

Adaptive Control of a Flexible Manipulator using Fuzzy pid Controller

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Abstract: In this paper Fuzzy PID controller is employed to control a flexible manipulator. The controller is used to control an uncertain Flexible Robotic Arm and its internal parameters in the motor dynamics. The efficacy of the proposed controller is tested against the conventional Integral and PID controller. The simulation results show the robustness of the proposed Fuzzy PID controller under motor dynamics.

Keywords— Flexible manipulator, fuzzy control, PID

I. INTRODUCTION

FLEXIBLE arm manipulators span a wide range of applications: space robots, nuclear maintenance, microsurgery, collision control, contouring control, pattern recognition, and many others. The system, described by partial differential equations (PDEs), is a distributed-parameter system of infinite dimensions. Its non minimum phase behavior makes it difficult to achieve high-level performance. Control techniques such as linear control, optimal control, adaptive control, sliding-mode control, neural networks, or fuzzy logic deal with the control of flexible manipulators and the modeling based on a truncated (finite dimensional) model obtained from either the finite-element method (FEM) or assumed modes method. These methods require several sensors to be used in order to obtain an accurate trajectory tracking, and many of them also require the knowledge of all the system parameters to design properly the controller. Here a new method is considered to cancel the vibration of the flexible beam which gathers an online identification technique with a control scheme in a suited manner, with the only measures of both the motor angle obtained from an encoder and the coupling torque obtained from a pair of strain gauges as done in the work in. In that paper, the nonlinearities effect in the motor dynamics, such as the Coulomb friction torque. Robust control schemes minimized this effect.

Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Irrationality can be described in terms of what is known as the fuzzjjective. Fuzzy Logic Control Technique has been a good replacement for conventional control Techniques. Many researchers have suggested that these controllers have the potential for robust control in the face of system parameter and load uncertainties. It is realized that fuzzy logic control can perform very effectively when the operating conditions change rapidly. These features make up very attractive for power system applications since power system is a highly non-linear and chaotic system.

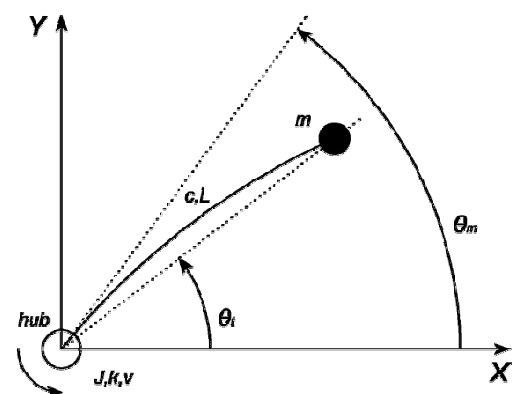


Fig. 1. Diagram of a single-link flexible arm.

II. MODEL DESCRIPTION

A. Flexible-Beam Dynamics

The flexible slewing beam studied in this paper is

considered to be a Euler–Bernoulli beam whose behavior is described by a PDE. Its dynamics involves infinite vibration modes. As the frequency of those modes increases, its amplitude decreases. This means that reduced models can be used, where only the low frequencies, usually more significant, are considered. In order to reduce the model, several approaches were proposed: 1) distributed parameters model where the infinite dimension is truncated to a finite number of vibration modes; and 2) lumped parameters models where a spatial discretization leads to a finite-dimensional model. In this sense, the spatial discretization can be done by both a FEM and a lumped-mass model.

