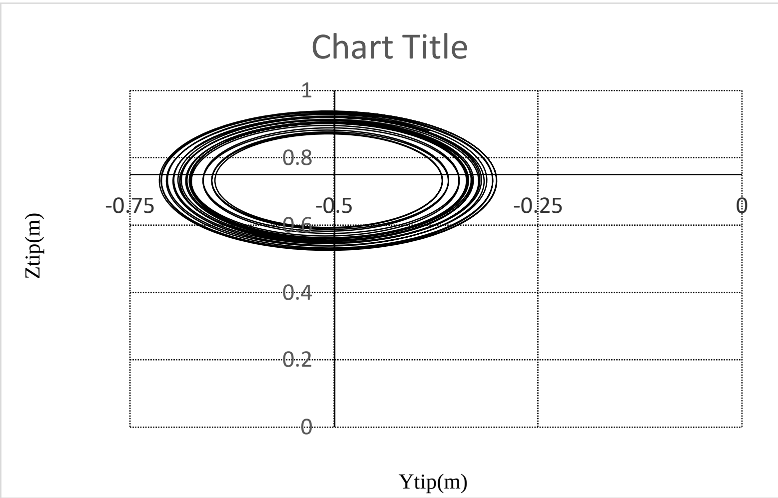

Figure 10: Tip trajectory of one arm flexible underwater robot with overwhelming controller with PID controller

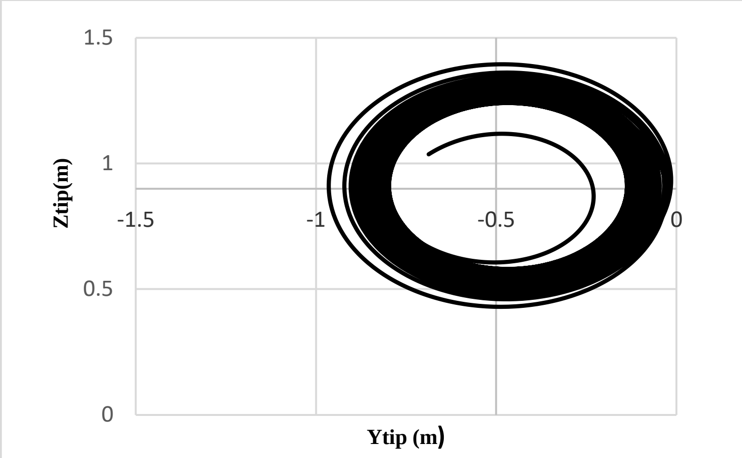

Figure 11: Tip trajectory of one arm flexible underwater robot with overwhelming controller with PI controller

Figure 9,10 and 11 shows the tip trajectory of underwater flexible manipulator arm controller by overwhelming PID and PI controllers respectively. It has been observed that there is significant reduction in amplitude variation with the use of overwhelming controller is 57% and 24.5% for the Z axis and Y axis respectively as compared to PID and PI controller where the variation is 60.3% and 27.9% in Z and Y-axis for PID and 64.2% and 30.1% in Z and Y-axis for PID controller. Also, the with the use of overwhelming controller the TIP follows the predetermined path in better way than the PID and PI controller.

V. CONCLUSIONS

The Bond graph modeling approach is used to compare the control behavior of manipulator arm in the underwater environment. Various forces required in the modeling of underwater robots are discussed in the paper. Overwhelming controller used to control the trajectory of flexible underwater robot has the advantage that it does not require the link dynamic parameters and the trajectory tracking is very good. The scheme requires tip velocity information of manipulator to be given in the controller. Simulation results shows that desired trajectory with better control is achieved in the case of overwhelming controller. The joint angle control of the manipulator is best with overwhelming controller, better with PID and are least good with PI controller. The TIP trajectory is in best control with overwhelming controller followed by PID and PI controllers respectively.

REFERENCES

[1] A.K. Ghosh, (1990), "Dynamics and Robust Control of Robotic Systems: A Bond Graph Approach", PhD thesis, Department of Mechanical Engineering, Indian Institute of Technology, Kharagpur.
[2] Amalendu Mukherjee et. al. (2006), "Bond graph in modeling, simulation and fault identification", I.K international publishing house Pvt. Ltd., New Delhi.
[3] Breedveld, P. C. and Dauphin-Tanguy, G., (1992), "Bond Graphs for Engineers", North-Holland, Amsterdam.
[4] Brown, F. T., (2001), "Engineering System Dynamics", Marcel Dekker, Inc, New York.
[5] D.Yoerger and J. Newman, (1985), "Demonstration of closed-loop trajectory control of an underwater vehicle", in Proc. IEEE Conf. Exhibition on OCEANS, vol. 17, San Diego, CA, 1028–1033.
[6] Fang Wang, Ye Li, Lei Wan and Yuru Xu, (2009), "Modeling and Motion Control Strategy for Autonomous Underwater Vehicles", Proceedings of the International Conference on Mechatronics and Automation, Changchun, China, 4851 -4856.
[7] Karnopp, D. C., Rosenberg, R. C. and Margolis, D. L., (1990), "System Dynamics: A Unified Approach", John-Wiley and Sons Inc., USA.
[8] Mukherjee, A. and Karmakar, R., (2000), "Modelling and Simulation of engineering System through Bond Graph", Narosa publishing House, New Delhi, reprinted by CRC press for North America and by Alpha Science for Europe.

[9] Periasamy T., Asokan T., Singaperumal M.,(2008), “Controller Design for Manipulator Trajectory Control of an AUV- Manipulator System” Third International Conference on Industrial and Information Systems, Kharagpur, INDIA, Paper Identification Number 474, 1-6.

[10] Periasamy Thangavel, Asokan Thondiyath, Singaperumal Makaram, (2010), “Optimized robust controller for AUV-Manipulator system”, IEEE, 945-950.

[11] R.K. Mittal and I.J. Nagrath (2003), “Robotics and control”,TMH publication New Delhi.

[12] R.J Schilling (2007),”Fundamental of robotics, Analysis and Control”, Pearson Education.

[13] Side Zhao and Junku Yuh, (2005), “Experimental Study on Advanced Underwater Robot Control”, IEEE transactions on robotics, vol. 21, no. 4.

[14] Symbol Sonata, (2013), “http://www.htcinfo.com/, High-Tech Consultants”,IIT Kharagpur.

[15] T.K Bera et. al. (2010),”Roboust overwhelming control of a hydraulically driven three degree of freedom parallel manipulator through simplified fast inverse model” Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering, Vol 224(2), 169-184.

[16] Yuh J., (1990), “Modeling and Control of Underwater Robotic Vehicles”, Transactions on Systems, Man, and Cybernetics, Vol. 20, No. 6, 1475-1483.

[17] Yuh J., olley W. E., (1988), “Application of discrete-time model reference adaptive control to industrial robots: A computer simulation,” J. Manufacturing Syst., vol. 7, no. 1, 47-56.

[18] Kumar, Sumit and Kumar, Sunil (2015), “Trajectory control of underwater flexible robot manipulator using overwhelming controller using bond graph approach”, International Journal for Science and Advance Research in Technology, vol. 1, issue 8, page 50-55.

[19] Kumar, Sumit et.al. (2015), “Modeling and Simulation of Underwater Flexible Manipulator as Raleigh Beam Using Bond Graph”, 7th International Conference on Robotics and Mechanical Engineering,