UNIVERSITI PUTRA MALAYSIA

GRIPPING CONTROLLER DESIGN FOR A ONE-DEGREE-OF-FREEDOM ROBOTIC HAND MODEL BASED ON SLIP DETECTION

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By

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

January 2016

DEDICATIONS

Throughout my life one couple has always been there during those difficult and trying times. This thesis is dedicated to my parents, who taught me the value of education and who made sacrifices for us, their children, so that we could have the opportunities they did not have. They always give me an incentive which conquers the desperation and illuminates my path among the harsh life realities. I also dedicate this dissertation to my friends who have supported me throughout the process.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

GRIPPING CONTROLLER DESIGN FOR A ONE-DEGREE-OF-FREEDOM ROBOTIC HAND MODEL BASED ON SLIP DETECTION

By

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January 2016

Chairman: Siti Anom Binti Ahmad, PhD
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Robotic hands are considered mechatronic instruments that have the ability to perform activities beyond human capabilities. Robotic hands are widely used in manufacturing and dangerous nuclear industries as well as in precise applications, such as military or medical implementations. Repetitive and maintenance tasks are achieved with high accuracy when robotic hands are used. Consequently, the evolution of robotic hands is necessary to cover a wide range of tasks and by adding sensors, the grasping force can be measured and detected when the object slips. Measuring the grasping force between the robotic hand and an object can be achieved by using Force-Sensing Resistor (FSR), which have been widely used in robotics applications. Although this type of sensor has good features to handle different objects, the robotic hands that are currently using this sensor have never mentioned the object slipping feature during grasping operation. Slip sensing is significant in advance robotic manipulation. Therefore, this research has paid attention in the slipping detection process that occurs after gripping operation as well as the re-gripping of the object. The proposed work focuses on detecting the slip of the object and measuring the features of this slippage, such as distance and velocity. In this study, the robotic hand model employs an accelerometer sensor to detect the acceleration signal of the object during slippage. Furthermore, a common type of rotary encoder device is used to measure the distance of the slipping situation and velocity. A circuit is designed and implemented to collect the data of the sensors that would be analyzed. The robotic hand system comprises a new algorithm for data extraction and signal processing analysis that are measured from an object re-gripping operation based on slip detection information. The experimental works have concentrated on gripping an object with different weights (from 0.4118 N to 3.187 N) and detecting the slip situation to securely re-grip the object. The empirical findings have presented the output voltage of the FSR is directly proportional to the weight of the object, the minimum and maximum measured voltage are 0.209 V and 2.093 V respectively. In addition, the experimental results determine the subsequent re-gripping control

mission based on slip events. The control system of an object re-gripping task is represented in Hooke's Law that estimates the required re-gripping force based on the distance of the object has slipped. The K values for accelerometer and rotary encoder are 0.0535±0.028 and 0.056±0.01 respectively. This conclude that the rotary encoder is better for slip detection in this robotic hand model.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKABENTUK KAWALAN GENGGAMAN UNTUK TANGAN ROBOTIK MODEL SATU-DARJAH-KEBEBASAN BERDASARKAN PENGESANAN GELINCIR

