IMPROVEMENT ON TRANSIENT RESPONSE OF PNEUMATIC GRASPER ROBOT POSITIONING USING DEADZONE COMPENSATOR

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Thesis submitted in fulfillment of the requirements
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ABSTRAK

Projek ini membentangkan reka bentuk dan pemodelan kompensator zon mati dengan satu kitaran tertutup bagi unit penggenggam robot pneumatik. Sistem Pneumatik sangat biasa dalam aplikasi perindustrian kerana kelebihan seperti penyelenggaraan yang mudah dan ringkas. Walaupun kelebihan ini, mereka mempunyai cabaran dan batasan dalam aplikasi kerana tidak linear dengan tingkah laku yang tidak menentu dan pengaruh zon mati. Zon mati adalah merujuk kepada nilai injap kawalan input tertentu tidak memberi tindak balas kepada operasi injap kerana aliran tekanan disekat. Oleh itu, kajian ini telah mengambil inisiatif untuk mencadangkan kaedah untuk mengimbangi kesan zon mati seperti fungsi zon mati songsang. Beberapa eksperimen perlu dilakukan untuk mengenal pasti zon mati sebelum melaksanakan kaedah yang dipilih dengan pengawal dalam sistem kawalan. Kerja-kerja pengenalpastian dilakukan untuk mengenal pasti ciri-ciri sistem pneumatik yang digunakan pada platform yang disasarkan; penggenggam pneumatik tiga jari (TPG). Selain itu, data daripada analisis zon mati digunakan untuk mereka bentuk persamaan pemampas dan digunakan pada pengawal PID sebagai pengawal terpilih. Hasilnya menunjukkan bahawa nilai offset hampir dengan pusat, dan nilai zon mati pada kedua-dua belah adalah seimbang. Pemampas yang dicadangkan. Percubaan dijalankan pada platform yang disasarkan untuk mengesahkan pemampas yang dicadangkan dengan pengawal tanpa pemampas. Hasilnya menunjukkan bahawa sistem kawalan PID dengan pemampas telah meningkatkan tindak balas sementara kedudukan hujung jari untuk sistem TPG.

ABSTRACT

This project presents the design and modeling dead zone compensator with the close-loop control of pneumatic robot grasper unit. Pneumatic system is a very common devices in industrial automation application due to the advantage such as easy and simple maintenance. However, there are some challenges and limitation in application due to its non-linearities with uncertain behavior including dead zone influences. Dead zone is referring certain input control valve values give no response to the valve operations as the pressure flow is blocked. Therefore, this study has taken initiative to propose the method to compensate with the dead zone effect such by using inverse dead zone function approaches. The identification works are done to identifying the characteristic of the pneumatic system used on the targeted platform; tri-finger pneumatic grippers (TPG). Moreover, the data from dead zone analysis was used to design the compensator equation and apply to the PID controller as selected controller. The result shows that the offset value is close to the center, and the dead zone values on both sides are balanced. The proposed compensator. The experiment carried on targeted platform to validate the proposed compensator with the controller without the compensator. The result shows that the PID control system with compensator have improved the transient response of a fingertip positioning for the TPG system.

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LIST OF ABBREVIATIONS

TPG	Tri-finger Pneumatic Grippers
PPVDC	Pneumatic Proportional Valve with Double-actin Cylinder
PID	Proportional-Integral-Derivative

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A pneumatic system is made up of a number of connected parts that work together to operate automated machines by using compressed air. Examples include a factory floor, a garage, or a dentist's office. One of the frequently used tools in industrial automation applications is the pneumatic system, which would have the benefits of high power/force to weight ratio, low electromagnetic interference, non-pollution, fireproof, explosion-proof, and cost-effectiveness.[1] These features are competitive in a wide range of motion control applications, including materials and components handling, packing machines, machine tools, robotics, food processing, and process industry.[2]

The majority of pneumatic systems, which hold, move, form, and process materials, are powered by pneumatic cylinders, rotary actuators, and air motors. Other pneumatic components are required in order to operate and regulate these actuators, such as air service units for the preparation of compressed air and valves for the regulation of the actuators' pressure, flow, and direction of movement.

Although pneumatic system is very common in industry, they have limitations in servo pneumatic applications that are caused by typical non-linearities of Pneumatics, as servo valve dead zone, air flow-pressure relationship through valve orifice, air compressibility and friction effects between contact surfaces in actuator seals. The dead zone is an inherent nonlinearity in pneumatic servo valves, where for a range of input control values, the valve gives no output flow.[3]

Therefore, this project has taken initiative to implement and analyze the dead zone compensator with the close-loop system on Tri-finger Pneumatic Grasper Unit (TPG). The compensator method is applied on pneumatic system by using inverse dead zone approaches. This method is chosen because this equation can compensate the influence of dead zone. Although complete dead zone compensation is impossible to achieve, its performance-degrading effects can be reduced by estimating the dimensions of the dead zone and increasing the softness in the range close to zero position.[3] The project is focused on one pneumatic valve as the targeted component that considered effect by dead zone and one pneumatic actuator. A variable step of activities is set to understands and identify the dead zone before implement the compensator on the system.

