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Research on Hand Tremors-Free in Active Joint Dental Automation

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Abstract

This research describes the design and implementation of nonlinear control strategies for three dimensions joint dental robot manipulators whose dynamic or kinematic models are uncertain. This technique describes the development of an adaptive task-space tracking controller for dental robot manipulators with uncertainty in the kinematic and dynamic models. The controller is developed based on the unit quaternion representation so that singularities associated with the otherwise commonly used three parameter representations are avoided. This controller requires the assumption that the manipulator models are nonlinearly parameterizable. However there might be scenarios where the structure of the manipulator dynamic model itself is unknown due to difficulty in modeling. These manipulators do not have rigid joints, hence, they are difficult to model and this leads to significant challenges in developing high-performance control algorithms. In this research to eliminate the hand tremors, PID controller is used and to improve the performance and reduce the steady state error PI based PD fuzzy rule base controller is used.

Keywords: *fuzzy control, Multi degrees of freedom joints, PID Controller, hybrid control, system's uncertainty*

1. Introduction

The control objective in many robot manipulator applications is to command the end-effector motion to achieve a desired response. The control inputs are applied to the manipulator joints, and the desired position and orientation is typically encoded in terms of a Cartesian coordinate frame attached to the robot end-effector with respect to the base frame (*i.e.,* the so-called task-space variables). Hence, a mapping (*i.e.,* the solution of the inverse kinematics) is required to convert the desired task space trajectory into a form that can be utilized by the joint space controller. If there are uncertainties or singularities in the mapping, then this can result in degraded performance or unpredictable responses by the manipulator. Several parametrizations exist to describe orientation angles in the task-space to joint-space mapping, including three-parameter representations (*e.g.,* Euler angles, Rodriguez parameters) and the four-parameter representation given by the unit quaternion. Three-parameter representations always exhibit singular orientations (*i.e.,* the orientation Jacobian matrix in the kinematic equation is singular for some orientations), while the unit quaternion represents the end-effector orientation without singularities. By utilizing the singularity free unit quaternion. Some previous task-space control formulations based on the unit quaternion can be found in [1-5], and the references therein. A quaternion-based resolved acceleration controller was presented in [2], and quaternion-based resolved rate and resolved acceleration task-space controllers were proposed in [4-5]. Output feedback task-space controllers using quaternion feedback were

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presented in [3] for the regulation problem and in [1] for the tracking problem. Multi degrees of freedom actuator is a type of nonlinear joints. These actuators are finding wide use in a number of Industries such as aerospace, Industrial medical and automotive. For high precession trajectory planning and control, it is necessary to replace the actuator system made up of several single-DOF motors connected in series and/or parallel with a single multi-DOF actuator [1-3]. The spherical motor have potential contributions to a wide range of applications such as coordinate measuring, object tracking, material handling, automated assembling, welding, and laser cutting [4]. All these applications require high precision motion and fast dynamic response, which the spherical motor is capable of delivering [5-6]. The spherical motor exhibits coupled, nonlinear and very complex dynamics. The design and implementation of feedback controllers for the motor are complicated. The controller design is further complicated by the orientation-varying torque generated by the spherical motor [7]. One of the significant challenges in control algorithms is a linear behavior controller design for nonlinear systems. Some of Multi degrees of freedom actuator which work in industrial processes are controlled by linear PID controllers, but the design of linear controller for Multi degrees of freedom actuator is extremely difficult in presence of hand tremors. To solve this challenge, linear model-free controller is a good candidate. Fuzzy logic controller is used to improve the controller performance [7-10].

In the literature sources, we can find different kinds of justification for fuzzy systems theory. Human knowledge nowadays becomes increasingly important – we gain it from experiencing the world within which we live and use our ability to reason to create order in the mass of information (*i.e.,* to formulate human knowledge in a systematic manner). Since we are all limited in our ability to perceive the world and to profound reasoning, we find ourselves everywhere confronted by uncertainty which is a result of lack of information (lexical impression, incompleteness), in particular, inaccuracy of measurements. The other limitation factor in our desire for precision is a natural language used for describing/sharing knowledge, communication, *etc*. We understand core meanings of word and are able to communicate accurately to an acceptable degree, but generally, we cannot precisely agree among ourselves on the single word or terms of common sense meaning. In short, natural languages are vague. Our perception of the real world is pervaded by concepts, which do not have sharply defined boundaries – for example, any, tall, much larger than, young, *etc.*, are true only to some degree and they are false to some degree as well. These concepts (facts) can be called fuzzy or gray (vague) concepts – a human brain works with them, while computers may not do it (they reason with strings of 0s and 1s). Natural languages, which are much higher in level than programming languages, are fuzzy whereas programming languages are not. The door to the development of fuzzy computers was opened in 1985 by the design of the first logic chip by Masaki Togai and Hiroyuki Watanabe at Bell Telephone Laboratories. In the years to come fuzzy computers will employ both fuzzy hardware and fuzzy software, and they will be much closer in structure to the human brain than the present-day computers are [11-18].

The Fuzzy Logic tool was introduced in 1965, also by Lotfi Zadeh, and is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership the important concept of computing with words'. It provides a technique to deal with imprecision and information granularity. The fuzzy theory provides a mechanism for representing linguistic constructs such as “many,” “low,” “medium,” “often,” “few.” In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. On the contrary, the traditional binary set theory describes crisp events, events that either do or do not occur. It uses probability theory to explain if an event will occur, measuring the chance with which a given event is expected to occur. The theory of fuzzy logic is based upon the notion of relative graded membership and so are the functions of mentation and cognitive processes. The utility of fuzzy sets lies in their ability to model uncertain or ambiguous data, Figure 1, so often encountered in real life [19-22].

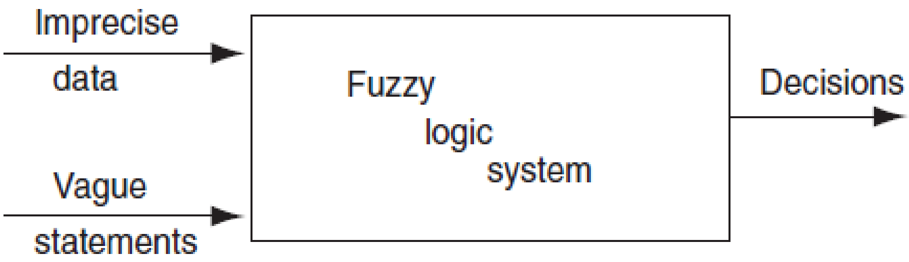

Figure 1. A Fuzzy Logic System, which Accepts Imprecise Data and Vague Statements Such as Low, Medium, High and Provides Decisions

Although the fuzzy-logic control is not a new technique, its application in this current research is considered to be novel since it aimed for an automated dynamic-less response rather than for the traditional objective of uncertainties compensation [8-9]. The intelligent tracking control using the fuzzy-logic technique provides a cost-and-time efficient control implementation due to the automated dynamic-less input. This in turn would further inspire multi-uncertainties testing for continuum robot [10]. In project we can used fuzzy logic theory when a plant can be considered as a black box with outputs available for measurement and a possibility of changing inputs. The plant is supposed to be observable and controllable. Some information about the plant operation or plant control is available, which can or cannot be of a quantitative nature, but it can be formulated as a set of rules (maybe after some processing). An acceptable fuzzy control solution is possible, which should satisfy design specifications. It must not be optimal in regard to some criteria as it is hard to prove that a fuzzy control system is optimal and even stable. However, a fuzzy controller is able to provide a stable and 'good' solution. However fuzzy logic controller used in many application but it has an important challenge namely; stability. To improve stability in certain condition, hybrid fuzzy controller is introducing [11-12].

In modern usage, the word of control has many meanings, this word is usually taken to mean regulate, direct or command. The word feedback plays a vital role in the advance engineering and science. The conceptual frame work in Feed-back theory has developed only since world war II. In the twentieth century, there was a rapid growth in the application of feedback controllers in process industries. According to Ogata, to do the first significant work in three-term or PID controllers which Nicholas Minorsky worked on it by automatic controllers in 1922. In 1934, Stefen Black was invention of the feedback amplifiers to develop the negative feedback amplifier [3]. Negative feedback invited communications engineer Harold Black in 1928 and it occurs when the output is subtracted from the input. Automatic control has played an important role in advance science and engineering and its extreme importance in many industrial applications, i.e., aerospace, mechanical engineering and robotic systems. The first significant work in automatic control was James Watt's centrifugal governor for the speed control in motor engine in eighteenth century [2]. There are several methods for controlling a multi degrees of freedom joint actuators, which all of them follow two common goals, namely, hardware/software implementation and acceptable performance. However, the mechanical design of robot manipulator is very important to select the best controller but in general two types schemes can be presented, namely, a joint space control schemes and an operation space control schemes [1]. Joint space and operational space control are closed loop controllers which they have been used to provide robustness and rejection of disturbance effect. The main target in joint space controller is design a feedback controller that allows the actual motion ($q_a(t)$) tracking of the desired motion ($q_d(t)$). This control problem is classified into two main groups. Firstly, transformation the desired motion $X_d(t)$ to joint variable $q_d(t)$ by inverse kinematics of robot manipulators [6]. Figure 2 shows the main block diagram of joint space controller. The main target in operational space controller is to design a feedback controller to allow the actual end-effector motion $X_a(t)$ to track the desired end effector motion $X_d(t)$. This control methodology requires a greater algorithmic complexity and the inverse kinematics used in the feedback control loop. Direct measurement of operational space variables are very expensive that caused to limitation used of this controller in industrial robot manipulators [6]. Figure 3 shows the main block diagram of operational space control.

