# AUTO-TUNING PID CONTROLLER FOR PIEZOELECTRIC ATUATOR

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## DEDICATION

This project report is dedicated to my late father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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# ABSTRACT

This project presents the development and implementation fuzzy logic based PID control algorithm for a piezoelectric actuator PZA. The piezoelectric actuators PZA based on the inverse piezoelectric effect are used in many fields due to their properties such as high stiffness, small volume and fast response. One problem of piezoelectric materials is that the hysteresis property which effect between the displacement and the electric field existing in PZA makes the modelling and the control of PZA difficult. . The piezoelectric actuator can be perceived as a challenging control problem due to it's the hysteresis high nonlinearity. In order to design a tracking controller with better tracking performance of PZA, The utilized model to describe the hysteresis nonlinearity behaviour and dynamic motion of 1-DOF PZA is Bouc-Wen (BW) model. The main objective of the controller is to propose a suitable solution for the problem associated with the control of piezoelectric actuator. A fuzzy controller was designed according to the process characteristics. The simulation results were carried out in MATLAB/SIMULINK. The corresponding figures and simulation results are presented. The performance of suggested fuzzy controllers is discussed and analysed. Comparing the performance of proportional, integral and derivative (PID) tuned by Zeiger-Nichols method (ZN) results depict that fuzzy logic based PID controller give a better performance in terms of transient responses, steady state responses and overshoot error.

# ABSTRAK

Kajian ini membentangkan perkembangan dan pelaksanaan mengenai kawalan algoritma fuzzy logik yang berasaskan PID untuk penggerakan piezoelektrik PZA. Penggerak piezoelektrik PZA yang berdasarkan kesan piezoelektrik songsang digunakan dalam pelbagai bidang kerana sifatnya yang kekakuan tinggi, nilai yang kecil dan tindak balas yang cepat. Antara salah satu masalah bahan piezoelektrik ialah sifat histerisis yang memberikan kesan antara anjakan dan medan elektrik, menyukarkan pemodelan dan kawalan PZA. Berdasarkan histerisis yang tinggi dan tidak tetap, pengawalan bagi penggerak piezoelektrik merupakan masalah yang mencabar. Bagi pengendali penjejak dengan prestasi penjejakan yang lebih baik dari PZA, Model yang digunakan untuk menggambarkan kelakuan histeris tidak lurus dan pergerakan dinamik PZA 1-DOF ialah model Bouc-Wen (BW). Objektif utama adalah untuk mencadangkan penyelesaian yang sesuai bagi masalah yang berkaitan dengan pengawalan penggerak piezoelektrik. Pengawal fuzzy direka mengikut ciri-ciri proses. Hasil yang telah dijalankan di MATLAB / SIMULINK. Keputusan yang sepadan dan hasil simulasi dipaparkan. Prestasi pengawal fuzzy yang dicadangkan serta dibincang dan dianalisis. Pembandingkan antara prestasi berkadar, integral dan derivatif (PID) yang diolah mengikut kaedah Zeiger-Nichols (ZN) menggambarkan bahawa pengawal PID berasaskan logik fuzzy memberikan prestasi yang lebih baik dari segi tindak balas sementara, tindak balas keadaan mantap dan ralat yang terlebih.

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| ANN | - | Artificial Neural Network |
| PSO | - | Particle Swarm Optimization |
| PZA | - | Piezoelectric Actuator |
| BW | - | Bouc-Wen |
| P-I | - | Prandtl-Ishlinskii |
| UTM | - | Universiti Teknologi Malaysia |
| PID | - | Proportional-Integral-Derivative |
| BP | - | Back Propagation |
| SISO | - | Single Input Single Output |
| ZN | - | Zigler – Nicoles |
| MAE | - | Mean Absolute Error |

## LIST OF SYMBOLS

| | | |
|---|---|---|
| $K_p$ | - | Proportional gain |
| $K_I$ | - | Integral gain |
| $K_D$ | - | Derivative gain |
| $u$ | - | Input voltage |
| $x$ | - | Output displacement |
| $m$ | - | effective mass |
| $b$ | - | Damping coefficient |
| $k$ | - | Mechanical stiffness coefficient |
| $d$ | - | effective piezoelectric coefficient |
| $h$ | - | Hysteresis nonlinear dynamics |
| $\alpha$ | - | Hysteresis magnitude |
| $\beta, \gamma$ | - | Hysteresis shape |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background Study

Recent times have witnessed the evolution of various approaches for proper micro-positioning stages of smart sensors such as piezoelectric actuator (PZA). Such a system is usually a non-linear and unstable system. In the last decade, engineers had an increased interest in modeling and controlling such a system.

