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ROBOT MANIPULATOR CONTROL USING INTELLIGENT CONTROL SCHEME

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ABSTRACT

An intelligent controller trained with inverse dynamics as well as kinematics neural network as well as Proportional-Integral-Derivative (PID) control for controlling a manipulator with n number of Degrees of freedom is presented. The controller design is built around the positive framework of Proportional-Integral-Derivative (PID) control with the added simplicity of neural network. The dynamic control technique in which the rigid-body dynamic model is inverted to compute the demand torque for the robot based on current joint angles and joint angle rates and demand joint angle acceleration. The neural network controller was trained for inverse dynamics of robot manipulator. Error converges to minimum swiftly by learning the inverse dynamics of manipulator. The performance of controller is simulated with acceptable outcomes.

KEYWORDS

PD/PI/PID Controller; Degree of Freedom; Radial Basis Function; Sliding Mode Neural Network; Backpropagation Network.

INTRODUCTION

By applying the PD as well as Proportional Integral Derivative (PID) controller, the stability of an industrial robot manipulator of 6 Degree of Freedom (DOF) has been investigated under model disparity. The position and velocity error upper bounds values are found by applying Craig's quadratic half-plane constraint analysis to guarantee the stability of the robot arm under Proportional Derivative (PD) as well as PID control [1].

A different design procedure and stability analysis for robotic variable structure controllers with PID like sliding surfaces has been presented with the help of two versions of the controller: regular and adaptive. Both controllers have shown robustness with respect to bounded external disturbances and some unmodeled dynamic effects. Testing results shown better stability, with minimum transient responses then traditional PD manifold controllers [2].

The PID tracking control problem of robotics manipulators have been solved with arbitrary small output tracking error and semiglobal stability by developing a different PID control configuration in terms of a parameter that is directly related with the size of the region of attraction and the size of the residual set. Tuning guidelines are extracted from the stability analysis [3].

Without solving the inverse Jacobian as well as inverse kinematics for deriving manipulator to a specified desired position and orientation in Cartesian space by using Lyapunov function with virtual artificial potential energy, a class of Complete transpose Jacobian-based nonlinear PID regulator is proposed for robot manipulators with uncertain kinematics on the basis of the set of all continuous differentiable increasing functions [4].

The position regulation problem of robot manipulators under constrained control input has been discussed. The robot system under a saturated linear PID control is semiglobally asymptotically stable, if the torque bounds are larger than gravitational torques, and if the proportional gain is large enough and the integral gain is small enough [5].

A sliding mode neural-network (SMNN) control system for the tracking control of an n rigid-link robot manipulator to achieve high-precision position control was presented to overcome some of the shortcomings of conventional robust controllers such as a model-based adaptive controller requires the system dynamics in detail; the fuzzy rule learning scheme has a latent stability problem; an adaptive control scheme for robot manipulator via fuzzy compensator requires strict constrained conditions and prior system knowledge. A neural network controller was developed to mimic an equivalent control law in the sliding-mode control, and a robust controller is designed to curb the system dynamics on the sliding surface for guaranteeing the asymptotic stability property [6].

To achieve high precision position control, an adaptive control system was proposed for the tracking control of an n-link robot manipulator. The adaptive control system was divided into three parts: a feedforward controller, a state feedback controller and an uncertainty alleviator. All online tuning algorithms in the adaptive control system are derived using Lyapunov stability analysis; so that system tracking stability can be guaranteed in the closed loop system whether the uncertainties occur. It has learning ability similar to intelligent control, but with a simpler control framework [7].

A scheme using a class of adaptive robust hybrid position/force control of robot manipulator with bound estimation and stability based on Lyapunov for nonlinear and time varying uncertainties was presented [8].

The extended controller as a computed-torque control with an external PID, whose gain matrices vary with the position and velocity of the robot joints was presented. In addition, in order to increase the controller robustness, an extension of the algorithms with saturation functions was carried out. The extension dealt with the resulting nonlinear equation of the closed loop error [9].