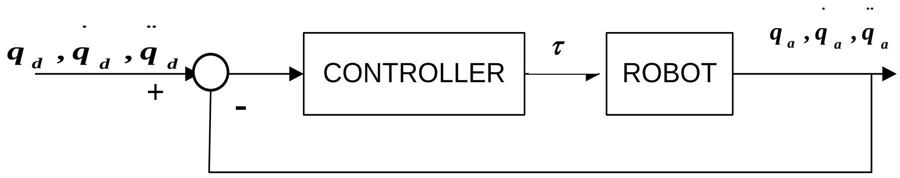

Figure 2. Block Diagram of Joint Space Control

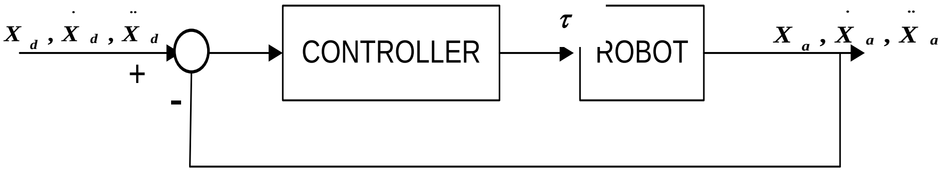

Figure 3. Block Diagram of Operational Space Control

One of the simplest ways to analysis control of multiple DOF robot manipulators are analyzed each joint separately such as SISO systems and design an independent joint controller for each joint. In this methodology, the coupling effects between the joints are modeled as disturbance inputs. To make this controller, the inputs are modeled as: total velocity/displacement and disturbance. Design a controller with the same formulation and different coefficient, low cost hardware and simple structure controller are some of most important independent-joint space controller advantages.

In this research, PID controller is used to reduce the hand tremors in certain condition. To improve the system uncertainty, PI fuzzy controller is applied to linear controller and the error performance will be reduced. This paper is organized as follows; Section 2, is served as an introduction to the dynamic of three degrees of freedom spherical motor, PID Controller and fuzzy logic algorithm. Part 3, introduces and describes the methodology algorithm. Section 4 presents the simulation results and discussion of this algorithm and the final section describe the conclusion.

2. Theory

Dynamic and Kinematics Formulation of Spherical Motor: Dynamic modeling of spherical motors is used to describe the behavior of spherical motor such as linear or nonlinear dynamic behavior, design of model based controller such as pure sliding mode controller which design this controller is based on nonlinear dynamic equations, and for simulation. The dynamic modeling describes the relationship between motion, velocity, and accelerations to force/torque or current/voltage and also it can be used to describe the particular dynamic effects (*e.g.*, inertia, coriolios, centrifugal, and the other parameters) to behavior of system. Spherical motor has nonlinear and uncertain dynamic parameters 3 degrees of freedom (DOF) motor.

The equation of a spherical motor governed by the following equation:

$$\boldsymbol{H}(\boldsymbol{q})\begin{bmatrix}\ddot{\boldsymbol{\alpha}}\\ \ddot{\boldsymbol{\beta}}\\ \ddot{\boldsymbol{\gamma}}\end{bmatrix}+\mathbf{B}(\boldsymbol{q})\begin{bmatrix}\dot{\boldsymbol{\alpha}}\dot{\boldsymbol{\beta}}\\ \dot{\boldsymbol{\alpha}}\dot{\boldsymbol{\gamma}}\\ \dot{\boldsymbol{\beta}}\dot{\boldsymbol{\gamma}}\end{bmatrix}+\boldsymbol{C}(\boldsymbol{q})\begin{bmatrix}\dot{\boldsymbol{\alpha}}^{2}\\ \dot{\boldsymbol{\beta}}^{2}\\ \dot{\boldsymbol{\gamma}}^{2}\end{bmatrix}=\begin{bmatrix}\boldsymbol{\tau}_{x}\\ \boldsymbol{\tau}_{y}\\ \boldsymbol{\tau}_{z}\end{bmatrix} \tag{1}$$

Where τ is actuation torque, H (q) is a symmetric and positive define inertia matrix, B(q) is the matrix of coriolios torques, C(q) is the matrix of centrifugal torques.

This is a decoupled system with simple second order linear differential dynamics. In other words, the component $\ddot{q}$ influences, with a double integrator relationship, only the variableq_i, independently of the motion of the other parts. Therefore, the angular acceleration is found as to be:

$$\ddot{\boldsymbol{q}}=\boldsymbol{H}^{-1}(\boldsymbol{q}).\{\boldsymbol{\tau}-\{\boldsymbol{B}+\boldsymbol{C}\}\} \tag{2}$$

This technique is very attractive from a control point of view.

Study of spherical motor is classified into two main groups: kinematics and dynamics. Calculate the relationship between rigid bodies and final part without any forces is called Kinematics. Study of this part is pivotal to design with an acceptable performance controller, and in real situations and practical applications. As expected the study of kinematics is divided into two main parts: forward and inverse kinematics. Forward kinematics has been used to find the position and orientation of task frame when angles of joints are known. Inverse kinematics has been used to find possible joints variable (angles) when all position and orientation of task frame be active.

The main target in forward kinematics is calculating the following function:

$$\boldsymbol{\Psi}(\boldsymbol{X},\boldsymbol{q})=\mathbf{0} \tag{3}$$

Where $\Psi(.)\in R^{n}$ is a nonlinear vector function, $X=[X_1,X_2,\dots\dots,X_l]^T$ is the vector of task space variables which generally task frame has three task space variables, three orientation, $q=[q_1,q_2,\dots.,q_n]^T$ is a vector of angles or displacement, and finally n is the number of actuated joints. The Denavit-Hartenberg (D-H) convention is a method of drawing spherical motor free body diagrams. Denvit-Hartenberg (D-H) convention study is necessary to calculate forward kinematics in this motor.

A systematic Forward Kinematics solution is the main target of this part. The first step to compute Forward Kinematics (F.K) is finding the standard D-H parameters. The following steps show the systematic derivation of the standard D-H parameters.

1. Locate the spherical motor
2. Label joints
3. Determine joint rotation (θ)
4. Setup base coordinate frames.
5. Setup joints coordinate frames.
6. Determineα_i, thatα_i, link twist, is the angle between Z_i and Z_{i+1} about an X_i.
7. Determine d_i and a_i , that a_i, link length, is the distance between Z_i and Z_{i+1} along X_i. d_i, offset, is the distance between X_{i-1} and X_i along Z_i axis.
8. Fill up the D-H parameters table. The second step to compute Forward kinematics is finding the rotation matrix (R_n^0). The rotation matrix from$\{F_i\}$ to $\{F_{i-1}\}$ is given by the following equation;

$$\boldsymbol{R}_{i}^{i-1}=\boldsymbol{U}_{i(\boldsymbol{\theta}_i)}\boldsymbol{V}_{i(\boldsymbol{\alpha}_i)} \tag{4}$$

Where $U_{i(\theta_i)}$ is given by the following equation;

$$\boldsymbol{U_{i(\theta_i)}} = \begin{bmatrix} \boldsymbol{cos(\theta_i)} & \boldsymbol{-sin(\theta_i)} & \boldsymbol{0} \\ \boldsymbol{sin(\theta_i)} & \boldsymbol{cos(\theta_i)} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{1} \end{bmatrix} \tag{5}$$

and $V_{i(\alpha_i)}$ is given by the following equation;

$$\boldsymbol{V_{i(\theta_i)}} = \begin{bmatrix} \boldsymbol{1} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{cos(\alpha_i)} & \boldsymbol{-sin(\alpha_i)} \\ \boldsymbol{0} & \boldsymbol{sin(\alpha_i)} & \boldsymbol{cos(\alpha_i)} \end{bmatrix} \tag{6}$$

So (R_n^0) is given by

$$\boldsymbol{R_n^0 = (U_1V_1)(U_2V_2) \dots \dots \dots (U_nV_n)} \tag{7}$$

The final step to compute the forward kinematics is calculate the transformation ${}_n^0T$ by the following formulation [3]

$$\boldsymbol{{}_n^0T = {}_1^0T.{}_2^1T.{}_3^2T \dots \dots . {}_n^{n-1}T = \begin{bmatrix} R_n^0 & 0 \\ 0 & 1 \end{bmatrix}} \tag{8}$$

Linear Control Algorithm: Linear control theory is used in linear and nonlinear systems. This type of theory is used in industries, because design of this type of controller is simple than nonlinear controller. However this type of controller used in many applications but it cannot guarantee performance in complex systems. Simple linear controllers are including proportional algorithm, Proportional-Derivative algorithm, Integral algorithm, Proportional-Integral algorithm and Proportional-Integral-Derivative algorithm.

Proportional Algorithm: It is used to responds immediately to difference of control input variables by immediately changing its influences variables, but this type of control is unable to eliminate the control input difference. Figure 4 shows the block diagram of proportional controller with application to nonlinear system.

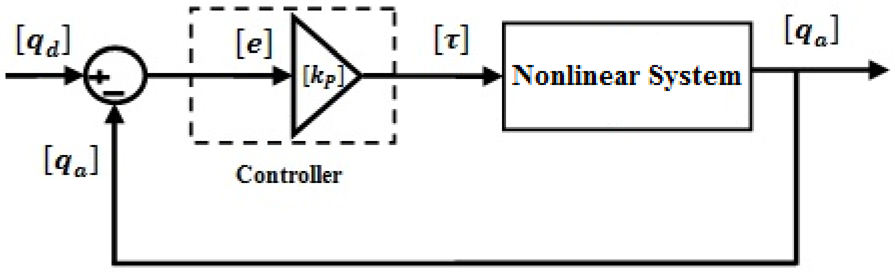

Figure 4. Block Diagram of Proportional Controller

Proportional plus Derivative (PD) control: This type of linear controller is widely used in control process where the results are sensitive to exceeded of set point. This controller, like Proportional controller, has permanent variation in presence of self-limitation control. In mathematically, the formulation of Proportional-Derivative part calculated as follows;

$$\boldsymbol{U_{PD} = K_p \times e + K_v(\frac{de}{dt}) = K_p \times e + K_v\dot{e}} \tag{9}$$

The Derivative component in this type of methodology is used to cancel outs the change process variables change in presence of quick change in controllers input. Figure 5 shows the block diagram of Proportional-Derivative (PD) control of nonlinear system.

