IMPROVED GENETIC ALGORITHM FOR DIRECT CURRENT MOTOR HIGH SPEED CONTROLLER IMPLEMENTED ON FIELD PROGRAMMABLE GATE ARRAY

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By

FALIH SALIH ALKHAFAJI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

December 2019

DEDICATION

To
My God
My parents
My loving family, wife and children
and
My siblings

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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December 2019

Chairman : Wan Zuha Wan Hasan, PhD
Faculty : Engineering

Direct Current (DC) motors are widely used in robotic systems in case of their simplicity, more accessible to be linear control and good speed controllability. However, these systems still poor performance if not comprise with a controller. Proportional Integral (PI) controller one of the most significant controllers that use to improve the speed performance of DC motors. There are many researches have been done to optimize PI controller based evolutionary algorithm, such as Genetic Algorithm (GA). However, it has several drawbacks come from randomly searching constraints that cause lousy optimization. There are very little studies to analyse the influence of modifying initialization constraints on GA based PI controller problems objectively. On the one side, the estimation Transfer Function (TF) of these motors is considered a significant problem in most previous studies which causes bad controller design, if the low estimation accuracy. Additionally, based on multi experiments that applied to tune PI controller, it is not necessarily all simulation results based on tuning gains such as negative values, are applicable in hardware design. On the other side, there is little pay attention to improve the speed of the DC motor controller to be measured in the microsecond unit. All of these problems have been considered in this research to be fixing by proposing multi new methodologies. The main objective is to improve the speed performance of DC motor based PI controller in terms of dead (td), rise time(tr), settling times(ts) by estimating precise TF, improving GA performances, and enhancing architecture design to be integrated on Field Programmable Gate Array(FPGA). It is chosen three different direct current motors, and there are three methodologies proposed. Firstly, to propose an accurate TF for the tested DC motors by designing High Speed Motor Data Acquisition System (HSMDAQS) to collect data in data to be imported into System Identification (Sys Ident). The obtained results show that the TF achieved an accurate estimation by increasing the best fit to 95 %. Secondly, is to improve the GA performance based PI controller, by Modified Initialization Fitness Function (MIFF) to overcome the downsides of random searching. Afterward, it is suggested a new procedure to Optimize GA Parameters and Operators (OGA_P0). Simulation results show that the proposed PI controller based Improved GA (IGA) for motors 1,2,3 produces a better improvement for Reduction Step Response Ratio (RSRR) compared with classical GA by 8,9,35 times and over Particle Swarm Optimization (PSO) by 3,3,10 times. The third methodology is to integrate the proposed controller on FPGA, using a new method to run the design based simulink model. Experimentally, it is observed that the Steady State Time (SST) to achieve maximum speed for motors1,2,3 minimized by 10.68%, 8.67%,3.91% respectively, where the significant reduction is achieved in motor 2 to capture 4000 (Revolution Per Minute) RPM at 12.4µs. Finally, the PI controller based IGA providing better speed performance to all experimental motors in terms of response time characteristics to be measured experimentally in the microsecond unit.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ALGORITMA GENETIK YANG DITAMBAH BAIKKAN UNTUK PENGAWAL MOTOR ARUS TERUS BERKELAJUAN TINGGI YANG DILAKSANAKAN DENGAN TATASUSUNAN PINTU BOLEH ATUR CARA MEDAN

