PID-PSO DC MOTOR POSITION CONTROLLER DESIGN FOR ANKLE REHABILITATION SYSTEM

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DECLARATION

I declare that this thesis entitled “PID-PSO DC Motor Position Controller Design For Ankle Rehabilitation 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 the candidature of any other degree.

Signature :

Name : Muhammad Azizul Raziq Bin Azizi

Date : 12/03/2023

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 Master of Science in Electronic Engineering.

Signature :

Supervisor Name : Dr. Khairuddin Bin Osman

Date : 12/03/2023

DEDICATION

This thesis is dedicated to my beloved family, especially my father and mother who unconditionally supports and prays for my success. Special thanks to my supervisors Dr. Khairuddin Bin Osman and En. Anuar Bin Jaafar who has been guiding me from the beginning of this journey as well as Nur Khairunisha Kamel Binti Muhammad Kamel, Mohamad Yusry Lee Bin Ikhwan Lee and Amierul Syazrul Azril Bin Azman for the assistance and encouragement.

ABSTRACT

In rehabilitation system application, precise output responses are important for position control on the mechanism's joint to avoid injury that occurs during physiotherapy. Hence, position control of DC motors has attracted considerable research with applied control system algorithms. This research aims to determine the mathematical modeling gain of the third-order transfer function for the DC motor that represents the features parameter of the Ankle Rehabilitation System. The transfer function is a model in Matlab software to validate the performance of the control system through simulation compared with real-time experiments. Next, the control algorithms are proposed to design and implement the Proportional-Integral-Derivative (PID) with Particle Swarm Optimization (PSO) controller technique for optimal Proportional (Kp), Integral (Ki) and Derivative (Kd) gains. The control algorithms also aim to be analyzed using an incremental rotary encoder sensor device as closed-loop feedback for dorsiflexion and plantarflexion movement. This rotary encoder sensor device converts rotary motion into electrical signals or pulse signals to count per revolution of the gearbox output shaft. The H-Bridge module is used for bi-directional motor control with pulse-width modulation (PWM) from the Arduino microcontroller. The control pulse-width modulation is calculated and realized by tuning the value of Proportional (Kp), Integral (Ki) and Derivative (Kd) with soft computing optimization techniques PSO controller. This proposed approach to develop optimal controller tuning parameters for proper computational performances position control efficiency and stable convergence characteristics. The simulation result of the PID-PSO controller with variables Kp= 6.542, Ki= 0.103 and Kd= 0.255 provide good performance with the rise time (T_R) is 0.0659sec, settling time (Ts) is 0.1183sec and maintain the steady-state error with zero overshoot. This gain tuning of Kp, Ki and Kd from the simulation was also implemented in real-time hardware for validation producing effectiveness for the controller to improvise the Ankle Rehabilitation System position control analysis. The statistical trajectory tracking error is evaluated using mean square error (MSE) and root mean square error (RMSE) achieving a small value. The percentage improvement for simultion from PID controller to PID-PSO shows the MSE made is almost 91% while the RMSE is 71%. The real-time experiment performance also have high percentage improvement with MSE is 97% and RMSE is 84%. It concludes that the PID-PSO controller effectiveness control strategies of DC motor can accurately track the sinusoidal setpoint rotational angle movement of the Ankle Rehabilitation System.

