UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

FORCE AND POSITION BASED HAPTIC BILATERAL CONTROL SYSTEM FOR SINGLE JOINT ROBOTIC ARMS

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

I declare that this thesis entitled "Force and Position Based Haptic Bilateral Control System for Single Joint Robotic Arms" 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 read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechatronics Engineering.

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Supervisor Name	:	Dr. Muhammad Herman bin Jamaluddin
Date	:	…………………..……………………..

DEDICATION

To my beloved family members; Mama, Baba, Makda, Dad, Mummy, Mima, Aqeela, Najmee, Ifnee, Raudha and my best friends; Aini and Hisham.

ABSTRACT

Haptics applying manipulation of touch sensation with the interaction of computer applications, machines or human touch. However, robots that used haptics' movement control are set up in lab-range and undevoted to works in substantial way particularly because of size factor and limited workspace. Majority of invented robot cannot recognize the surfaces textures on the object that they are handling. Application of the common force sensors have a lot of limitations and handicap to the system. There are some uncertainties, instability and delay occurred in the system. This research embarks to design a model of bilateral master-slave haptic system and simulate with controllers of Proportional (P), Proportional-Derivative (PD) and Proportional-Integral-Derivative (PID) also implementation of Disturbance Observer (DOB) and Reaction Force Observer (RFOB). Next, analyze the ability and performance of the proposed controller in terms of position and force reading on single joint. To cut cost and duration, a small, commercial industrial robot is used as mechanism to work with haptic bilateral control system. Additionally, DOB and RFOB managed to transmit vivid force sensation by rejecting disturbance force and attain a robust motion control. Literally, the system is required to adjust according to the target position and compensate the forces earn from surrounding. Observation and study on the feedback of new adaptive design method DOB and RFOB is presented to compare with the conventional controller P, PD, and PID inside a bilateral control system. The performances of the proposed design are measured inside a simulation platform. From experiments, results signified that K_p=5, K_d=0.1 is the best value for PD and K_p=5, K_i=0.001, K_d=0.1 for PID. System employed with observers are more accurate and faster when ω_n=50 for Differential Mode and ω_n=500 for Common Mode. Apart from that, this research is potential to be apply on surgical robots or manufacturing for industry.

ABSTRAK

Haptik menggunakan manipulasi dalam sesuatu bentuk sentuhan kepada interaksi komputer, mesin mahupun sentuhan manusia. Walau bagaimanapun, robot yang menggunakan kawalan gerakan haptik biasanya diuji hanya di dalam makmal dan tidak bertumpu dalam tugas yang lebih penting disebabkan faktor saiznya dan ruang kerja yang terhad. Majoriti robot yang telah dicipta tidak mampu mengenalpasti tekstur permukaan bagi sesuatu objek yang dipegang. Aplikasi sensor daya mempunyai banyak had keupayaan dan kekurangan dalam sistem. Ini disebabkan terdapat ketidakpastian, ketidakstabilan dan kelewatan berlaku dalam sistemnya. Kajian ini dimulakan dengan merekabentuk model kawalan Tuan-Hamba untuk sistem haptik dua hala dan simulasi dengan kawalan Berkadaran (P), kawalan Terbitan Berkadaran (PD) dan kawalan Terbitan Kamilan Berkadaran (PID) juga pelaksanaan Pemerhati Gangguan (DOB) dan Pemerhati Daya Tindak Balas (RFOB). Berikutnya, menganalisis keupayaan dan menilai prestasi bagi kaedah yang dicadangkan dari segi bacaan kedudukan dan daya dari sendi tunggal robot. Untuk menjimatkan kos dan masa, robot industri yang komersial, kecil, digunakan sebagai mekanisme untuk bekerja dengan sistem kawalan haptik dua hala. Tambahan, DOB and RFOB mengendalikan kuasa yang lebih jelas dengan menyingkirkan gangguan dan mendapat kawalan gerakan yang lebih teguh. Harfiahnya, sistem ini perlu melaras berdasarkan sasaran kedudukan dan mengimbangi daya yang diterima dari persekitaran. Tinjauan dan kajian yang dilakukan untuk tindak balas reka bentuk suaian baru ini dibincangkan untuk membandingkan pengawal P, PD dan PID yang lazim didalam sistem kawalan. Prestasi untuk cadangan reka bentuk telah diukur didalam platform simulasi. Dari eksperimen, hasil menunjukkan K_p*=5,* K_d*=0.1 ialah nilai terbaik untuk PID dan* K_p*=5,* K_i*=0.001,* K_d*=0.1 untuk PID. Sistem yang menggunakan pemerhati lebih tepat dan pantas apabila nilai untuk mod pembezaan,* ω_n*=50 dan mod biasa,* ω_n*=500. Selain itu, penyelidikan ini berpotensi untuk digunakan pada robot pembedahan atau industri pembuatan.*

