DESIGN AND DEVELOPMENT OF POSITION CONTROL FOR ROBOT GRIPPER MECHANISM

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DESIGN AND DEVELOPMENT OF POSITION CONTROL FOR ROBOT GRIPPER MECHANISM

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in partial fulfillment of the requirements for the degree of
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2019

DECLARATION

I declare that this thesis entitled " DESIGN AND DEVELOPMENT OF POSITION CONTROL FOR ROBOT GRIPPER MECHANISM " 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.

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APPROVAL

I hereby declare that I have checked this report entitled "Design and Development of Position Control for Robot Gripper Mechanism" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

Praise to our Almighty God for His grace and blessing in guiding me through this final year project, nothing is possible without Him. In this humble column, I would like to express my sincere gratitude and appreciation to my supervisor, Prof Madya Dr Rozaimi bin Ghazali, who has never been tired in attending to my problem and mentored me in every way. I wouldn’t have gone this far without his advises from the very beginning until the submission. Thanks for the time well spent with me throughout the project.

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ABSTRACT

A robotic gripper is an end effector of robot arm that enables the automation system to manipulate and handling object. The objective of this project is to design and fabricate a robotic gripper mechanism with single degree-of-freedom (DOF) gripper coupled with DC geared brushed encoder motor using 3D printed parts. Besides, this project also aimed to design and compare the controller for position control of gripper mechanism using step inputs as well as to evaluate the performance of chosen controller under different testing environment and trajectory motion. The major challenge in this project is to obtain precise position of gripper validated through different input applied to the gripper as well as while it is undergoing a series of trajectory motion. In this project, a mechanical structure of robot gripper is fabricated with supported parts such as support frame and flange coupling are sketched in SOLIDWORKS and 3D printed for assembly. Controller tuning is done manually in Arduino IDE until minimal overshoot and shortest rise time and settling time are obtained and the control gains K_P, K_I, K_D are identified. The result showed that PID control appeared to be the best choice for development of position control for robot gripper mechanism as it provides moderate overshoot correction without sacrificing accuracy and reduction in rise time and settling time that ensures robot gripper's efficiency. The robot gripper is further tested on its performance under applied resistance and trajectory motion. PID position control is achieved as the gripper jaw is able to move to the desired position with minimal position error in shortest time. Error analysis supported the choice of PID controller to be applied in the development of position control for robot gripper mechanism with a RMSE value of 19.629 over a 12000 datum range. Experiments on object gripping revealed that the relationship between the rotation angle at actuating link and the displacement at target link is linear with a factor of 5/6. In a nutshell, this robot gripper can be applied and utilized in various application with the acceptable gripping position accuracy.

ABSTRAK

Penggenggam robot adalah pengeluar akhir lengan robot yang membolehkan sistem automasi memanipulasi dan mengendalikan objek. Objektif projek ini ialah mereka bentuk mekanisme penggenggam robot dengan satu *degree-of-freedom* (DOF) ditambah dengan motor penderia DC dilengkapkan dengan bahagian bercetak 3D. Selain itu, projek ini juga bertujuan untuk merekabentuk dan membandingkan pengawal untuk kawalan kedudukan mekanisme penggenggam menggunakan unit langkah serta untuk menilai prestasi pengawal terpilih di bawah persekitaran ujian yang berbeza dan gerakan trajektori. Cabaran utama dalam projek ini adalah untuk mendapatkan kedudukan yang tepat dari penggenggam yang disahkan melalui unit langkah yang berbeza yang digunakan untuk penggenggam serta satu siri gerakan trajektori yang mempunyai kedudukan berlainan. Dalam projek ini, struktur mekanikal penggenggam robot dibuat dengan bahagian yang disokong seperti bingkai sokongan dan penyambung aci motor yang dilukis dalam SOLIDWORKS dan dicetak secara 3D. Penalaan pengawal dilakukan secara manual di Arduino IDE hingga lajakan minimum dan waktu kenaikan terpendek dan masa penyelesaian diperoleh dan keuntungan kawalan K_P, K_I, K_D dikenalpasti. Hasilnya menunjukkan bahawa kawalan PID merupakan pilihan terbaik untuk pembangunan kawalan kedudukan untuk mekanisme penggenggam robot kerana ia menyediakan pembetulan lajakan yang sederhana tanpa mengorbankan ketepatan dan pengurangan masa meningkat dan masa penyelesaian bagi memastikan kecekapan robot penggenggam. Pengenggam robot akan diuji lagi pada prestasinya di bawah rintangan dan gerakan trajektori. Kawalan kedudukan PID dicapai apabila rahang penggenggam dapat bergerak ke posisi yang diinginkan dengan ralat kedudukan minima dalam waktu yang singkat. Analisis ralat menyokong pilihan pengawal PID untuk diaplikasi dalam pembinaan kawalan posisi bagi mekanisme penggenggam robot dengan nilai RMSE sebanyak 19.629 dalam lingkungan data sebanyak 12000 set. Eksperimen genggaman objek menunjukkan bahawa hubungan antara sudut putaran pada pautan penggerak dan anjakan pada pautan sasaran adalah linear dengan faktor sebanyak 5/6. Konklusinya, pengggenggam robot yang direkabentuk dalam tesis ini boleh diaplikasi dan digunakan dalam pelbagai aplikasi kegunaan with ketepatan penggenggaman yang boleh diterima.

