Faculty of Engineering

Enhancement of the control performance of a mechatronic micropositioning control system using piezoelectric actuators

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By

Mostafa Abdelaziz Mostafa Abdelaziz

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Supervisors:

Prof. Farid Abdel Aziz Tolbah

Prof. Magdy M. Abdelhameed

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Statement

This thesis is submitted in the partial fulfilment of master degree in Mechanical Engineering to Ain Shams University.

The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or qualification at any other university.

Signature

Mostafa Abdelaziz Mostafa Abdelaziz Ghoz

Examiners Committee

The undersigned certify that they have read and recommend to the Faculty of Engineering – Ain Shams University for acceptance a thesis entitled “Enhancement of the control performance of a mechatronic micropositioning control system using piezoelectric actuators” submitted by Mostafa Abdelaziz Mostafa Abdelaziz, in partial fulfillment of requirement for the degree of Master in Science in Mechatronic Engineering.

Signature

Prof. Dr. Mohamed Ibrahem Elaadawy
Faculty of Engineering – Helwan University

Prof. Dr. Taher Gamal Abou Elyazid
Faculty of Engineering – Ain Shams University

Prof. Dr. Farid Abd El Aziz Tolbah
Professor in Design and Production Engineering Dept.
Faculty of Engineering – Ain Shams University

Prof. Dr. Magdy Mohamed Abdelhameed
Professor of Design and Production Engineering Dept.
Faculty of Engineering – Ain Shams University

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"Enhancement of the control performance of a mechatronic micropositioning control system using piezoelectric actuators"

Abstract

Piezoelectric actuators are used in a wide variety of precise Nano-positioning applications. Due to the effect of the nonlinear hysteresis, the positioning accuracy of the piezoelectric actuators is limited. Hence, developing a high precise control scheme is considered a great challenge. It is desirable to take the effect of nonlinear hysteresis into consideration for enhancing the tracking positioning accuracy of the piezoelectric actuators. In this thesis Robust μ-Synthesis and Hybrid Fuzzy Robust control schemes have been developed for a positioning system driven by piezoelectric actuator. Moreover the Hybrid Fuzzy Robust Controller gives better tracking error than the Robust μ-Synthesis controller. The effectiveness of the proposed control schemes has been validated.

Keywords

Precision positioning, robust control, fuzzy control, hysteresis, piezoelectric actuator.

Summary of the M.Sc. Thesis

"Enhancement of the control performance of a mechatronic micropositioning control system using piezoelectric actuators"

By: Mostafa Abdelaziz Mostafa Abdelaziz

Because of the advantages of their nanometer displacement resolution, fast response, high stiffness, and no backlash, piezoelectric actuators have been used in micro positioning applications. Piezoelectric materials are ferroelectric, they are fundamentally non linearities their response to an input voltage, exhibiting a hysteresis effect between the displacement and the input voltage. A control technique should be applied to compensate the hysteresis effect and maintain the stability of the system.

Chapter 1 presents a survey of previous work. Piezoelectric actuators and hysteresis nonlinearities problem have been addressed by many researchers who used many different ways to find out a suitable controller. The proposed controllers have been designed using feed-forward control, nonlinear control, neural networks, adaptive control, or robust control.

The objective of this work is to model a piezoelectric actuator in positioning mechanism, by applying Both Robust Control and Hybrid Robust Control to the piezoelectric positioning mechanism and studying the effect of the hysteresis and the tracking error after applying the proposed control techniques.

In chapter 2, the modeling of the piezoelectric actuator and the positioning mechanism had been introduced in order to use the mathematical model in the proposed controllers' algorithms. Simulating the piezoelectric actuator has been discussed by using the mathematical model.

In chapter 3, in order to achieve the required objectives of this research, two proposed controller have been built using μ-synthesis and Fuzzy logic control. A mathematical model has been built on a modeling environment, taking into account the uncertainty of the non linear hysteresis effect.

Practical implementation has been discussed in chapter 4, starting from the proposed mechanism, piezoelectric actuator and strain gauge amplifier. Several experiments have been done using traditional PID, Robust controller and the Hybrid Fuzzy Robust for comparing the results.

The model which had been proposed in chapter 2, has been used to test the system with traditional PID controller, robust controller and the proposed Hybrid Fuzzy Robust controller. The results of these experiments have been listed in chapter 5. Also comparative discussion based on root mean square error and mean absolute error have been presented.

Based on this work, some conclusions and future research have been introduced in chapter 6.

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Notation and Symbols

K	Spring coefficient
d_e	Effective piezoelectric actuator
b	Damping coefficient
u	Input voltage
h	Hysteresis effect variable
x	Displacement
m	Mass
α	Parameter controls restoring force amplitude
β, γ	Parameters control shape of hysteresis loop
σ	Singular Value
μ	Structured singular value
$\lVert . \rVert_\infty$	Infinity norm
F_L, F_U	Lower and Upper Linear Fractional Transformation
X_∞, Y_∞	Solutions of Riccati equation
Δ	Uncertainty matrix
A	System dynamics (state space matrix)
A_K, B_K,, C_K,, D_K,	State space matrices of the controller
B_1	selector matrix for the external input (state space matrix)
B_2	selector matrix for the control action (state space matrix)
C_1	selector matrix for the closed-loop output (state space matrix)
C_2	selector matrix for the output to the controller (state space matrix)
D	disturbance
D_{11}	state space matrix from external input to closed-loop output
D_{12}	state space matrix from external input to feedback output