Trajectory control of underwater flexible robot manipulator using overwhelming controller using bond graph approach

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Abstract- *The use of underwater robot manipulator is increasing day by day for the applications like sea exploration, laying cables and optical fibers in the ocean beds. Many technologies are in use to control and operate these vehicle. This paper presents an approach in which an overwhelming controller is used to control the trajectory of a flexible manipulator.*

Keywords- overwhelming controller, trajectory control, flexible manipulator

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.There exist various control strategies that can be applied for the control of manipulators. The control issue of UVMs is very challenging due to the nonlinearity, time-variance, unpredictable external disturbances. The widely used linear controllers are incompetent to address various issues of underwater system. Generally first of all the manipulator is locked in place and the vehicle is moved until the end effectors get close to the desired position, and then the manipulator is controlled toward the final target while the vehicle is maintained as steady as possible. [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 advantages of the use of adaptive control techniques for various nonlinear dynamic systems such as industrial robots are discussed by author.[15]He described a dynamic model and an adaptive control system forROVs. The dynamic model of the ROV is a set of six nonlinear, time-varying differential equations accompanied by unknown parameters. These parameters may be identified by doing the hydrodynamic testing on the vehicle.[13]The author developed theory of the adaptive plus disturbance observer (ADOB) controller for underwater robots. The theory seems to be robust with respect to external disturbance and uncertainties in the system. This control scheme consists of disturbance observer (DOB) as the inner-loop controller and a non regressor based adaptive controller as the outer-loop controller.[9] The researchers have designed a trajectory controller for an underwater manipulator mounted on an Autonomous Underwater Vehicle (AUV). The bond graph technique was used for dynamic modeling of the system. The effect of factors such as added mass, viscous drag, buoyancy force, etc. on vehicle motion, and on the coupled dynamics between the vehicle and the manipulator have been modeled and simulated.[6] The author has designed the motion control strategy capable of both position and speed control for different work assignments of autonomous underwater vehicles (AUV). The simulation results show that the proposed mathematical model can provide an efficient test for simulation and control of underwater vehicles.[10]The authors did the optimization of robust controller for an Autonomous underwater vehicle (AUV) manipulator system. They used the overwhelming concept and the system had been modeled using the bond graph technique.[15] The researchers worked with overwhelming controller to control a hydraulically driven 3 degree of freedom 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.

II. OVERWHELMING CONTROLLER

Consider a system as shown in Fig.1 where (m+Δm) is a simple plant with nominal inertance of m and a time and state independent variation Δm. Let this plant is describe a trajectory x(t),the force to be applied on the mass (m+Δm) required would be

$$F_m = (m + \Delta m)\ddot{x}(t) \qquad (0.1)$$

Due to uncertainty and variation of Δm the determination of the force $F_m(t)$is difficult.

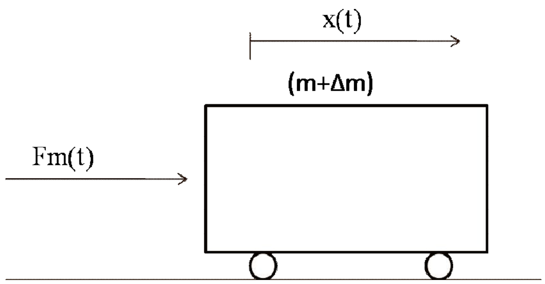

Fig.1 A moving plant

Consider a case Fig. 2 where we rigidly attach the nominal mass m with Δm variations to a very large mass M which is known.

$$M >> m + \Delta m \qquad (0.2)$$

The trajectory is being prescribed to the M. Therefore, given the condition of the equation above, force needed to obtain the trajectory would be

$$F = M\ddot{x}(t) \qquad (0.3)$$

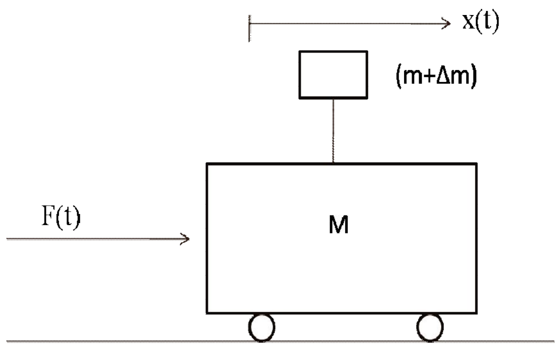

Fig.2 A moving plant attached with Known mass M

The force, $f_m(t)$, needed to drag along the nominal mass will be automatically decided by the reaction force at the rigid link between the large mass M and the nominal mass m. The dynamics of the feedback system depends solely on the ghost mass M and under high gain conditions the ghost mass M overwhelms plant mass (m+ Δm).