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LIST OF SYMBOLS AND ABBREVIATIONS

P	-	Proportional term
I	-	Integral term
D	-	Derivative term
DC	-	Direct current
AC	-	Alternating current
K_P	-	Proportional gain
K_I	-	Integral gain
K_D	-	Derivative gain
PID	-	Proportional Integral Derivative
PWM	-	Pulse width modulation
MSE	-	Mean squared error
IDE	-	Integrated development environment
USB	-	Universal serial bus
DOF	-	Degree of Freedom
CAD	-	Computer aided design
SMA	-	Shape memory alloy
ppr	-	Pulse per revolution
emf	-	Electromotive force
ICSP	-	In circuit serial programming
RMSE	-	Root mean squared error

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Robotics is the applied science of motion control for multi-axis manipulators and is a large subset of the field of "mechatronics" (Mechanical, Electronic and Software engineering for product or systems development, particularly for motion control applications). The tremendous challenge of 21^{st} century is to develop robots and machines "intelligent" enough to learn how to perform tasks automatically and adapt to unforeseen operating conditions or errors in a robust and predictable manner, without the need for human guidance, instructions or programming [1]. At the current escalating rate of knowledge growth in the areas of robotics and automations, it is convincing to tell that "the best is yet to come" and the technology advancement in robotics will keep on improving to the point where almost all possible physical jobs will be completely automated at a very low production cost.

End effector is a generic term that includes all the devices that can be installed at a robot arm. In robotics, an end effector is a device or tool that is connected to the end of a robot arm [2]. Grippers are the most common type of end effector. Brands of robot grippers include Schunk, Robohand, PHD, SOMMER and Robotiq. There are numerous types of robotic gripper applications of where a robotic gripper can be used. Some common applications are grippers for known environment where parts are placed at predefined orientations; grippers for unknown environment such as pick and place task where flexibility of performing task is highly demanded; grippers for fragile object and medical applications. The most commonly used grippers are finger grippers, generally are two opposing fingers or three fingers like a lathe chuck. While choosing a gripper, several design considerations have to be taken in account, such as gripping force, weight, and supply of services.

International Federation of Robotics (IFR) has reported that global industrial robot sales have doubled over the past five years. Industrial robots play an increasingly important role in material handling and pick and place operations. The world's first working robot named Unimate joined the assembly line at the General Motors plant in Ewing Township in 1961. Robots have revolutionized the industrial workplace ever since. Robots are changing the face of manufacturing. They are designed to move materials, as well as to perform a variety of programmed task in manufacturing and production settings. Massive effort has been emphasized on the development of an efficient robotic workforce with the introduction of Horizon 2020 and Industry 4.0 [3].

