Artificial Intelligence Techniques Applied to Control and Identify Parameters in variable DOF Robotic Manipulators for Industrial Automation

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Abstract: An industrial robot manipulator must be able to translate its static collection of joint angles into position coordinates before calculating the end effect's appropriate positioning with forward kinematics.A robotic manipulator has now become an integral part of industrial automation, greatly reducing the need for human labour, increasing the accuracy of work as well as reducing the time required to accomplish tasks.Each rotation must be controlled using servomotor feedback. MATLAB® Robotics Toolbox is used to verify the kinematic model for the activation of three revolving joints.The purpose of this paper is to provide an overview of an end-effect-based DC servomotor platform with intelligent controller for five degrees of freedom (5-DOF). A DenavitHarterberg (DH) representation was used to model forward and inverse kinematics. PID controllers with fuzzy logic are used to implement various blurring strategies. Simulated results from MATLAB show that PID produces better transient parameters than a conventional PID.Compared to the Fuzzy logic controller, PID has a better overshoot performance than FLC and both controllers can achieve the desired output when subjected to steady state responses, although FLC outperforms PID.

Keywords: *PID Controller,Robotic arm manipulator,Servomotor drive, DenavitHarterberg, Fuzzy logic Controller.*

1. Introduction

Increasing efficiency and productivity have been achieved through the use of robot technology in industrial and commercial systems. Over the past few years, many sea control investments have been made and a number of control implementations have been implemented. Medical applications, commercial applications, and educational applications all rely on robotic manipulators. There are a variety of unpredictable, dangerous, and hospitable circumstances in which it can function that humans are not able to handle.

The most commonly used robots in industrial settings are arm manipulators. Robot manipulators can automate a variety of applications. Robotic assembly, robotic welding, robotic material removal, robotic palletizing, and robotic pick-and-place are a few of the most common. New applications such as robotic 3D printing have been automated due to technological advances that have improved the accuracy and precision of robotic manipulators. In parallel with the advancement of manipulators, robotic applications are becoming more sophisticated. Automation of industrial robots improves the efficiency, reliability, and productivity of manufacturing processes. Several arm manipulators can be moved cross-nationally or rotated, having a number of joints connecting the links. The end-effector of each joint is connected to the actuator at the base. Robot manipulators are designed similarly to human hands, and their end-effectors can be modified to perform whatever task is desired[1]. Using these robots in those circumstances to work with high accuracy has become necessary due to their wide range of applications, which have prompted the development and manufacture of industrial robot manipulators and the testing of different control techniques. The mathematical equation for the system behavior needs to be developed before the performance and tracking control design can be achieved[2]. A dynamic model equation has to be identified along with the system's mapping forces in order for the dynamic model equation to be validated. The article also discusses the movement of industrially based robot manipulator parameters such as joint position, velocity, and acceleration. Dynamic robot manipulator model[3] is constructed using these mathematical equations. Linear motion or positioning can be accomplished in a number of ways. There are several types of linear motors that can be used for a linear motion system, some of which are induction motors, stepper motors, DC motors, synchronous motors, and hybrid motors. DC servo motors were among the first linear motors. DC servo motors are electric linear motors that have a built-in rotation sensor that detects rotational movement in real time. Robots move their arms by turning servo engines[4]. So if something knocks the robot's arm, the robot will know, for instance, because the engine will transmit data concerning the level of revolution axis to the robot. Field transition and armature current are straightforwardly related to force created on the engine shaft. As a result of brushes and commutators, DC servo engines are more extravagant than air conditioning servo engines. There is nothing difficult about controlling DC engines, and their characteristics are quite straight. The torque-to-volume and torque-to-inertia ratios are low, but they still have many of the characteristics of piston engines. The robot controller has been designed with different regulators. As far as execution records are concerned, there are various forms of these regulators. In the early years of commercial applications, the proportional integral derivative (PID) regulator has been commonly used[5].