Oleh

FALIH SALIH ALKHAFAJI

Disember 2019

Pengerusi : Wan Zuha Wan Hasan, PhD
Fakulti : Kejuruteraan

Motor Arus Terus (DC) digunakan secara meluas dalam sistem robotik kerana keringkasannya, lebih mudah untuk kawalan linear dan untuk kawalan kelajuan yang baik. Walau bagaimanapun, sistem ini masih kurang baik jika tidak dibina dengan pengawal. Kawalan kamiran berkadaran (PI), salah satu daripada pengawal yang paling penting yang digunakan untuk menambah baik prestasi kelajuan motor DC. Terdapat banyak penyelidikan yang telah dilakukan untuk mengoptimumkan algoritma evolusi berasaskan pengawal PI, seperti Algoritma Genetik (GA). Tetapi, ia mempunyai beberapa kelemahan seperti dikekang oleh pencarian rawak yang menyebabkan pengoptimuman buruk. Terlalu sedikit kajian yang telah menganalisis pengaruh perubahan kekangan permulaan pada pengawal PI berdasarkan GA secara objektif. Pada satu situasi, anggaran Fungsi Pemindahan (TF) bagi motor-motor ini dianggap sebagai masalah besar dalam kebanyakan kajian terdahulu iaitu menyebabkan reka bentuk pengawal yang tidak bagus, jika ketepatan adalah rendah bagi anggaran. Di samping itu, berdasarkan pelbagai eksperimen yang digunakan untuk menala pengawal PI, didapati tidak semestinya semua hasil simulasi berdasarkan kelebihan penalaan seperti nilai negatif, boleh dipakai dalam reka bentuk perkakasan. Selain itu, hanya perhatian rendah diberikan untuk meningkatkan kelajuan pengawal motor DC untuk diukur dalam unit mikrosaat. Kesemua masalah ini telah dipertimbangkan dalam penyelidikan ini untuk diperbaiki dengan mencadangkan pelbagai kaedah baru. Objektif utama adalah untuk meningkatkan prestasi kelajuan pengawal PI berasaskan motor DC dari segi "dead rise" (td), masa naik (tr), masa penetap (ts) dengan menganggarkan TF yang tepat, meningkatkan prestasi GA, dan meningkatkan reka bentuk seni bina untuk disepadukan pada Tatasusunan Pintu Boleh Atur Cara Medan (FPLA). Tiga motor DC berbeza dipilih, dan terdapat tiga metodologi yang dicadangkan. Pertama, untuk mencadangkan TF yang tepat untuk motor DC yang diuji, dengan merekabentuk Sistem Pemerolehan

Data Motor Berkelajuan Tinggi (HSMDAQS) untuk mengumpul data dalam data yang akan diimport ke dalam Sistem Pengenalpastian (Sys Ident). Hasil yang diperoleh menunjukkan bahawa TF mencapai anggaran yang tepat dengan meningkatkan kesesuaian kepada 95%. Kedua, adalah untuk meningkatkan pengawal PI berasaskan prestasi GA, dengan Fungsi Kecergasan Inisialisasi Modified (MIFF) untuk mengatasi kelemahan carian rawak. Selepas itu, prosedur baru dicadangkan untuk Parameter GA dan Operator yang Dioptimalkan (OGA_P0). Keputusan simulasi menunjukkan bahawa Peningkatan GA (IGA) yang berasaskan pengawal PI yang ditugaskan untuk motor 1, 2, 3 menghasilkan peningkatan yang lebih baik untuk Nisbah Respon Langkah Pengurangan (RSRR) berbanding dengan GA klasik sebanyak 8, 9, 35 kali dan lebih dari Partikel Swarm Pengoptimuman (PSO) sebanyak 3, 3, 10 kali. Metodologi ketiga adalah untuk mengintegrasikan pengawal yang dicadangkan pada FPGA, menggunakan kaedah baru untuk menjalankan model simulink berasaskan reka bentuk. Secara eksperimen, diperhatikan bahawa “Steady State Time” (SST) untuk mencapai kelajuan maksimum untuk motor 1, 2, 3 diminimumkan masing-masing sebanyak 10.68%, 8.67%, 3.91%, di mana pengurangan yang signifikan dicapai dalam motor 2 untuk mengumpul 4000 (Revolusi Per Minit) RPM pada 12.4µs. Akhirnya, IGA berasaskan PI pengawal memberikan prestasi kelajuan yang lebih baik kepada semua motor percubaan dari segi ciri-ciri masa tindak balas yang diukur secara eksperimen dalam unit mikrosaat.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Wan Zuha Wan Hasan, PhD
Associate Professor
Faculty of engineering
Universiti Putra Malaysia
(Chairman)

Nasri b. Sulaiman, PhD
Senior Lecturer
Faculty of engineering
Universiti Putra Malaysia
(Member)

Maryam bt. Mohd. Isa, PhD
Senior Lecturer
Faculty of engineering
Universiti Putra Malaysia
(Member)

Raja Mohd Kamil b. Raja Ahmad, PhD
Associate Professor,Ir.
Faculty of engineering
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