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LIST OF ABBREVIATIONS

3D	-	3-Dimension
API	-	Application Programming Interface
CAD/CAE	-	Computer Aided Design/Computer Aided Engineering
CT	-	Computed Tomography
DOB	-	Disturbance Observer
DOF	-	Degree of Freedom
EMG	-	Electromyography
fMRI	-	Functional Magnetic Resonance Imaging
IFR	-	International Federation of Robotics
IoT	-	Internet of Things
IR 4.0	-	Industrial Revolution 4.0
LPF	-	Low Pass Filters
MIS	-	Minimally Invasive Surgery
MM	-	Markov Models
MRI	-	Magnetic Resonance Imaging
P	-	Proportional
PAMV	-	Power-Assisted Mobile Vehicle
PD	-	Proportional Derivative
PID	-	Proportional Integrate Derivative
PM	-	Permanence Magnet
RFOB	-	Reaction Force Observer
TCSCR	-	Teleoperation Control System of Construction Robot
VR	-	Virtual Reality

LIST OF SYMBOLS

H	-	Hadamard transformation
C_f	-	Force controller
cmd	-	Command value
cmp	-	Compensation value
C_p	-	Position controller
D	-	Viscous friction factor
F_{com}	-	Total force
F_{dis}	-	Disturbance force
F_{ext}	-	External force
F_{fric}	-	Friction force
F_{int}	-	Interactive force
g	-	Cut-off frequency
G_r	-	Gear ratio
I_a	-	Torque electric current
I_{cmp}	-	Compensation current
I_{cmp}	-	Compensating current
J_m	-	Inertia of the motor shaft
K_d	-	Derivative term
K_f	-	Force coefficients
K_i	-	Integral term
K_p	-	Position coefficients/Proportional term
K_t	-	Torque constant
K_v	-	Velocity coefficients

m	-	Master system
M	-	Mass
n	-	Nominal value
ref	-	Reference value
res	-	Response value
s	-	Slave system
T_{dis} / T_{ref}	-	Motor torque
t_{fm} / t_{fs}	-	Final time taken for master / slave robot
t_{im} / t_{is}	-	Initial time taken for master / slave robot
T_m / T_s	-	Torque of master / slave manipulator
X	-	Position
$\ddot{x}_{dif}$	-	Total acceleration
x_m / y_m	-	Initial position for master / slave robot
y_m / y_s	-	Final position for master / slave robot
Z_c	-	Impedance of environment
θ_{cmd}	-	Command angle of motor rotation
θ_{res}	-	Respond angle of motor rotation
ξ	-	Damping ratio
ω_n	-	Natural frequency

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CHAPTER 1

INTRODUCTION

1.1 Overview

In robotic technology, haptic system is recognized to be a medium that can emulate force sensation to user from a real environment. This system refers to the application and manipulation of touch (tactile) sensation to the interaction with computer applications or human touch. In this new century, haptics has started to include human-machine/robot interactions and the environments can be real, virtual or teleoperated. Consequently, various area of sciences such as biomechanics, neurosciences, robotic surgery, psychology, robotics design and control, mathematical simulation and other engineering fields has congregated to explore and evolve with haptics.

Generally, haptic system can be in synchronous and asynchronous multilateral control for walking motion. On the other hand, haptic information can be transmitted into two directions which are unilateral and bilateral. Unilateral system is a transmission of information in one direction only without giving any feedback such as sight and hearing, while bilateral system is a transmission of information comprising action and reaction from real environment contact. For a general haptic controller, a disturbance observer (DOB) is implemented for the transmission of vivid force sensation in motion control because it has wider bandwidth than force sensor. DOB is able to make sampling brief and at same time increase the observer gain (Jamaluddin et. al, 2014). Some instance of bilateral haptic system is telerobotic and video games simulators that uses concept of master and slave to achieve same interaction via disturbance observer (DOB) and also reaction force observer

(RFOB). DOB is implemented as an acceleration control while RFOB is able to estimate value of external force from environment.