PZA is one degree of freedom (DOF) system that is a device based on the counter piezoelectric effect; applying a voltage to it creates displacement and vibrating it generates a voltage. PZA actuator is a controllable and perfect micro-displacement actuator that is driven by an electric field. PZA actuator has a very high-speed response, a small volume, a little quantity of heat and a relatively light mass. One of the critical fields in the study of piezoelectric actuator modeling is the hysteresis disturbance, which occurs via applied voltage and induced displacement which made this system non-linear system, to design a precise tracking controller to enhance the tracking precision in piezoelectric actuator system, a mathematical model is express to describe the hysteresis nonlinearity of PZA, there are two main categories hysteresis models: the first category is Physics-based models, such as JA model and Domain wall model [1], the second category is phenomenological models, such as Preisach model Peng and Chen [2], Bouc-Wen (BW) model and Prandtl-Ishlinskii (P-I) model Xiao and Li [3], are the most well-known phenomenological models particularly.

In this project, “I” used the Bouc-Wen model to model the hysteresis behavior and dynamic model of the PZA system, this model with its limitations is considered to be a challenge for engineers to control and model, Youssef [4]. The model of the system is a third-order system, depending on the modeling equations taken into consideration.

To control such systems, many control methods were introduced, conventional methods such as proportional-integral (PI), proportional-integral-derivative (PID) controllers. To increase the efficiency of the controlled system, artificial intelligence (AI) algorithms was introduced such as fuzzy logic Li, et al. [5], artificial neural network (ANN) Zhang, et al. [6], and particle swarm optimization (PSO) Marinaki, et al. [7], Moreover, hybrid controllers were introduced to maximize the efficiency, robustness and stability of the system such as PSO-PID controller and Fuzzy-PID controller.

## 1.2 Problem Statement

The modeling and control of the non-linear and third-order system is a challenging idea for engineers. In addition, the presence of the hysteresis disturbance originated from applied voltage and induced displacement effect between the displacement and the electric field of the PZA made the process more difficult than before. The non-linear relationship between the voltage input and displacement output of the PZA complicates the modeling of such a system. Thus, to control the PZA using a linearized model using conventional controllers decreased the efficiency of the system and are not accurate.

Based on this information, the need for using an intelligent or even hybrid controller is a must to enhance the performance of the system. The controller must be able to show good results even with the effect of the hysteresis disturbance.

## 1.3 Objectives

The objectives of the research are:

(a) To obtain the mathematical model of PZA.

(b) To design a Self-Tuning Fuzzy PID controller (STFPIDC) for PZA.

(c) To evaluate and compare the performance between STFPIDC and conventional controller (PID) when the system is subjected to hysteresis disturbance.

## 1.4 Scope of the Objectives

(a) The conventional PID tuning method will be limited to the Ziegler-Nichols method.

(b) The non-linear model of PZA will be used for simulation.

(c) We will use the physical parameters of the PZA as described in these references Youssef [4], Rakotondrabe [8], Ismail, et al. [9].

(d) Analysis and simulation of PZA output will be carried out using MATLAB SIMULINK.

## 1.5 Organization of this Report

The rest of this thesis is organized as follows: Chapter 2 reviews related to previous design controllers used for PZA and evaluate its effectiveness and present the basis of this work. Chapter 3 discuss the modeling of the PZA and methodology used to design the STFPIDC. While chapter 4 highlights the preliminary results found for the design of the controller and its impact on the PZA. Chapter 5 discuss the results found and presents a conclusion for our results obtained.

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