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Signature:	______________________
Name of Chairman of Supervisory Committee:	Associate Professor Dr. Wan Zuha Wan Hasan
Signature:	______________________
Name of Member of Supervisory Committee:	Senior Lecturer Dr. Nasri b. Sulaiman
Signature:	______________________
Name of Member of Supervisory Committee:	Senior Lecturer Dr. Maryam bt. Mohd. Isa
Signature:	______________________
Name of Member of Supervisory Committee:	Associate Professor,Ir. Dr. Raja Mohd Kamil b. Raja Ahmad

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LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog to Digital Converter
AI	Artificial Intelligence
AMIGO	Approximate M–constrained integral gain optimization
AMIGO_OBT	AMIGO on optimization based tune
ASIC	Application Specific Integrated Circuit
AEFF	Augmented Error Fitness Function
AMEFF	Augmented Minimizing Error Fitness Function
CHR	Chien-Hrones-Reswick
CHR_OBT	CHR on optimization based tune
CMOS	Complementary metal oxide semiconductor
DAC	Digital to Analog Converter
DAQ	Data Acquisition
DC	Direct Current
DHES	Dual Hall Encoder Sensor
DSP	Digital Signal Processor
DW	Digital Write
EA	Evolutionary Algorithm
ER	Encoder Read
FF	Fitness Function
FPGA	Field Programmable Gate Array
FPGA_SoC	Field Programmable Gate Array based system on chip
GA	Genetic Algorithm

GA_MIFF	GA based MIFF
Gbest	Global best position
GR	Gear Ratio
ICD	Injected collected data
IGA_PI	Improved GA based PI controller
IR	Improvement ratio
ISE	Integral squared error
IAE	Integral absolute error
ITAE	Integral time absolute error
Iter	Iteration
Kp_CHR_OBT	Proportional gain on CHR based OBT
Ki_CHR_OBT	Integral gain on CHR based OBT
Kp_MIFF	Proportional gain-based MIFF
LPF	Low pass filter
MIFF	Modified Initialization Fitness Function
MM	Mathematical Model
MOGA	Multi-objective Genetic Algorithm
NN	Neural network algorithm
OBT	Optimization based tune
OF	Objective Function
OGA_PO	Optimization GA parameters and operators
PI	Proportional Integral
PID	Proportional Integral Derivative
PMDC	Permanent magnetic direct current

PSO	Particle Swarm Optimization
pbest	Local best position
RTL	register-transfer level
SA	Simulated Annealing
SIMC	Skogestad Internal Model Control
SoC	System on chip
SISO_OBT	SISO optimization-based tune
SIMC_OBT	SIMC on optimization based tune
Sys Ident	System Identification
SYS GEN	System Generator
TF	Transfer Function
VHDL	Very high description language
Z_N	Ziegler-Nichols

LIST OF SYMBOLS

AESR	Average error step response
EPSR	Error percentage step response
Fil_c	Filter constant
Fo	Cut off frequency
Kd	Derivative gain
Ki	Integral gain
Kp	Proportional gain
SSE	Steady state error
SST	Steady state time
td	Dead time
tp	Peak time
tr	Rise time
ts	Settling time
PoS	Peak overshoot
V	Volt

CHAPTER 1

INTRODUCTION

1.1 Research Overview

During the last decade, there are extensive researches in the developing of robotic applications that automated by electric motors have been done, especially for DC motors. DC motors are a central part and a common actuator in control systems that have been extensively utilized in numerous robotic systems, such as mobile robots, system, autonomous systems, medical actuators, and electrical vehicles, due to high-performance, effortlessness, high stability, easy maintenance, flexibilities, besides offers smooth speed control in both directions. Recently, speed control DC motor has attracted considerable investigate, and numerous methods have been evolved[1]–[6].

Significantly, DC motors provide superior control of speed for deceleration and acceleration over AC motor, and applicable of use as adjustable speed machines [7]. In most DC motor applications, the current in field winding is kept constant, and the current in armature winding is varied or vice versa which gives a magnificent speed control performance over a vast range of desired values[8, 9]. However, DC motors need to be controlled to improve their speed performance.