Using PID power was the first approach due to its simplicity of design and execution. As input variables, the joint coupled angular displacement error and the shift time rate were used in the fuzzy controller. The angular displacement of the base joint is characterized both by the presence of free oscillations and a time-consuming process based on both theoretical and experimental evidence. A six-axis serial manipulator is controlled by a fuzzy-PID controller.In comparison to PID and two fuzzy controls, fuzzy-PID had small steady state errors. A hybrid of fuzzy and classical controllers has been developed in recent years to provide a sea-appropriate solution for regulating robot manipulators using fuzzy logic supervision (FLS) combined withfuzzy plus PID[6].This article aims to accomplish a specific goal, which is the tracking of the 5DOF robot manipulator arm through fuzzy logic supervision, which is the shoulder, elbow, and wrist for trajectory position tracking with 5DOF, the manipulator arm consists of the five degrees of freedom arm. Performance comparisons of controllers were conducted based on transient and step steady state characteristics.

2. Robot ManipulatorKinematic Modelling

There are various motions that a robot needs to perform to be able to perform a kinematic model problem. In order to create motion, it is not about the forces that are involved. There are two types of kinematics: forward kinematics and inverse kinematics. An end-effector's coordinates and the joint angle a joint achieves are dealt with by forward kinematics. There are several methods for kinematic modeling that are widely used, the most popular being successive screw displacement and the DenavitHartenberg, whereas the Denavit-Hartenberg formulation describes the Denavit-Hartenbergparameter which has the enamored knowledge of parameters and the kinematic model for robots [7]. Using an inverse model for robotic kinematics, you can find joint angles by giving coordinates, whereas a forward kinematic model computes them for the given coordinates and is typically more complex. The four Denavit-Hartenbergparameters represent the relationship between individual robot manipulator joints and the location and coordination of end-effectors. The parameters of the links of length, twist, offset, and joint angleareexpressed as ai, αi, di, θirespectively[8].Equation (1) describes the dynamics of a serious n-link rigid robot.

$$M(\dot{q})\ddot{q} + C(q,\dot{q}) + g(q) = \tau \qquad (1)$$

DenavitHartenberg convention was used to analyze Direct Kinematics:

$$A_i = \begin{bmatrix} \cos(\theta_i) & -\cos(\alpha_i)\sin(\theta_i) & \sin(\alpha i)\sin(\theta_i) & a_i\cos(\theta i) \\ \sin(\theta_i) & \cos(\alpha_i)\cos(\theta_i) & -\sin(\alpha_i)\cos(\theta_i) & a_i\sin(\theta_i) \\ 0 & \sin(\alpha i) & \cos(\alpha_i) & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The end-effector position vector is defined as follows:

$$X = \frac{1}{2}d_5\sin(\theta 1+\theta 3+\theta 4+\theta 2) + \frac{1}{2}d_5\sin(-\theta 1+\theta 3+\theta 4+\theta 2) + \frac{1}{2}a3\cos(-\theta 1+\theta 2+\theta 3) + \frac{1}{2}a3\cos(\theta 1+\theta 2+\theta 3) + \frac{1}{2}a2\cos(-\theta 1+\theta 2) + \frac{1}{2}a2\cos(\theta 1+\theta 2)$$

$$Y = \frac{1}{2}d_5\cos(-\theta 1+\theta 3+\theta 4+\theta 2) - \frac{1}{2}d_5\cos(\theta 1+\theta 3+\theta 4+\theta 2) + \frac{1}{2}a3\sin(\theta 1+\theta 2+\theta 3) - \frac{1}{2}a3\sin(-\theta 1+\theta 2+\theta 3) + \frac{1}{2}a2\sin(\theta 1+\theta 2) - \frac{1}{2}a2\sin(-\theta 1+\theta 2)$$

$$Z = -d_5\cos(\theta 3+\theta 4+\theta 2) + a3\sin(\theta 2+\theta 3) + a2\sin(\theta 2) + d_1$$

The inverse Kinematic problem involves determining a manipulator robot's joint variables given the end effector location and coordination of an inverse Kinematic model.A forward kinematic model problem is much simpler than an inverse kinematics model problem. The following mathematical expression can be used to describe it:

$$\theta_k = f_k\,(x, y, z, \alpha, \gamma, \emptyset) \qquad (2)$$

A robot manipulator's inverse kinematics problem can be solved by following the following steps:

- Analyze the final transformation matrix of the robot manipulator based on the general transformation matrix

$$H_i^0 = \begin{bmatrix} r_{11} & r_{12} & r_{13} & x \\ r_{21} & r_{22} & r_{23} & y \\ r_{31} & r_{32} & r_{33} & z \\ 0 & 0 & 0 & 1 \end{bmatrix} = A_1 A_2 \dots A_i \qquad (3)$$

- In both matrices, define:

a) A joint variable is contained in one element.

b) Only one joint variable is shared by two elements.

c) A joint variable appears in more than one element, or combination of elements.