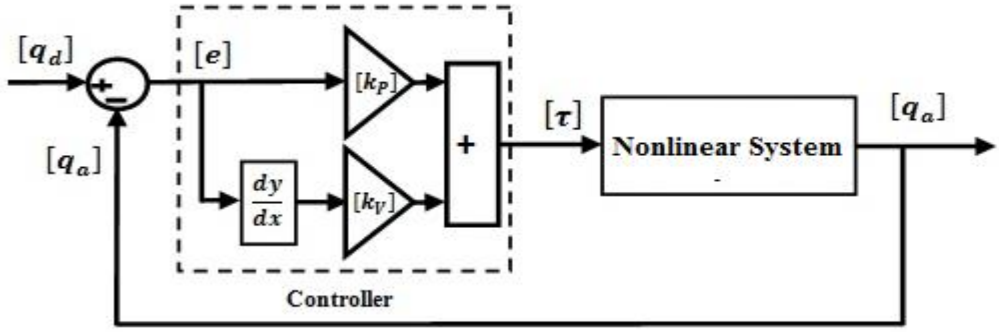

Figure 5. Block Diagram of PD Control

Integral (I) Control: This category, integrate the input signal deviation over a period of time. This part of controller is used to system stability after a long period of time. Figure 6 shows the block diagram of Integral (I) controller with application to nonlinear system. In contrast of Proportional type of controller, this type of controller used to eliminate the deviation.

In mathematically, the formulation of integral part calculated as follows;

$$\boldsymbol{I = \frac{1}{T}\int e.dt = \sum e} \tag{10}$$

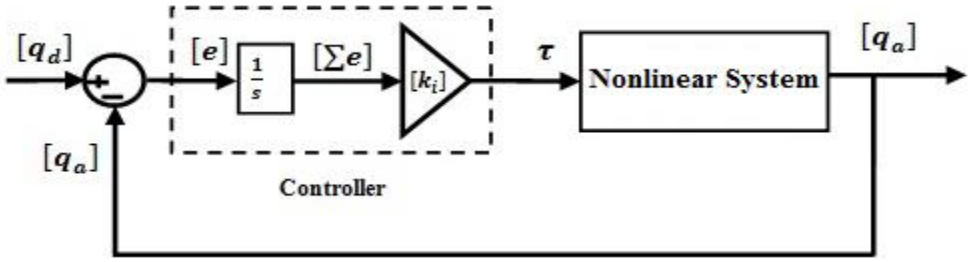

Figure 6. Block Diagram of Integral Control

Proportional Plus Integral (PI) Control: According to integral type of controller, it takes relatively long time. The proportional type controller used to immediately response to the input variations. The proportional-integral (PI) controller has the advantages of both proportional and integral controller; it is rapid response to the input deviation as well as the exact control at the desired input. Figure 7 shows the block diagram of PI control.

$$\boldsymbol{U_{PI} = K_p \times e + K_i(\frac{1}{T}\int e.dt) = K_p \times e + K_i \sum e} \tag{11}$$

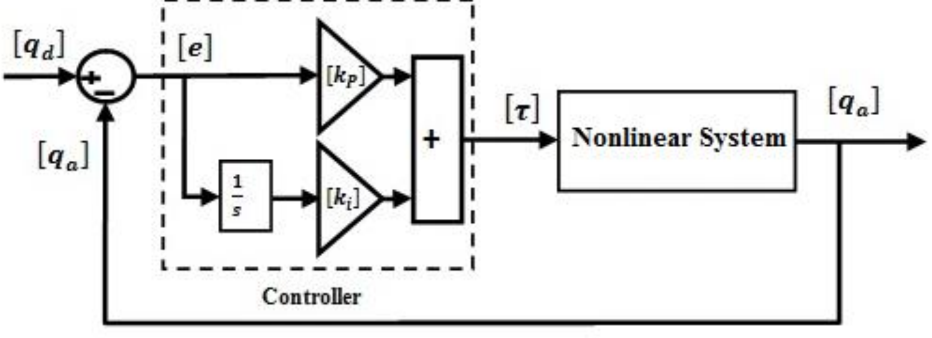

Figure 7. Block Diagram of PI Control

Proportional-Integral-Derivative (PID) Control: The combination of proportional (P) component, integral (I) component with a derivative (D) controller offered advantages in each case. This type of controller has rapid response to the input deviation, the exact control at the desired input as well as fast response to the disturbances. The PID controller takes the error between the desired joint variables and the actual joint variables to control. A proportional-derivative integral control system can easily be implemented. This method does not provide sufficient control for systems with time-varying parameters or highly nonlinear systems. Figure 8 shows the block diagram of PID control. The formulation of PID controller calculated as follows;

$$U_{PID} = K_p \times e + K_i(\frac{1}{T}\int e.dt) + K_v(\frac{de}{dt}) = K_p \times e + K_i \sum e + K_v \dot{e} \quad (12)$$

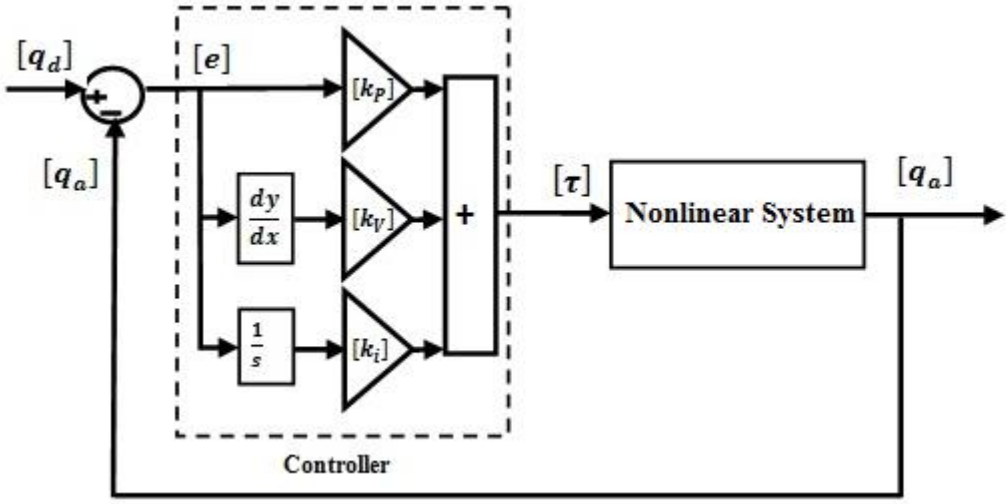

Figure 8. Block Diagram of PID Control of Robot Manipulator

Fuzzy Control Algorithm: It is important to observe that there is an intimate connection between Fuzziness and Complexity. As the complexity of a task (problem), or of a system for performing that task, exceeds a certain threshold, the system must necessarily become fuzzy in nature. Zadeh, originally an engineer and systems scientist, was concerned with the rapid decline in information afforded by traditional mathematical models as the complexity of the target system increased. As he stressed, with the increasing of complexity our ability to make precise and yet significant statements about its behavior diminishes. Realworld problems (situations) are too complex, and the complexity involves the degree of uncertainty – as uncertainty increases, so does the complexity of the problem. Traditional system modeling and analysis techniques are too precise for such problems (systems), and in order to make complexity less daunting we introduce appropriate simplifications, assumptions, *etc.*, (*i.e.,* degree of uncertainty or Fuzziness) to achieve a satisfactory compromise between the information we have and the amount of uncertainty we are willing to accept. In this aspect, fuzzy systems theory is similar to other engineering theories, because almost all of them characterize the real world in an approximate manner. Fuzzy sets provide means to model the uncertainty associated with vagueness, imprecision, and lack of information regarding a problem or a plant, etc. Consider the meaning of a "short person." For an individual X, the short person may be one whose height is below $4'25''$. For other individual Y, the short person may be one whose height is below or equal to $3'90''$. This "short" is called as a linguistic descriptor. The term "short" informs the same meaning to the individuals X and Y, but it is found that they both do not provide a unique definition. The term "short" would be conveyed effectively, only when a computer compares the given height value with the reassigned value of "short." This variable "short" is called as linguistic variable, which represents the imprecision existing in the system. The uncertainty is found to arise from ignorance, from chance and randomness, due to lack of knowledge, from vagueness (unclear), like the fuzziness existing in our natural language. Lotfi Zadeh proposed the set membership idea to make suitable decisions when uncertainty occurs. Consider the "short" example discussed previously. If we take "short" as a height equal to or less than 4 feet, then $3'90''$ would easily become the member of the set "short" and $4'25''$ will not be a member of the set "short." The membership value is "1" if it belongs to the set or "0" if it is not a member of the set. Thus membership in a set is found to be binary *i.e.*, the element is a member of a set or not.