To study the motion of the robot it is necessary to identify the forward as well as inverse of dynamics in addition to kinematics of a robot manipulator. One can use already derived methods based on Denavit Hartenberg (DH) algorithm for forward as well as inverse kinematics plus the Lagrange method or Recursive Newton Euler formulation for calculating the forward as well as inverse dynamics of any robot manipulator [10].

Adaptive evolutionary switching PD control was proposed for iterative operations of robot manipulators. The proposed control method was a combination of the feedback of PD control with gain switching and feedforward using the input torque profile obtained from the previous iteration. The asymptotic convergence of the control method is theoretically proved using Lyapunov method. The philosophy of the switching control strategy was interpreted in the context of the iteration domain to increase the speed of the convergence for trajectory tracking of robot manipulators [11].

A state space model free robust control approach was proposed for position control of robot manipulators. The control approach was verified analytically to be robust subject to uncertainties including external disturbances, unmodeled dynamics, and parametric uncertainties. The proposed control approach could guarantee the robustness of control system [12].

A population based adaptive tuning for dynamic position control of robot manipulators was proposed in which the PID controller parameters were tuned using cross-entropy optimization to minimize the error in tracking a repeated desired trajectory in real-time. As the dynamic behaviour of a robot manipulator is highly nonlinear, and the positional control is conventionally achieved by inverse dynamics feedforward and PID feedback controllers. The stability was achieved by switching the inappropriate settings to a stable default using a real-time cost evaluation function [13].

Since the model-based adaptive control can completely account for nonlinear structure of robot dynamics, the associations between the kinematics design and tracking performance of the model-based adaptive control were studied by convergence of the position tracking error of three serial manipulators with joint types of Revolute-Revolute (RR), Revolute-Prismatic (RP) and Prismatic-Prismatic (PP). The physical parameters and desired trajectories were assumed same for the proper comparison [14].

A neural network global PID sliding mode control method for the tracking control of robot manipulators with bounded uncertainties was presented by tuning the switching gain through a Radial Basis Function (RBF) neural network on the reachable condition of sliding mode. Due to this, the effect of chattering can be alleviated. Apart from this, global sliding mode was realized by designing an exponential dynamic sliding function. Stability and convergence of the control system was proved mathematically [15].

A new approach for the control of Two link robotic manipulator systems using Neural Network and PD/PID controller was presented, in which the first method is based on PD control and the second method is based on PID controller, the third method is based on artificial Neural Network based PD controller, and the forth method is based on artificial Neural Network based PID controller for control of Two link robot [16].

An output feedback PID controller for anti-windup design by using a one-order linear filter is employed to estimate the joint velocity of robot manipulators. By forcing the constraints on the integral action of PID controller, the problems raised from integrator windup was solved and robustness as well as asymptotic stability of the resulting system was guaranteed in the presence of Jacobian uncertainty [17].

An adaptive PID controller based on tuning of back propagation (BP) neural network was presented by keeping in mind that according the requirements of system output performance, the BP neural network can auto adjust its weights to vary k_p (Proportional gain), k_i (Integral gain) and k_d (Differential gain) parameters. The simulated electro-hydraulic position servo control system using adaptive PID controller based on BP neural network showed that it can get better control characteristics and adaptability, strong robustness in the nonlinear and time vary system [18].

A self-tuning PID controller based on improved BP neural network to solve the difficult problem that how to reduce the overshot and shorten the regulating time of the PID controller based on BP neural network was presented. The rand noise was added to the input to test the robustness. The parameters of the PID controller were calculated by an improved BP Neural Network according to the input and output and the error of the PID controller. The Fletcher-Reeves conjugate gradient method was used for the dynamic adjustment for learning rate to improve [19].

A saturated nonlinear PID regulator for industrial robot manipulators was presented. Mainly three problems were considered. Firstly, the natural saturation problem given by the output of the control computer, second was the saturation phenomena of the internal PI velocity controller in the servo driver plus and third was the actuator torque constraints of the robot manipulator was presented. An approach based on the singular perturbations method was used to analyse the exponential stability of the closed-loop system [20].