1.2 OBJECTIVE AND SCOPE

With reference to the problem statements outlined in the previous section, the objectives are listed as follows.

i. To design the dead zone compensator for transient response improvement on position control of Tri-finger pneumatic grippers (TPG) system.
ii. To analyze and verify the designed compensator with selected close-loop control on transient response, overshoot, rising time and steady-state error.

The scope of the project should be focused on:

i. Dead-zone identification and analysis on the current pneumatic valve used on TPG platform.
ii. Compensator design as co-junction to the PID controller as selected control system for single finger of TPG.
iii. Validation of proposed compensator on the valve controller of TPG.

1.3 ROADMAP THESIS

The thesis contains detail discussion, explanation and verification through experiment in laboratory. The chapters are organized as follows.

Chapter 1: A discussion about the project background that introduce the development and purpose of the project. This chapter also contains the problem statement, objectives which includes with the project's scope, and thesis roadmap

Chapter 2: Discussion on general literature review about overview of pneumatic system the mathematical model for the pneumatic system that contain four part which pneumatic valve dynamics, pneumatic friction dynamics, pneumatic pressure dynamics and pneumatic cylinder rod-piston dynamics. In this chapter, there is mathematical model for dead zone, dead zone compensator method and summary.

Chapter 3: Focused on discussion about the conceptual design of TPG system circuit, Dead zone identification and analysis and overview about dead zone compensation design.

Chapter 4: In this chapter, discussion is focused on the analysis of the dead zone from the experiment.

Chapter 5: Conclusion about the overall progress and a recommendation for future planning and development that can be done on Dead zone compensator.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW OF PNEUMATIC SYSTEM

A typical sort of actuator system used in industries with applications including a movement of control is the pneumatic system. For industrial industries that are involved in automation control, pneumatic actuators offer numerous benefits.[4] Numerous applications, including motors, robots, cargo ship steering, and inverted pendulums, have been successfully run using neural networks and fuzzy control over the past few decades.

The five fundamental parts of a pneumatic actuator system are the primary motor, the compressor unit, the storage tank, the pneumatic valve, and the actuator device. When used properly, such as in applications with lower loads, pneumatic systems are viable alternatives. Pneumatic actuators have the following benefits and drawbacks.

2.1.1 Comparison of Pneumatic with other Positioning System

Pneumatic linear actuators consist of a piston inside a hollow cylinder. Pressure from an external. An external pneumatic pump applies pressure, which causes the piston to move inside the cylinder. As the pressure builds, the cylinder travels along the piston's axis, producing a linear force. A spring-back force or the supply of fluid to the piston's opposite side causes the piston to return to its initial position.

High cycle times are possible because to pneumatics, which are the fastest on the market. Greater productivity is possible with increased duty cycling. Profitability and a fantastic investment return follow from there. Pneumatic actuators typically cost less to buy than hydraulic or electric equipment.[5] This results in less capital being invested up front and a faster rate of return. For light- and medium-duty applications, pneumatic actuators are a cost-effective option. The comparison of pneumatic with other positioning system were shown in Table 2.1.

Table 2.1: Comparison of pneumatic, electrical and hydraulic system

Characteristics	Pneumatic	Hydraulic	Electrical
Linear Actuator	Cylinder with medium force	Cylinder and very high force	Short motion via solenoid
Controllable force	Controllable medium force	Controllable high force	Possible with solenoid and DC motor
Rotary Actuators	Wide speed range	Low speed	AC and DC motor
Complexity	Simple	Medium	Medium/High
Energy source	Electric motor/diesel driven	Electric motor/diesel driven	Usually outside supplier
Energy cost	Highest	Medium	Lowest
Maintenance cost	Low	High	Low

Figure 2.1 show the example system of pick and place arm constructed of metal that is pneumatically powered. It displays how a pick and place mechanism can be accomplished using a pneumatic power. It demonstrates the use of pneumatic power to operate a pick and place device. The system uses four pneumatic actuators, and four pneumatic valves control the robotic arm. In order to control the movement of the cylinder stroke, the valves regulate the air supply to the pneumatic actuators. A manual control over the full arm movement is provided by the valves. The system's gripper arm, which is pushed by a small cylinder, was used to operate the grasp. To control air flow to the gripper actuator and subsequently the gripping, it is controlled by the fourth pneumatic valve. The other valves cooperate to complete the arm movement, which is kept together by a network of linkages and connection rods.

