Faculty of Electrical Engineering

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DEVELOPMENT OF BILATERAL MASTER-SLAVE TELEROBOTIC ARM MANIPULATOR SYSTEM

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Bachelor of Mechatronics Engineering with Honours

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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 Bachelor Degree of Mechatronic Engineering.

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A report is submitted in partial fulfilment of requirements for the
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DECLARATION

I declare that this thesis entitle "DEVELOPMENT OF BILATERAL MASTER-SLAVE TELEROBOTIC ARM MANIPULATOR SYSTEM" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
Name	:	....
Date	:	....

DEDICATION

To my beloved lovely family

Thank you for your unconditional love and spiritual support.

Yours sacrifices and loves have helped me in accomplish this achievement.

Dear supervisor and lecturers

Thank you for your support, helping, knowledge and guidance.

Dear friends

Thank you for your encouragment, support, and selflessness sharing.

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ABSTRACT

Bilateral master-slave telerobotic arm manipulator system is an advanced technology used to helps human to interact with environments that are inaccesible to human, due to its remoteness or hazardous. The system has been used in different area such as telesurgery, exploring to space or sea exploration, and handling harzadous or explosive material. It is useful for development of science and society, however there is still not a common technology in Malaysia. The problem statement of this project is the time-delay occurred bilateral master-slave telerobotic arm manipulator system has degraded the system performance. Moreover, there is still do not have researchers implement the bilateral master-slave telerobotic arm manipulator system to an industrial robot in Malaysia which could be useful to the industrial development. Hence, objective of this project are to study the bilateral master-slave telerobotic arm manipulator system, develop it and applied it on industrial robot which is KUKA youBot, and finally analyse the performance and time-delay. However, in this thesis, it will present a development of bilateral master-slave telerobotic arm manipulator system to an industrial robot which is Kuka youBot in a simulation only. In methodology, simulation is carried out by using two software which are V-REP and python. Three controllers are used which are P, PD and PID on this system to compare their effect on the system. In the result, common mode and differential mode of bilateral system have been proved in the experiments. The result of experiments showed that the overall accuracy of the designed system is over 95% and time-delay between master and slave robot is merely about 0.2s, which showed a good performance. Through experiments, the best controllers have been chosen and the best value of proportional, derivative and integral term for controller has been identified. At last, through experiment findings, the best controllers to be used are PD and PID controller which PD controller is better in accuracy whereas PID controller has shorter time-delay. Hopefully, this research might give a little contribution to whether the education, industrial or society.

ABSTRAK

Sistem dua hala 'master-slave' telerobotik adalah teknologi yang canggih dan banyak digunakan untuk membantu manusia berinteraksi dengan persekitaran yang tidak dapat dicapai oleh manusia. Faktor manusia tidak mampu mencapai persekitaran itu boleh disebabkan terpencil atau berbahaya. Sistem ini banyak dilaksanakan pada pelbagai bidang iaitu telepembedahan, penerokaan angkasa atau laut dalam, dan pengendalian bahan berbahaya dan bahan letupan. Teknologi ini amat memanfaatkan social dan memajukan bidang sains negara, malah teknologi ini masih tidak banyak diberi perhatian di Malaysia. Pernyataan masa projek ini adalah penangguhan masa menyebabkan sistem dua hala ini tidak stabil. Selain itu, tiada penyelidik pernah melaksanakan teknologi sistem telerobotik ini dalam robot industri yang dapat memanfaatkan pembangunan bidang industri. Oleh itu, objektif tesis adalah mempelajari sistem dua hala 'master-slave' telerobotik ini, membinakan sistem ini dan membuat analisis tentang prestasi dan penangguhan masa. Bagaimanapun, dalam tesis ini, sistem ini akan dibentangkan dalam simulasi sahaja. Dalam projek ini, V-REP dan python akan digunakan untuk simulasi ini. Pengawal P, PD dan PID akan digunakan untuk berbanding prestasi dengan sama satu lain. Keputusan eksperimen menunjukkan ketepatan keseluruhan adalah melebihi 95%. Melalui eksperimen, sistem pengawal yang terbaik untuk sistem ini telah dipilih. Pengawal PD dan PID adalah terbaik untuk digunakan dalam sistem dua hala 'master-slave' telerobotik ini, pengawal PD lebih baik dalam ketepatan malah pengawal PID memiliki penangguhan masa yang lebih pendek. Harapan penyelidikan ini dapat memberi sedikit sumbangan kepada bidang pendidikan, bidang industri atau social masyarakat.