III. UNDERWATER FLEXIBLE MANIPULATOR WITH CONTROLLER

The flexible manipulator is modeled as a Rayleigh beam in the underwater environment. The forces which are considered are buoyancy force, gravity force and hydrostatic force. The effect of added mass and damping forces is neglected. The effect of surface waves is ignored for the robot maneuvering at the depth of 30m or more. The total dynamic model of the underwater manipulator vehicle is given by equation

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

where,
(F,τ): External input forces and torques
$(M+\bar{M})$: Mass and added mass-inertia matrices
$(M_C+\overline{M_C})$: Coriolis and centripetal matrices
B: Buoyancy force matrix
W: Gravity force matrix
D: Damping forces
V: Linear velocity matrix
ω: Angular velocity matrix

The physical description of underwater flexible manipulator is shown in the fig. 3.The position and orientation of the arm is calculated from the absolute frame {A}.The coordinates of centre of mass of the vehicle are (Y_{cm}, Z_{cm}) in the vehicle frame {V}. The frame {0} is located at the base and frame {1} is located at the first joint and frame {2} is located at the tip of the manipulator and r is the distance between CM of the vehicle and robot base. Angle (φ) represents the rotation of the vehicle frame with respect to absolute frame and angle (θ) is the rotation of joint with respect to absolute frame. The joint motor is mounted on the base. The mass of the joint motor is m_1 and (τ) is the torque applied by it on the link. The kinematic analysis of the link is done to draw the bond graph model of the flexible manipulator.

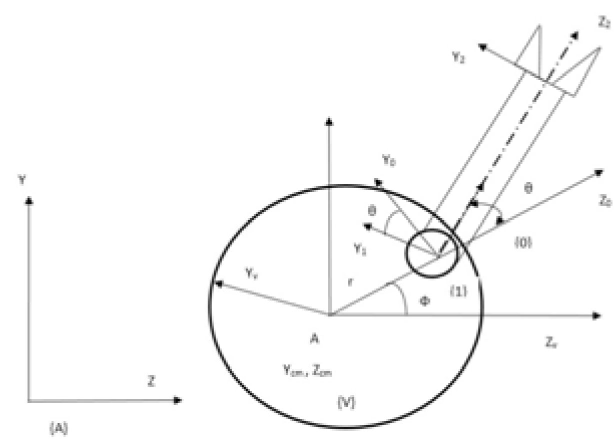

Fig. 3 Schematic diagram of 1 DOF manipulator

The bond graph [2]-[4], [7],[8], [11], [12],[14] of the flexible manipulator modeled as Rayleigh beam in underwater situation with overwhelming controller is shown in the following fig.4

In present work flexible link of underwater robot has been modeled as Rayleigh beam. In Rayleigh beam model both lumped inertia of the beam as well as rotary inertia is taken into account without considering the shear deformation.

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. The overwhelming controller is attached to the manipulator to control the motion of the arm. The Fig. 4 shows the model of the flexible manipulator with robust overwhelming controller.

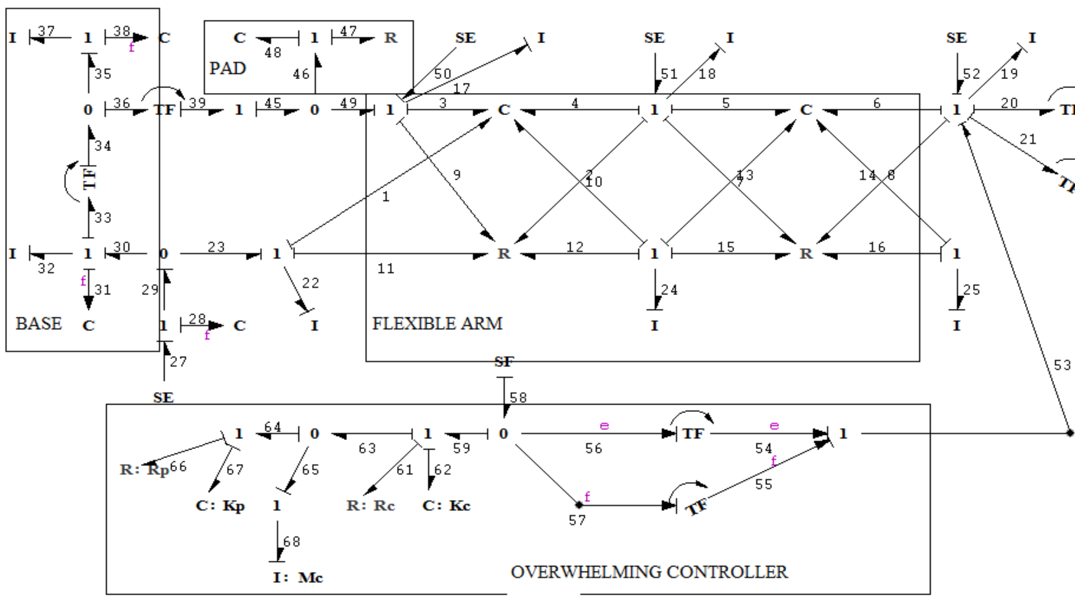

Fig. 4 Bond graph model of one arm flexible underwater robot with overwhelming controller

IV. SIMULATION AND RESULTS

The simulation on underwater flexible manipulator with overwhelming controller is carried out in order to investigate the effect of overwhelming controller on the maneuverability of the flexible manipulator. The simulation is done for 5 seconds. The parameters used in simulation are given in Table 1

Fig. 5 shows the joint angle variation with respect to time which decreases exponentially to a maximum value of -1.6 rad. The trend line has become smooth with the use of controller as compared to joint angle variation without the use of controller.