A neural network based chattering free sliding mode control (SMC) by incorporating a PID controller for robot manipulators was presented for structured and unstructured uncertainties in both manipulator and actuator dynamics. By doing this, the robustness property of SMC and good response characteristics of PID were combined together to improve performance of robot manipulator. Uncertainties were compensated by a two-layer neural network. External disturbance and approximation error were tried to neutralize by robust signal with adaptive gain [21].

ROBOT DYNAMICS

To describe more a robot consists of a set of moving rigid links which are connected in a serial chain and its motion equation is given by:

$$M(q).\ddot{q} + V(q,\ddot{q}).\dot{q} + G(q) = \tau \qquad (1)$$

Where,

q: *nx1* position vector,

$M(q)$: *nxn* inertia matrix of the manipulator,

$V(q,\dot{q})$: *nx1* vector of Centrifugal and Coriolis terms

$G(q)$: *nx1* vector of gravity terms

τ: nx1 vector of torques

By writing the velocity dependent term $V(q,\dot{q})$ in a different form, all the matrices become functions of only the manipulator position; in this case the dynamic equation is called configuration space equation and has the following form:

$$\tau = M(q).\ddot{q} + B(q).[\dot{q}.\dot{q}] + C(q).\left[\dot{q}^2\right] + G(q) \qquad (2)$$

Where,

$B(q)$: nxn(n-1)/2 matrix of Coriolis torques

$C(q)$: nxn matrix of Centrifugal torques

$[\dot{q}.\dot{q}]$: n(n-1)/2x1 vector of joint velocity products given by:

$$\begin{bmatrix} \dot{q}_1.\dot{q}_1, \ \dot{q}_1.\dot{q}_3, \dots, \ \dot{q}_1.\dot{q}_n, \ \dot{q}_2.\dot{q}_3, \ \dot{q}_2.\dot{q}_4, \\ \dots, \dot{q}_{n-2}.\dot{q}_n, \dot{q}_{n-1}.\dot{q}_n \end{bmatrix}$$

$[\dot{q}^2]$: nx1 vector given by:

$$\left[\dot{q}_1^2, \dot{q}_2^2, \dots, \dot{q}_n^2\right]$$

To derive the model of the robot arm started by generating the kinetic energy matrix and gravity vector symbolic elements by performing the summation of either Lagrange's or the Gibbs-Alembert formulation; these elements are then simplified by combining inertia constants that multiply common variable expressions. The Coriolis and centrifugal matrix elements are then calculated in terms of partial derivatives of kinetic energy, and then reduced using four relations that hold on the partial derivatives. Finally, the necessary partial derivatives are formed, and the Coriolis and centrifugal matrices are found. A simplification step is then done by combining the inertia constants that multiply the common variable expressions.

PID CONTROLLER

Industrial controllers may be classified according to their control actions as:

(A). Proportional controllers
(B). Integral controllers
(C). Proportional-plus-integral controllers
(D). Proportional-plus-derivative controllers
(E). Proportional-plus-integral-plus-derivative controllers

For a controller with proportional control action, the relationship between the output of the controller $u(t)$ and the actuating error signal $e(t)$ is: -

$$u(t) = k_p e(t) \quad (3)$$

Where $e(t)$ the error is signal and k_p indicates proportional gain. Proportional term is not sufficient to be a controller in practical cases to meet a specified requirement like small overshoot, good transient response, because the large proportional gain gives fast rising time with large overshoot and oscillatory response. So a derivative term is added to form Proportional Derivative (PD) controller, which is able to regulate the response as the process approaches the set point. The output of PD controller is calculated based on the sum of both current error and change of error with respect to time. The effects of PD give a slower response with less overshoot than a proportional controller. Mathematically, PD controller is represented as:-

$$u(t) = k_p e(t) + k_d \frac{de(t)}{dt} \quad (4)$$

Where k_d represents derivative gain.