With the rise of robotic technology and applications, there have been increasing interest in the development of controllers for their particular design [10]. The chosen controllers play an essential role in the design of any system. The PI and Proportional, Integral, Derivative (PID) control algorithm have been widely used in the design of robot control systems, due to their advantages, such as easy tuning, robust, effectiveness, simple algorithm and can be realized easily in engineering [11]–[13]. Control system performance is often estimated by applying a step signal to measure the step response characteristics by estimating characterized waveform parameters. Figure 1.1 shows the parameters of step response time characteristics dead time (td), rise time(tr), settling time(ts) and peak overshoot (PoS). The td is represented a delay between when a process variable changes, and when that change can be observed, tr is the amount of time the system takes to go from 10% to 90% of the final amplitude value, ts is the time required for the process variable to settle to within a certain percentage equal to 5% of the final amplitude[14, 15].

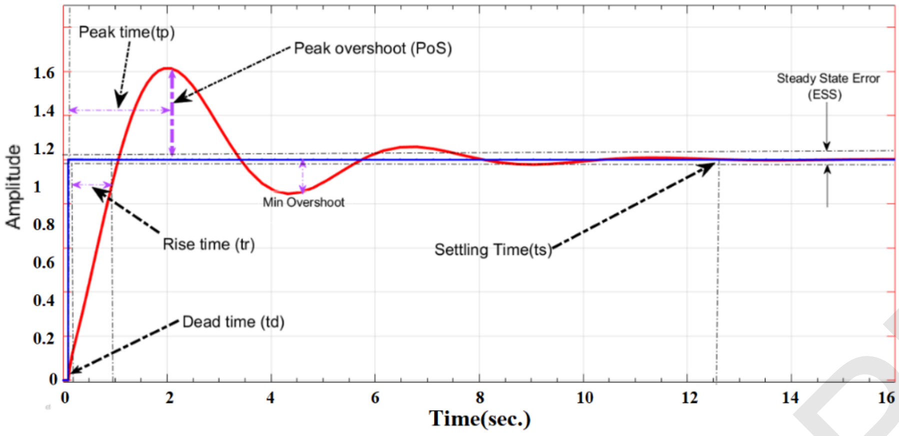

Figure 1.1 : Response time characteristics [14]

By contrast, PI and PID controller are the latest control strategies, where the PID controller is used to controlling all the model of linear processes, where the most industrial processes are non-linear and some process is challenging to establish the model, such as the TF form to be designed controller properly. Therefore the general PID control cannot achieve precise control of such plant systems if the TF not accurately estimated [16]. Figure 1-2 illustrates the block diagram of a closed-loop system controlled by the PID controller to generate an output $u(t)$ to drives the system to matches the reference signal $r(t)$ with its output $y(t)$, to minimize the error as close to zero as possible. Structurally, PID consists of three main proportional parameters, like proportional gain (Kp), integral gain (Ki), derivative gain (Kd). The main function of these parameters as follows; Kp is to minimize the present error $e(t)$in the system; Ki is to accumulate all past errors depends on the duration of error and reduce it; Kd is to predict the future error and to reduces overshoot. The algorithm that describes PID controller behavior in continues time domain and s-domain with respect to error e(t) are given in equations 1.1 and 1.2 respectively, where the plant system can be represented in s-domain as in equation 1.3 [17]–[19]. It is essential in designing PID controller to understand how the system of interest behaves and how it responds to different controller designs. The Laplace transform is a valuable tool that can be used to solve differential equations and obtain the dynamic response of a plant system in s-domain. The poles and zeros of a system, which are the main focus of this module, provide information on the characteristic terms that will compose the response[20,21].

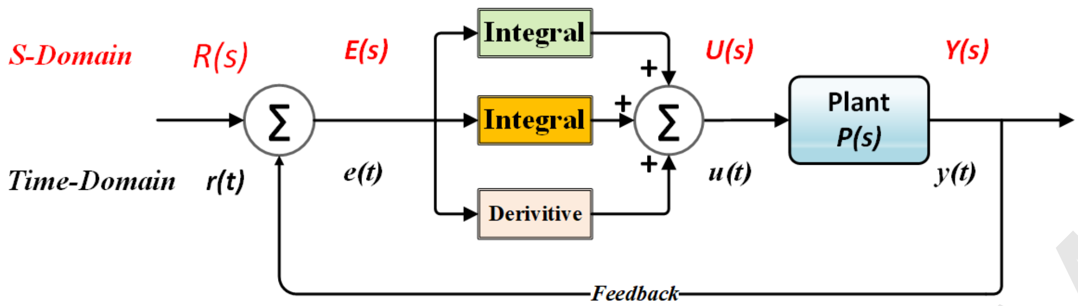

Figure 1.2 : Closed loop PID controller [21]