The foundation and introduction of fuzzy logic theory is discussed in this section [34-35]. Supposed that U is the universe of discourse for example in this research error, change of error and torque are the sample of universe of discourse and x is the element of U it means that if error is positive and small or if change of error to be defined as positive and small, all these part of the elements of error and change of error. A crisp set to be defined as a set such as error or change of error which consists of different elements (x) such as negative and small in error will all or no membership in a defined set. In crisp set the membership degree is zero or one such as logical systems. A crisp set (C) in a universe of discourse U is defined by a following membership function ($\boldsymbol{\mu_C}$);

$$\boldsymbol{\mu_C}: \boldsymbol{U} \rightarrow \{\boldsymbol{0}, \boldsymbol{1}\} \tag{13}$$

A fuzzy set is a set such as error or change of error that different element has different membership grade between zero to one. A fuzzy set (F) in a universe of discourse U is defined by a following membership function ($\boldsymbol{\mu_F}$);

$$\boldsymbol{\mu_F}: \boldsymbol{U} \rightarrow [\boldsymbol{0}, \boldsymbol{1}] \tag{14}$$

The membership function $(\mu_F(x))$ of fuzzy set F has value between zero to one which each element of universe of discourse$\boldsymbol{U}$ mapped a values between zero to one and this value is called membership degree. Figure 9 shows the fuzzy membership function.

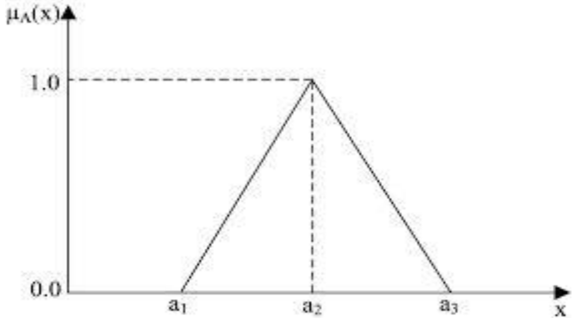

Figure 9. Fuzzy Membership Functions

If the membership functions value $\mu_C(x)$ equal to zero or one it is a crisp set. Based on literature numerical membership function and functional membership function are two important technique to define fuzzy membership function. In numerical membership function the numerator of fraction shows the degrees of membership function and the denominator of fraction shows the universe of discourses point. In functional membership function standard functions in fuzzy sets is used to define membership function and membership degrees. According to the literature the famous functional membership function in practical applications are:

- triangular function
- trapezoidal form
- Gaussian form

According to the literature the formulation of Trapezoidal membership function is;

$$\mu_{F(x)} = \begin{cases} \mathbf{0} & , (x < a) or (x > d) \\ \frac{x-a}{b-a}, & a \leq x < b \\ \frac{d-x}{d-c}, & c \leq x < d \\ \mathbf{1} & , b \leq x \leq c \end{cases} \tag{15}$$

Figure 10 shows the Trapezoidal membership function.

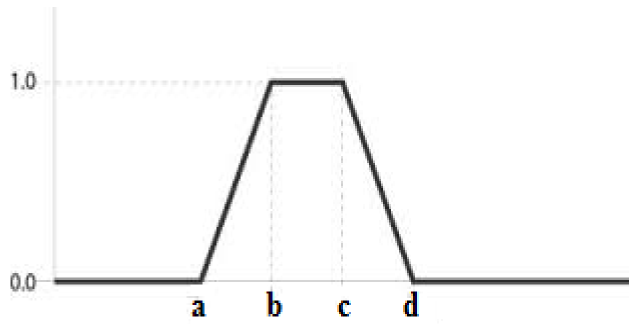

Figure 10. Trapezoidal Membership Functions

The formulation of Triangular membership function is;

$$\mu_{F(x)} = \begin{cases} \mathbf{0} & , x < a \\ \frac{x-a}{m-a}, & a \leq x < m \\ \frac{b-x}{b-m}, & m \leq x \leq b \\ \mathbf{0} & , x > c \end{cases} \tag{16}$$

Figure 11 shows the Triangular membership function.

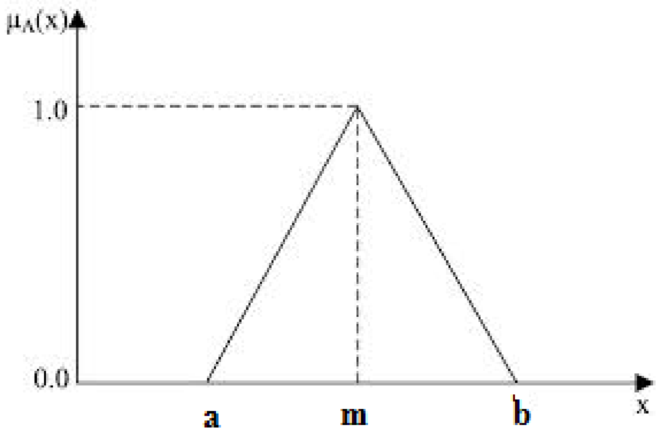

Figure 11. Triangular Membership Functions

Based on literature the Gaussian membership function is formulated by:

$$\mu_{F(x)} = e^{\frac{-(x-m)^2}{2K^2}} \tag{17}$$

Figure 12 shows the Gaussian membership function.

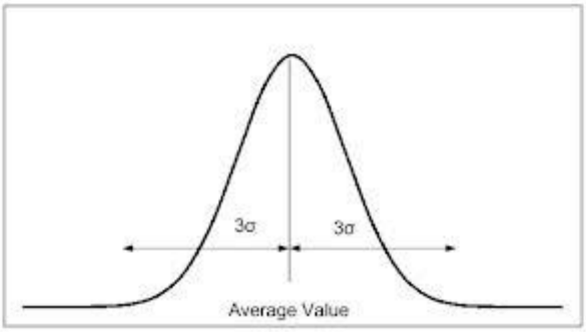

Figure 12. Gaussian Membership Functions

The variable in crisp set is numerical variable but in fuzzy logic theory the variables are linguistic variable. This item is used to describe the values of universe of discourse such as error by any words and sentences. Linguistic variable opens a window to application of fuzzy logic theory in many applications. In a fuzzy logic theory all numerical variables are replaced by words or sentences. For example various words of linguistic variables for any inputs or outputs are: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), Positive Big (PB). Figure 13 shows the membership function and linguistic variables in this graph the universe of discourse is error, the membership function is triangular and the linguistic variables are Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Big (PB).

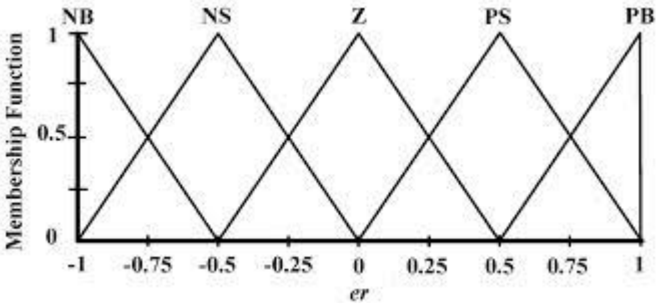

Figure 13. Membership Function and Linguistic Variables

According above discussion, fuzzy set used a membership function to support the membership value of its elements. Universe of discourse is defined by several linguistic variable and different membership functions. To define the behaviour of fuzzy logic set rule base is played important role. If-then rule is the main part to design rule base and rule table. If-then rule statements are used to formulate the condition statements in fuzzy logic theory. A fuzzy if-then rule is divided into two main groups:

- single fuzzy if-then rule
- Multiple fuzzy if-then rule

According to the literature if-then rule has two main parts:

- Antecedent part
- Consequent part

In single fuzzy if-then rule the antecedent part has one variable and it has only one part, following rule shows the single fuzzy if-then rule:

$$FR: If\ e\ is\ NB\ Then\ U\ is\ PB \quad (18)$$

e is input variable which in design controllers defined by fuzzy logic input, U is output variable, NB and PB are the Linguistic variables that can be defined by fuzzy set, the part of "$e\ is\ NB$" is called the antecedent part and the part of "$U\ is\ PB$" is called the Consequent or Conclusion part. In most of fuzzy controllers antecedent part has multiple parts; the following rule shows the multiple antecedent parts:

$$\boldsymbol{FR}: \boldsymbol{If\ e\ is\ NB\ and\ \dot{e}\ is\ ML\ then\ T\ is\ PB} \tag{19}$$

$e\ and\ \dot{e}$ are inputs, T is output, Negative Big (NB), Medium Left (ML) and Positive Big (PB) are the linguistic variables, the part of "$\boldsymbol{If\ e\ is\ NB\ and\ \dot{e}\ is\ ML}$" is antecedent part and it multiple, in this state the fuzzy operations (AND/OR) is used and the part of "$\boldsymbol{then\ T\ is\ PB}$" is the consequent part. In most of fuzzy logic controllers, fuzzy controller inputs are used in antecedent part and the output of controller defined by consequent part.