Integral control if added to PD control, it reduces the effect of steady state error that may be caused by the proportional gain. The general form of the PID controller in continuous time is given as:-

$$u(t) = k_p e(t) + k_i \int_0^t e(t)\, d(t) + k_d \frac{de(t)}{dt} \quad (5)$$

Each of the three components of PID controller, is amplified by an individual gain, the sum of the three terms is applied as an input to the robot manipulator to adjust the parameters. It is important to see that the purely derivative or integral plus derivative variants never used. In all cases except proportional control, the PID compensator gives at least one pole and one zero.

The transfer function of the PID controller can be represented in serial as well as parallel form as follows:-

$$G_{series}(s) = \left(k_p + \frac{k_i}{s}\right)(k_d s + 1) \quad (6)$$

$$G_{parallel}(s) = k_p + \frac{k_i}{s} + k_d s \quad (7)$$

CONTROLLER STRUCTURE

The NN controller has been trained by the input as well as output data set of inverse dynamics of PUMA ROBOT manipulator. The NN controller can work alone as the controller if one wants to work for inverse dynamics of robot manipulator or it can be used in parallel with other controllers. First started with simple structure to get the satisfactory results and then by increasing the complexity of controller and solve the problem using trained NN controller. The first model is shown in FIGURE 1. After training the network with some known trajectories it was observed that the controller was not stable initially and couldn't trace the path. It seemed that the problem was very odd for the network to be solved and the NN controller needs lot of samples in order to learn the inverse dynamics of the system. With a simple calculation one can see that more than millions of samples are required in order to train the ANN for a 3 DOF robot.

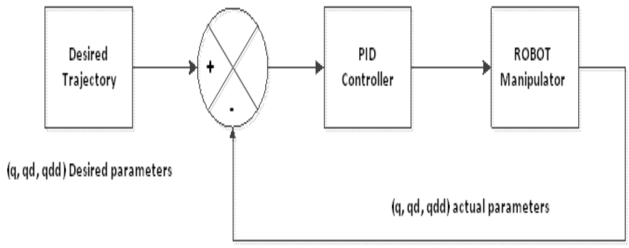


FIGURE1:Neural Network Control of ROBOT Manipulator

The problem is due to the fact that the search space for finding proper weights for neurons are very large and the NN controller inputs make a very wide dominance. To narrow the search space, first a simple but effective PID controller to trace the desired path is used. The PID accepts the angle and angular velocities of the joints and generates the required torque for the motors. Though PID controller generally doesn't perform well when the error is not within satisfactory range, but the data collected from the PID controller can be used for training the NN controller. After training the NN controller by input output data which was received from PID controller, the NN controller was used as a controller in parallel to PID and new data samples for training were generated. The sampled data from simulation of PID and ANN can be used to further train the ANN and increase its performance. With this configuration the NN controller tried to solve the inverse dynamics of the system within a close range to the desired path and it generates the toques that are required to be applied by the motors such that the robot manipulator follows the desired path. If the NN controller solves the inverse dynamics of the system without error then the output of PID is zero and the controller can trace the path without error. But if there is an error in the output of the NN controller, the PID controller will compensate it. Apparently maximum number of times the robot manipulator is doing a monotonous job and the path that joints are following is periodic. If period is define of the robot manipulator path as one cycle then the NN controller is trained in every cycle and the network recognizes the robot manipulator performance in more detail. It means that after completion of every cycle the performance of the robot manipulator improved and the error between desired trajectory path and the trajectory robot manipulator follows tends to minimum. After carrying out simulations, the results showed that the error converges to minimum and it can be reduced further to arbitrary value by applying enough number of trainings. FIGURE 2 shows the structure of this controller.