- After defining these elements, solve the equations to identify the joint variable's value by equating them with the corresponding elements in the other matrix.
- Identify all elements in the two matrices by repeating step (3).
- When one solution is inaccurate, a new one is sought.
- In case there is more than one joint variable, multiply equation (3) by the inverse matrix of the specific link.

The steps (2) through (6) should be repeated until all joint variables have been solved.

3. Manipulator control system for a robot

There are various devices and tools used to control robot manipulators including sensors, controllers, and knowledge bases. As the controller moves, the robot manipulator gathers information about its state and surrounding circumstances a sensor or feedback system is used during the working environment. Based on the data obtained by a sensor or feedback system, the system is then improved or modified[9]. There are some functions provided for the plant (robot arm) by the control system, including a robot manipulator that can be moved around the environment, finding and collecting information about the robot manipulator on the work site and the data is stored, then provided to the manipulator, then updated instantly[10].

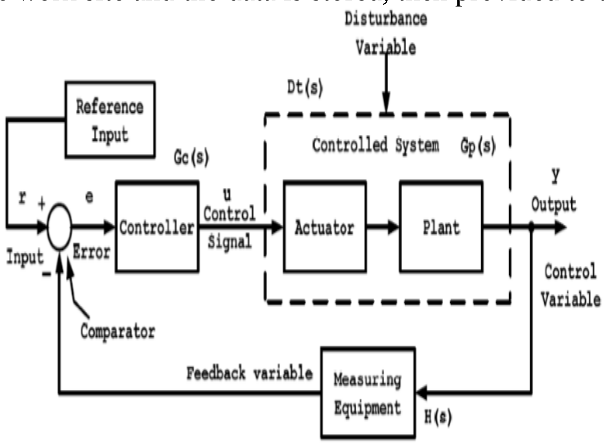

Figure 1: Diagram of an automated system with a closed loop

In order to accomplish a mission, rotating the end-effector is necessary as part of the control of manipulators.

An overview of automated system with a closed loop is shown in Fig.1. An input reference or set point value for a feedback control system is called r(t), the controlled plant is called y(t), and the closed loop is called the feedback control system.The Gp(s), represents the component of the process (e.g., the manipulator on the robot), actuators, gears, and mechanical components are all included[11].By normalizing the signal error e(t), the feedback controller Gc(s) modifies physical system performance.Feedback controllers aim to eliminate the error between set point values and feedback signals as much as possible through reduced error between set point values and feedback signals.

In control applications, proportional integral derivative (PID) controllers are most commonly used. Many applications and control engineers use the proportionally integral derivative controller on a daily basis[12]. By varying the parameters of a process, PID control provides a simple method for monitoring it. Furthermore, when parameters are properly adjusted, it provides consistent and robust efficiency. The use of PID variants in control systems is estimated to be between 90% and 95% by a number of sources, including JEMIMA[13]. Despite its limitations, the PID variant can provide satisfactory performance only when the process parameters vary in a reasonable manner and the requirements are reasonable[14].Assuming a PID controller is used for controlling a robot manipulator, the system disturbance compensator, Gcd(s), has the following transfer function:

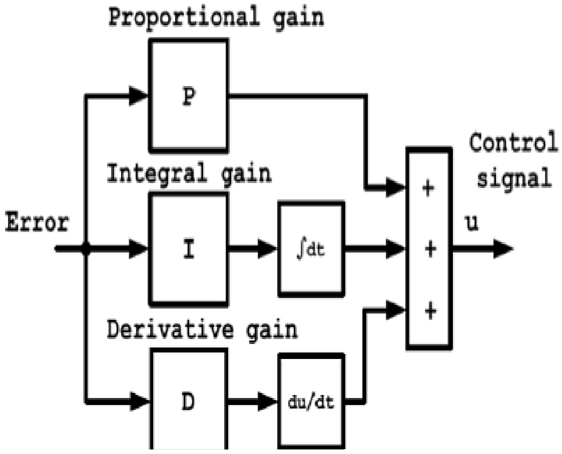

Figure 2: Controller structure for PID

$$G_{cd}(s) = \frac{L_a s^2 + R_a s}{K_t(K_D s^2 + K_p s + K_I} \qquad (4)$$

In SIMULINK, a proportional, integral, and derivative controller is used to control and reject disturbances. There are many stages in the main structure. A five-degree-of-freedom robot arm is used as a case study in this study to demonstrate independent joint control.According to the error e(t) = r(t)-y(t), each motor's position is given, along with its angle and load disturbance. This error is then used to determine the position of each motor. If e(t) = r(t) - y(t) is high, then Kp and Ki will be high, whereas Kd will be low when e(t) = r(t) - y(t) is high.