3. Methodology

Proportional-Integral-Derivative (PID) controller has rapid response to the input deviation, the exact control at the desired input as well as fast response to the disturbances. The PID controller takes the error between the desired joint variables and the actual joint variables to control the three dimension of joint. The equation of PID controller for control of 3 degrees of freedom joint is;

$$\begin{bmatrix}\widehat{\tau_1}\\ \widehat{\tau_2}\\ \widehat{\tau_3}\end{bmatrix} = \begin{bmatrix}K_{i1}\sum e_1 + K_{v1}\dot{e}_1 + K_{p1}e_1\\ K_{i2}\sum e_2 + K_{v2}\dot{e}_2 + K_{p2}e_2\\ K_{i3}\sum e_3 + K_{v3}\dot{e}_3 + K_{p3}e_3\end{bmatrix} \tag{20}$$

Where $e = q_d - q_a$, q_d is desired joint variable and q_a is actual joint variable.
In PID controller the control law is given by the following equation;

$$\boldsymbol{\tau = K_p e + K_v \dot{e} + K_i \sum e} \tag{21}$$

Where $\boldsymbol{e = q_{i_d} - q_{i_a}}$
In this theory $\boldsymbol{K_p}$, $\boldsymbol{K_i}$ **and** $\boldsymbol{K_v}$ are positive constant. To show this controller is stable and achieves zero steady state error, the Lyapunov function is introduced;

$$\boldsymbol{V = \frac{1}{2}\left[\dot{q}^T A(q)\dot{q} + e^T K_p e\right] =} \tag{22}$$

$$\boldsymbol{\frac{1}{2}\frac{d}{dt}\left[\dot{q}^T A\dot{q}\right] = \dot{q}\,\tau}$$

If the conversation energy is written by the following form:

$$\boldsymbol{\frac{1}{2}\frac{d}{dt}\left[\dot{q}^T A\dot{q}\right] = \dot{q}\,\tau}$$

Where $(\boldsymbol{\dot{q}\,\tau})$ shows the power inputs from actuator and $\boldsymbol{\frac{1}{2}\frac{d}{dt}\left[\dot{q}^T A\dot{q}\right]}$ is the derivative of the robot kinematic energy.

$$\boldsymbol{\dot{V} = \dot{q}^T\left[\tau + K_p e\right]} \tag{23}$$

Based on $\boldsymbol{\tau = -K_{p_i} e - K_{v_i}\dot{e} - K_i \sum e}$, we can write:

$$\boldsymbol{\dot{V} = \dot{q}^T K_p \dot{q} \leq 0} \tag{24}$$

If $\boldsymbol{\dot{V} = 0}$, we have

$$\boldsymbol{\dot{q} = 0 \to \ddot{q} = 0 \to \ddot{q} = A^{-1}K_p e \to e = 0} \tag{25}$$

In this state, the actual trajectories converge to the desired state.
A three dimensions joint consider as a nonlinear and MIMO system with outputs available measurement and possibility to input change. However the application of fuzzy

logic controller is really wide, all types of fuzzy logic controllers consists of the following parts;

- Choosing inputs
- Scaling inputs
- Input fuzzification (binary-to-fuzzy[B/F]conversion)
- Fuzzy rule base (knowledge base)
- Inference engine
- Output defuzzification (fuzzy-to-binary[F/B]conversion)
- Scaling output

Figure 14 shows the block diagram of fuzzy controller operation.

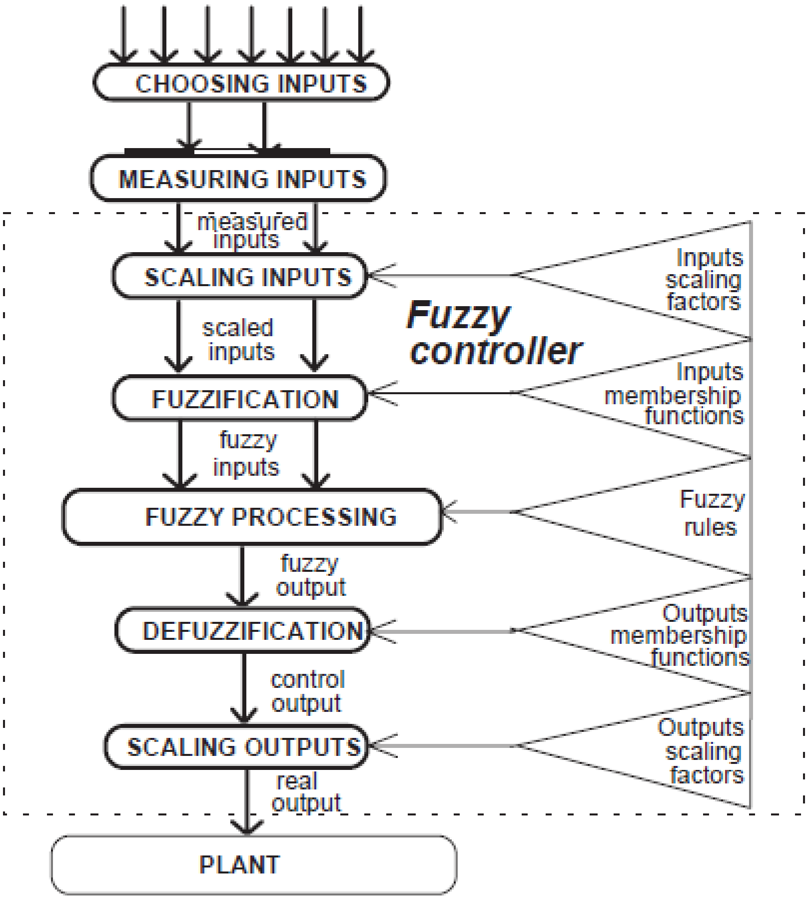

Figure 14. Block Diagram of Fuzzy Controller Operation

Define the Inputs and Control Variables: based on controllers' design select the type of inputs is very important to design controller. In most of industrial controllers error and the functional of error are used as inputs to design controller. According to design the linear controller, PI, PD and PID are three types of linear controller. If PI like fuzzy controller is design, error and integral of error are introduced as fuzzy input. In PD like fuzzy controller error and change of error are used to define as controllers' inputs. According to design PID controller, PID like fuzzy controller has three inputs; error, change of error and integral of error. To design fuzzy controller, if one has made a choice of designing a type of PD like fuzzy controller, PI like fuzzy controller or PID like fuzzy controller, this already dealing the choice of process state and control output variables, as well as the content of the antecedent and consequent parts for each rule.

Scaling Inputs/Outputs: in fuzzy logic controller to define membership function, first of all one needs to consider the universe of discourse for all inputs and outputs linguistic variables. If universe of discourse indicates by small range of scaling input or output, the data can be off the scaling. Figure 15 shows the wrong small scaling input/output. Conversely, if universe of discourse indicates by large range of input scaling, the membership function area can be wide on the left or right side if scaling input or output. Figure 16 shows the wrong large scaling input/output. The role of a right choice of scaling factors is obviously shown by the fact that if your choice is bad, the actual operating area of the inputs/outputs will be transformed into a saturation or narrow situation. Input scaling factors have played important role to basic sensitivity of the controller with respect to the optimal choice of the operating areas of the input signals. When the scale output is scaled, the gain updating factor of the controller is scaled. This item affects the closed loop gain and caused to modify the stability and oscillation tendency. Because of its strong impact on stability and reduce the oscillation, this factor is important factor to design fuzzy controller. The right choice of input/output scaling factor shows in Figure 17.

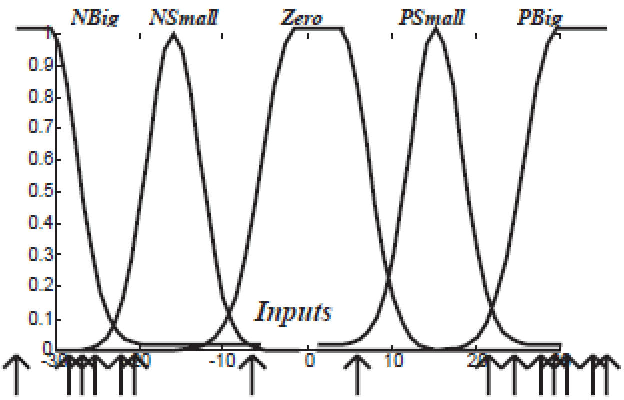

Figure 15. Choice of the Scaling Factor (Small Scaling Factor)

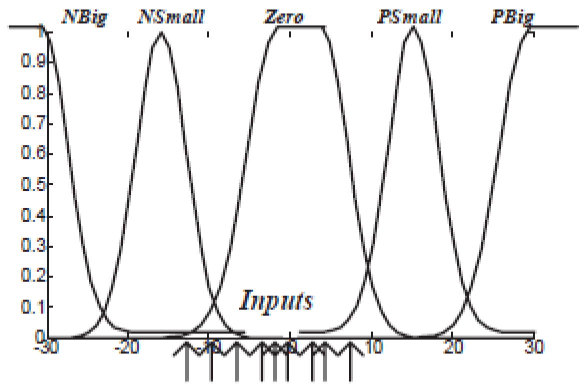

Figure 16. Choice of the Scaling Factor (Large Scaling Factor)

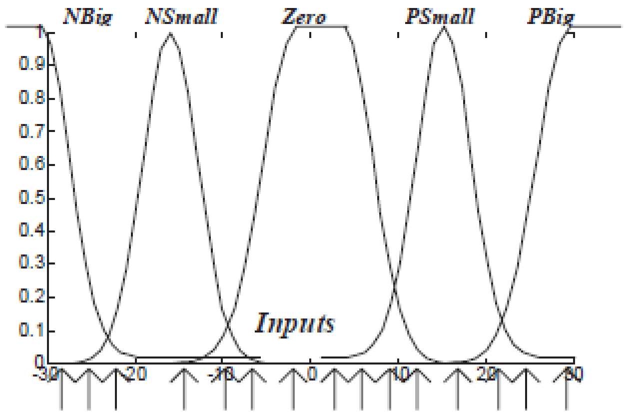

Figure 17. Right Choice of the Scaling Factor

Input Fuzzification (Binary-To-Fuzzy [B/F] Conversion): fuzzification is used to change the crisp set into fuzzy set. This part is divided into three main parts;

- Linguistic variables
- Scaling factor (normalization factor)
- Inputs membership function

A linguistic variable is a natural language based on the quantity of interest. These variables are words or sentence and this is the main difference between linguistic variable and numerical variable. Linguistic variables can be divided into three sub parts:

- Primary terms, which are the labels of location of the universe of discourse (*e.g.*, $Negative\ or\ Positive\ or\ Zero$).
- Connective terms $AND, OR,$ and NOT.
- Limitation terms such as $Small, Medium\ and\ Big$.