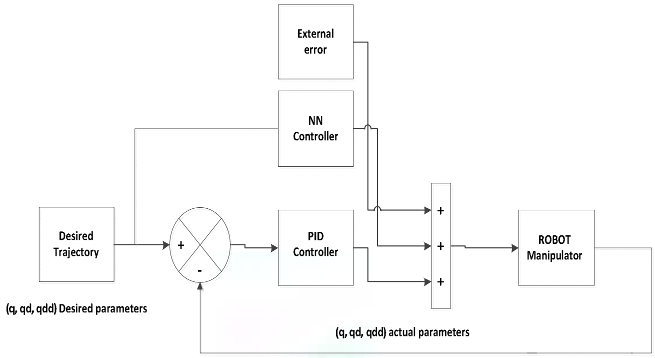


FIGURE2: PID+Neural Network Control of ROBOT Manipulator

A. Neural Network structure

1) Inputs and outputs

In order to simplify the problem of inverse dynamics for every joint one neural network was constructed. In other words every neural network outputs one torque for a motor and for an N DOF robot manipulator, the NNC (Neural Network Controller) consists of n separate networks. The input of every network is joint angle, angular velocity and angular acceleration of all the joints. The NNC in our case consists of 6 ANN with total 18 inputs and one output. Another candidate for the structure of the robot manipulator is having only one input per joint which can be the joint angle and developed the network as a dynamic network with delays in the first layer in order to rebuild the angular acceleration and velocity of every joint. The sample time of the controller loop must be fixed with the change in controller frequency to retrain the network from the start. For training neural networks with recursive layers was avoided due to need of longer time duration but these networks are more efficient for solving differential equations with nonlinearity.

2) Network structure

Neural network consists of two hidden layer was used in which the sigmoid function was used for first layer output function and linear function was used for the second layer output function.

3) Training Method

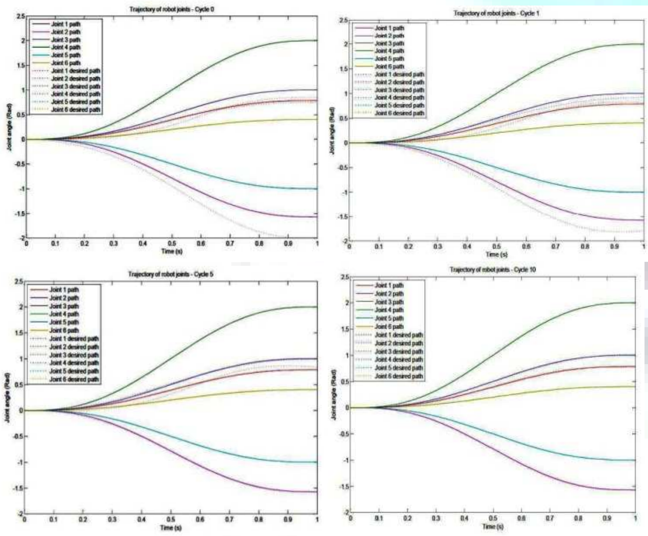
The data was received from the inverse dynamics of the system by the use of Simulink diagram created with the help of Matlab. The complete neural network was trained in the back propagation mode and all the weighs were updated according to the new tainting data. Both the incremental learning and Back Learning were used but the incremental learning is very slow and more often the weights are trapped in the local minimum.

