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INTELLIGENT CONTROLLER FOR LIGHT WEIGHT ROBOT

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ABSTRACT

In this work the description of a control system for plan two-link robot-manipulator is presented. The second link is considered flexible. The assumed mode method is used to model the flexible link. The model reference neuro-controller has been proposed for the tip position control based on the artificial Neural Networks (ANN). The dynamics of the flexible manipulator is identified by the neural network. Then the resulting identified model is utilized to design the model reference adaptive controller for regulating the tip position of the manipulator.

***Keywords* -** light weight robot; flexible-link; neural networks; intelligent controller.

1. INTRODUCTION

The necessity for applications of light weight robots arise in the industry, where the weight and design of the robot play important role; specially in the nuclear, wood industry and space. When the mass of the link is reduced, the ratio of it's length to it's cross-sectional area is increased. Therefore the link can not be considered rigid. The control of flexible link is very difficult due to present of vibration and elastic deformation. The controller should move the flexible link to track the desired trajectory and damp the vibration.

In this work the description of a control system for plan two-link robot-manipulator is presented. The second link is considered flexible. Among the known mathematical methods applied to model the elastic behavior of flexible link are: Finite Element method [1], Finite Difference method and the assumed mode method [2].

The Dynamic model for flexible link is obtained by using the assumed mode method. The model reference neuro-controller has been proposed for the tip position control based on the artificial Neural Networks (ANN). The dynamics of the flexible manipulator is identified by the neural network. Then the resulting identified model is utilized to design the model reference adaptive controller for regulating the tip position of the manipulator.

2. CONSTRUCTION OF DYNAMIC MODEL OF FLEXIBLE LINK

The dynamic model of flexible link is obtained through the usage of Lagrange's equations:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i(t)}\right) - \frac{\partial L}{\partial q_i(t)} = Q_i,$$

where $L = E_K - E_P$, E_K and E_P - kinetic and potential energies, $q_i(t)$ - the generalized coordinate, Q_i - the generalized force.

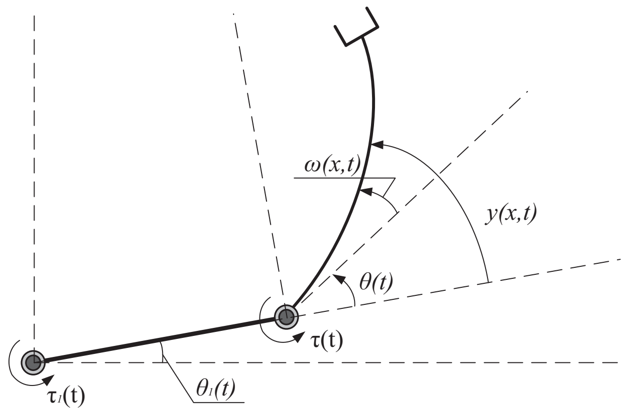

Figure 1 Kinematics of robot with single flexible link

According to the assumed mode method, the total tip displacement of flexible link can be obtained as the sum of both the rigid motion $\theta(t)$ and flexible motion $\omega(t,x)$. The elastic deflection is represented by a finite number of separable harmonic modes. The modes are truncated to a finite number to obtain a system of finite dimension [2]. Thus

$$y(x,t) = \theta(t) \cdot x + \omega(t,x),$$

where $\omega(x,t) = \sum_{i=1}^{\infty} \phi(x) \cdot q_i(t)$, $\phi(x)$ - assumed modes, $q_i(t)$ - the generalized coordinates caused by elastic properties of a part. The total tip displacement is obtained as the sum of the rigid displacement and the three harmonics.