A linguistic variable is defined by;

- Symbolic name of inputs/outputs variables such as $error, change\ of\ error$ and $Torque$.
- Set of linguistic values that can take on some variables such as, Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB).
- Scaling factor as actual physical domain over which the meaning of the linguistic value, for example and based on literature and experience knowledge if error is between -1 and +1.
- Interpretation of linguistic value in terms of the quantities values.

Select the membership function has a below challenges;

- Select the general parameters, such as the number of membership functions to support all the values of the linguistic variable on the universe of discourse
- The location of membership functions on the universe of discourse
- Width of the membership functions
- Continous parameters, such as the shape of a particular membership function

Figure 18 shows the fuzzification part for PD like fuzzy controller system, this PD like fuzzy controller has two inputs (error and change of error), any input is described with five linguistic values; Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Big (PB), they are quantized into four levels between -2 and +2, and triangular membership functions are used for error and change of error inputs.

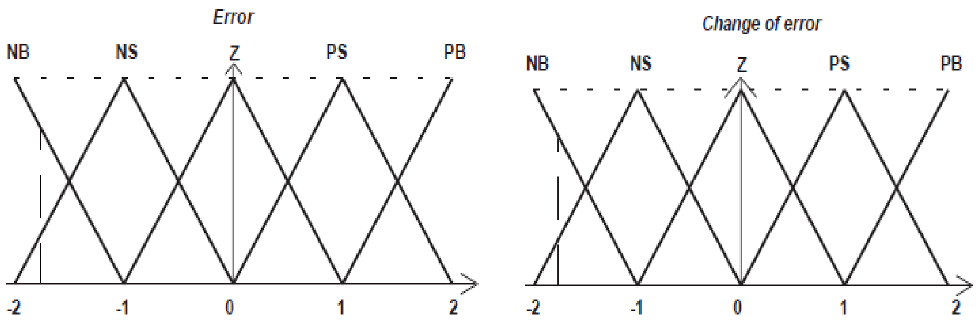

Figure 18. Fuzzification Part in PD Like Fuzzy Controller

Fuzzy Rule Formulation: the role of the rules in fuzzy logic controller is extremely significant and the main approaches and source of fuzzy logic controller rules are;

- Expert experience and knowledge base
- Learning based on operators' control action
- Identification of fuzzy model system under control action
- The application of learning technique

According to above, the main approach comes from an expert knowledge of system because any fuzzy controller is expert system to solve the control problem. Based on linguistic variables, fuzzy rule base provides a natural theory for human thinking and knowledge base formulation. In practice to find the rule base two method are introduced;

- Design rule base based on redeveloping literature, manuals and research papers
- Design and develop of rule base based on the inquiry operator using questionnaire.

In practice fuzzy rule base divided into main three parts: antecedent part, consequent part and connective terms (AND, OR, NOT). The OR term of two fuzzy set e and $\dot{e}$ is a new fuzzy set which the new membership function is given by

$$\boldsymbol{S(a,b)} = \boldsymbol{\mu_{e\ OR\ \dot{e}}} = \mathbf{max}\{\boldsymbol{\mu_{\dot{e}(u)}}, \boldsymbol{\mu_{e(u)}}\}, \qquad \forall \boldsymbol{u} \in \boldsymbol{U} \tag{26}$$

The AND term of two fuzzy set e and $\dot{e}$ $(T - norm)$ is a new fuzzy set which the new membership function is given by

$$\boldsymbol{T(a,b)} = \boldsymbol{\mu_{e\ AND\ \dot{e}}} = \mathbf{min}\{\boldsymbol{\mu_{e(u)}}, \boldsymbol{\mu_{\dot{e}(u)}}\} \tag{27}$$

In fuzzy set and the $NOT\ e$ operation can be replaced by $1 - e$ operation in fuzzy set. Frequently the rules are formulated one by one base on experience knowledge and any other methods and rule table is design after complete all rule bases. Rule table is the dynamic behavior of fuzzy logic theory and it necessity to have three significant parts;

- Continuous
- Complete
- Consistent

Inference Engine (Fuzzy Rule Processing): The fuzzy inference engine recommends a fuzzy method to transfer the fuzzy rule base to fuzzy set. Fuzzy rule processing is divided into two main techniques;

- Mamdani method
- Sugeno method

Mamdani anticipated controlling the system by realizing various fuzzy rule bases. In Mamdani controllers' design, in order to improve the control quality, he increased the number of control inputs and used the change of variable error in his design. He designed his controller on the PDP-8 computer. It contained 24 fuzzy rule bases. According to his experiments, the quality of the fuzzy controller based on the 24 fuzzy rules was found to be better than the best result of the fixed conventional controller, as a result fuzzy controller opening a new epoch in a design controller. This type of fuzzy inference is easily understandable by human experts, simple to formulate rules and proposed earlier and commonly used.

Michio Sugeno is changed a part of the rules, in consequent part of fuzzy rule base. According to this method, the consequent part is a mathematical function of the input variables. This type of fuzzy inference is more efficient computationally, more suitable in mathematical analysis, and guarantee the output continuity surface. The following definition shows the Mamdani and Sugeno fuzzy rule base

$$\begin{aligned}&\boldsymbol{Mamdani}\quad \boldsymbol{F.R^1: if\ e\ is\ NB\quad and\quad \dot{e}\ is\ NB\quad then\quad T\ is\ PB}\\&\boldsymbol{Sugeno}\quad \boldsymbol{F.R^1: ife\ is\ NB\quad and\quad \dot{e}\ is\ NB\quad then\ 0.3\times e+0.6\times \dot{e} is\ PB}\end{aligned} \tag{28}$$

In these two types inference engine the antecedent part are the same but the main difference between these two methods are in consequent part. Fuzzy inference system has four main parts;

- Rule evaluation
- Activation degree
- Aggregation degree
- Defuzzification

Rule evaluation is used to illustrate the fuzzy operation (AND/OR) impact to the antecedent part of the fuzzy rules. The activation degree is the rule of antecedent part's membership degree into consequent part membership degree and the aggregation degree is used to aggregate the consequent part. This part is used to aggregate two neighbouring fuzzy rules and makes a new consequent part. It is note that activation degree is the impact of antecedent part to consequent part and aggregation degree is the impacts of the first modify consequent part in the second one. Several methodologies are used to calculate aggregation degree;

- Max-Min aggregation
- Sum-Min aggregation
- Max-bounded product
- Max-drastic product
- Max-bounded sum
- Max-algebraic sum
- Min-max aggregation

The formulation of Max-min aggregation is

$$\boldsymbol{\mu_U(x_k,y_k,U)=\mu_{\bigcup_{i=1}^r FR^i}(x_k,y_k,U)=\max\left\{\min_{i=1}^r\left[\mu_{R_{pq}}(x_k,y_k),\mu_{p_m}(U)\right]\right\}} \tag{29}$$

The formulation of Sum-min aggregation is;

$$\boldsymbol{\mu_U(x_k,y_k,U)=\mu_{\bigcup_{i=1}^r FR^i}(x_k,y_k,U)=\sum\min_{i=1}^r\left[\mu_{R_{pq}}(x_k,y_k),\mu_{p_m}(U)\right]} \tag{30}$$

where r is the number of fuzzy rules activated by x_k and y_k and also $\mu_{\bigcup_{i=1}^r FR^i}(x_k,y_k,U)$ is a fuzzy interpretation of i^{th} rule. Defuzzification it is used to convert fuzzy logic set to crisp or logic set. To calculate defuzzification some methods introduced by researchers which the name of two famous methods are: Centre of gravity method (COG) and Centre of area method (COA).

The formulation of COG method is;

$$COG(x_k, y_k) = \frac{\sum_i U_i \sum_{j=1}^{r} \cdot \mu_u(x_k, y_k, U_i)}{\sum_i \sum_{j=1}^{r} \cdot \mu_u(x_k, y_k, U_i)} \tag{31}$$

The formulation of COA method is

$$COA(x_k, y_k) = \frac{\sum_i U_i \cdot \mu_u(x_k, y_k, U_i)}{\sum_i \mu_U \cdot (x_k, y_k, U_i)} \tag{32}$$

According to above two formulations, $COG(x_k, y_k)$ and $COA(x_k, y_k)$ illustrates the value of defuzzification output, U_i is the element of the fuzzy set, $\mu_U(x_k, y_k, U_i)$ is the membership function, and r is the number of fuzzy rule bases. In this research PI-like fuzzy logic controller is design based on PD-like fuzzy to reduce the time to design fuzzy rule base. Due to previous discussion, fuzzy rule bases are the controller's behavior and design two types of fuzzy rule bases are difficulties. To design PI like fuzzy logic controller based on PD like fuzzy logic controller integral term is added to the PD controller's output. The formulation of PI controller is;

$$U_{PI} = K_p \times e + K_i(\frac{1}{T} \int e.dt) = K_p \times e + K_i \sum e \tag{33}$$

If the derivative, with respect to time is taken for (33);

$$\frac{dU_{PI}}{dt} = K_p \times \frac{de}{dt} + K_i e(t) = K_p \times \dot{e} + K_i e \tag{34}$$

According to (34) to calculate the output control system integral term is used as follows;

$$\int \frac{dU_{PI}}{dt} = [K_p \times \int \left(\frac{de}{dt}\right) dt + K_i \int (e(t)dt)] = K_p \times e + K_i \times \sum e \tag{35}$$

Figure 19 shows PI controller based on PD controller. According to Figure 19 PI like fuzzy logic controller is design based on PD like fuzzy logic controller. Figure 20 shows PI like fuzzy logic controller based on PD like fuzzy logic controller.