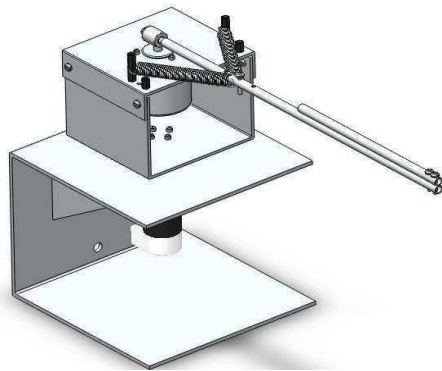


Fig. 2. Solid model design of flexible joint arm

A single-link flexible manipulator with tip mass is modeled, as developed in, that can rotate about the Z-axis perpendicular to the paper, as shown in Fig. 1. The axial deformation and the gravitational effect are neglected, because the mass of the flexible beam is floating over an air table which allows us to cancel the gravitational effect and the friction with the surface of the table. Since structural damping always increases the stability margin of the system, a design without considering damping may provide a valid but conservative result.

The real structure studied in this paper is made of carbon fiber, with high mechanical resistance and very small density. We study it under the hypothesis of small deformations with all its mass concentrated at the tip position because the mass of the load is bigger than that of the bar, then the mass of the beam can be neglected. In other words, the flexible beam vibrates with the fundamental mode; therefore, the rest of the modes are very far from the first one and they can be neglected. Thus, we only consider one mode of vibration. The main characteristic of this model is that the influence of the load changes can be modeled in a very easy manner, thus

adaptive controller can be easily applied.

Based on these considerations, we propose the following model for the flexible beam:

$$mL^2\ddot{\theta}_t = c(\theta_m - \theta_t) \quad (1)$$

where m is the unknown mass at the tip position. L and $c = (3EI/L)$ are the length of the flexible arm and the stiffness of the bar, respectively, assumed to be perfectly known. The stiffness depends on the flexural rigidity EI and on the length of the bar L . θ_m is the angular position of the motor gear. θ_m and θ_t are the unmeasured angular position and angular acceleration of the tip, respectively.

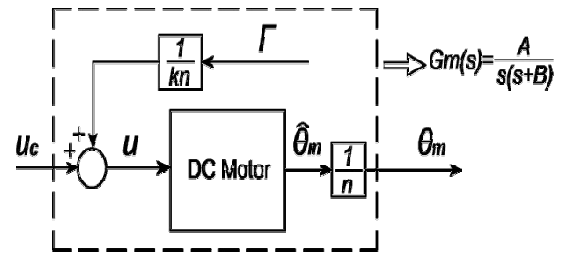


Fig.3. compensation of coupling torque in a hub

B. DC-Motor Dynamics

A common electromechanical actuator, in many control systems, is constituted by the dc motor. The dc motor used is supplied by a servo amplifier with a current inner loop control. We can write the dynamic equation of the system by using Newton’s second law.

$$ku = j\ddot{\theta}_m + v\dot{\theta}_m + \hat{\Gamma}_c(\hat{\theta}_m, u) + \frac{\Gamma}{n} \quad (2)$$

The dynamics of the complete system, actuated by a dc motor, is given by the following simplified model:

$$mL^2\ddot{\theta}_t = c(\theta_m - \theta_t) \quad (3)$$

$$ku = j\ddot{\theta}_m + v\dot{\theta}_m + \hat{\Gamma}_c + \frac{\Gamma}{n} \quad (4)$$

$$\Gamma = c(\theta_m - \theta_t) \quad (5)$$

Equation (3) represents the dynamics of the flexible beam;(4) expresses the dynamics of the dc motor; and (5) stands for the coupling torque measured in the hub and produced by the translation of the flexible beam, which is directly proportional to the stiffness of the beam and the

difference between the angles of the motor and the tip position, respectively.

$$G(s) = \frac{\theta_t(s)}{\theta_m(s)} = \frac{\omega^2}{s^2 + \omega^2} \quad (6)$$

Where $\omega = (\frac{c}{mL^2})^{\frac{1}{2}}$ is the unknown natural frequency of the bar due to the lack of precise knowledge of m. The coupling torque can be canceled in the motor by means of a compensation term. In this case, the voltage applied to the motor is of the form;

$$u = u_c + \frac{\Gamma}{kn} \quad (7)$$

Where u_c is the voltage applied before the compensation term.

