Faculty of Manufacturing Engineering

DESIGN OF NONLINEAR ADAPTIVE INTERACTION ALGORITHM CONTROLLER FOR IMPROVEMENT OF TRACKING PERFORMANCE OF X-Y TABLE BALL SCREW DRIVE SYSTEM

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A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "Design of Nonlinear Adaptive Interaction Algorithm Controller for Improvement of Tracking Performance of XY Table Ball Screw Drive System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : ZAIN BINTI RETAS

Date : 10 February 2023

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

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Date : 10 February 2023

DEDICATION

To my beloved family

I couldn't finish this study without full support of my beloved parents Hanim Othman and Retas Abdullah. Their love, encouragements and continuous pray makes me stronger each and every day to complete this study.

To my husband, Syed Najib Syed Salim, who always gives full support and love. The one who pushes me to be the best of me, responsible and always taking care of me.

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ABSTRACT

Recently, the main interest in machine tools are to obtain precise positioning, robust tracking, low-cost manufacturing as well as adaptivity towards disturbances. These recent requirements or paradigm shift have led to a new and challenging era in the area of machining tools and control. However, the presence of disturbances during machining processes in the form of cutting forces and friction forces have greatly reduced positioning and tracking accuracy of the system. Basically, there are three main objectives in this thesis. Firstly, to identify the mathematical model of machine tool for XY table using system identification technique through frequency response function (FRF) of the system. Secondly is to design a new control strategy that will provide good tracking performance of the XY table. The final objective is to validate the proposed technique through simulation using MATLAB/Simulink software and experimental work using real plant of Googoltech XY table. The methodology of this research is conducted based on the set objectives. This thesis proposes one new approach and contribution to compensate cutting force disturbances. The contribution is Nonlinear Adaptive Interaction Algorithm (NAIA). The controller is developed based on the enhancement and modification of the basic Adaptive Interaction Algorithm Controller (AIA). The NAIA controller is designed by integrating a modified nonlinear function to the base AIA controller. This thesis has successfully demonstrated that the tracking performance of a machine tool was increased significantly through the newly proposed technique that was compared with the basic PID controller. Results showed that the newly proposed NAIA control strategy managed to provide up to 60.2% improvement in comparison with PID (frequency, f = 0.6 Hz) and 53.55% improvement in comparison with CasPAi (at f = 0.2 Hz). In addition, results showed that the NAIA provides an improvement of 86.29% in terms of Root Mean Square Error (RMSE) for f = 0.6 Hz in comparison with PID and 78.68% improvement in comparison with CasPAi. However, further improvements are still needed. It is recommended for future work; the compensation of friction forces should be considered so that it enables further reduction of the tracking error especially in the segment of quadrant glitch.

REKABENTUK PENGAWAL ALGORITMA INTERAKSI PENYESUAIAN TIDAK LINEAR UNTUK PENAMBAHBAIKAN PRESTASI PENJEJAKAN SISTEM PACUAN SKRU BEBOLA MEJA X-Y

ABSTRAK

Mutakhir ini, di dalam bidang perkakas mesin adalah penting untuk mendapatkan ketepatan sistem kedudukan, keteguhan pengesahan posisi, pembuatan kos rendah serta penyesuaian terhadap gangguan proses pemesinan. Keperluan atau anjakan paradigma baharu ini telah membawa kepada era dan cabaran baru dalam bidang perkakas mesin dan kawalan. Walau bagaimanapun, kehadiran gangguan proses pemesinan dalam bentuk daya pemotongan dan daya geseran telah banyak mengurangkan ketepatan sistem posisi dan pengesahan posisi. Secara asasnya, terdapat tiga objektif utama dalam tesis ini. Pertama ialah untuk mendapatkan model matematik bagi perkakas mesin XY menggunakan kaedah sistem pengenalpastian melalui fungsi tindak balas frekuensi (FRF) bagi sistem ini. Kedua, merekabentuk strategi kawalan baharu untuk menghasilkan ketepatan dan keteguhan posisi di dalam perkakas mesin XY. Objektif terakhir ialah membuat pengesahan terhadap teknik yang dicadangkan melalui simulasi perisian MATLAB/Simulink dan kerja eksperimen menggunakan sistem sebenar perkakas mesin Googoltech XY. Kaedah kajian ini dilaksanakan berdasarkan objektif yang telah ditetapkan. Tesis ini mencadangkan satu kaedah baharu yang juga merupakan sumbangan terhadap kajian kearah memampas gangguan daya pemotongan. Sumbangan itu ialah 'Nonlinear Adaptive Interaction Algorithm, (NAIA)'. Kedua-dua sistem kawalan yang dibangunkan adalah berdasarkan kepada penambahbaikan dan pengubahsuaian terhadap pengawal asas 'Adaptive Interaction Algorithm (AIA)'. Pengawal ini direkabentuk berdasarkan dengan menghubungkan fungsi ketaklelurus yang diubahsuai terhadap pengawal asas AIA. Tesis ini telah berjaya menunjukkan bahawa prestasi pengesahan posisi perkakas mesin meningkat secara ketara melalui kedua-dua teknik yang telah dicadangkan yang telah dibandingkan dengan pengawal asas 'Proportional Integral Derivative (PID)'. Keputusan kajian menunjukkan bahawa strategi pengawal NAIA berjaya menambahbaik sehingga 60.2% berbanding pengawal PID (frekuensi, f = 0.6 Hz) dan 53.55% penambahbaikan berbanding CasPAi pada f = 0.2 Hz. Sebagai tambahan, keputusan menunjukkan NAIA memberi penambahbaikan sebanyak 86.29% dari aspek 'Root Mean Square Error, (RMSE)' pada f = 0.6 Hz berbanding pengawal PID dan 78.68% lebih baik berbanding pengawal CasPAi. Walau bagaimanapun, penambahbaikan berterusan masih diperlukan. Adalah dicadangkan agar kajian lanjut mengambilkira pemampasan daya geseran supaya dapat mengurangkan lagi ralat pengesahan posisi, terutamanya di dalam segmen ralat sukuan.