Considering, that $\int_0^l \rho\phi_i(x)\phi_j(x)dx = \rho l^3\delta_{ij}$,

$\int_0^l EI \frac{\partial^2\phi_i(x)}{\partial x^2}\frac{\partial^2\phi_j(x)}{\partial x^2}dx = \rho l^3\omega_i^2\delta_{ij}$,

$\int_0^l \rho x\phi_i(x)dx = \frac{2\rho l}{\lambda_i^2}$, kinetic and potential energy of a part will look like:

$$E_K = \frac{1}{2}\int_0^l \rho\left(\frac{\partial y(x,t)}{\partial t}\right)^2 dx + \frac{1}{2}I_M\left(\frac{\partial\theta(t)}{\partial t}\right)^2 = \frac{1}{2}\int_0^l \rho\left(\dot\theta(t)x + \sum_{i=1}^{\infty}\dot q_i(t)\phi_i(x)\right)^2 dx + \frac{1}{2}I_M\dot\theta(t)^2$$

$$E_P = \frac{1}{2}\int_0^l EI\left(\frac{\partial^2\omega(x,t)}{\partial x^2}\right)^2 dx = \frac{1}{2}\int_0^l EI\left(\sum_{i=1}^{\infty}q_i(t)\frac{\partial^2\phi_i(x)}{\partial x^2}\right)^2 dx$$

$$E_K = \frac{1}{2}\left(\left(\frac{\rho\cdot l^3}{3}+I_M\right)\cdot\dot\theta_i(t)^2 + 4\rho\cdot l\cdot\dot\theta_i(t)\sum_{i=1}^{\infty}\frac{\dot q(t)}{\lambda_i^2} + \rho\cdot l^3\sum_{i=1}^{\infty}\dot q(t)^2\right)$$

$$E_P = \frac{1}{2}\rho\cdot l^3\sum_{i=1}^{\infty}\dot q(t)^2\cdot\omega_i^2$$

Lagrange equations for the four generalized coordinates:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial\dot q_i(t)}\right) - \frac{\partial L}{\partial q_i(t)} = 0,\ i=1,\ 2,\ 3;$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial\dot\theta_i(t)}\right) - \frac{\partial L}{\partial\theta_i(t)} = \tau(t),$$

where

$$L = E_K - E_P = \frac{1}{2}\left(\left(\frac{\rho\cdot l^3}{3}+I_M\right)\cdot\dot\theta_i(t)^2 + 4\rho\cdot l\cdot\dot\theta_i(t)\sum_{i=1}^{\infty}\frac{\dot q(t)}{\lambda_i^2} + \rho\cdot l^3\sum_{i=1}^{\infty}\dot q(t)^2\right) - \frac{1}{2}\rho\cdot l^3\sum_{i=1}^{\infty}\dot q(t)^2\cdot\omega_i^2$$

then

$$\left(\frac{\rho\cdot l^3}{3}+I_M\right)\cdot\ddot\theta_i(t) + \sum_{i=1}^{\infty}\frac{2\rho\cdot l}{\lambda_i^2}\ddot q_i(t) = \tau(t),$$

$$\frac{2\rho\cdot l}{\lambda_i^2}\ddot\theta_i(t) + \rho\cdot l^3\cdot\ddot q_i(t) + \rho\cdot l^3\cdot\omega_i^2\cdot q_i(t) = 0,\ i=1,\ 2,\ \dots,\ \infty.$$

The obtained equations can be presented in the matrix form:

$$M\cdot\ddot q_i(t) + K\cdot q(t) = \tau(t), \qquad (1)$$

where

$$M = \begin{bmatrix} \left(\frac{\rho\cdot l^3}{3}+I_M\right) & \frac{2\rho\cdot l}{\lambda_1^2} & \frac{2\rho\cdot l}{\lambda_2^2} & \frac{2\rho\cdot l}{\lambda_3^2} \\ \frac{2\rho\cdot l}{\lambda_1^2} & \rho\cdot l^3 & 0 & 0 \\ \frac{2\rho\cdot l}{\lambda_2^2} & 0 & \rho\cdot l^3 & 0 \\ \frac{2\rho\cdot l}{\lambda_3^2} & 0 & 0 & \rho\cdot l^3 \end{bmatrix},$$

$$q(t) = \begin{bmatrix} \theta(t) \\ q_1(t) \\ q_2(t) \\ q_3(t) \end{bmatrix},$$