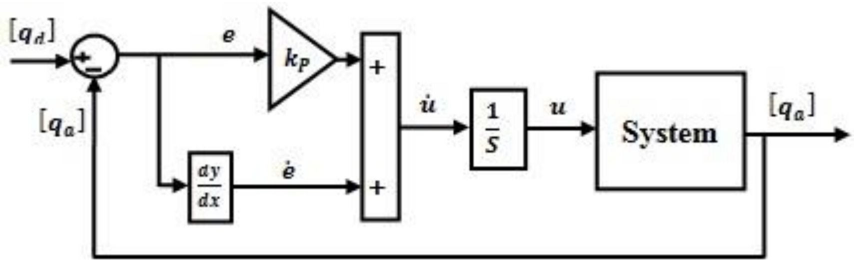

Figure 19. Design PI Controller Based on PD Controller

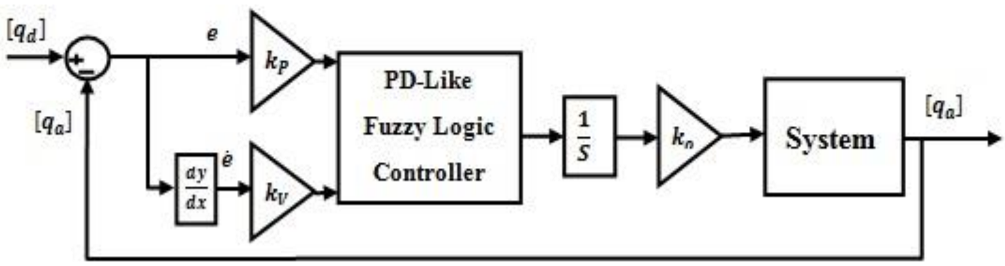

Figure 20. Design PI like Fuzzy Controller Based on PD like Fuzzy Controller

To design PI like fuzzy logic controller based on PD fuzzy logic controller following seven steps are recommended as well as design PD like fuzzy logic controller.

- Choosing inputs

- Scaling inputs
- Input fuzzification (binary-to-fuzzy[B/F] conversion)
- Fuzzy rule base (knowledge base)
- Inference engine
- Output defuzzification (fuzzy-to-binary[F/B] conversion)
- Scaling output

Figure 21 illustrates the general structure of the PID+PI like fuzzy logic controller, which consists of two main components. The PID+PI like fuzzy logic controller is built using PD like fuzzy logic controller. According to design PD like fuzzy controller and PI like fuzzy controller based on PD fuzzy rule base, design PID+PI like fuzzy controller is introduced based on the following formulation;

$$\boldsymbol{U} = \boldsymbol{U_{PI}} + \boldsymbol{U_{PID}} = \left(\boldsymbol{K_p}\right) \times \boldsymbol{e} + \boldsymbol{K_i}\left(\frac{\boldsymbol{1}}{\boldsymbol{T}}\int \boldsymbol{e.dt}\right) + \boldsymbol{K_v}\dot{\boldsymbol{e}} + [(\sum_{l=1}^{M} \boldsymbol{\theta^T}\, \boldsymbol{\zeta}(\boldsymbol{x}))_{e,\sum e} \quad (36)$$

$$\boldsymbol{U_{PIlike\ fuzzy}} = [(\sum_{l=1}^{M} \boldsymbol{\theta^T}\, \boldsymbol{\zeta}(\boldsymbol{x}))_{e,\sum e} \quad (37)$$

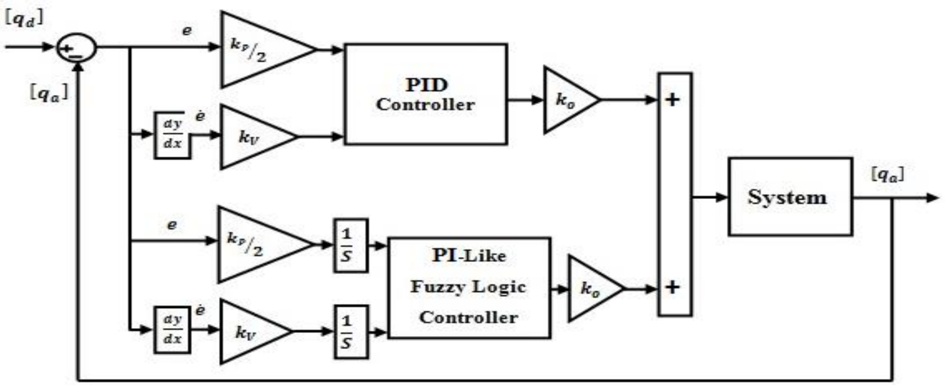

Figure 21. Design PID+PI Like Fuzzy Controller

Define the Inputs and Control Variables: In PI-like fuzzy controller, error and change of error are used to define as controllers' inputs. Therefore the antecedent part of rule base is comprised of two parts. In this part fuzzy controller's inputs are error (e) and change of error $(\dot{e})$ and the fuzzy controller output is PI fuzzy output $\left(U_{PI-fuzzy}\right)$.

Scaling variables and Input Fuzzification (Binary-to-Fuzzy [B/F] Conversion): Proposed PI like fuzzy logic controller has two inputs $error, change\ of\ error$ and $PI\ fuzzy\ output$. Error defined as seven linguistic variables: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB). Based on experience knowledge the range of scaling factor for error is $[-0.1\ to\ 0.1]$ and it is quantized into eleven levels as follows: $e = \{-0.1, -0.08, -0.06, -0.04, -0.02, 0, 0.02, 0.04, 0.06, 0.08, 0.1\}$. The linguistic values for change of error are: Negative (N), Zero (Z) and Positive (P) and the range of scaling factor for change of error is $[-1\ to\ 1]$ and it is quantized into eleven levels as: $\dot{e} = \{-1, -0.8, -0.6, -0.4, -0.2, 0, 0.2, 0.4, 0.6, 0.8, 1\}$. The linguistic variables for PI like fuzzy logic controller are: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Positive Big (PB) and the scaling factor for them are $[-1.5\ to\ 1.5]$.

Fuzzy rule Base: the main approach comes from an expert knowledge of system because fuzzy controller is one of the expert system to solve the control problem. According to fuzzification the error has seven linguistic variables, the change of error has three linguistic variables and the PI like fuzzy logic controller have seven linguistic variables. The PI like fuzzy rule table shows in Table 1.

Table 1. Rule Table in PI Like Fuzzy Logic Controller

e / *ė*	***PB***	***PM***	***PS***	***Z***	***NS***	***NM***	***NB***
P	NB	NB	NB	NB	NM	NS	Z
Z	NB	NM	NS	Z	PS	PM	PB
N	Z	PS	PM	PB	PB	PB	PB

Inference Engine (Fuzzy Rule Processing): In this research 21 rules bases Mamdani fuzzy inference engine is used as fuzzy rule processing.

Defuzzification: defuzzification is the last step to design fuzzy logic controller and it is used to transform fuzzy set to crisp set. In PI like fuzzy logic controller COG method is used for defuzzification.

4. Results and Discussion

In this research, conventional PID controller and PID+PI fuzzy like controller are compared.

Comparison of the Tracking Data and Information: the trajectory following for conventional PID controller and PID+PI like fuzzy controller are compared. According to Figure 22, traditional PID controller has 4% overshoot but this controller is a robust. In rise time point of view, PID+PI like fuzzy controller is faster than PID controller. In error point of view, proposed method (0.006) is better than conventional PID controller (0.009).

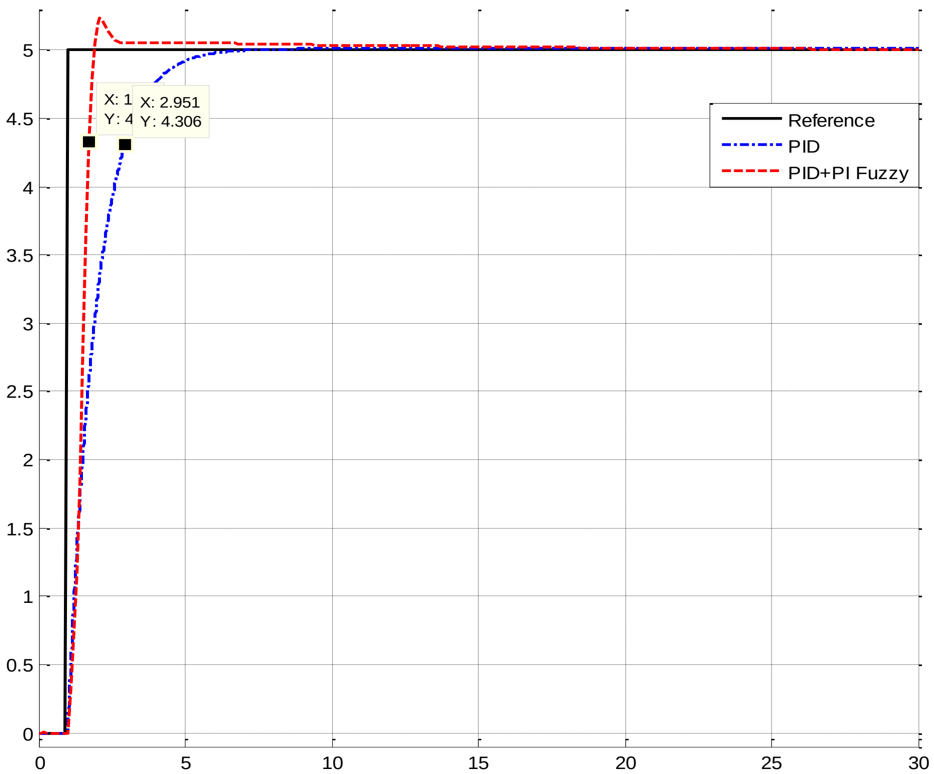

Figure 22. Tracking Data: Conventional PID and PID+PI Like Fuzzy Controller

Comparison the Disturbance Rejection: the power of disturbance rejection is very important to robust checking in any controllers. To test the disturbance rejection band limited white noise with 30% amplitude is applied to conventional PID controller and PID+PI like fuzzy controller. In Figure 23, trajectory accuracy is shown.

