# Simulation of Manipulator Control System for Drilling of Top Cover Component of Airplane

SUHAIL ABDULRAHMAN ABDO ESMAIL



BACHELOR OF MECHATRONICS ENGINEERING WITH HONOURS
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# Simulation of Manipulator Control System for Drilling of Top Cover Component of Airplane

**SUHAIL ABDULRAHMAN ABDO ESMAIL**

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## DECLARATION

I declare that this thesis entitled “Simulation of Manipulator Control System for Drilling of Top Cover Component of Airplane” 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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|---|---|---|
| Signature | : | SUHAIL |
| Name | : | SUHAIL ABDULRAHMAN ABDO ESMAIL |
| Date | : | 20/06/2021 |

**APPROVAL**

I hereby declare that I have checked this report entitled "Simulation of Manipulator Control System for Drilling of Top Cover Component of Airplane" 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 : DR. MOHD FAID BIN YAHYA

Date : 20-06-2021

## DEDICATIONS

To my beloved parents, siblings and my uncle Esmail

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# ABSTRACT

This project is mainly focusing on investigating the suitable control method that can be used to control Kuka yobot. Hence, the controller designed can give the desired optimal performance. As the manual drilling is outdated method that have different problems in hole quality. Automatic drilling is one of the important application used in robot manipulator. The problem of this report is concerned with controlling the Kuka youbot in order to automate the drilling process for top cover component of airplane (circle shape). Many control method has been used to control the robot manipulator with different optimal performance, flexibility and robustness. The control method that will be used to control the robot manipulator is the PD fuzzy logic control method. PD Fuzzy logic control method is chosen due to the optimum capacity of the controller to handle the non-linearity of the robot manipulator. First, robot manipulator will be drawn in SolidWork and with the help of SimMechanics tool the mathematical design of the robot will be created and then convert to simscape where it can be used in MATLAB. The simscape created will be controlled by PD controller alone and then FLC will be added to improve the output. Moreover, the trajectory path planning of the robot manipulator, Cartesian space method will be used to enable the robot to move from one point to another. The proposed idea is designed to achieve the objectives of the report depending on the methodology, first by drawing the robot parts, mechanical design will be generated using the SimMechanics tool and then transfer to the Simulink using the ‘smimoprt’ function then PD controller will be set and test, after that FLC will be designed with special memberships functions and rule bases and then added to enhance the output. The result will be shown in terms of transient response, rising time, settling time, overshoot, and steady state error. Second, The Kuka youbot path will be created on the circle as waypoints. This path will be as 4 points with angle of 90 degree between point to another, the robot will stop for six seconds for the purpose of drilling simulation. Third, Kuka youbot will be simulated in Coppeliasim as a fulfillment of simulation of the drilling process.

## *ABSTRAK*

Projek ini memfokuskan pada penyiasatan kaedah kawalan yang sesuai yang dapat digunakan untuk mengawal youbot Kuka. Oleh itu, alat kawalan yang dirancang dapat memberikan prestasi optimum yang diinginkan. Sebagai penggerudian manual adalah kaedah ketinggalan zaman yang mempunyai masalah berbeza dalam kualiti lubang. Penggerudian automatik adalah salah satu aplikasi penting yang digunakan dalam manipulator robot. Masalah laporan ini berkaitan dengan mengendalikan youbot Kuka untuk mengotomatiskan proses penggerudian untuk komponen penutup atas kapal terbang. Banyak kaedah kawalan telah digunakan untuk mengawal manipulator robot dengan prestasi, kelenturan, dan ketahanan optimum yang berbeza. Kaedah kawalan yang akan digunakan untuk mengawal manipulator robot adalah kaedah kawalan logik kabur PD. Kaedah kawalan logik PD Fuzzy dipilih kerana kapasiti pengawal yang optimum untuk menangani ketidaklarisan manipulator robot. Pertama, manipulator robot akan dilukis di SolidWork dan dengan bantuan alat SimMechanics, reka bentuk matematik robot akan dibuat dan kemudian ditukarkan ke simscape di mana ia boleh digunakan dalam MATLAB. Simscape yang dibuat akan dikendalikan oleh PD controller sahaja dan kemudian FLC akan ditambahkan untuk meningkatkan output. Lebih-lebih lagi, perancangan lintasan lintasan manipulator robot, kaedah ruang kartesian akan digunakan untuk membolehkan robot bergerak dari satu titik ke titik yang lain. Idea yang dicadangkan dirancang untuk mencapai objektif laporan bergantung pada metodologi, pertama dengan melukis bahagian robot, reka bentuk mekanik akan dihasilkan menggunakan alat SimMechanics dan kemudian dipindahkan ke Simulink menggunakan fungsi 'smimoprt' maka pengawal PD akan diatur dan diuji, selepas itu FLC akan dirancang dengan fungsi keahlian khas dan asas peraturan dan kemudian ditambahkan untuk meningkatkan output. Hasilnya akan ditunjukkan dari segi tindak balas sementara, waktu meningkat, masa penyelesaian, kesalahan tembak, dan ralat keadaan mapan. Kedua, Laluan youbot Kuka akan dibuat pada bulatan sebagai titik jalan. Laluan ini akan menjadi 4 titik dengan sudut 90 darjah antara satu titik ke titik yang lain, robot akan berhenti selama enam saat untuk tujuan simulasi penggerudian. Ketiga, Kuka youbot akan disimulasikan di Coppeliasim sebagai pemenuhan simulasi proses penggerudian.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| PID | - | Proportional Integral Derivative |
| SMC | - | Sliding Mode Control |
| FLC | - | Fuzzy Logic Control |
| DH | - | Denavit Hartenberg |
| LQR | - | Linear Quadratic Regulator |
| DoF | - | Degree of Freedom |
| VSC | - | Variable Structure Control |
| PD | | Proportional Derivative |