$$K = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \rho\cdot l^3\cdot\omega_1^2 & 0 & 0 \\ 0 & 0 & \rho\cdot l^3\cdot\omega_2^2 & 0 \\ 0 & 0 & 0 & \rho\cdot l^3\cdot\omega_3^2 \end{bmatrix},$$

$$\tau(t) = \begin{bmatrix} \tau(t) \\ 0 \\ 0 \\ 0 \end{bmatrix}.$$

Also equation (1) can be written as

$$\ddot q(t) = \frac{1}{M}\left[\tau(t) - Kq(t)\right] \qquad (2)$$

After transformation of the equation (1) in the form of (2), the result of modeling flexible link is presented in Fig. 2.

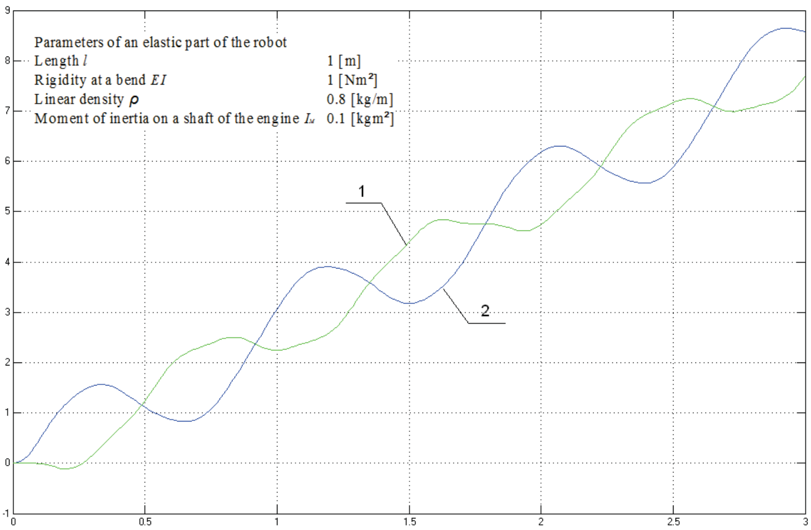

Figure 2 Result of simulation due to impulse input torque: 1- The tip total displacement for flexible link; 2-The hub's angular displacement

It is clear from Fig.2, that the characteristic of flexible link is deferent from that for rigid link due to the presence of harmonics. The designed controller should move the flexible link to track the desired trajectory and damp vibration.

3. DESCRIPTION NEURAL NETWORK OF THE CONTROLLER

The proposed neural network controller is based on model reference. The neural model reference control architecture uses two neural networks: a controller network and a plant model network as shown in Fig.3. The plant model is identified first, and then the controller is trained so that it can generate the controlling signal. The regulator is adaptive since the desired input and system output are used as inputs for neural network, which is learning on-line using dynamic back propagation [3, 4].