The industrial robotics market around the globe is expected to outstrip USD 40 billion by 2020, according to a new study by Grand View Research, Inc. [4]. Another suggestion by the same research agency suggests that the automotive robotics market will grow to USD 13.6 billion by 2025 and this represents annual growth of almost 14 per cent from 2016. The new World Robotics Report shows that a new record high of 381,000 units were shipped globally in 2017 – an increase of 30 percent compared to the previous year [5]. The tremendous growth of the robotic industries has a close relationship to the utilization of different of robotic actuators especially electrical motors. Therefore, it is utterly important for us to have brief of overview of electrical motor particularly in this project, a DC geared brushed motor with quadrature encoder is used as the actuator of the robotic gripper.

To understand what builds up the driving force of the motor, in its principle as stated in Faraday's law, any change in the magnetic environment of a coil of wire will cause a voltage (emf) to be "induced" in the coil. The theory is explained when generators are able to produce voltage through mechanical energy to electrical energy conversion. Motors operate exactly in reverse of generators where electrical energy is converted to mechanical energy and used to manipulate mechanical part attached to the motor shaft. In motors, magnetic field created by permanent magnets in the stator interacts with current that is fed into the armature winding. The armature starts to rotate when the interaction between two magnetic fields occurs. In this project, a quadrature encoder is mounted at the rear shaft of the DC motor. The working principle and overview of motor is discussed as follow.

A motor encoder is an electrical mechanical device mounted to an electric motor that provides closed loop feedback signals by tracking the speed and/or position of a motor shaft.

A wide variety of motor encoder configurations such as incremental or absolute, optical or magnetic, shafted or hub/hollow shaft are available for different applications. Selection of motor encoder that will be utilized in desired application is dependent generally a few factors such as motor type, the application requiring closed-loop feedback, and the mounting configuration required.

Robotic gripper has been one of the most promising tools utilized by the emerging fast-paced competitive manufacturing industries in performing task that human bare hands can hardly carry out in terms of repeatability and precision handling [6]. A gripper coupled with microcontroller for position control will be developed, with carefully designed position control algorithm. Intelligent controller will be designed to control DC motor with encoder via Arduino microcontroller.

1.2 Problem Statements

This project primarily aimed to integrate a gripper mechanism that is able to manipulate object in production line for object shaping and pick-and-place function without causing damage to the object or to meet its performance requirement in terms of its functionality and flexibility. Type of gripper that will be deployed is to be highlighted as different functionality in terms of degree of freedom (DOF) and type of motor gives different level of performance. The mechanical design of the robotic gripper will decide its gripping capability and fundamental success of using an automated solution.

Mass production in assembly line of product requires not only the flexibility of the robotic manipulator but also its accuracy and efficiency of completing task. Therefore, design of controller will be the main challenge in accordance to the control target, such as position control, force control, stiffness control or compliance control. In this context, effect of noise and disturbance from environment or from mechanical part might affect the motor desired position and hence affects the performance of gripper in term of accuracy. Position control in this project focuses on DC motor and its position feedback encoder using a suitable controller.

In this project, the construction of the gripper mechanism consists of a metallic gripper module, a DC motor with encoder, mounted with a flange couple 3D printed with the help of computer aided design (CAD) software. The measured value from the DC motor encoder will be fed to the controller for position adjustment. Control parameters are to be determined in order to minimize the deviation of output value from its set point value.

1.3 Objectives

The objectives of this project are:

1. To design and fabricate a robotic gripper mechanism with single degree-of-freedom (DOF) gripper coupled with DC geared brushed encoder motor using 3D printed parts.

2. To design and compare the controller for position control of gripper mechanism using step inputs.

3. To evaluate the performance of chosen controller under different testing environment and trajectory motion.

1.4 Scope of the Project

This project will only deploy a single DOF robotic gripper with a total weight of the mechanism not exceeding 1kg. A higher weight of gripper would not be ideal for installation at the end of robot arm. On the other hand, this project will only focus on position control of robot gripper by manipulating the rotation of motor linked to the coupling attached to the gripper jaws. Position control of the gripper is achieved through commands from Arduino microcontroller tested through different types of controller and trajectory motion. Robot gripper deployed in this project is a simple gripper with two jaws linked to a flange couple that are driven by DC motor with incremental encoder mounted at rear shaft of the motor as feedback sensor. Maximum turning angle of robotic gripper does not exceed 65˚ from original closed position. This is corresponding to the maximum gripping length of not exceeding 55mm measured from original closed position.