# CHAPTER 1

# INTRODUCTION

## 1.1 Motivation

Robot manipulator is one of the most important applications that can be found in industry. The earliest robot was invented in the early 1950s by George C. Devol with the purpose of pick and place [1]. In the recent years numerous of control authors and large number of control applications were presented mostly regarding controlling the robot manipulator [2]. Robotic manipulator is one of the vital fields in industries, academic and medical applications. It can perform hazardous work in unreachable areas[3].

Drilling application can be found in different aspects like airplane industries where quality and high efficiency have the priority interest. Previously, manual drilling was used in aircraft fabrication, which was tiresome, time-consuming, quality of the holes is unstable, and requires lots of manpower [4]. The airplane body is made of aluminum, titanium, steel, and other different composites with different portion these materials are too strong which made the manual drilling difficult [5]. Moreover, if the drilling made manually, the small particles from the composite material might be inhaled by the workers which may adversely affect on their health. It would also offer the opportunity to reduce or minimize human exposure to dangerous and hazardous conditions, which would eliminate most safety-related problems as several activities occur at the same time. These factors are motivating the development of an automatic robot manipulator system [2].

These days, new fabrication technologies are the basis for the development of innovative solutions that make it possible to produce parts or additive features with short time and increased safety. Automation of the drilling process using the robot manipulator contribute to make progression on the industries depending on the drilling. The efficiency and high quality in making the holes of the aircraft made the robotic manipulator the best choice for perfect holes matching with their rivets.

## 1.2 Problem Statement

Controlling robotic motion is a fundamental yet challenging task in robot manipulator-based robotic application, which essentially plays a significant role in achieving more complex task. Performing robotic manipulation is not a trivial task due to its complexity in terms of the sort of applications that need to be performed. Thus, building manipulator's mathematical model is essential to achieve a specific robotic task, however mathematical model of manipulator is more difficult due to its computational complexity, where many equations need to be taken in consideration for force, torque, and forward and inverse kinematic. Increasing the degree of freedom (DoF) raise complexity of building the robotic manipulator model, which is mostly prone to error. The complexity task of drilling on the airplane surface is highlighted as the problem statement in this research to be overcome with accurately controlling the position and speed of Kuka youbot [3]. Performing drilling task is not trivial task to be performed, which need accurate and reliable mathematical model to generate path planning for achieving the drilling task with Kuka youbot.

## 1.3 Objectives

The objectives of this research are:

i) To obtain the mechanical design of the robot manipulator using Solidwork and SimMechanics tool.

ii) To develop PD fuzzy logic controller to control the position of the robot manipulator.

iii) To investigate the requirements of path planning and simulate drilling on the top cover component of airplane, (circle shape) using Kuka youbot.

## 1.4 Scope and Limitation

The scope of this project is focusing on several points related to control system method used to control robot manipulator.