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	$5 kg\text{-}m^2$
12	Volume of base	Volbase	$0.216 m^3$
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

Table No.1 Simulation Parameters

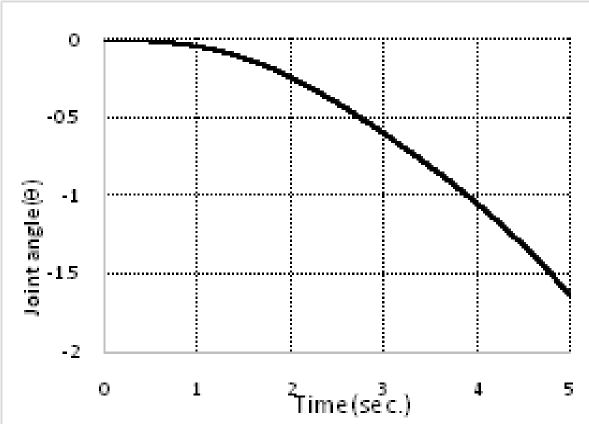

Fig. 5 Plot showing variation in joint angle (θ) with respect to Time

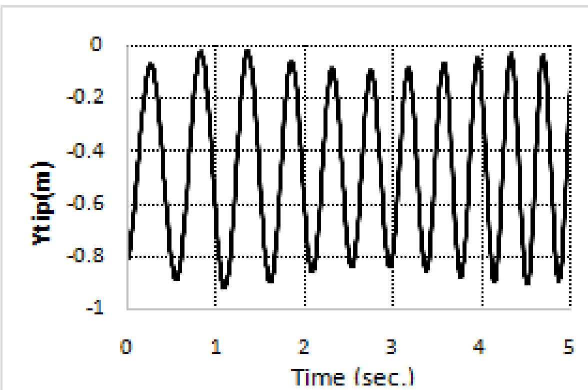

Fig. 6 Plot showing tip deflection in Y-direction with respect to time

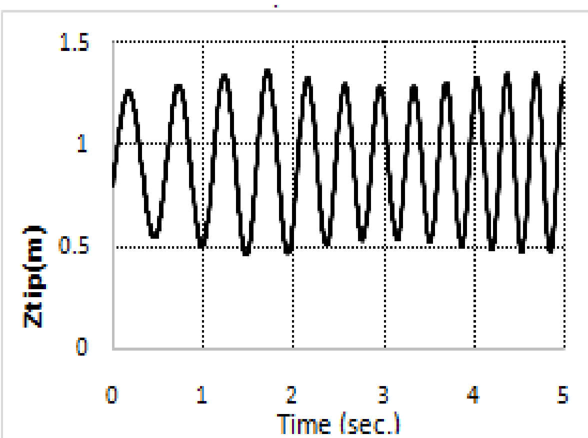

Fig. 7 Plot showing tip deflection in Z-direction with respect to time

Fig. 6 shows the variation of tip deflection in Y-direction with respect to time. The initial position of Ytip is -0.8m at T=0 sec., the tip follows the sinusoidal path with varying amplitude. The maximum amplitude observed is -0.914 m and Fig. 7 shows the deflection of tip in Z-direction with respect to time. At time t=0 the position of Ztip is 0.931 m this also follows the sinusoidal path with respect to time. The maximum amplitude observed is of 0.931 m.The varying sinusoidal behaviour is observed due to non-holonomic system but the amplitude variation has been reduced with the use of overwhelming controller.

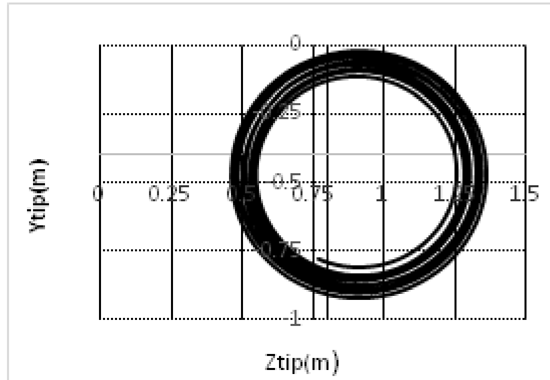

Fig.8 Tip trajectory of one arm flexible underwater robot with overwhelming controller

Fig.8 shows the trajectory of the tip of link of underwater arm controller by overwhelming controller. It has been observed that amplitude variation reduction with the use of overwhelming controller is 57% and 24.5% for the Z axis and Y axis respectively as compare to flexible manipulator without the controller.

V. CONCLUSIONS

The dynamic model of one arm flexible underwater robot has been constructed using Bond graph technique. 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 can be achieved effectively with decrease in deflection of trajectory.The results in the underwater environment are observed both with and without the controller.It has been observed that amplitude variation reduction with the use of overwhelming controller is 57% and 24.5% for the Z axis and Y axis respectively as compare to flexible manipulator without the controller.

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