$$u(t) = Kp.e(t) + Ki\int_0^t e(t).dt + Kd.\frac{d}{dt}\,e(t) \tag{1.1}$$

$$U(s) = Kp + \frac{Ki}{s} + Kd.s \tag{1.2}$$

$$P(S) = \frac{Y(s)}{U(s)} = \frac{b_m s^m + b_{m-1}s^{m-1} + \quad + b_1 s + b_0}{s^n \quad + a_{n-1}s^{n-1} \quad + \quad + a_1 s + a_0} \tag{1.3}$$

Although the PID controller is inexpensive and commercially available, it is surprisingly difficult to find the right tuning for them without systematic procedures and tools. Presently, a lot of different tuning methods for PID controller design for continuous systems exist. These methods are compared in terms of quality of control. There are four major characteristics of the closed-loop step response tr, PoS, ts, and steady-state error (SSE) [22]–[25]. Considerably, the PID controller is unique to each application, and some implementations may use only one or two parameters, such as PI, PD, P, I to provide the appropriate control of the system [26]. Experimentally, Kp will have the effect of reducing tr and will reduce; but never eliminate the steady-state error, (Ki) will have the effect of removing the steady-state error, but it may make the transient response worse. (Kd) will have the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response[27]. Therefore, to improve response time characteristics, the proportional gains Kp, Ki, Kd should be appropriately tweaked. The system can still be brought to stability by adjusting the three components jointly[28].

The determination of proportional Kp, derivative Kd, and integral Ki constants are known as tuning of PID controller. By contrast, tuning the gains of PI and PID is a significant procedure in the control system and should be appropriately tuned to accomplish an optimized value of the desired response, leads to obtain a desired closed-loop system performance[29, 30]. Many researchers have attempted to develop the design tuning methods for the PI and PID controller from the last decade up to now, to minimize response time characteristics. A portion of these tuning methods has been developed by considering more than one objective as a criterion for their tuning methods, while others considered one criterion [31, 32]. There have been developed efficient and straightforward procedures for tuning parameters of industrial controllers, as well as optimization procedures of the controllers to minimize IAE (Integrated Absolute Error) under constraints to robustness[33, 34].

Based on a survey, the widely used tuning methods are the Ziegler-Nichols (Z-N)tune [28,35,36], Chien Hornes Reswick(CHR)tune [31], Cohen Coon tune[37], while others used Approximate M-constrained Integral Gain Optimization (AMIGO) rule-based PI as the best solution for control problems where load disturbance rejection is a significant concern [38]. Other studies use Internal Mode Control (IMC)tune to minimize percentage overshoot specification [39]–[42], Skogestad Internal Model Control (SIMC) tuning method is demonstrated in [43]. Specifically, the majority of these works focused on improving the performance of PI and PID controller design to achieving the desired closed-loop response. By contrast, there are several essential drawbacks in Z-N, poor damping, poor robustness, and inappropriate to a simple second-order process, and it can only be used with processes for which the phase lag exceeds -180 degrees at high frequencies. These drawbacks have been known for a long time, and there have been many efforts to overcome them[38,39,44,45]. Also, there are several limitations in the Cohen-Coon tuning algorithm, in case of some math required, good for only first-order processes [28]. In reality, using just a tuning method not enough to produce better proportional gains.

Recently, the evolutionary computations have proposed GA and particle swarm optimization (PSO) as open paths to a new generation of advanced process control. Based on a survey, GAs and PSOs are the most evolutionary algorithm that is used as an alternative tool in a widespread range of industrial applications, especially for optimization PI and PID controller problems, in case of capillarity of handling issues with non-linear constraints, multiple objectives, and dynamic components properties [46, 47]. For two decades, GA is used in a wide range application to improve system performance but sometimes not providing a better solution in case of randomly finding initialize constraints through searching constraints in a population. Additionally, GAs have many parameters, and operators need to be modified before tackled fitness function (FF). Based on a survey in a field of the genetic PI controller, there are minimal works considered these two points to resolve both randomly searching initial constraints or to fix the problem of how to select better GA parameters and operators to overcome the drawbacks that happened in classical GA[48]–[50].