- Study on the control system methods in order to choose the smooth and accurate method in controlling the robot manipulator.
- Create the mechanical design of the robot using the tool SimMechanics in SolidWork.
- The simulation and the performance analysis of the PD and PD fuzzy logic controller using MATLAB and Simulink environment.
- Study on the trajectory generation methods in order to choose the smooth and accurate method.
- Use Kuka youbot manipulator to simulate the drilling process in Coppeliasim.
- The effect of the drilling, rotation, motion and the force and pressure applied to the surface are not considered in this project.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter has the purpose of summarizing and encompassing a critical and comprehensive review of the research in relation with the topic and present the work from open literature review that is relevant for previous researchers to manipulator control system. Today, the automation drilling process is widespread and utilized by most of the fabrication fields.

Manual drilling process is an outdated way to be used in aircraft manufacturing. Moreover, it is tiresome, time-consuming, quality of the holes is unstable, and requires lots of manpower [4]. If we look at the materials that are involved in fabrication of the aircraft body, they are aluminum, titanium, steel, and other different composites with different portion. The materials are used due to their strength-to-weight and optimum corrosion resistance [5]. Due to these criteria of the aircraft body, the drilling using the conventional method, the manual drilling is very difficult to be used. Hence, a new approach for drilling process is needed with automated system.



In recent years, physical drilling has been done just using the conventional drilling method where drilling is one of the important stages in fabricating the parts. With the development of the technology in the recent years, automation has played an important role in the drilling process [6].

The drilling using the robotic manipulator has been recently widely used in different industrial aspects, especially in airplanes assembly [7]. The assembly of the aircraft is the most significant part in the aircraft manufacturing, where it is holding more than 50% of the workload of the whole manufacturing of the airplane [8]. The efficiency and high quality in making the holes of the aircraft made the robotic manipulator the best choice for perfect holes matching with their rivets.

## 2.2 Manipulator Control Method

In the period of the automatic and intelligent industry, the application of the robotic manipulator has been progressively applied to different sectors as a replacement of the humankind [9]. In the robot manipulator, the control system is the most important to adjust and control the robot. There are several types of manipulators with different criteria, for example, the number of degrees of freedom the number of joints and links, and type of controller used. Hence, the controller in the manipulator plays a crucial role. Controlling of the robot requires position tracking by certain control strategy [10]. The most essential goal of the control is to make sure that the robot manipulator is to sustain a desired dynamic behavior.

Nowadays, there are  a big number of control methods that are used to control the motion of the robotic manipulator [11]. The control methods have a basic control concept that are shared among all control systems. All control system is a series of steps starting from the input, control technique, system, and output. Moreover, control system has two classes, either open loop or close loop. Close loop is considered as the best due to the feedback loop where the open loop does not have feedback loop.



### 2.2.1 Proportional Integral Derivative Control Method (PID Controller)



Proportional Integral Derivative in short PID controller is considered as one of the most famous type of controller used in industry. It is a linear control system; it is a bit hard to set the system to give the best performance. What makes the PID controller prominent and accepted by researchers either in academic field or in industry is due to its little cost, optimum performance for different applications, the simple design of its own and clear physical meaning for its three gains [12].

The PID is a type of close loop system, It Provides fast response, excellent control of the system stability and no high steady state error. Even though there is still low steady state error, but PID is designed to correct the error between the measured valued and the desired set point by the process of calculating the error and then give out the corrective action which can modify the process correspondingly [10]. Hence, the PID controller is better than the conventional PD controller. Moreover, PID does not need the specific ideal mathematical model for the purpose of implementation. One of the cons of the PID controller is that it has low flexibility and robustness. When the payload is changing, the sliding motion controllers produce better response in comparison to the PID controller [13]. In terms of uncertainty when the PID controller is utilized tracking the error is increased [13].

The algorithm of the PID controller is mainly consisting of three significant parameters that are proportional, integral, and derivative gains. Each parameter in the PID has its own effect towards the system. For instance, the proportional gain has the ability to reduce the rising time and reduce the steady state error, but it never gets rid of the steady state error entirely. If we go to the integral gain, it got an effect toward the steady state error by eliminating it completely, but it causes delay to the response and raise the overshot. Finally, for the derivative gain, it is able to increase the stability of the system by shifting the close loop pole to the left-hand side of the s-plane, it also decreases the overshooting [14]. As it is illustrated in Figure 2.1, $K_p$, $K_i$ and $K_d$ stand for proportional, integral, and derivate gains, respectively. The terms $e(t)$ and $u(t)$ represent the error and control signal, respectively.