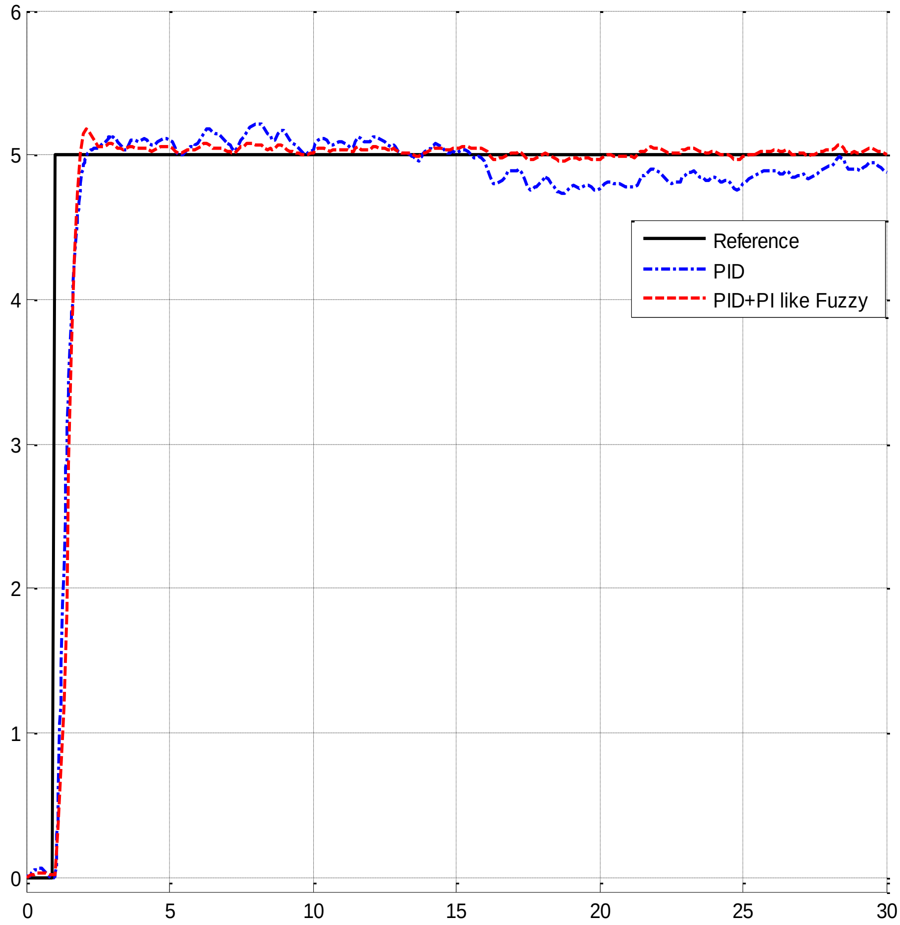

Figure 23. Tracking Data: Conventional PID and PID+PI Like Fuzzy Controller in Presence of Uncertainty

According to above graph, however PID+PI like fuzzy controller has a little oscillation in presence of uncertainty but it is more robust than PID controller. PID controller has very much fluctuation in presence of external disturbance.

5. Conclusion

This research has studied PID+PI like fuzzy control design for the dynamics of multi degrees of freedom joints without knowledge of the boundary of the disturbances/uncertainties, using fuzzy controls as robust controls for the dental joints and as a solution to the problem of robustness. To elucidate this, fuzzy plus linear control for the n-DOF dental joint which includes the unknown bounded disturbances and uncertainties is studied. A Proportional-Integral-Derivative control is introduced as a model-free control and improve by fuzzy algorithm, which provides ultimate accuracy in the presence of the matched bounded disturbances/uncertainties. Stability and robustness are introduced as a problem that accompanies the introduction of a control; the stability and robustness may actually damage components and cause loss of accuracy of output in uncertainty. As a solution, fuzzy logic algorithm is introduced. In this design PI like fuzzy is design based on PD rule base. We can improve the steady state error, transient error and rise time in this research.

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Iranian center of Advance Science and Technology (IRAN SSP) is one of the independent research centers specializing in research and training across of Control and Automation, Electrical and Electronic Engineering, and Mechatronics & Robotics in Iran. At IRAN SSP research center, we are united and energized by one mission to discover and develop innovative engineering methodology that solve the most important challenges in field of advance science and technology. The IRAN SSP Center is instead to fill a long standing void in applied engineering by linking the training a development function one side and policy research on the other. This center divided into two main units:

- Education unit
- Research and Development unit

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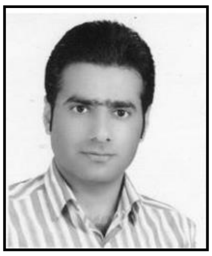
Farzin Piltan, is an outstanding scientist in the field of Electronics and Control engineering with expertise in the areas of nonlinear systems, robotics, and microelectronic control. Mr. Piltan is an advanced degree holder in his field. Currently, Mr. Piltan is the Head of Mechatronics, Intelligent System, and Robotics Laboratory at the Iranian Institute of Advanced Science and Technology (IRAN SSP). Mr. Piltan led several high impact projects involving more than 150 researchers from countries around the world including Iran, Finland, Italy, Germany, South Korea, Australia, and the United States. Mr. Piltan has authored or co-authored more than 140 papers in academic journals, conference papers and book chapters. His papers have been cited at least 3900 times by independent and dependent researchers **from around the world including Iran, Algeria, Pakistan, India, China, Malaysia, Egypt, Columbia, Canada, United Kingdom, Turkey, Taiwan, Japan, South Korea, Italy, France, Thailand, Brazil and more**. Moreover, **Mr. Piltan has peer-reviewed at least 23 manuscripts for respected international journals in his field**. Mr. Piltan will also serve as a technical committee member of the upcoming EECSI 2015 Conference in Indonesia. Mr. Piltan has served as an editorial board member or journal reviewer of several international journals in his field as follows: International Journal Of Control And Automation (IJCA), Australia, ISSN: 2005-4297, International Journal of Intelligent System and Applications (IJISA), Hong Kong, ISSN:2074-9058, IAES International Journal Of Robotics And Automation, Malaysia, ISSN:2089-4856, International Journal of Reconfigurable and Embedded Systems, Malaysia, ISSN:2089-4864.

Mr. Piltan has acquired a formidable repertoire of knowledge and skills and established himself as one of the leading young scientists in his field. Specifically, he has accrued expertise in the design and implementation of intelligent controls in nonlinear systems. Mr. Piltan has employed his remarkable expertise in these areas to make outstanding contributions as detailed follows:Nonlinear control for industrial robot manipulator (2010-IRAN SSP), Intelligent Tuning The Rate Of Fuel Ratio In Internal Combustion Engine (2011-IRANSSP), Design High Precision and Fast Dynamic Controller For Multi-Degrees Of Freedom Actuator (2013-IRANSSP), Research on Full Digital Control for Nonlinear Systems (2011-IRANSSP), Micro-Electronic Based Intelligent Nonlinear Controller (2015-IRANSSP), Active Robot Controller for Dental Automation (2015-IRANSSP), Design a Micro-Electronic Based Nonlinear Controller for First Order Delay System (2015-IRANSSP).

The above original accomplishments clearly demonstrate that Mr. Piltan has performed original research and that he has gained a distinguished reputation as an outstanding scientist in the field of electronics and control engineering. Mr. Piltan has a tremendous and unique set of skills, knowledge and background for his current and future work. He possesses a rare combination of academic knowledge and practical skills that are highly valuable for his work. **In 2011, he published 28 first author papers, which constitute about 30% of papers published by the Department of Electrical and Electronic Engineering at University Putra Malaysia.** Additionally, **his 28 papers represent about 6.25% and 4.13% of all control and system papers published in Malaysia and Iran, respectively, in 2011**.



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Dr. Nasri Sulaiman has employed his remarkable expertise in these areas to make outstanding contributions as detailed below:

- Design of a reconfigurable Fast Fourier Transform (FFT) Processor using multi-objective Genetic Algorithms (2008-UPM)
- Power consumption investigation in reconfigurable Fast Fourier Transform (FFT) processor (2010-UPM)
- Crest factor reduction And digital predistortion Implementation in Orthogonal frequency Division multiplexing (ofdm) systems (2011-UPM)

- High Performance Hardware Implementation of a Multi-Objective Genetic Algorithm, (RUGS), Grant amount RM42,000.00, September (2012-UPM)
- Nonlinear control for industrial robot manipulator (2010-IRAN SSP)
- Intelligent Tuning The Rate Of Fuel Ratio In Internal Combustion Engine (2011-IRANSSP)
- Design High Precision and Fast Dynamic Controller For Multi-Degrees Of Freedom Actuator (2013-IRANSSP)
- Research on Full Digital Control for Nonlinear Systems (2011-IRANSSP)
- Micro-Electronic Based Intelligent Nonlinear Controller (2015-IRANSSP)
- Active Robot Controller for Dental Automation (2015-IRANSSP)
- Design a Micro-Electronic Based Nonlinear Controller for First Order Delay System (2015-IRANSSP)