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LIST OF ABBREVIATIONS

API	Application Programming Interface
DOB	Disturbance Obeserver
LAN	Local Area Network
LED	Light Emitting Diode
PC	Personal Computer
RFOB	Reaction Force Observer
ROS	Robot Operating System
WOB	Workspace Observer

LIST OF SYMBOLS

θ	angle in radians
f_m	force of master manipulator
f_s	force of slave manipulator
G_r	Gear Ratio
I_a	Torque electric current
J_m	Inertia of the motor shaft
K_d	Derivative Gain in PD controller
K_p	Proportional Gain in PD controller
K_t	Torque constant
x_m	angle in radians
x_s	angle in radians

CHAPTER 1

INTRODUCTION

1.1 Overview

In the overview of introduction section, it covers the topic explain about motivation, problem statement, objective and scope of project.

1.2 Problem Statement

Bilateral master-slave telerobotic is a potential useful tool for human in complete some difficult task. The efficiency of the master-slave robot in term of synchornization of position between master and slave arm and time-delay depands on the accuracy required from the tasks. However in stability analysis and the study of control design of teleoperation system, a main problem is still remained which is the time-delay. In the complexity of communication network between computer and master-slave telerobotics system, time-delay is unavoidable during the data packet exchanged between master and slave robot.[1].

Nevertheless, the time-delay of data transimission in telerobotics system becomes larger when the distance between the master robot and slave robot become further. Telerobotic arms always involve in haptic technology, this is because the sense of human is important to let the human operator 'feel' as close as it is happens on the remote environment. The force-feedback system is applied in the master-slave telerobotic arms, often the tranmission data time from master to slave robot which called forward time-delay is different with the transmission data duration from slave to master robot which called backward time-delay. This kind of time-delay is described as time varying delay. Moreover, the time-delay is not only varying but also asymmetric due to the complexity of the communication network[2]. As a result, the application of remote control of bilateral master-slave telerobotic system, the time-delay problem could cause destabilisation and degrade the tracking performance of closed-loop telerobotic system[3].

Hence, it is still an open problem awaiting researchers and experts to solve and design a stabilising control system for internet-based telerobotic systems for which communication delays are time-varying and asymmetric. Over the years, there are few researchers have proposed some control methods in the paper to solve the problem of time delay in network-based telerobotic systems, the examples are from[4],[5], and many others. But then there is still do not have a perfect solution in reducing the time delay problem. Also, there is still do not have a bilateral master-slave telerobotic arm manipulator system being developed and applied on an industrial robot yet.

In conclusion, development of bilateral master-slave telerobotic arm manipulator system in an industrial robot is proposed in this thesis to analysis the time-delay and the performance of robotic arm system in term of accuracy and efficiency.

1.3 Motivation

Bilateral master-slave telerobotic arms have become an emerging technology in this century. This techonology is important because it can helps human to interact with environments that are not accesible to human, it could due to the remoteness or hazards environment. There are five basic parts involved in a master-slave telerobotics system which include human operator, master robot, slave robot, communication channel and the environment. In real world problem, there are many special task cannot be easily completed by human being, these made the remote bilateral teleoperation techonology has many potential applications.

The motivation of improving bilateral master-slave telerobotic arms manipulator system come from few reasons, which is saving life, to be used in further human's exploration, and improve the industrial performance. Bilateral master-slave telerobotic that involve saving life include it can helps human to handle hazardous and dangerous object and robotic telesurgery has become more famous in the medical industry. On the another hand, bilateral master-slave telerobotics arms can be used in exploration such as space and undersea exploration which is not easy to be accessed by human.

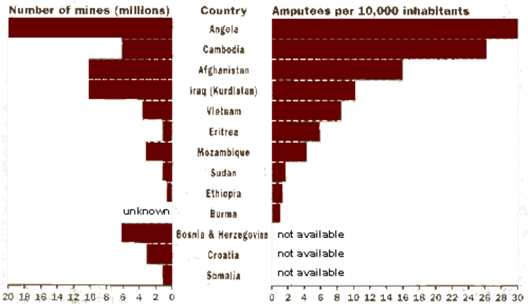

Figure 1.1: Statitics shows graph about number of mines in different countries.

From research statistic provided by[6], there is approximately 110 million active mines dispersed all over 70 countries as shown in Figure 1.1. In short, there is one for every 52 humans in our world. Also, it mentioned that every month, there are estimated 2,000 victims are involved in landmine accidents. In other words, there is one people involved in the accident every 20 minutes. Among the victims, about 800 will passed away, the remain will be maimed. Besides, from the statistics, for every 5,000 mines cleared by deminer, one will be killed and two will be injured. So far, there are approximately 100,000 mines are eliminated every year, but unfortunately until recently, 2 million mines were still being planted. According to the rate of demining, to get rid of all the mines in the world, it would take about 1,100 years. Also, statistics stated that majority of the death are involved men soldier, which is 76% in Afghanistan and 80% in Cambodia. However, in some countries, over 30% of the casualties is women and children . This incident happened because of the coincides with a period of refugee returning to mined areas, and this makes the number of casualties of civilians overwhelming. There is a case that happened in 1991 in northern Somalia, children whose born to be playfulness have made up of 75% of mine victims, this put vulnerable children a great risk. It is approximately 80% life of children cannot be saved before reaching a hospital. Moreover, there is 80% death in the mine accident is civilians in Georgia (1994-1995), 68% in Mozambique (1994), and 88% is in Namibia (1980). Hence, it is utmost important that the development of bilateral master-slave telerobotics system in a help to reduce the unnecessary casualties by replacing human to de-mine the implanted mine.