The system in (4) is then given by

$$ku_c = J\ddot{\theta}_m + v\dot{\theta}_m + \hat{\Gamma}_c \quad (8)$$

The controller to be designed will be robust with respect to the unknown piecewise constant torque disturbances affecting the motor dynamics $\hat{\Gamma}_c$. Then, the perturbation-free system to be considered is the following:

$$ku_c = J\ddot{\theta}_m + v\dot{\theta}_m \quad (9)$$

where $K = k/n$. To simplify the developments, let $A = K/J$ and $B = v/J$. The dc-motor transfer function is then written as

$$G_m(s) = \frac{\theta_m(s)}{u_c(s)} = \frac{A}{s(s+B)} \quad (10)$$

Fig. 3 shows the compensation scheme of the coupling torque measured in the hub.

The regulation of the load position $\theta_t(t)$ to track a given smooth reference trajectory $\theta_t^*(t)$ is desired. For the synthesis of the feedback-control law, we are using only the measured motor position θ_m and the measured coupling torque Γ . One of the prevailing restrictions throughout our treatment of the problem is our desire of not to measure, or compute on the basis samplings, angular velocities of the motor shaft or of the load.

The parameterization of θ_m in terms of θ_t is given, in reduction-gear terms, by

$$\theta_m = \frac{mL^2}{c}\ddot{\theta}_t + \theta_t = \frac{1}{\omega^2}\ddot{\theta}_t + \theta_t \quad (11)$$

System (11) is a second-order system in which to regulate the tip position of the flexible bar θ_t towards a given smooth reference trajectory, $\theta_t^*(t)$ is desired, with θ_m acting as an auxiliary control input. Clearly, if there exists an auxiliary open loop control input $\theta_m^*(t)$ that ideally achieves the tracking of $\theta_t^*(t)$ for suitable initial conditions, it satisfies then the second order dynamics, in reduction-gear terms.

$$\theta_m^*(t) = \frac{1}{\omega^2}\ddot{\theta}_t^*(t) + \theta_t^*(t) \quad (12)$$

Subtracting (12) from (11), an expression in terms of the angular tracking errors is obtained

$$\ddot{e}_{\theta_t} = \omega^2(e_{\theta_m} - e_{\theta_t}) \quad (13)$$

Where $e_{\theta_m} = \theta_m - \theta_m^*(t)$,

$e_{\theta_t} = \theta_t - \theta_t^*(t)$. Suppose for a moment, that we are able to measure the angular-position tracking error e_{θ_t} , then the outer loop feedback incremental controller could be proposed to be the following PID controller:

$$e_{\theta_m} = e_{\theta_t} + \frac{1}{\omega^2} \left[-k_2 \dot{e}_{\theta_t} - k_1 e_{\theta_t} - k_0 \int_0^t e_{\theta_t}(\sigma) d\sigma \right] \quad (13)$$

In such a case, the closed-loop tracking error e_{θ_t} evolves, governed by

$$e_{\theta_t}^{(3)} + k_2 \ddot{e}_{\theta_t} + k_1 \dot{e}_{\theta_t} + k_0 e_{\theta_t} = 0 \quad (14)$$

The design parameters $\{k_2, k_1, k_0\}$ are then chosen so as to render the closed-loop characteristic polynomial into a Hurwitz polynomial with desirable roots.

III. INNER LOOP CONTROLLER

The angular position θ_m , generated as an auxiliary control input in the previous controller design step, is now regarded as a reference trajectory for the motor controller. We denote this reference trajectory by θ_{mr}^* . The design of the controller to be robust with respect to this torque disturbance is desired. The following feedback controller is proposed:

$$e_v = \frac{v}{K} \dot{e}_{\theta_m} + \frac{1}{K} \left[-k_3 \hat{e}_{\theta_m} - k_2 e_{\theta_m} - k_1 \int_0^t e_{\theta_m}(\sigma) d(\sigma) - k_0 \int_0^t \int_{\sigma_2}^{\sigma_1} e_{\theta_m}(\sigma_2) d(\sigma_2) d(\sigma_1) \right] \quad (15)$$