REKA BENTUK PENGAWAL KEDUDUKAN MOTOR DC PID-PSO UNTUK SISTEM PEMULIHAN PERGELANGAN KAKI

ABSTRAK

Dalam aplikasi sistem rehabilitasi, tindak balas yang tepat adalah penting untuk kawalan kedudukan pada sendi mekanisme bagi mengelakkan kecederaan yang berlaku semasa fisioterapi. Oleh itu, kawalan kedudukan motor DC telah menarik banyak penyelidikan dengan penggunaan sistem algoritma kawalan. Penyelidikan ini bertujuan untuk menentukan pendapatan pemodelan matematik untuk fungsi pemindahan tertib ketiga bagi motor DC yang mewakili ciri parameter Sistem Pemulihan Buku lali. Fungsi pemindahan adalah model dalam perisian Matlab untuk mengesahkan prestasi sistem kawalan melalui simulasi berbanding dengan eksperimen masa nyata. Seterusnya, algoritma kawalan dicadangkan untuk mereka bentuk dan melaksanakan Berkadaran-Integral-Derivatif (PID) dengan Pengoptimuman Kawanan Zarah (PSO) teknik pengawalan untuk mendapatkan Berkadaran (Kp), Integral (Ki) dan Derivatif (Kd) yang optimum. Algoritma kawalan juga bertujuan untuk dianalisis menggunakan peranti penderia pengekod berputar tambahan sebagai sistem maklum balas litar tertutup untuk pergerakan dorsiflexion dan plantarflexion. Peranti pengesan pengekod berputar ini menukarkan gerakan berputar kepada isyarat elektrik atau isyarat nadi untuk mengira setiap putaran aci keluaran kotak gear. Modul H-Bridge digunakan untuk kawalan motor dwiarah dengan modulasi lebar nadi (PWM) daripada mikropengawal Arduino. Modulasi lebar nadi kawalan dikira dan direalisasikan dengan menala nilai Berkadaran (Kp), Integral (Ki) dan Derivatif (Kd) dengan teknik komputer pengawal pengoptimuman PSO. Pendekatan yang dicadangkan ini bertujuan untuk membangunkan parameter penalaan pengawal yang optimum untuk prestasi pengiraan yang betul kecekapan kawalan kedudukan dan ciri penumpuan yang stabil. Hasil simulasi pengawal PID-PSO dengan pembolehubah Kp= 6.542, Ki= 0.103 dan Kd= 0.255 memberikan prestasi yang baik dengan masa naik (TR) ialah 0.0659sec, masa menetap (Ts) ialah 0.1183sec dan mengekalkan kadar ralat dalam keadaan tetap dengan terlebih tembakan sifar. Penalaan kadar Kp, Ki dan Kd daripada simulasi ini juga dilaksanakan dalam peralatan masa nyata untuk pengesahan dan menghasilkan keberkesanan bagi pengawal untuk menambah baik analisis kawalan kedudukan Sistem Pemulihan Buku lali. Ralat penjejakan trajektori statistik dinilai menggunakan ralat min kuasa dua (MSE) dan ralat min kuasa dua punca (RMSE) yang mencapai nilai yang kecil. Peratusan penambahbaikan bagi simualasi daripada pengawal PID kepada PID-PSO menunjukkan MSE yang dibuat adalah hampir 91% manakala RMSE ialah 71%. Prestasi percubaan masa nyata juga mempunyai peningkatan peratusan yang tinggi dengan MSE ialah 97% dan RMSE ialah 84%. Ia menyimpulkan bahawa keberkesanan pengawal PID-PSO strategi kawalan untuk motor DC boleh menjejaki dengan tepat titik tetapan sinusoidal pergerakan sudut putaran Sistem Pemulihan Buku lali.

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LIST OF SYMBOLS AND ABBREVIATIONS

ABF	-	Auditory Biofeedback
AC	-	Alternating Current
ACO	-	Ant Colony Optimization
ATFL	-	Anterior Talofibular Ligament
ANN	-	Artificial Neural Network
CFL	-	Calcaneo Fibular Ligament
DC	-	Direct Current
FPGA	-	Field Programmable Gate Array
IDE	-	Integrated Development Environment
MRI	-	Magnetic Resonance Imaging
MAE	-	Mean Absolute Error
MHz	-	Mega Hertz
MSE	-	Mean Square Error
PSO	-	Particle Swarm Optimization
PID	-	Proportional-Integral Derivative
PWM	-	Pulse Width Modulation
PTFL	-	Posterior Talofibular Ligaments
$\%e_{ss}$	-	Percentage Steady-State Error
%OS	-	Percentage Overshoot
RMSE	-	Root Mean Square Error
T_R	-	Rise Time
T_s	-	Settling Time
Sec	-	Second
t	-	Time
VBF	-	Visual Biofeedback