CHAPTER 2

LITERATURE REVIEW

2.1 Organization of the Report

This chapter will present the theory and concept of the project in a more detailed structure which the discussion will be divided into several sub-chapters. The past studies that will be reviewed includes mechanism or mechanical design of robotic gripper which emphasizes on DOF, type and number of jaws/fingers, type of controller that will be utilized in controlling motor, design and optimization method used and field of applications of robotic gripper. Literature review is essential in this project as it provides a wide range of past reference from sources such as reference book, thesis, journal article, review paper, and also online materials that enlighten the path of searching best solution for this project.

2.2 Mechanical Design and Fabrication

2.2.1 Gripper Jaw Design

A. Krishnaraju et al. [6] designed a three fingered robot mechanism which aims to achieve various functionality in moving objects where it claims to be having higher gripper ratio. Gripper ratio is calculated by dividing maximum pay load in kilogram by the gripper weight. Therefore, we can observe the effect of the type of gripper mechanism, the driving power source and gripper opening and grip structure on the gripper ratio that a gripper module may have. The mechanism highlighted the design criteria which are kinematic structure selection, DOF calculation, skeleton material selection and dimensioning through torque requirements. In terms of performance, gripper force can be evaluated by multiplying applied force and the coefficient of friction. The gripper is designed to open about an angle of 28˚ when actuated using a servo motor of 12V which turns 90˚ in either direction, which gives a total of 180˚ movement. On the other hand, load carrying capacity may differs due to the robot application nature.

Zhang, Tao et al. [7] suggested a gripper jaws based on trapezoidal modules as in Figure 2.1 where the gripper jaws are capable of guiding the part into alignment and achieve the maximal linear contact with the part at its desired orientation. A numerical algorithm is developed based on enumeration on feasible design that exploits part geometry. The algorithm provided location of contacts, pushing, toppling, jamming and liftoff constraints. The form-closure grasp is optimal by measuring its total contacting length. The orientation of the trapezoidal gripper jaw is tested for assembly and found that it is at $\theta = 25^{\circ}$ while the analysis yields the optimal jaw design of L= 16.2cm. Future objectives are set to validate the modular jaws design performance in terms of mass distribution, friction, shape variation and its reliability.

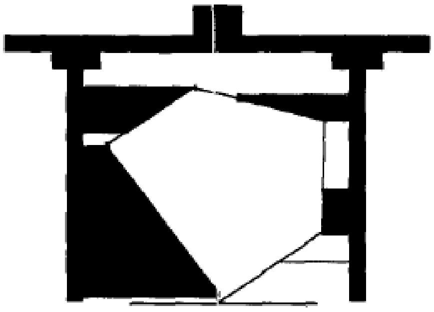

Figure 2.1 An example of optimal trapezoidal jaw design

Manz, Marc et al. [8] have worked extra miles in increasing dynamic payload capacity by implementing a gripper reflex mechanism. They developed a self-adaptive two-fingered robotic gripper that is capable of gripping parallel and non-parallel surface objects. A single motor is utilized in actuating the sampling system which consists of two fingers while the actuator is comprised of a BLDC external rotor motor and a strain wave gear. Tendon mechanism helped to distribute the operating power of this actuator to the fingers. This design of kinematics allows a stiff gripping characteristic for objects with parallel gripping surfaces and a self-adaptive gripping characteristic for non-parallel surfaced object. This design enables gripper to manipulate small objects and even objects that are bigger than the gripper itself and henceforth it is capable to grab objects at a position that is out of its center of mass.