1.2 Motivation

Bilateral master-slave industrial robotic arm manipulator system is an advanced technology used to help human to interact with environments that are unreachable to human, due to its remoteness or hazardous. This system has been used in different areas such as telesurgery, autonomous teleoperation for sea and space operation and handling explosive or high radiation operation fields. It is beneficial both for science and society. Commonly, researchers need to build a new model of robot to carry out the work. This needs a longer time, hardwork and money for working on a new prototype of robot. The robot also usually works in lab-scale setup and not devoted to work in substantial way. Alternatively, industrial robot is able to automate and manoeuvre the daily job tasks. Moreover, they are sturdy, programmable and capable of movement on three or more axes. Some robots are mobile and easy to be handled. Hence, two similar youBot manufactured by Keller Und Knappich Augsburg (KUKA) company are preferred as the mechanism for modelling a bilateral master and slave control system.

Inspired by the concept and the perks of applying DOB and RFOB into a system, the application of DOB and RFOB is expected to improve the feedback of bilateral haptic inside the system. By doing so, the study of the system performance in terms of force and position control can be improved. The integrated system is also able to distinguish between different range of external and internal forces as well as manipulation of touch sensory.

1.3 Problem statements

In engineering process, most of machines and controller are not 100% accurate and precise. There must be an error or glitch happens during the operation. The productivity and quality of the outcome product could be affected too. This happened when there is instability, slow processing or delay on information carried inside the control system. In this matter, these issues can happen on a bilateral control system although the transmission of data afford to be in two way of direction and the system able to reflect the feedback to another sub-system and vice versa.

On the other part, every closed-loop control system makes use of feedback and adapt to certain circumstances to some extent. The feedback loop ensures a control action to control a process variable at the same value as the set point. Nonetheless, the feedback experiences noise and time delay from various sources. This problem happens in haptic system too. It is difficult and tricky to follow the object and at the same time perform the manipulation task when the object has different texture and rigidity. For instance, the cardiac surgery requires the da Vinci robot to adapt with the heartbeat pattern of the patient to avoid wrong incisions especially on the narrow vessels.

Remarkably, industrial robot technology has been associated with manufacturing and product inspection. They can assist for material handling with high endurance, speed and precision. However, in operation of industrial robot worldwide, they have some major drawbacks. The robot cannot recognize and identify the surfaces textures on the object that they are handling. The applied pressure in contact with the object sometimes might be too high or too low. When it is too high, the object could be deformed or broken and when it is too low, the object might drop. This is the part that we need to take into account.

From the past studies made by researchers all over the world, there is technical limitations on the previous methods. The approaches are engaged on improving the control system itself with a readymade and simple equipment such as keyboard, joystick, data glove and simple manipulator link. Many of them did not applying the DOB and RFOB techniques on a real industrial robot arm. It is impractical and waste for not implementing these techniques as DOB and RFOB have been provenly good to improve reactions on control system in numerous past studies. The integration of force control and position control to the robotic arm bilateral system should be given preference to find the disparity and novelty between the common, smaller device comparing to industrial robotic arm.

With all that said, an approach to design a bilateral control system to apply on industrial robot is necessary. Since 1980, haptic technology evolved and has been performed by many researchers to investigate about its control system, communication and applications. Studies in DOB and RFOB in last 4 decades shows that control action and the feedback inside a haptic system can be enhanced up to 90% in accuracy in compare to the common system without DOB and RFOB which suffers about 25% to reach the desired value. The effectiveness after the implementation of DOB and RFOB helps the infallibility of control process in identical time. Hence, the consideration of applying the DOB and RFOB technique in the designed system, should be given priority.

Moreover, study on development of bilateral control system with force control and position control on industrial robotic arm are not common in our country. The implementation of bilateral manipulator control system in industrial robot is perceived to be useful in the imminent industry and the development over country and human life, specifically for production yield and human operator. Furthermore, the devised method helps in the navigation and manipulation task of moving objects. The system will be able to adjust and perform accordingly on the movement of the target and structure of object surface before handling the job in actual time.