As a result, the output of the system will be sped up. Generally, if there is a very small error in the current measurement, According to the PID parameters, the proportional gain value should be smaller, and both the integral constant value and derivative gain value should be larger. This will reduce the overshoot of the output by reducing the fast response of the PID based system[15]. Tuning the PID controller parameters was accomplished via a MatlabSimulink block. As shown in Figure 3, parameter initial values were established and the new parameters were modified in only a few iterations[16]. Consequently, tuning parameters has become more efficient and less time-consuming.

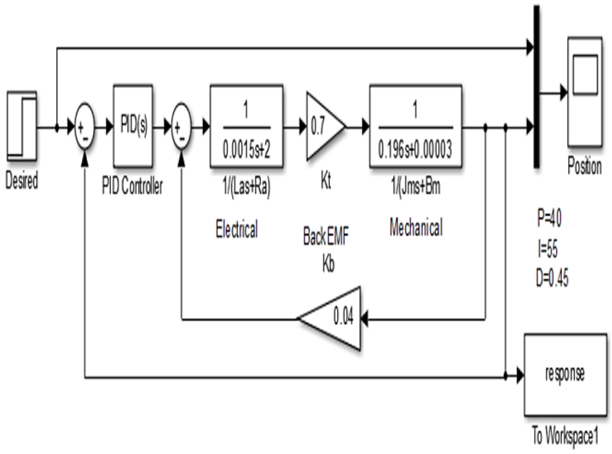

Figure 3: This block diagram shows how a PID controller is used to control a servomotor.

4. Supervisory controller with fuzzy logic

The fuzzy supervisory PID controller provides integral control directly while only proportional and expressed estimations are injected into the fuzzy controller to minimize the steady state error[17]. Fuzzy-PID controller, joint position error and velocity error are input crisp variables. Using a fuzzification component, both inputs are fuzzified[18]. It is defined in MathWorks that a triangular membership function exists distributes linguistic terms evenly between rank [-1 1] for input and output variables[19].

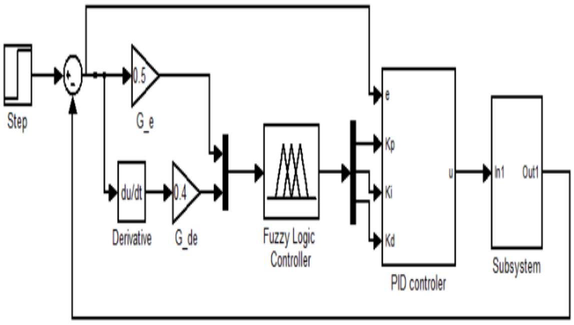

Figure 4: Fuzzy Supervisory PID Controller for closed-loop systems.

$$f(x,a,b,c) = \max\left(\min\left(\frac{x-a}{b-a},1,\frac{c-x}{c-b}\right),0\right) \quad (5)$$

The fuzzy logic rules later supervise the servo motor inference to infer the fuzzy variable performance[20]. NEL(-0.9046), NL(-0.3342), N(0.6642), ZO(-2.0715e-18), P(0.3342) and PL(0.658) for all languages are the index settings, as well as the record types, for each input variable as well as the record types for the crisp variable. For all languages, the index settings are: NEL(-0.9046), NL(-0.3342), N(0.6642), and ZO(-2.0715e-18). A total of seven linguistic fluids are fuzzzified into each input crisp variable. The Mamdani style FPD controller is trained with 49 rules. This transforms the fuzzy output into crisp output. Fig.5 shows this process.

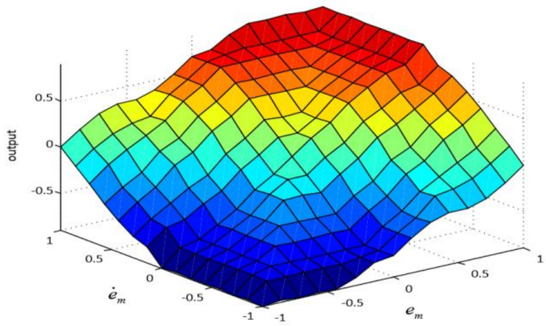

Figure 5: Supervisory PID Controller with Fuzzy Output Surface.