LIST OF PUBLICATIONS

Indexed Journal

Azizi, M.A.R., Jaafar, A., and Osman, K., 2020. Performance analysis for sprain ankle rehabilitation system using gyro sensor. *International Journal of Advanced Science and Technology*, 29 (6), pp.860–872.

Azizi, M.A.R., Jaafar, A., Osman, K., and Suzumori, K., 2021. PID controller design for DC motor position analysis and application to ankle rehabilitation system. *Journal of Advanced Manufacturing Technology (JAMT)*, 15 (3), pp.55–66.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Recently, the evolution of innovative robotic technology constantly developed in the robotic field, especially in the medical field z(Qian and Bi, 2015; Guo et al., 2021). These new trends in the robotic field have drawn the attention of researchers conducting studies in terms of development for the rehabilitation robots application such as power-assist devices integrating sensors (Kawase et al., 2017). The invasion of robots application in medical industries helps to improve faster recovery for rehabilitation treatment control systems and provides power assistance with data acquisition (Gao et al., 2020). Rehabilitation is a mainstay treatment where robots can give a significant impact on patients treatment who suffer from injuries (Gassert and Dietz, 2018). Several studies revealed that a sprained ankle injury can happen to almost everybody especially active people because turned unexpected movement directions (Roos et al., 2017). This injury causes damage severity to the ankle ligament which can stretch or tear either partially or fully in the worst situation (Delahunt et al., 2018). The rehabilitation application system is created to perform therapeutic exercises with repetitive movement and measure mechanical parameters objectively using sensors for ankle strength recovery (Atlihan et al., 2014).

The existing sprain ankle rehabilitation system consists of two types which are traditional manual rehabilitation and robotic technology rehabilitation. The traditional manual rehabilitation treatment approach mainly uses a simple device available at any physiotherapist outlet or clinical (Shi et al., 2021). Examples of primitive passive device or simple devices for manual rehabilitation therapists is elastic bands, roller foams and wobble boards. Unfortunately, these primitive passive devices or only can perform with the patient's effort strength, restrict patient training time and lack of function to produce any data acquisition for patients resulting outcomes exercise (Saglia et al., 2019; Collins and Jackson, 2013). As compared to robotic rehabilitation is capable of providing more intensive training with more motivation, better quantitative feedback and improved functional outcomes for patients (Chen et al., 2013). It also could give moral motivation with interesting strategies for patients to involve in the training session and recover from ankle injuries.

Nowadays, electric motors actuator such as Direct Current (DC) motor is widely used in industry application constantly developed for robot manipulators, electric traction and the medical industry (Mohamed et al., 2020). Robotic rehabilitation system technology used for medical needs to be concerned with several mechatronic device elements in terms of actuator mechanism’s joint, control system, mechanical design structure and safety (Khalid et al., 2015). In this research, the actuator mechanism’s joint using a DC motor was chosen that can achieve speed control and position by varying the terminal voltage incorporated with an incremental encoder as the closed-loop feedback. The encoder pulse is counted when the disk is rotating while the rotary encoder consists of two output sensors to determine the steps each time the signal changes. However, there are uncertain and nonlinear characteristics that affect the robustness and stability of the system especially when there is load disturbance (Guermouche et al., 2015). Therefore, control system algorithms are applied in the DC motor application plant system for robust control of position and velocity. The angular position is determined by using a rotary encoder as the closed-loop feedback

Since 1940, the PID controller has been used for several decades in industries to process control system applications (Hassan et al., 2017). Traditionally, Proportional Integral Derivative (PID) algorithm controller is the most preferable controller because of