1.2 Motivation

Several motivations have been explored that support getting started this research. The motivations generate a merge among interested DC motors as a plant system from one side, and the PI controller as a corrected error between the speed demand and the output response time characteristics to achieve minimum td, tr, ts, PoS for a DC motor. This approach has intensive investigations and harvested excellent outcomes. However, there are still some efforts towards system integration and efficiency optimization. This section discusses several of these motivations.

1.2.1 Estimation of Transfer Function

To design a PI controller for a DC motor, it should be knowing the mathematical form, such as state-space representation or TF. However, not all manufactured motors are provided their specifications, which considered the first problem in the field of controller system. The capability to estimate precise TF of a dynamic system is the foundation for some control methodologies. That is, without an accurate TF of a physical plant, the implementation of traditional methods for compensator design and stability analysis is rendered insufficient. Therefore, the proper way to estimate accurate TF is by using the method of acquiring data from the DC motor to be imported into the Sys Ident application. Literarily, there are several studies used digital devices, such as oscilloscope to collect data in data out to be imported into Sys Ident. However, there is a drawback in this method that comes from lousy collection data with limited sampling, causing the lowest fitting between injected signal and angular speed (θ), which leads to lousy estimation TF form. Other studies used data acquisition instruments to collect data, but not focuses on how to minimize the noise that comes from the encoder sensor, which also leads to reduce the accuracy of the estimation. Both methods motivated this study to overcomes previous research to achieve the best solution for estimating TF by minimizing the distortion associated with the information signal coming from the encoder sensor. Based on this assumption, it is proposed to design HSMDAQS to accurately collect both input voltage and angular speed(θ) and to be imported the data into Sys Ident application with the lowest noise. Experimentally, this approach requires a Dual Hall Encoder Sensor (DHES), and HSMDAQS precise hardware to be connected with PC through com port, and the experimental motor is running in the open loop using hardware in loop (HIL) technique.

1.2.2 GA based PI controller

One of the most famous algorithms that are used through two decades to optimize the PI controller for DC motors is the GA algorithm. Classical GA has several advantages, and limitations could be mentioned, for instance, GAs is robustness algorithm in case of, always operates in a whole population of points (strings), leading to improves the chance for reaching to the global optimum solution, and to reduce the risk of becoming trapped in a local stationary point. Furthermore, GA can be applied to any continuous or discrete optimization problem, in case of do not need to use any extra information about the objective function value, such as derivatives, the main thing to be done is to indicate a significant decoding function.

Currently, classical GA is not the best solution with respect to PSO. Profoundly negative side in GA comes from the way to compute the new generation after the first generation, which has some random components that cause corrupt generation values in the primary stages of global searching. Thus, the quality of the initial population of individuals influences significantly to specify an optimum solution. The specific initial population seeding technique for a problem improves the efficiency of GAs to find the optimal solution, where the proposed methods for the initial population seeding are limited. The additional limitation comes from unsystematic setting GA parameters, and operators lead to reduce the performance for better-searching constraints. The limited number of this approach motivates this study, as there is still room for enhancing and finding a better initial population. To overcomes these drawbacks towards improving GA performance, it is proposed a new technique to be applied on GA to become more precisely searching constraints by introducing a new modified initialization Fitness Function(MIFF)technique, besides proposed systematic procedure to optimize GA's parameters and operators (OGA_PO). The proposed new algorithm and procedure have been applied to the PI controller based TF forms of DC motors to improve their speed performances.

1.2.3 Integration proposed Algorithms on hardware circuitry

Experimentally, integrating controller-based hardware circuitry is considered a very crucial point, especially for precise applications, such as the controller-based optimization algorithms. Therefore, the right selection hardware is a significant issue to reduce the deviation between simulation and experimental results to obtain the highest possible efficiency. To implement an effective real-time industrial control system, designers have a choice between three leading families of digital device technologies. Firstly, using an Application Specific Integrated Circuit (ASIC) that could be in charge of reducing errors, minimize the area of design, and improve power efficiency. But ASIC is quite rigid, and their programmability is low, so their functionality cannot be updated much once fabricated. Secondly, based on microcontrollers to implement hardware circuitry. This strategy usually requires a higher number of devices on the PCB board, leads to consuming areas through construction design as well as more complex wiring. However, this approach allows the design to be updated by just programming it again. Thirdly, FPGA is between both previous strategies considered the best choice. FPGA is one of the most powerful chips, in case of high flexibility for modern embedded systems design, reprogrammable, rising integration scale, high dynamic performance. However, this technology needs more time to learn how to integrate algorithm circuitry, besides needing expensive software to generate VHDL or Verilog language. There are very few works based FPGA technology focusing on integrating the hardware circuitry of the PI controller for DC motor. For these reasons, it is necessary to investigate the best solution with more simplicity and no additional expensive software to generate VHDL code without needing more experience in these hardware languages. It is proposed a new methodology to integrate the proposed algorithm on FPGA_SoC by finding an appropriate solution to automatically generated VHDL. This new method can produce a high-quality controller platform that can overcome the previous significant works, achieving better speed performance and opening an original path for designing an accuracy PI controller for DC motor.