According to statistic provided by[7], a report named "To Err Is Human" which is published by the Institute of Medicine stated that there is up to about 98,000 people each year die due to the mistakes in hospitals. This report have shocked the medical community due the overwhelming number in the statistic. At the beginning, the number is being doubted and argued, but now is widely accepted by medical community in 2014, and quoted often in the media.

In short, based on the statistical data given above and mentioned global issues, it is obviously shown that the development of bilateral master-slave telerobotic arms is utmost important for the a better future to the next generation. This is to help people to perform the difficult task without scarifying human life. In addition, the Office of Inspector General for Health and Human Services mentioned that 180,000 patients is dead in Medicare in year 2010 due to bad hospital care. Unfortunately, in a recent study, an issue that stated by Journal of Patient Safety, it mentioned that the numbers of patients between 210,000 and 440,000 who go to the hospital suffered the preventable harm and cause to death has increased. Among the case, 20% of the death are caused by operation mistake did by inexperienced doctor. This medical errors have contributed the cause of death in America become the third-leading killer, just behind heart-disease and cancer, which is the first place and the second respectively.

1.4 Objective of Project

Objectives of this project include:

1. To study bilateral master-slave telerobotic arm manipulator system.
2. To develop bilateral master-slave telerobotic arm manipulator system.
3. To analyse the time-delay and performance of the bilateral master-slave telerobotic arm manipulator system.

1.5 Scope of Project

Scope or limitation of this project include:

1. The bilateral master-slave telerobotic arm manipulator system is designed and tested in simulation only.
2. The bilateral master-slave telerobotic arm manipulator system is only applied to Kuka youBot.
3. The bilateral master-slave telerobotic arm manipulator system is applied on the identical master and slave robot arms.
4. The bilateral master-slave telerobotic arm manipulator system's motion is restricted to linear motion of joint 1 for KUKA youBot arm only.
5. The bilateral master-slave telerobotic arm manipulator system do not have the micro-macro scaling function.
6. The trajectory planning and accuracy of robotic arm reach to the desired coordinate is not in the scope of this project.
7. Compensation of friction force is not in the scope.

1.6 Summary

As a conclusion of this section, this section had briefly mentioned about the motivation of this project, problem statements, objective and scope of this project. In the next section, it will cover about the literature review which discuss about the methods in the past work research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter delves into the past works of robotic system with an overview of the bilateral master-slave telerobotics system. This chapter also touches requirement needed in bilateral master-slave telerobotics system, challenges in implementing telerobotics system, proposed control system from past works, and the analysis methods. At the end of this chapter, the summary of this chapter is presented.

2.2 Master-slave Telerobotics System Overview

In [2], it mentioned that the master-slave bilateral telerobotics system is useful to human because the technology enable human to interact to the environment that is not easy to approach due to its remoteness and dangerous. This technology is useful and important because from [3], it explained that this technology with the remote operation functionnality, brings up benefit to human with various potential application. For example, exploration to an unaccessible place like space exploration and sea exploration. Moreover, bilateral master-slave telerobotics technology also can be useful in telediagnosis and telemedicine which improve the level of health among humans. Lastly, this technology can avoid human to be sacrified in handling of dangerous material such as demining and nuclear leak. A basic components needed in a telerobotics system is shown in Figure 2.1 which it consists of a human operator, master robot, slave robot, a communication channel and lastly the environment[2].

In master-slave telerobotics system, haptic technology carries one of the important

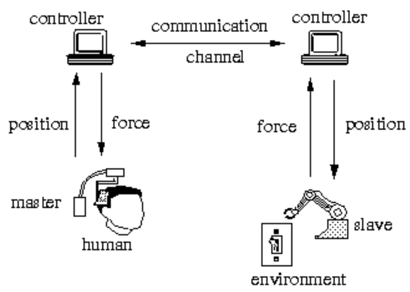

Figure 2.1: Basic components of telerobotics system.

role to make the system useful. In human daily activities have involved haptic sense nowadays. The purpose of haptic technology is the establish a bridge between human and unknown environment. This sense is just similar with the auditory and visual senses, the invention of telephone extends human hearing communication while the creation of television or webcam has provide a better visual communication to human. Currently, haptic communication is a challenging techonology to extend human touch sense in various applications such as telesurgery, nuclear engineering, cell injection and space exploration[8].