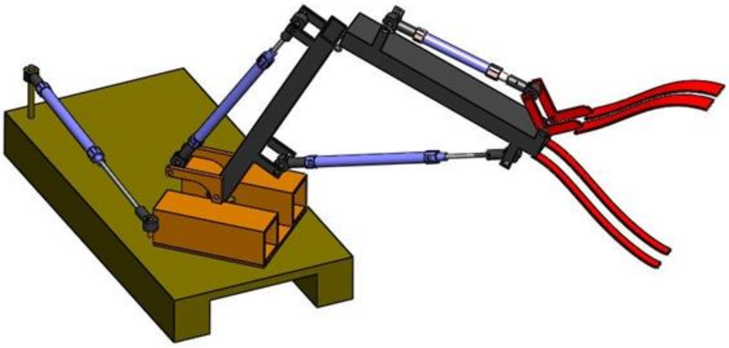

Figure 2.1: Example of Pneumatic Grasper Robot [5]

2.2 PPVDC MODEL OF PNEUMATIC SYSTEM

PPVDC model plant is divided into two interconnected subsystems; pneumatic subsystem and mechanical subsystem as introduced by as in Figure 2.2. The input control signal will be in the effective region of the valve orifice, and each subsystem has a relationship with each other.[6]

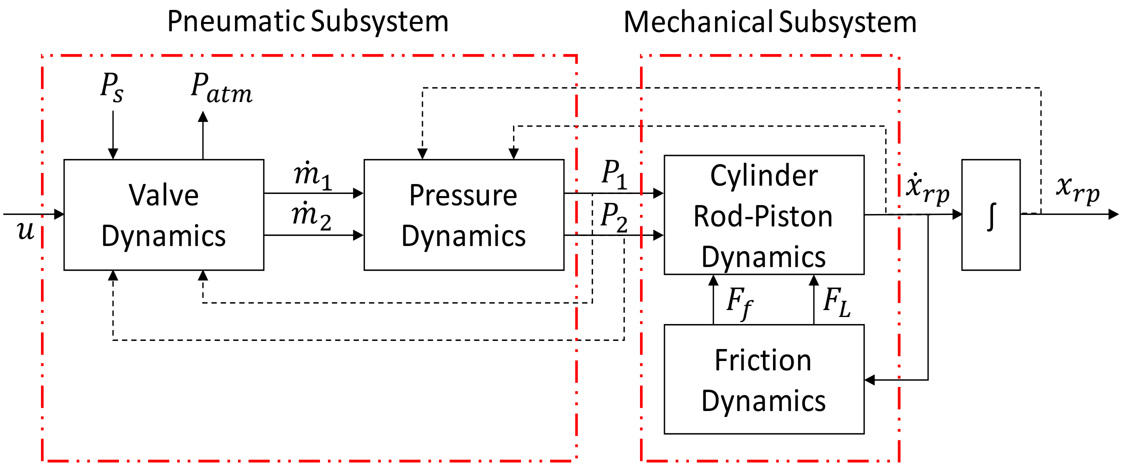

Figure 2.2: Model plant for PPVDC system [6]

2.3 REVIEW ON DEAD ZONE ISSUES

Many electrical and mechatronic equipment, including ultrasonic motors, servo valves, smart actuators, and sensors, have systems with harsh input non-linearities. Dead-zone is one of the most frequently occurring non-smooth non-linearities among those hard non-linearities, particularly in recently created smart actuators. [7] The dead-zone input non-linearity, which describes a non-sensitivity for modest excitation inputs, is a non-differentiable variable. As a result, the literature reports that the presence of dead zones in control systems could significantly reduce system performance. Evidently, this presents intrinsic challenges for the control schemes.[8]

One of the reasons that limits the effectiveness of feedback control loops is the presence of dead zones in a system, although components without such flaws are typically more expensive to produce and typically require specialist staff to maintain. Dead zone may also be required in specific circumstances, such as when hydraulic valves are used in vehicle suspension systems to maintain height when the car is parked and the engine is off and prevent internal leaks. The effect of the dead zone in this case, however, is harmful when the suspension is in place, and it must be "removed" by an acceptable compensation in the control scheme. Conventional control techniques are based on the inverse dead-zone compensation, where the inverse of the dead-zone dynamics is created in the controller output, so that the influence of dead-zone in the actuator may be removed. This method is used to handle the dead-zone input in the actuators. To accomplish this, detailed dead-zone dynamics should be predicted using mathematical formulas. As a result, the control design first recommended and utilized a natural linear formulation of the dead-zone. Figure 2.3 show the signal trajectories from Uzm(t) 0 volts to 10 volts with the dead zone band (from u(t) of 3 volts to 7 volts).