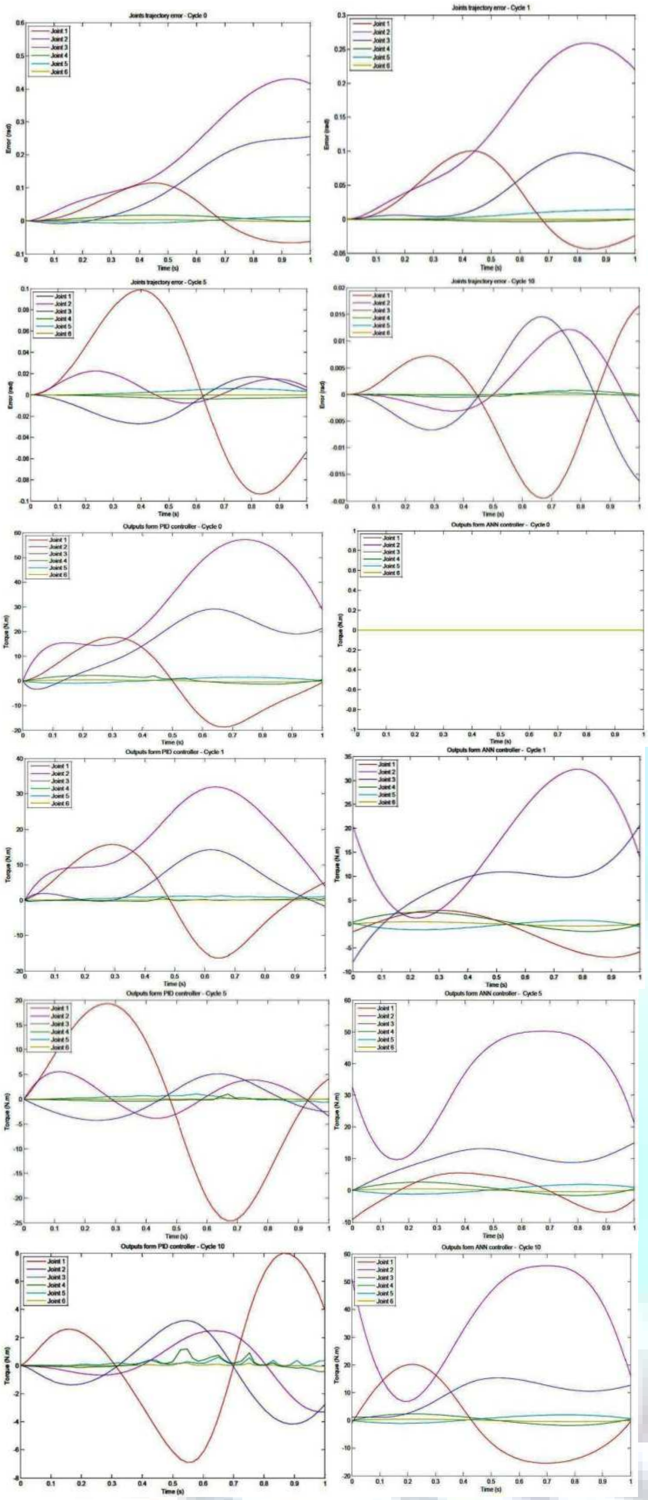
RESULTS AND DISCUSSION

Performance of the controller has been validated using 2 DOF as well as 6 DOF robot manipulators. First manipulator is a two DOF planner manipulator robot and second one is PUMA560. The parameters for both have been taken from [22].

The motion of robot between two points in joint space is illustrated in the following graphs. Robot manipulator path was generated by simulating the mathematical equations for computing joint space trajectory between two points of a path from [HYPERLINK \l "Lew93" 22] and is a polynomial to the order of 5. The values for the PID controller are $K_P = 100$, $K_D = 50$ and $K_I = 5$. In the graphs the trajectory path of the robot manipulator as well as error of the controller is shown. The other graphs show a comparison between the output of PID controller and the output of NN controller. It is shown that as the training continues the PID controller's output reduces and the NN controller generates the main signal for the robot manipulator control.

It was observed that after the first cycle of training the controller solves the inverse dynamics of the robot manipulator very fast. The performance of the system depends on the number of neurons in the controller network as while increasing the number of neurons increases, but on the contrary the error of the system decreases in same ratio and all it depends on amount of training data.





CONCLUSION

In this paper an efficient method for control of a manipulator with n degrees of freedom is presented. The Neural Network Controller (NNC) is used to identify both the dynamics and the kinematics of a manipulator. Though the controller is only getting fair results during the first cycles of a new path but later converging to minimum during repetitive performance of robot manipulator. The controller design is independent from parameters of the system and controller learns the system parameters during its operation.

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