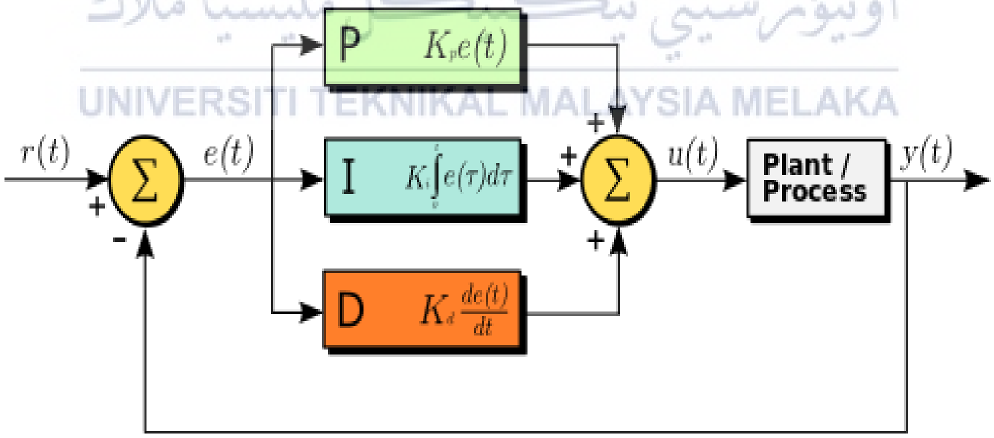


Figure 2.1: PID Control Structure

Transfer function of PID controller in parallel can be represented by equation 2.1 where $T_1 = K_p/K_i$ and $T_D = K_d/K_p$ are the integral and derivative time constant, respectively.

$$G_{PID}\,(s) = K_p(1 + \frac{1}{T_1 s} + T_D s) \qquad 2.1$$

The other type of PID controller called the serial form, and it is represented mathematically as in the equation 2.2 below.

$$G_{PID_{series}}\,(s) = (K_p + \frac{K_i}{s})(K_d s + 1) \qquad 2.2$$

For designing the PID parameters there are two methods: time domain and frequency domain method [2]. Although the time domain method is widely used, lots of these methods are depending on trial-and-error strategy. In terms of popularity, time domain method is more popular than frequency domain method for setting the tune of the PID parameters [2]. However, if the system mathematical model is known, the frequency domain method is more convenient. To design the PID controller we have to follow one of the tuning methods which are manual tuning method, Ziegler-Nichols frequency domain method, Ziegler-Nichols frequency domain technique, Cohen-Coon technique and root locus technique.

#### 2.2.1.1 Proportional Derivative Control Method (PD Controller)

Proportional Derivative is a sub-system classified under the proportional integral derivative controller, it is used to improve the transient response and maintaining the steady state error [15]. PD controller has a linear system compatibility with feedback, the control system can easily be designed. The optimal configuration is hard to be reached. In terms of flexibility and robustness, this controller has very low flexibility and robustness [15].

#### 2.2.1.2 PID with Advancement

Due to the limitation of the PID which make some obstacles and difficulties to control the robot manipulator, there are some advancements to the PID to enhance its ability to control the motion of the robot manipulator. There are a number of the methods that have been successfully used to control the robot manipulator such as, fuzzy PID, neural adaptive PID and genetic algorithm based PID. Fuzzy PID, a problem of output accuracy of manipulator which is law due to some factors [16]. Fuzzy gain scheduling saturated PID is another vital method that can be used to support the robustness of the control system [17]. The use of the PID with advancement in robot manipulator is widely used.

### 2.2.2 Sliding Mode Control Method

Sliding Mode is another method that can be used to control the robotic arm manipulator, it is also called the variable structure control (VSC). Sliding mode control (SMC) is a non-linear control method with a bit of complex design and has distinguishing characteristics such as, no sanitation towards parameters changes, disturbance rejection, great accuracy, and easy tuning implementation [18]. The use of the sliding mode control in robot manipulator is widely used. The sliding mode control method has been used in different applications for optimal and robust performance, it is a bit difficult to set the system to give the best performance such as controlling robot manipulator, tracking trajectory and so many other applications [19].



Sliding mode control technique has a fundamental idea which is bringing the states of the system to a specific surface in the sliding surface [20]. Whenever the system states attain the sliding surface, the task of the controller is to maintain them as close as possible to the surface. Hence, the design of the sliding mode control is based on two steps that are the sliding surface is designed to meet the requirement of the system and establishing a control law for the purpose of driving the states of the system to the surface.