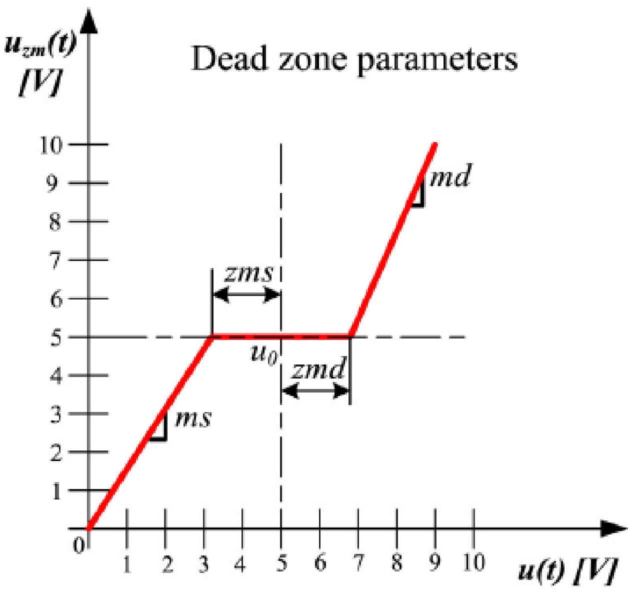

Figure 2.3: Signal Trajectory with Dead Zone effect [7]

The term "dead-zone" refers to a static relationship between the actuator input v(t) and the actuator output u(t), in which the output u(t) is zero for a range of input values v(t), whereas the output u(t) appears and is a function of the input when the input v(t) is outside of this band, and the slope between the input and the output is constant (linear model) or time (non-linear model) are shown in Figure 2.4 and Figure 2.5.

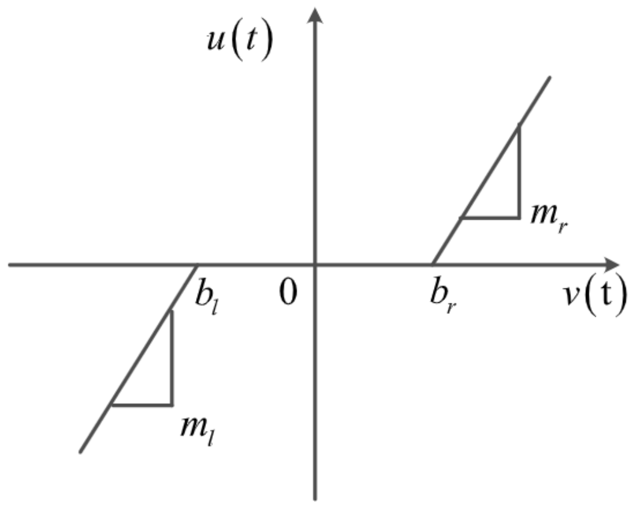

Figure 2.4: Linear Dead Zone [7]

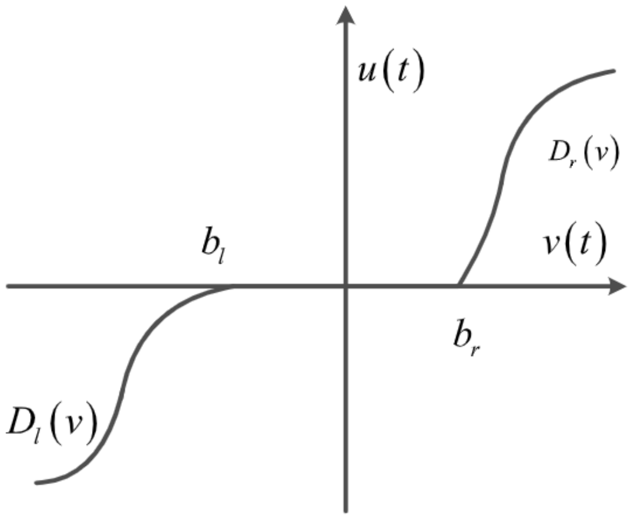

Figure 2.5: Non-linear Dead Zone [7]

2.3.1 Dead Zone in Pneumatic Proportional Valve

The dead zone is found in the dynamic system of proportional pneumatic valves used for directional control. The proportional valve model consists of two components: a nonlinear model defined by a static flow equation, and a linear dynamic system model linking the voltage delivered to the valve to the position of the spool.[9] A thorough explanation of the three-lands, five-ways spool valve's components and operation will be provided in order to help the understanding grasp this phenomenon. Figure 2.6 show the block diagram of dead zone input in proportional valve.