The following integral reconstructor for the angular-velocity error signal \hat{e}_{θ_m} is obtained:

$$\dot{\hat{e}}_{\theta_m} = \frac{K}{J} \int_0^t e_v(\sigma) d(\sigma) - \frac{v}{J} e_{\theta_m} \quad (16)$$

Replacing $\dot{\hat{e}}_{\theta_m}$ in (25) into (24) and, after some rearrangements, the feedback control law is obtained

$$(u_c - u_c^*) = \frac{\alpha_2 s^2 + \alpha_1 s + \alpha_0}{s(s + \alpha_3)} (\theta_{mr}^* - \theta_m) \quad (17)$$

The open-loop control $u_c^*(t)$ that ideally achieves the open-loop tracking of the inner loop is given by

$$u_c^*(t) = \frac{1}{A} \ddot{\theta}_m^*(t) + \frac{B}{A} \dot{\theta}_m^*(t) \quad (18)$$

The inner loop system in Fig. 4 is exponentially stable. We can choose to place all the closed-loop poles in a desired location of the left half of the complex plane to design the parameters $\{\alpha_3, \alpha_2, \alpha_1, \alpha_0\}$. As done with the outer loop, all poles can be located at the same real value, and $\alpha_3, \alpha_2, \alpha_1, \alpha_0$ can be uniquely obtained by equalizing the terms of the two following polynomials:

$$(s + p)^4 = s^4 + 4ps^3 + 6p^2s^2 + 4p^3s + p^4 = 0 \quad (19)$$

$$s^4 + (\alpha_3 + B)s^3 + (\alpha_3B + \alpha_2A)s^2 + \alpha_1As + \alpha_0A = 0 \quad (20)$$

Where the parameter p represents the common location of all the closed-loops poles, this being strictly positive.

IV. FUZZY-PID CONTROLLER

Here, A classical FLS is represented as in Fig-4. As shown, rules play a central role in the FLS framework. Rules can be provided by experts or can be extracted from numerical data. The IF-part of a rule is an antecedent while the THEN-part of a rule is its consequent. Fuzzy sets are associated with terms that appear both in the antecedent and in the consequent, while Membership Functions (MFs) are used to describe these fuzzy sets.

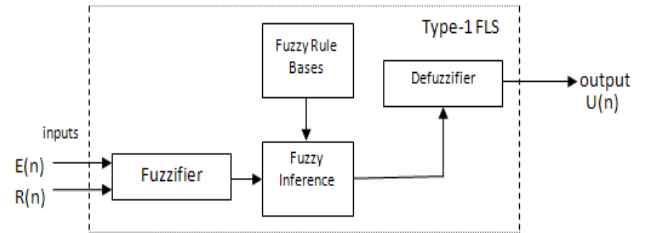


Fig.4., structure of the fuzzy logic controller

Table:1 Control rules of the fuzzy controller

	Input1	N	Z	P
Input2	N	P	N	N
	Z	N	P	P
	P	N	N	N

Fuzzification: Translates inputs (real values) to fuzzy values. **Inference System:** Applies a fuzzy reasoning mechanism to obtain a fuzzy output. **Type Defuzzicator/Reducer:** The defuzzicator transduces one output to precise values; the type reductor transforms a fuzzy set into a Type-1 fuzzy set.

Knowledge Base: Contains a set of fuzzy rules, and a membership functions set known as the database. The two normalized input variables, input1 and input2, are first fuzzified by two interval t fuzzy sets i.e., ‘positive’ and ‘negative’ represented by $\mu_p(\text{input1})$ and $\mu_N(\text{input2})$ respectively.