Haptic sense is different from other senses, it occurs bilaterally: it worked by a human applying a motion to an environment, the reaction force is feedback and cause the human feeling the distortion of the environment. Hence, a mechatronics system and a bilateral control system is needed to implement the haptic technology. In a basic haptic system, the hardware should consists of a master robot, a slave robot, and a communicatin channel which allow the motion and force data could be transmitted along the master and slave robot.The system is shown in Figure 2.2.

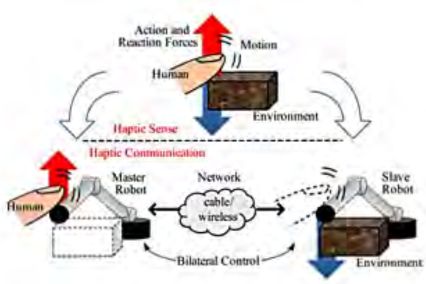

Figure 2.2: Haptic sense and haptic communication through network.

However, in this paper, not only the communication and synchronization of movement between master and slave arms are focused, but the haptic technology or force feedback is also emphasised. To implement the locomotion of robot arm, the robot basically has a close loop system as shown in Figure 2.3 refer from [9].

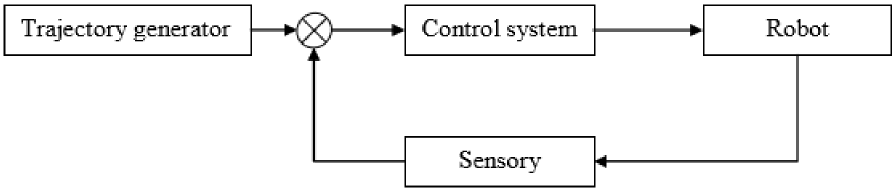

Figure 2.3: Basic of robotic system.

From Figure 2.3, the system trajectory generation where the system generates position, velocity,or acceleration profile. There are two types of trajectory generation, which is 1) Joint space schemes where the trajectory generated is implemented to joint and 2) Cartesian space scheme where the trajectory generated is the motion of a point in space. Both types are used a cubic polynomial function with certain, and the higher the polynomial order, the smoother the motion becomes. To reduce the complexity, trajectory planning is not in the scope in this paper, rather than assign the robotic arms to reach a presice location, this paper only study the communication and how close could slave arm follow the motion of its master arm. Thus, only simple linear motion will be implemented in this paper.

From Figure 2.3, the system will undergo a control scheme after a motion trajectory has been generated. In this scheme, comparison between the trajectory given with the input from the sensory units is made to ensure the actual trajectory is always the same as the generate trajectory from the trajectory generator. There are many types of control such as PID, PD, Fuzzy, artificial neural network(ANN) and state feedback. Those control system will make adjustments or corrections based from the sensory feedback that is usually embedded in the robotic system. However, ensuring the actual trajectory is same as planned is not in the scope of this paper. Instead of inserting control system among a robot arm itself, the control design in this paper is implemented between the master and slave arm along the communication channel as shown in Figure 2.4 to ensure synchronization master-slave arms.

Figure 2.4: Example of closed-loop teleoperation of surgery which control unit is between master and slave arm.

2.3 Requirement in Telerobotics System

In master-slave telerobotics and haptic communication system, the key issue is about transparency to make the system realised[10]. In a bilateral telerobotics system, transparency is an evaluation index[11]. Definition of transparency is that there is matching impedance between human operator from master system and environment impedance from slave system. In more technical way, the meaning of high transparency reflects that both master and slave robot have achieved the high accuracy of force and position control, i.e. f_m= -f_s and $x_m = x_s$, where f_m means the external force exerted on a master robot, f_s denotes that external force exerted on a slave robot, x_m means the position of master robot and x_s means the position of the slave robot.

Normally, force and position parameters between the master and slave is often used in the bilateral master-slave telerobotics system control. Besides of transparency, [11] mentioned about that a quality of communication is affected by the robust stability. The stabity is defined as there is no oscillation or overshoot at the positions and forces between master and slave. Hence, stability of a telerobotics system is important so that a system always has a stable performance.

2.4 Challenges in Telerobotics System

To achieve a high transparency and robust stability telerobotics system, the communication channel and control system carries an important role. In stability analysis and wireless telerobotics system's control design, time-delay is still remain a critical problem[1]. In the communication of telerobotics system between robots and computer, the time-delay transmission of data packet between them can hardly be avoided.