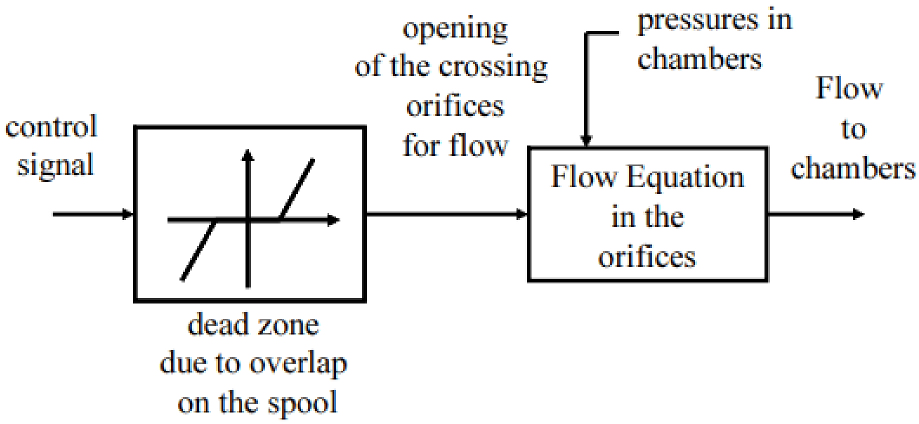

Figure 2.6: Block Diagram of the Proportional Valve with Dead Zone Input [9]

In Figure 2.6, an illustration of a common spool valve in section view, showing the mechanical components that allow it to function as a proportional valve. A magnetic force is provided to the valve spool as a result of the control signal U energizing the solenoids in the valve. Festo is an illustration of an industrial spool proportional pneumatic valve.[10]

When the spool is in the null position in closed centre or overlapped valves, the land width is greater than the port width, leading to the presence of the dead zone nonlinearity. One of the main causes of the system's response being delayed and making mistakes is the dead zone nonlinearity. It is recommended that the relationship between flow rate and control signal in proportional valves be linear. If there is no compensation, the dead zone's presence also harms this relationship.

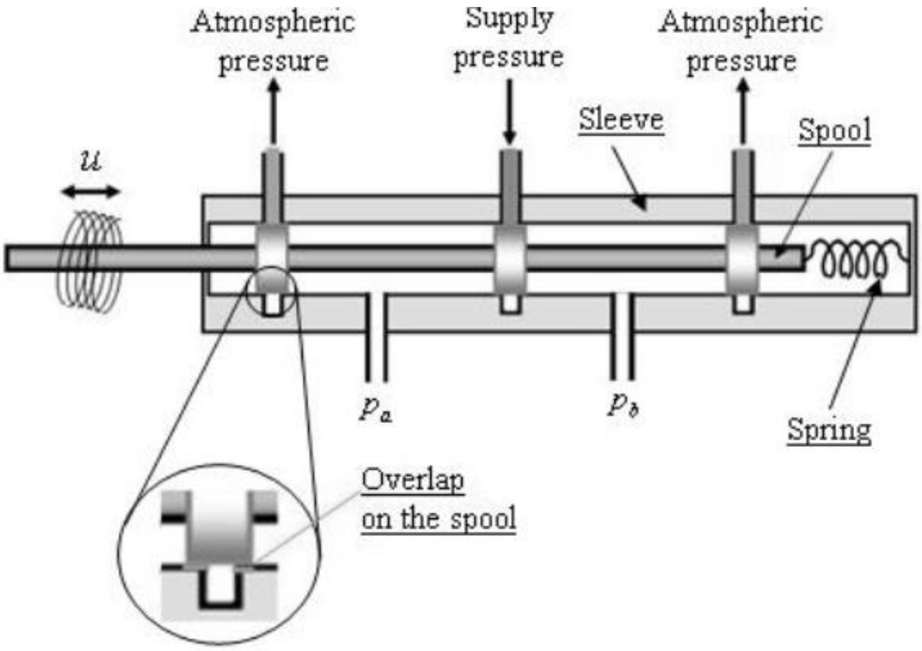

Figure 2.7: Sectional View of spool valve of proportional valve with mechanical elements [10]

2.3.2 Inverse Dead Zone Method

Applying a dead-zone inverse function that has already been created is the most obvious option for mitigating dead-zone nonlinearity. The dead-zone nonlinearity was compensated using the inverse equation, but the potential chattering problem generated by the inverse equation has been disregarded. Thus, the following is a novel, smooth inverse function $v_{in} = u_{zm}$ for compensating non-symmetric dead zones. [11, 12] The inverse dead zone is dead-zone inverse function use to compensate the dead zone nonlinearity. The non-symmetric dead zone compensation is introduced as follows in equation 2.1.

$$u_{zm} = \alpha(u) = \beta_p(u)\left[\left|\frac{2\dot{\hat{z}}_p}{\pi}\right| \arctan(ku) + \frac{u(t)}{\hat{y}_p}\right] + \beta_n(u)\left[\left|\frac{2\hat{z}_n}{\pi}\right| \arctan(ku) + \frac{u(t)}{\hat{y}_n}\right] \quad 2.1$$

where $\hat{y}_p$, $\hat{y}_n$, $\hat{b}_p$ and $\hat{b}_n$ are the offline identified dead-zone parameters of y_p, y_n, b_p and b_n respectively. $u(t)$ is the desired control signal that would achieve the desired control performance when there is no dead-zone nonlinearity. $\beta_p(u)$ and $\beta_n(u)$ are defined as below: [13]

$$\beta_p(u) = \begin{cases} 1, & if \;\; u \geq 0, \\ 0, else \end{cases} \qquad 2.2$$

$$\beta_n(u) = \begin{cases} 1, & if \;\; u < 0, \\ 0, else \end{cases} \qquad 2.3$$