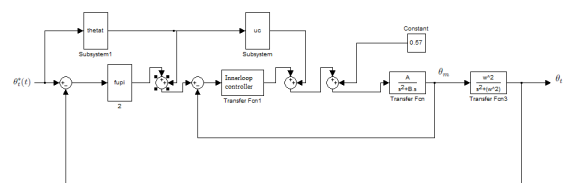


Fig.5., Block Diagram Of The Single Link Flexible Manipulator Using Fuzzy PID Control

V. SIMULATION & RESULTS

The major problems associated with the control of flexible structures arise from the structure is a distributed parameter system with many modes, and there are likely to be many actuators.

There are three types of controllers used to control the system which are simulated and compared for better results.

They are;

1. Integral controller
2. Conventional PID controller
3. Fuzzy PID controller

The simulation results of the above controllers and given bellow

I) Using Integral Controller

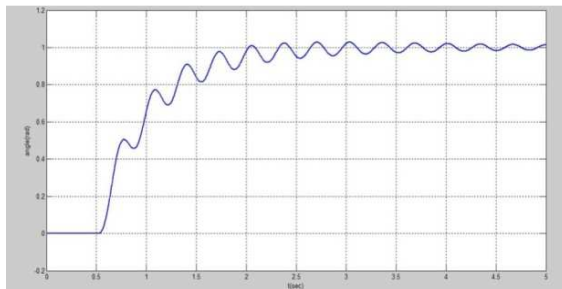


Fig.6, the simulation result of integral controller

II) Using Conventional PID Controller

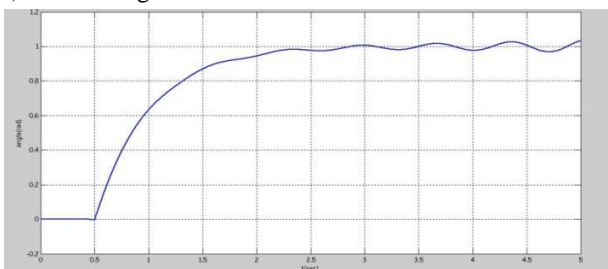


Fig.7, the simulation result of the conventional pid controller

III) Using Fuzzy PID Controller

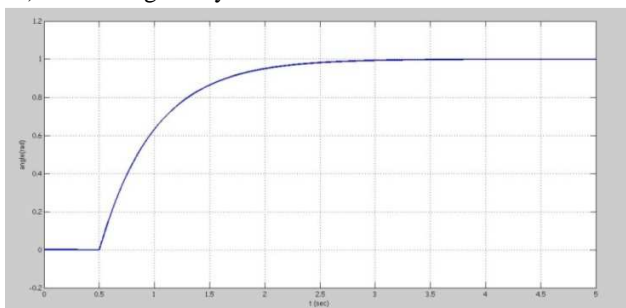


Fig.8. the simulation result of the fuzzy PID controller

IV) The Combined Figure Of The Output Simulated

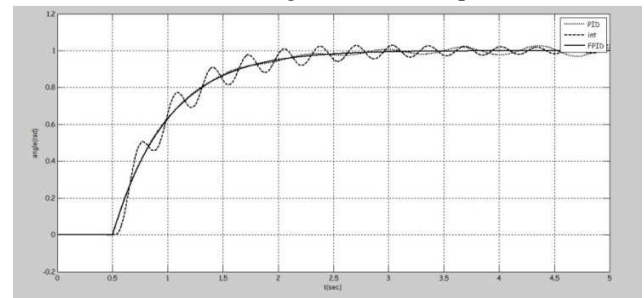


Fig.9. The Combined Figure Of The Output Simulated

Therefore, the above results prove that the system controlled by the fuzzy PID controller has better n accurate results when compared to other controllers.

VI. CONCLUSION

Here, fuzzy PID controller is designed to control the single link flexible manipulator . The proposed controller is being designed based on the conventional PID controller. The proposed Fuzzy PID controller is tested for different motor dynamics. Simulation results show the efficiency of the proposed controller in terms of its response parameters like settling time.

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