1.3 Problem Statement

During the last decade, there have been significant efforts in the developing of autonomous robots actuated by DC motors. However, DC motor drives usually are less precise for most horsepower rating. Therefore, these plant systems need to be controlled to improve speed performance in terms of response time characteristics. The controller is a device that can sense information from a linear or nonlinear system to enhance the systems performance. The main targets in designing control systems are the stability and small tracking error to achieve better performance[51]. The previous majority studies used P, PI, PID to control in DC motor, but it should be satisfying tuning gains to engage better performance. Therefore, most researchers use optimization algorithms or adaptive PID controllers for better optimization results, which caused drawbacks, such as increasing complexity of the algorithm and computational effort [52]. By contrast, GA is widely utilized to pick the ideal evaluation of the tuning gains [53]–[55]. One of the most crucial problems in traditional PI and PID controller-based GA cannot get satisfactory results in a real control system in case of a nonlinear plant, time-variant, difficulties of obtaining an accurate TF form of plant model, beside limitation GA tuning performance. Additional, there is a leakage of engagement between the industrial design and the academic researches [11,34,56, 57]. Due to the lack of GA and PSO suffer from several drawbacks, such as difficulty in the selection of control parameters, increased calculation time depending on the size of the system studied, and initial random calculation which is a significant problem in GA. Currently, there is no precise algorithm for the best solution to optimize the PI controller for speed DC motor systems [58]. This controller approach is no so easy to engage maximum performance because it depends on several criteria should be accurately acquired in simulation parts, such as the TF form and an appropriate proportional controller gains and the accuracy searching of the optimization algorithm, wherein experimental part the precise of hardware is considered a critical issue to engage better performance.

Hence, studying a new modification to improve GA performance is an essential and observable problem for researchers. By contrast, the GA constitutes a standard option for the solution of such issues, but their basic operating mode is not always well suited to any constraint treatment [59]. These essential points are considered to propose a systematic procedure to determine which operator and parameter are the best selective solution for designing PI controller and to overcome the randomly searching constraints in GA by proposing a new MIFF technique and new OGA_PO procedure. Hence, this research focusing on the previous drawback to resolve all aforementioned problems to be designed high speed PI controller for DC motor, providing better minimizing response time characteristics to be measured in the microsecond unit. The following points demonstrate briefly the challenging problems that faced this study through designing and integrating the proposed PI controller:

- Firstly, the TF form of the plant model should be estimated accurately. However, modeling TF not so straightforward in case not all manufactured motors are provided their specifications [60], and it is not so easy to estimate proper TF form of the plant model accurately through designing a PI or PID controller. The design appropriate PI controller depends on precise TF form. Based on these consecutive points, this study focuses on estimating an accurate TF form for the DC motor.

- Secondly, PI controller based classical GA algorithms carry out some downsides through searching constraints (Kp, Ki) in a global population, these drawbacks come from three points:1) randomly initial searching leads to augmented error fitness function(AEFF); 2)bad selecting GA parameters and operator that should be properly selected before running GA.
- Thirdly, experimentally, it is noticed that not all obtained results based GA could be applied whether for simulation or experimental, specifically in negative proportional gain values.
- Fourthly, integrating PI controller-based hardware is considered a crucial point. Based on a survey, the implementation of PI and PID controllers using microprocessors and DSP chips is old and well known, whereas very little works can be found in the literature on how to integrate the hardware of PI or PID controllers based FPGAs[61].
- Fifthly, it is not found any research can accomplish the highest reduction responses to be measured in the microsecond unit whether for simulation or experimental. Additionally, the major GA researches didn't provide the best value to overcome the PSO algorithm or other optimization algorithms.