W. Chen et al. [9] proposed a new flexure-based dual-axis compliant gripper that is driven by two piezoelectric actuator (PEAs). The gripper is developed with an asymmetric structure which can be divided into two parts each one of left and right parts and that made it into a 2 DOF micromanipulation for achieving grasping and rotating purposes. This is achieved when the left part generates lateral motion at the left jaw to grip a micro-object, while the right part produced vertical motion at the right jaw to rotate the micro-object. Pseudo-rigid-body model method is utilized in modelling the flexure-based compliant mechanisms. Both the gripping force and jaw's position are measured by three groups of calibrated strain gage sensors.

Early work on humanoid hand can be seen through the design and development of DIST-hand Dextrous gripper presented by Caffaz, Andrea et al. [10]. It is a 4-fingered 16 DOF tendon driven device. Each finger has 4 links connected by 4 joints that has rotation angle of greater 90 degrees which is very similar to human hands. The actuation of each finger involves 6 tendons made of polyester, routed through pulleys and driven by 5 DC motors. Ad Hoc rotation sensor is mounted on each joint to resolve the problem of controlling finger's motion using position and velocity feedback directly from the motor axes. The sensor is based on the use of solid-state Hall effect transducer which is contactless to the joint and significantly immune to noise.

It is extremely difficult and not cost-friendly for a robotic gripper especially when a multi-fingered humanoid hand is to be developed when it goes to general uses or educational purposes. Telegenov, Kuat et al. [11] developed an open source 3D printed 3-finger gripper platform that can fulfill the mentioned purposes. The underactuated fingers that are utilizing pulley and tendon driven mechanism which is light and inexpensive as well as high degree of adaptability but also on the contrary has low load capacity and wear resistance. Therefore, in this solution the researchers have proposed a mechanical linkage system and gear train transmission system as a substitute to the conventional pulley/tendon system as shown in Figure 2.2 below.

Figure 2.2 Worm wheel arrangement connecting to actuating worm in 3D view

2.2.2 Soft Robotic Gripper

Soft robotic grippers have been greatly deployed due to its ability to grasp and manipulate a wide range of objects. Elastomer is the most-widely utilized material in soft robotic grippers thanks to its large strains. Soft gripping can generally be categorized into three major categories which are actuation, controlled stiffness and controlled adhesion. However, there are some drawbacks in soft robotic gripper which
are the challenges in miniaturization, lack of long term robustness, speed, and integration of sensing and control [12].

Modabberifar, Mehdi et al. [13] on the other hand introduced a gecko-inspired gripper using shape memory alloy for grasping flat surfaced objects. The gripper presented by the team claimed to be lighter in weight, cheaper, simpler and smaller without affecting the ability to maintain its adhesive pressure. This design uses a set of three opposing gecko-like adhesive pad actuated by SMA wire that are robust to the moments around the X and Y axes. The adhesive pad moves horizontally toward the gripper's center by a rapid contraction of the SMA wire. However, experiments on relationship between input voltage and shear and normal adhesion force revealed that the gripper has relatively low efficiency and demands a relatively large time interval for the subsequent SMA wire grasps to return to its original position.

Haibin, Yin et al. [14] also established a shape-memory-alloy made force grasping model for soft robotic gripper but focuses on variable stiffness. Embedded sets of SMA fibers in a variable stiffness mechanism was developed. Biology-inspired gripper where ideas are adapted from octopus's leg, elephant trunk usually exhibit a safer and more compliance control characteristics compared to rigid gripper that may exhibit precise positioning using different control strategies and algorithm. Series of conducted tests and experiments showed that grasping force is highly related to the stiffness and to the object's offset and coefficient of friction. The grasping force of the soft robotic gripper strengthen by a marked 48.7% when the Young's modulus of the SMA-2 wires elevated by 52%.

Reddy, P.V. Prasad et al. [15] commented on the ability of a universal gripper where the current industrial deployment of grippers are all highly specially designed by the industry for specific tasks. A robotic gripper is very much limited compared to human hand in terms of its mechanical complexity, practical utility and dynamic flexibility. Multi-fingered hand comprises of high complexity of high number of mechanical joints that might require force sensing or visual feedback in order to manipulate objects securely. On the other hand, universal gripper that consists of a single mass of granular material actuated pneumatically has great capability of grasping a wide variety of objects without any closed-loop feedback system.