5. Results and outputs of simulations

As a result of the dynamic nature of a robotic manipulator such as a PUMA-560, MATLAB 2012b was used to simulate the behavior of a 5 degree of freedom robot manipulator such as a PUMA-560. Simulations are carried out using various controllers. An evaluation of the proposed fuzzy PID controller can be made by analyzing the output response, which clearly indicates that the controller is sufficiently efficient for tracking the desired trajectory with minimal steady state error. For the phase time of the first joint in the job (Base 1), 900 units were to be moved in 8 seconds. Fig.7 shows the position time response of a DC servomotor using a fuzzy logic controller, Simulation result is indicated by a solid line and desired signal by a dashed line.

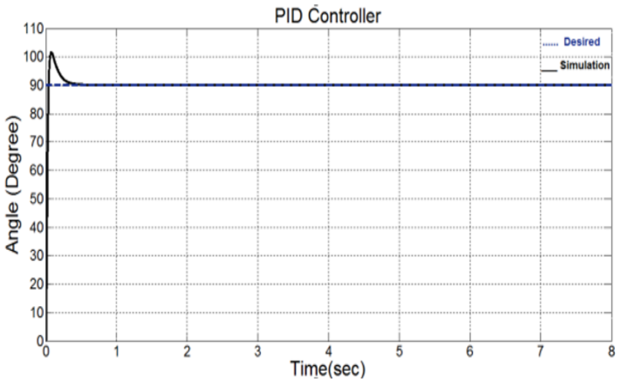

Figure 6:Position response of DC servo motor using PID Controller

Fig.7 shows the position time value of a DC servo motor using a fuzzy controller. Simulated results are represented by solid lines, whereas desired signals are represented by dashed lines.

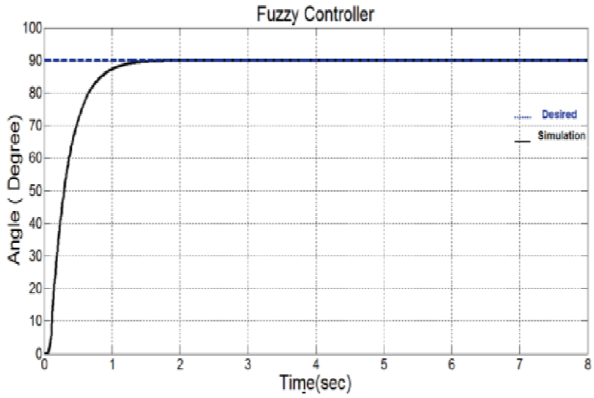

Figure 7:DC servo motors are controlled by fuzzy PID controllers

Table 1.

Different strategies for defuzzing fuzzy logic controllers are compared

Type of Controller	SystemCharacteristics		
	Mp%	***tr(sec)***	***SSE***
PID	-	0.0913	0.0351
Fuzzy supervisory	0.061%	0.063	0.0041

6.Conclusion

This article is focused on the use of a DC linear servomotor as a main actuator for the linear motion of a robotic arm. Each actuator controller is tuned by several controllers to ensure accuracy and robustness.Linear systems are typically controlled by PID-based controls. However, PID-based control is not well suited for nonlinear systems, especially in terms of robustness. PID parameters can be adjusted using several traditional methods. Based on the starting points, they consume sea time. To simplify the evaluation process of tuning the parameters of the PID controller in order to power a 5DOF robot arm system, the fuzzy logic-based controller was implemented. In comparison to regular PID controllers, the output response of fuzzy PID supervised controllers exceeded the regular PID controllers. Fuzzy controller logic outperformed conventional methods in tuning PID parameters in this study. Fuzzy computation has the main disadvantage of taking a long time to compute than PID based algorithms. This research compares FCC and PID strategies in terms of design and performance.As a result of using a step input signal, the simulation output can be characterized in conjunction with its response and the simulation results show that PID has the ability to predict transients better than PID formulas.It is important that the fuzzy logic controller and the PID controller both operate in a consistent manner for the desired output to be achieved. However, when in a state of overshoot, the fuzzy logic controller outperformed the PID controller.

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