Sliding mode control is a technique that has several advantages. First, it is possible to customize the plant dynamic response by choosing a suitable sliding function. Second, feedback loop behavior got insensitivity to parametric uncertainties like disturbances. [20] Sliding mode controller is one of the best controllers that can be used in uncertainty and non-linear system with high flexibility and very high robustness. Another example of the advantages of the sliding mod controller are good transient performance, fast response, robustness of stability. As illustrated below in Figure 2.1the block diagram of the (SMC).

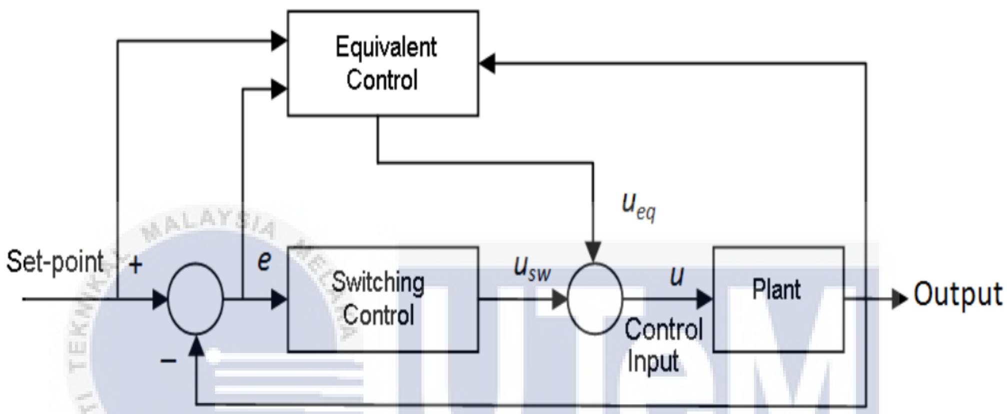


Figure 2.2: Conventional sliding-mode control for a plant [21]

On the other hand, sliding mode method has some disadvantages. The chattering phenomenon, it is essentially the fluctuation and oscillation of the control signal of the input which caused by the discontinuous behavior of the control method. The existence of this oscillation is roughly dangerous to the system, which might be entirely destroyed. Another major problem that the sliding mode controller facing is, it is sensitive to some disturbances like noise when the signal of the input is too close to the zero. Las but not least, the non-linearity of the equivalent dynamic formulation is considered as essential problem for having a good performance, and it is hard to calculate because it depends on the non-linear dynamic equation [22].

#### 2.2.2.1 Chattering

Chattering can be described as the unwanted finite frequency and amplitude that are associated with the signal of the input control and the major reason causing these oscillations is the large frequency switching of the controller and the discontinuous behavior of the control method as it is shown in Figure 2.3. Due to the dangerous situation that may destroy the control system, this phenomenon must be eliminated. The elimination of this phenomenon is definitely essential to make this method a practical control solution.

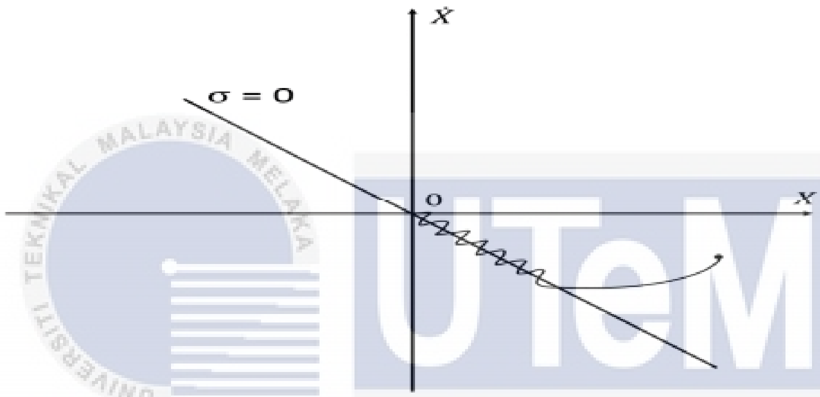


Figure 2.3: chattering effect



To overcome this phenomenon which adversely affect the system there is a technique called boundary layer method, it is the most widely used approach to eliminate the chattering. This method can help to reduce or eliminate the chattering phenomenon [20].

#### 2.2.2.2 Sliding Mode Control Method with Advancement

According to the previous paragraph, chattering is the essential problem which cause a problem of discontinuity in the control method behavior. As a result, there are a number of advancements that can be added to the to alleviate the chattering. Fuzzy sliding mode control technique [23]. Moreover, the adaptive sliding mode control is another technique that can optimize the trajectory tracking control and decrease the effect of the chattering [24].