2.3.3 Robust Adaptive Control Method

The creation of an inverse dead-zone nonlinearity to reduce the impacts of dead-zone is a trait shared by the methodologies discussed above. However, alternative strategies might also be used. In this study, a new method for adaptive control of linear or nonlinear systems with dead-zones is introduced without creating the inverse of the dead-zone, based solely on the intuitive concept and piecewise description of dead-zones. The new control rule guarantees maximal tracking and global stability for the entire adaptive system. [14]

The system that needs to be controlled comprises of non-linear plants that are preceded by dead-zone actuators. In other words, the dead-zone is present as the nonlinear plant's input in series.

$$x^{(n)}(\mathrm{t}) + \sum_{i=1}^{r} a_i Y_i(x(t), \dot{x}(t), \ldots., x^{(n-1)}(t)) = \mathrm{bmv(t)} + \mathrm{bd(v(t)} \qquad 2.4$$

From equation 2.4 the control problem's state variables linearly relate to the input signal v (t). The fact that d(v(t)) is uniformly bounded is crucial to understand. A limited term and a linear function of the input signal v(t) are used to express the signal w(t). In this situation, the controller design can make use of the present robust control techniques. This is why the intuitive simplified dead-zone model was created.

For a class of continuous-time nonlinear dynamic systems preceded by a dead-zone, a reliable adaptive control architecture is proposed. This robust adaptive control technique is built without creating a dead-zone inverse by employing a new description of a dead-zone and by intuitively demonstrating the attributes of this dead-zone model. The new control rule accomplishes both stabilization and tracking with the requisite precision and guarantees overall system stability.

2.3.4 Fuzzy Logic Control Method

In several fields, including feedback control, the use of fuzzy logic (FL) systems has increased recently. Even though FL control applications are typically haphazard, a solid mathematical foundation has already been established. In some unique circumstances, FL control design methods with stability proofs have been provided. FL dead zone correction techniques are presented in [15], and the last two references provide an analysis of steady-state performance based on a linear plant of Type 0.

The function approximation property, the classification property, the ability to choose initial parameter values based on sound control engineering experience, and the ability to tune the parameters adaptively to yield guaranteed closed-loop performance are some of the key characteristics of FL systems that make them useful in feedback control.[16] Figure 2-6 show the tracking control using fuzzy logic dead zone compensation.

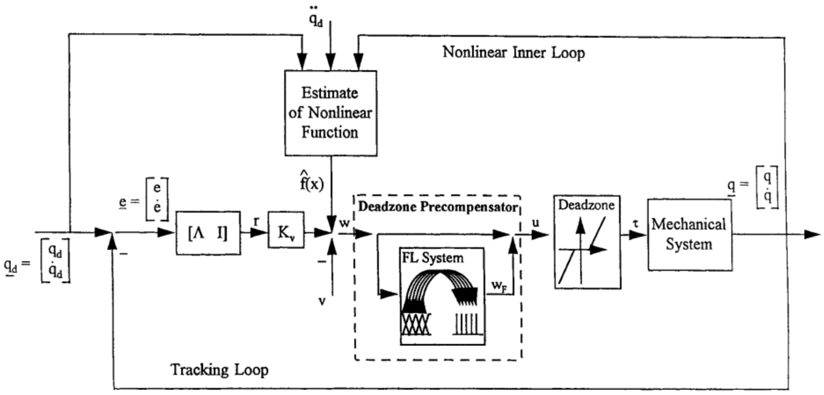

Figure 2.8: Tracking Control with Fuzzy Logic dead zone compensation [16]

2.4 SUMMARY

From the reviews from several of journal, articles and paper, the overview of pneumatic system and PPVDC model has been shown. Pneumatic valve is the control element for the system that control the flow of air and place for nonlinear behaviors, as dead zone. The inverse dead zone was chosen as method for the dead zone compensator. The understanding for this model is important to develop the compensator or equation to eliminate the dead zone effect. Inverse dead zone is the most suitable method for compensation due to it can avoid the discontinuity near to the zero position when the parameter of (zme, zmd, me and md) is known.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The proposed to compensate the existence of dead zone in pneumatic system is inverse dead zone. Before that, several experiments need to be run in order to identify and analyze the dead zone. This is important to determine the most suitable compensator for the dead zone in the system with controller. Generally, the proposal for the dead zone compensator project consists of three phases of development:

Phase 1: TPG system Setup

Reconstructing the Tri-finger Pneumatic Grasper Robot system, Testing connection of TPG circuit and analyze the target parameter.