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LIST OF SYMBOLS

F_n	-	Fréchet
$\hat{G}$	-	Open-Loop Transfer Function
K_e	-	Nonlinear Gain
K_d	-	Gain Values for Derivative (D)
K_i	-	Gain Values for Integeral (I)
K_p	-	Gain Values for Proportional (P)
L_{pid}	-	Position Open Loop
$ReG_{openloop}$	-	Real Open-Loop Transfer Function
$S_{pid}(s)$	-	Sensitivity Function
T_{pid}	-	Position Close Loop
V_{ol}	-	Speed Close Loop
$u_n(t)$	-	Outward Input Signal
x_n	-	Integral Input Signal
y_n	-	Integrable Output Signal
α_c	-	Adjustment Mass
Δe	-	Change of Errors
e	-	Position Errors
$E(s)$	-	Position Error
e_{max}	-	Highest Error Value
$Ep(t)$	-	Position Error
$e_{p(t)}$	-	Position Tracking Error

F_x	-	Force Measurement
KO	-	Amount of Difference for the Nonlinear Gain
K_v	-	Ratio Gain
N	-	Subsystem
s	-	Estimated Speed
T_d	-	Time Delay
$V_{est}(s$	-	Single Continuous Derivative
$Z(t)$	-	Output Position
$Z_{input}(t)$	-	Position Input Signal
Z_{ref} (t)	-	Input Signal Reference Position
ζ	-	Damping Ratio
ω_o	-	Natural Frequency
$ImG_{openloop}$	-	Imaginary Open-Loop Transfer Function
$N(t)$	-	Noise Signal
$d(t)$	-	Response Force Disturbance

LIST OF ABBREVIATIONS

AFLC	-	Adaptive Fuzzy Logic Control
AGSMO	-	Adaptive Gain Sliding Observer
AIA	-	Adaptive Interaction Algorithm
AIAE	-	Alternative Integral Absolute Error
ANN	-	Artificial Neutral Network
API	-	Application program interface
APT	-	Automatically programmed tool
ASMCC	-	Adaptive Sliding Mode Contouring Control
ASPR	-	Almost Strictly Positive Real
BLWN	-	Band Limited White Noise
CAD	-	Computer-aided design
CAM	-	Computer-aided manufacturing
CasFzP PI	-	Cascade Fuzzy Proportional + Proportional Intergral
CasPAi	-	Cascade Proportional Adaptive Interaction
CBECM	-	Combined Battery Equivalent Model
CC	-	Cohen Coon
CHR	-	Chien Hrones Reswick
CL	-	Cutter location
CNC	-	Computer numerical control
COM	-	Component object model

CPG	-	Central Pattern Generator
DAC	-	Digital to Analog Converter
DSP	-	Digital Signal Processing
DSP	-	Digital Signal Processor
EA	-	Evolutionary Algorithms
EANN	-	Evolutionary Artificial Neural Network
EAs	-	Evolutionary Algorithms
FDIDENT	-	Frequency Domain System Identification
FF	-	Feed Forward
FFT	-	Fast Fourier Transform
FIR	-	Finite impulse response
FLC	-	Fuzzy Logic Control
FRAC	-	Frequency Assurance Criterion
FRF	-	Frequency Response Function
GA	-	Genetic Algorithm
GUI	-	Graphical User Interface
I/O	-	Input / Output
IPSO	-	Enhanced Particle Swarm Optimization
LTI	-	Linear Time Invariant
MATLAB	-	Matrix Laboratory Numerical
MMI	-	Man Machine Interface
MPC	-	Model Predictive Control
MRAC	-	Model Reference Adaptive Control
NAIA	-	Nonlinear Adaptive Interaction Algorithm
NB	-	Negative Big

NC	-	Numerical control
NCasFF	-	Nonlinear cascade Feed-Forward
NCF	-	Nonlinear Cascade Feed-Forward
NLS	-	Non-linear Least Squares
NM	-	Negative Medium
NN	-	Neural Network
NPID	-	Nonlinear Proportional Integral Derivative
NS	-	Negative Small
NSS	-	Nonlinear Sliding Surface
OD	-	Orthogonal Diagonalization
P	-	Proportional
PB	-	Positive Big
PDF	-	Pseudo derivative feedback
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
PM	-	Positive Medium
PS	-	Positive Small
PSO	-	Particle Swarm Optimization
RMSE	-	Root Mean Square Error
RPM	-	Revolution per minute
SA	-	Simulated Annealing
SISO	-	Single Input Single Output
SMC	-	Sliding Mode Control
STH	-	Smart Tool Holder
SOC	-	State of change

ZE	-	Zero
ZN	-	Ziegler-Nichols

LIST OF APPENDICES