1.4 Objective

The purpose of this research is to propose IGA_PI controller to improve the speed performance of DC motor controller, reduce the deviation error between experimental and simulation results, and to overcome classical GA and PSO based PI controller.

It could be summarized the main objective of this research in four points, which are:

- To propose an accurate TF form of the models based on selected experimental DC motors by proposing HSMDAQS.
- To improve the IGA_PI controller by proposing a new modified initialization fitness function technique tackled with GA and a new procedure to optimize parameters and operators of GA.
- To validate the speed performance of the proposed IGA_PI controller design based on response time characterization of improved GA through simulation and experiment using FPGA.
- To propose a new method for generating VHDL based simulink model to integrate hardware circuitry on FPGA.

The target of this study is to design high performance PI controller to accomplish the highest reduction responses, especially for tr to be measured bellow than 100µsec experimentally and to reduce SST to achieve maximum speed to be measured bellow 300µs. Furthermore, to decrease the deviation of the step response time between experimental and simulation, and to accomplish Average Error Step Response (AESR) bellow 10%.

1.5 Scope and limitation of the study

This study focuses on the development of the speed performance of a DC motor based proposed PI controller in terms of response time characteristics to be measured in a microsecond unit that can appreciate more advanced technology, such as multi-arm robotic controller systems. The research manages to achieve several objectives through real-time experimental implementations to deliver the lowest divergence compared with simulation results, as well as by laboratory experiments undertaken at University Putra Malaysia. The main points that defined this scope can be listed as follows:

- Studying the methods for estimating TF of a DC motor, such as Sys Ident application, and the methods used to acquire data.
- Proposing HSMDAQS to be used with Sys Ident application for better estimation TF models for DC motor.
- Studying the drawbacks of classical GA based PI controller.
- Proposing to improve the performance of GA to be used with the PI controller.
- Using classical GA and PSO as a benchmark comparison with proposed IGA-PI.
- The proposed IGA-PI prototype integrated based FPGA, by using some new software, such as Embedded coder based MATLAB2018b, HLS, and HLX Vivado 2016.3 for generating VHDL code-based design. However, there are not much research has been done yet in implementing whether for classical GA or improved GA technique on FPGA_SoC.

For the purpose of designing the PI controller on the aforementioned scientific problems, a series of experiments are designed to test the performance of the controller in terms of response time characteristics. This study achieved the stipulated objectives. However, there are several limitations in this study, which are:

- There are extensive range variables that should be considered through the investigation of using optimization algorithms.
- Through experimental testing, sometimes, any inaccuracy voltage caused leakage or noisy through acquiring data, especially for reading response time.
- Based multi experiments is done, it is noticed that not all obtained results by GA can be applied experimentally on a PI controller, such as negative proportional gain values.
- Experimentally, it is tough to correspond to the results-based simulation. However, the best corresponding can be measured by using the Sys Ident toolbox.

- Not all manufacturer motors are provided their specifications. Therefore, it is necessary to propose a hardware design to collect data in data out to be imported into Sys Ident application to find an accurate TF for a DC motor without needing motor specifications.

1.6 Thesis Layout

This thesis consists of seven chapters. The following chapter presents the literature review of GA and PSO based PI and PID controller, besides showing the comparative performance between them. Also, the survey covered all methods that are used in previous works to estimate TF of a DC motor. Additionally, it has proceeded a review for PI and PID controller based DC motor for both simulation and experimental. Chapter three demonstrates the main methodology to enhance the response time characteristics of the PI controller based proposed Improved GA. In the next chapter, a proposed TF model based proposed HSMDAQS is presented for three types of DC motor. This chapter included all experimental and simulation results. Chapter five presents how to improve the performance GA based PI controller, to become a superior algorithm for improving controllers-based DC motors. GA and PSO have been carried out as a benchmark simulation comparison to determine the performance of the proposed controller (IGA _PI) based experimental DC motor. Chapter six covers the experimental DC motor drive system and practical realization of the phase proposed IGA_PI controller, besides discussion the effectiveness of the hardware platform based FPGA board. In the final chapter, the general conclusion with contributions are drawn, and suggestions are made for future work.

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