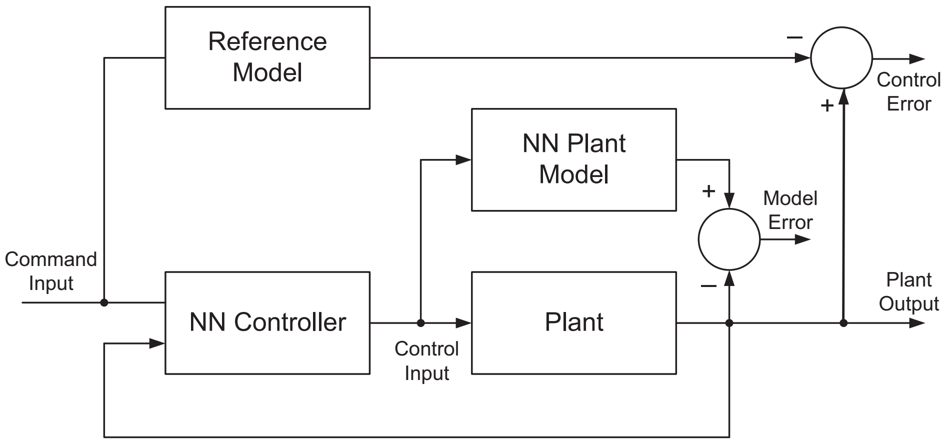

Figure 3 The block diagram of a control system with reference model

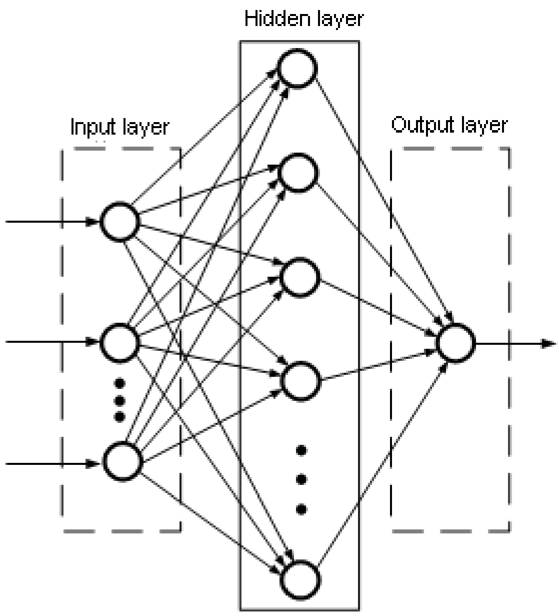

Figure 4 Structure of a neural network

The structure of a neural network regulator is described by a structure 5 - 40 - 1 (5 inputs, 40 neurons on the hidden layer and one output), that is contains two layers (Fig. 4). The inputs are the desired acceleration, the desired and real velocity and displacement. Also the neural network for plant consists of two layers also, it contains 4 inputs, 20 neurons in the hidden layer and one output.

Owing to presence of a feedback error back propagation in a control system, the weights are adapted on-line, that leads to improve the performance of the regulator.

4. SIMULATION ANALYSIS

The plant is first identified, and then the controller is trained so that the plant output follows the reference model output. The sinusoidal desired input is used to test the controller. The results of simulation are shown in Figs. 5 and 6.

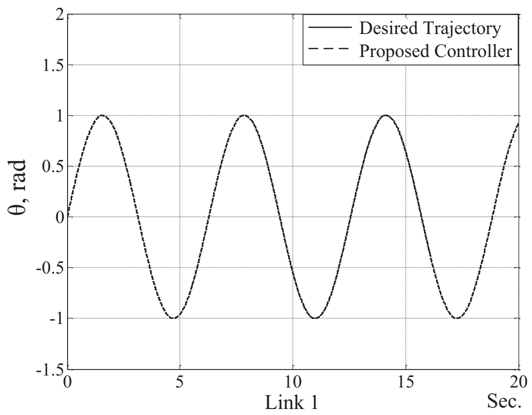

Figure 5 The Desired and Actual Trajectory for Rigid Link

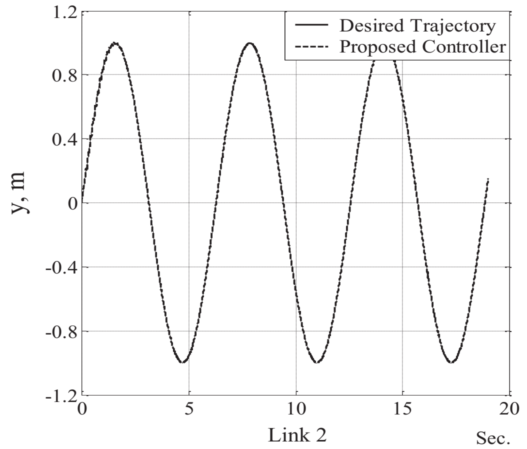

Figure 5 The Desired and Actual Trajectory for Flexible Link

The results of simulation show that the tip displacement of flexible link follows the desired trajectory with maximum deviation of 0.15 mm.

5. CONCLUSIONS

The presented neural network controller with reference model is one of possible control systems for light weight robots. Advantage of the presented controller is that the plant can be identified so as to generate the desired control signal.

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