Phase 2: Dead zone Identification and Analysis

The target parameter is selected, and the experiment run to identify the dead zone in pneumatic system. The suitable compensator chooses from the data analysis of dead zone.

Phase 2: Dead zone Compensator Design and Validation

To implement the dead zone compensator with controller in servo pneumatic system and verify it by compared data system with and without dead zone compensator.

Data will be analyzed to verify if output signal follow the desired signal with implementing the controller to the system. The PID controller is chosen and will be implemented along with suitable dead zone compensator.

Figure 3.1 shows that the flow of the project as shown in the flowchart shows that the Reconstructing of Tri-finger Pneumatic Grasper Robot. If the system is completed, it will then proceed to testing the circuit connection (signal conditioning circuit). Next, identify dead zone for target pneumatic system by run the experiment. If the data is significant where the graph show the existent dead zone, then the analysis of dead zone from identified data is done. The method for dead zone compensator will be choose and implement it along with controller in system. The design will be then analyses and verified. If the designed is better than system without compensator, where the output signal follow the desired signal. The design will be established.

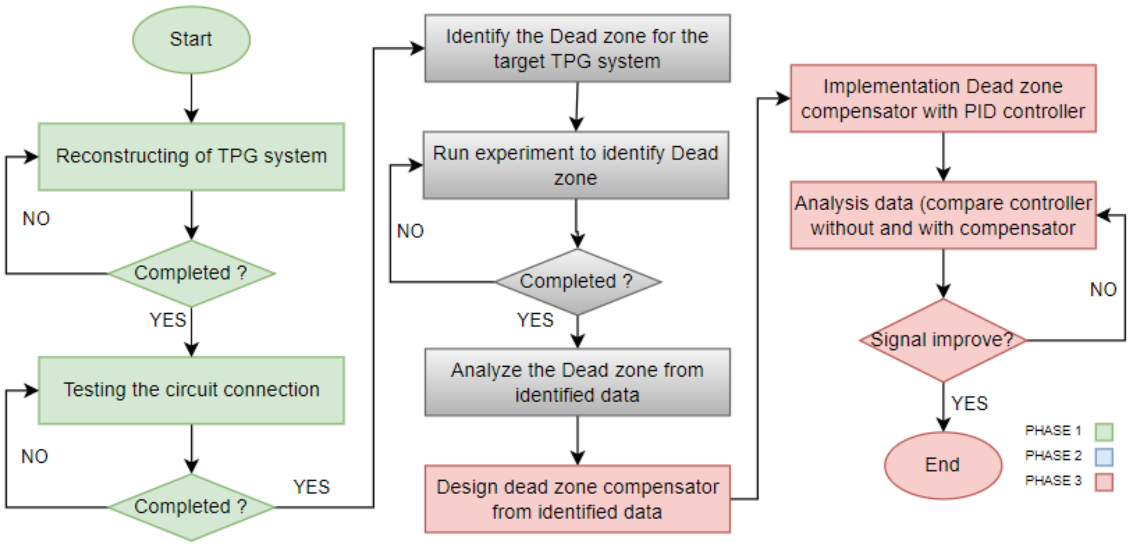

Figure 3.1: Flow of project activities

3.2 TPG SYSTEM SETUP

The pneumatic model is constructed to understand the flow of process from input until output. Constructing is important to help clarify what existing system does and can used as a basis for discussing its strengths and weaknesses. Figure 3.2 shows the Control system diagram of pneumatic system from input (air compressor) until output (pneumatic actuator).