Oleh

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Tangan robotik dianggap sebagai suatu instrumen mekatronik yang berkeupayaan untuk melaksanakan aktiviti-aktiviti di luar kemampuan manusia. Tangan robot digunakan secara meluas dalam sektor pembuatan dan merbahaya seperti industri nuklear dan juga dalam aplikasi tepat, seperti bidang ketenteraan atau perubatan. Pengunaan tangan robotik membolehkan tugas-tugas penyelenggaraan dan berulang mencapai ketepatan yang tinggi. Oleh yang demikian, evolusi tangan robot adalah perlu untuk menampung pelbagai tugas dan dengan menambah pengesan, daya genggaman boleh diukur dan dikesan apabila objek tergelincir. Mengukur daya genggaman antara tangan robot dan objek dapat dicapai dengan menggunakan Force-Sensing Resistor (FSR), yang telah digunakan secara meluas dalam aplikasi robotik. Walaupun pengesan jenis ini mempunyai ciri-ciri yang baik untuk mengendalikan objek yang berbeza, tangan robotik yang sedang menggunakan pengesan ini tidak merangkumi ciri gelincir semasa operasi menggenggam objek. Pengesan gelincir adalah penting dalam bidang manipulasi robot maju. Sehubungan dengan itu, kajian ini memberi tumpuan kepada proses pengesanan gelincir yang berlaku selepas operasi menggenggam serta menggenggam semula objek. Kerja yang dicadangkan itu memberi tumpuan kepada mengesan apabila objek tergelincir dan mengukur ciri-ciri gelinciran ini, seperti jarak dan halaju. Dalam kajian ini, model tangan robot menggunakan meter pecut untuk mengesan isyarat pecutan objek semasa tergelincir. Untuk tambahan, peranti pengekod putar digunakan untuk mengukur jarak keadaan tergelincir dan halaju. Litar direka dan dilaksanakan untuk mengumpul data sensor yang akan dianalisis. Sistem tangan robot terdiri daripada algoritma baru untuk pengekstrakan data dan analisis pemprosesan isyarat yang diukur dari objek operasi semula menggenggam berdasarkan maklumat pengesanan slip. Kerja-kerja eksperimen telah tertumpu pada menggenggam objek dengan berat yang berbeza (dari 0.4118 N kepada 3.187 N) dan mengesan keadaan slip untuk selamat semula cengkaman objek. Hasil kajian empirikal menunjukkan voltan keluaran daripada FSR adalah berkadar terus dengan berat objek, dimana voltan minimum dan maksimum yang diukur adalah

0.209 V dan 2.093 V. Di samping itu, keputusan eksperimen menunjukkan misi kawalan-menggenggam semula berdasarkan keadaan tergelincir. Sistem kawalan untuk menggenggam semula objek diwakili dalam Hukum Hooke yang menganggarkan daya-menggenggam semula yang diperlukan berdasarkan kepada jarak objek yang telah tergelincir. Nilai K untuk pemecut dan pengekod putar adalah 0.0535±0.028 dan 0.056±0.01 masing-masing. Sebagai kesimpulan, pengekod putar adalah lebih baik untuk mengesan gelinciran dalam model tangan robot ini.

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I certify that a Thesis Examination Committee has met on 29 January 2016 to conduct the final examination of Abdulrahman Abdulkareem Sattoori Al-Shanoon on his thesis entitled "Gripping Controller Design for a One-Degree-of-Freedom Robotic Hand Model Based on Slip Detection" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

IC	Integrated Circuit
SCARA	Self-Compliance Automatic Robotic Arm
MCU	Microcontroller
IR	Infrared Sensor
DC	Direct current
DOF	Degree Of Freedom
MEMS	Microelectromechanical systems
PE sensor	Piezoelectric sensor
PWM	Pulse Width Modulation
FSR	Force Sensing Resistor
PCB	Printed Circuit Board
avg	Average
sum	Summation
max	Maximum
R^2	Residual
SD	Standard deviation

CHAPTER 1

INTRODUCTION

1.1 Introduction

The human hand is an essential organ of the body. The hands are created with tremendous structure and exact capability and have adequate ability to perform maneuver motions and accomplish complex actions [1, 2, 3, 4]. However, the human hand still has some limitations in terms of execution of tasks such as dangerous or sophisticated operations in military and medical applications. In addition, the high probability of errors could take place in repetitive and maintenance tasks because the human hand is restricted by limited human ability.

Thus, in recent years, significant efforts have been devoted to improve robotic manipulators, such as robotic hand or robotic claw. Robotic hands have begun to become indispensable, especially because they have been broadly implemented in significant applications [5, 6]. Robotic hands are widely used in automotive manufacturing industries, such as in pick-and-place, sorting, packaging, and palletizing, as well as in assembly and material handling production lines, substituting human hands [7, 8, 9].

Grasping objects could be achieved by using dexterous robotic hands, as presented in [10], to grasp both pliable and rigid objects. In [11] and [12], gripping operations have been implemented by robotic hands that use special types of tactile sensors that employ physical properties and events through contact with objects. Many tactile sensors have been developed, and the sensor hardware has evolved to achieve certain gripping tasks. To accomplish gripping mechanism by using robotic hands, efforts have been expended to develop tactile pressure sensor structures, such as those in [13] and [14]. In most recent studies, advanced robotic manipulations have used tactile pressure sensors that have been implemented in different applications. The interesting issue in advanced robotic manipulation tasks is that robotic hands have to be equipped with distributed tactile pressure sensors that can continuously provide information about the magnitude and direction of forces at all contact points between the sensing area and the subjected object. Numerous studies have proposed methods that use tactile sensor information through physical contact between the sensor and the object to detect both pressure force and the hardness of an object [15]. In addition, several studies have documented that tactile pressure sensors have been successfully utilized in different design concepts and action principles. Those tactile sensors have presented the process of determining physical features with the environment [16, 17], measuring the applied forces exerted over an object and the art in tactile sensing, as well as investigating the trends [18, 19, 20].

One of the well-known tactile sensors is Force-Sensing Resistor (FSR), that is also called piezoresistive sensor, which has been frequently used in robotics gripping implementations, such as gripping an object with different weights and shapes [21, 22, 23]. A key aspect of pressure sensors is that they have the ability to indicate the touch situation or continuous pressure force that occurs between the subjected object and pressure sensor. This indication happens according to the changing of FSR resistance corresponding with the applied force. However, one of the main obstacles is that FSR does not provide information of the slipping of the gripped object. Thus, robotic hands that use FSR still have some defects in terms of gripping operation. In other words, the current robotic hands have not introduced the slipping information during the gripping operation. At the same time, none has mentioned the algorithm of re-gripping the object after slip situation is detected. Subsequently, the current gripping operation is not reliable, and attention has not been paid to slipping detection. Pieces of evidence presented thus far support the significance of detecting slips.

1.2 Problem Statement

Grasp planning is an interesting issue in studies that have dedicated efforts by using tactile explorations [24, 25]. Successful robotic grasping operation is required to solve the well-known problem in intelligent robotic hands, that is, slip detection; otherwise, stable grasps will not be achieved. Grasping operation has been achieved in [26] and [27] with different weight measurements, but nothing has been addressed about the slip situation of subjected objects. In addition, grasping operations fail when the object's weight is increased during the particular grasping operation.

Another motivation to tackle these weaknesses is slippage features, such as distance and velocity. These features have to be estimated to develop the intelligent robotic hand. Slippage features should not be ignored or be ambiguous, as safely gripping an object is the priority of this research. Hence, continued efforts are needed to focus on slip detection.

In this study, these weaknesses have been treated by designing and implementing a new approach to the robotic hand model that has the ability to manipulate the slip situation. This ability is lacking in current robotic hands. In this research, acceleration information that occurs when the object begins to slip is estimated by using an accelerometer sensor. In addition, the proposed work uses a rotary encoder device to evaluate the distance of the object slipping and velocity. The data of sensors have been utilized to deter the continuity of the object slippage.

The study aims to develop robotic hand system using rotary encoder for re-gripping operation based on slip detection. The proposed algorithm in this research was prepared to interface between the sensors: FSR, IR, accelerometer, rotary encoder, and microcontroller system that receive data and analyze them accordingly.

1.3 Objectives

In this research, the proposed work focuses on applying an approach of gripping an object with different weights based on slip detection. The research objectives are as follows:

1- To develop a robotic hand model system for gripping an object with different weights based on slip detection.

2- To determine the slip detection and acceleration features; distance and velocity, to securely re-grip the object.

3- To develop an automatic feedback gripping algorithm to achieve a reliable robotic hand system.

1.4 Scope and Limitations

The main goal of this research is design a robotic hand model and develop its ability for gripping an object with different weights based on the slip detection. Along with, the simplicity and uncomplicated traits are found in this research. Notwithstanding the following limitations, the objectives of this research have been achieved properly. The robotic hand has been designed and assembled in dimensions (100 $\times$205$\times$ 215 mm). The robotic hand consist of only one claw, the maximum open dimension is (60 mm). This claw can be moved by using D.C servo motor within only one degree of freedom (DOF) in X-axis. The robotic hand can hold weight up to (3.187 N). In this study, the flat rectangular object has been taken as a sample to be gripped. The weight and dimensions of this object are 42 g (0.4118 N) and (84 $\times$ 17 $\times$ 130 mm) respectively. Definitely, the dimension of the object should be larger than the claw of robotic hand model to ensure that the object covers the entire sensing area of the pressure sensor that is attached on this claw.

Two tactile pressure sensors (FSR) are used at both sides of robotic claw for measuring the continuous gripping force that is produced between the robotic hand and object. This sensor works with diverse force range, regarding to the proposed design the force range is (0-111 N). The sensing area of (FSR) is (25.4 mm) in diameter and the thickness is (0.203 mm).

In addition, rotary encoder device is considered as a high accuracy instrumentation that is used for measuring distance and velocity. This device produces (500) pulse per rotation. The diameter of roller which has been attached on the shaft of encoder is (5.2cm). Along with, an accelerometer sensor is used to measure the acceleration force of slip situation with a minimum full-scale range of $\pm$ 3 g. Furthermore, IR sensor plays an important role in the motion of robotic hand, is used for detecting the existence of the object between the robotic hand claws in order to provide the system with automatic robotic motion.

The Micro-Controller Unit (MCU) is Arduino Uno R3. This MCU has been chosen with respect to the following purposes which are ADC, motor driver, Pulse Width Modulation signals (PWM), digital In/out pins, analog input pins, available at low cost, and the good compatibility with external components. The Integrated

Circuit (IC) that has been implemented in MCU is ATmega328. Moreover, in this study the Printed Circuit Board (PCB) has been designed and implemented utilizing electronic components that have high quality performance as well as low power consumption. These circuits are used in order to obtain the purposes of experimental works that are gripping the object, detecting the slip situation, and re-gripping the object again based on slip detection.

1.5 Thesis Layout

This research comprises of five chapters. The first one gives an introductory overview about the robotic hand applications and brief information about the importance of developing the robotic hand. In this chapter, the problem statement has argued the weaknesses in current robotic hands and the consequences about these weaknesses. In addition, it has been suggested an alternative method in order to figure out the weaknesses and treat the issue that was not addressed in the current robotic hands. After that, the main research objectives are mentioned obviously as well as the scope and limitations in order to achieve the research destination. Finally, thesis layout is presented as the last section in this chapter.

The second chapter introduces the literature review related to this study. This chapter explains the information about tactile pressure sensors that have been widely used in different applications in order to measure the pressure force between the particular object and robotic hand. After that, many types of robotic hands are presented in this chapter. Then, the chapter focuses on the mechanisms of slip and slip detection sensors. Eventually, accelerometer operation and design have presented in this chapter. The proposed methodology in this research is presented in the third chapter. The first section in this chapter presents the proposed robotic hand model and the experimental setup requirements. Then, the operation of the proposed robotic hand model and signal processing and data extraction for gripping the object are illustrated. After that, the next section demonstrates the slip detection, the proposed algorithm of slip detection, data extraction and signal processing, and re-gripping control system based on slip detection.

In fourth chapter, the empirical findings of gripping an object and slip detection have been analyzed and discussed. In addition, it has been compared between the experimental results of gripping an object and experimental results of the object slipping and re-gripping again.

Eventually, the last chapter concludes the concise information about the whole results that have been extracted from gripping an object and slip situation. In this chapter, the results obtained from the re-gripping analysis based on slip detection are summarized. Furthermore, the recommendations are presented in fifth chapter based on the norms of this research.

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