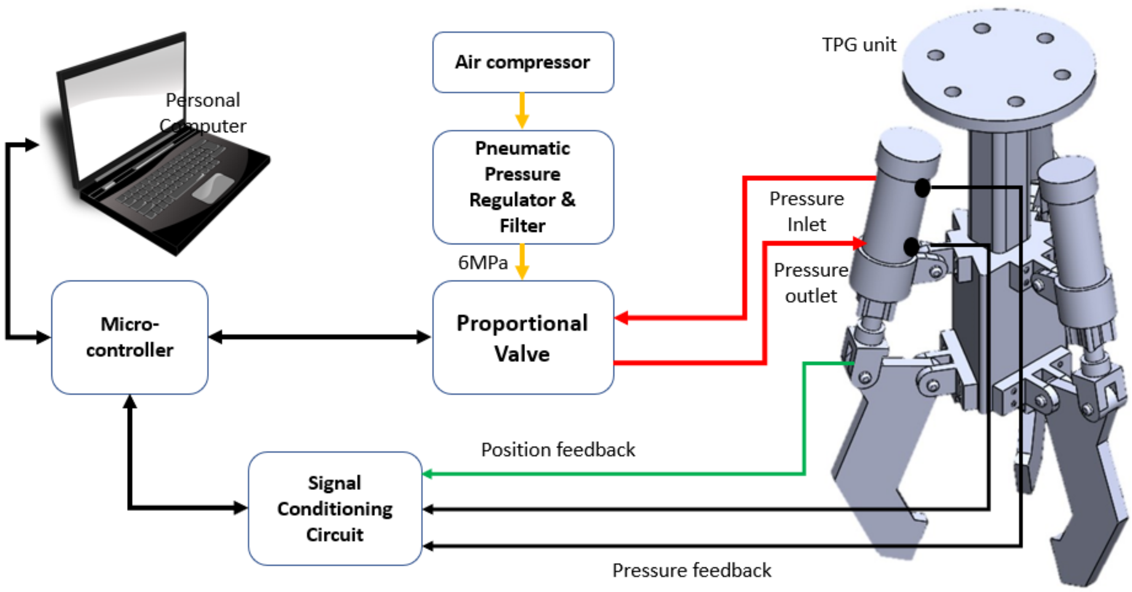

Figure 3.2: Control System Diagram of TPG

In the control system diagrams Figure 3.3, the components are arranged the way that the flow of energy always flows from the bottom up. Other than the computer unit, the air compressor, and the direct current (DC) power supply, the pneumatic proportional valve, pressure sensors, and encoder are the most crucial parts of this platform. The system is set up with multiple input and single out (MISO), with one control input for the microcontroller board's control of a pneumatic proportional valve and two outputs for feedback measurement from rotary encoders for rod-piston displacement and pressure transducers for feedback on cylinder piston pressure. [17]

A 5/3-way pneumatic proportional valve is the control element where it the targeted component for this project and rotary encoder and pressure transducers at the pneumatic cylinder inlet and outlet provide the signal conditioning circuit with two measured outputs as feedback. Air compressor is the main power source to the TPG along with pressure regulator and filter that use for air pressure adjustment. Force transducers have been set as another additional sensor. In order to assess external disturbances for experimental research, this sensor measures the pressure at the tip of the pneumatic grasper. All three types of transducers provide signals to a 32-bit microcontroller, which then sends signals to a pneumatic proportional valve with a specially designed signal conditioning system.

A personal computer is used to send and receive signals to a 32-bit microcontroller in real-time using a MATLAB/SIMULINK software. This TPG setup was set up according to the equipment specification that listed in Table 3.1

Table 3.1: List of Components in TPG

Equipment	Value
Air Compressor	SWAN SVP202 Air Compressor
Pneumatic Proportional Valve	Festo MPYE-5-1/4-010-B
Pneumatic Pressure regulator & Filter	AirTAC SR200
Pneumatic Cylinder	CKD Air Cylinder CAC4_A-50B-75-Y/Z
Pneumatic Pressure Transducer	Festo SPTW-P10R-G14-A-M12
Rotary Encoder	Rotary encoder – 500ppr

The creation of a signal conditioning system is critical for collecting high-quality, accurate signals as well as protecting the microcontroller board from overcurrent and overvoltage. The current 32-bit microcontroller is 3.3v tolerant, meaning it can only accept 3.3v at its maximum. The signal range for all devices utilized for TPG pneumatic system control is shown in Table 3.2. The amplifier module is designed with a very low tolerant resistor (0.1 percent tolerant) to generate a more precise and cleaner signal output for both pressure transducer and pneumatic proportional valve signals. The circuit board of layout design for the customize signal conditioning system for TPG control and the complete detail schematic circuit for the customize signal conditioning system that has been developed for TPG control system were shown in Appendix B.

Table 3.2 Signal Conditioning System Configuration

Device	Signal Voltage	Signal Conditioning	Signal Pin
Pressure Transducer	0-10V	Amplifier	Analog Pin
Rotary Encoder	0-5V	Level Shifter	Digital Pin
Force Transducer	0-5V	Level Shifter	12C
Pneumatic Proportional Valve	0-10V	Amplifier + MCP4725	12C

3.3 DEAD ZONE IDENTIFICATION

Dead zone identification has been introduced to analyze the presence of the dead zone. An open loop test of actuator system with proportional valve and pneumatic actuator is proposed with a slow cos control signal(10 volts of amplitude and 50 seconds period) expressed by equation 3.1 [18]

$$u(t) = -10cos\left(\frac{2\pi}{50}\right) \qquad 3.1$$

The slopes of dead zone, me and md can be regulated such as me = md = 1 in a compensation block in the controller with the control signal set in range of 0 to 10 volts

Figure 3-3 show the flowchart of dead zone identification where the open loop equation applied in the Math model code using SIMULINK software. Next, math model code will be test to see the signal for pressure versus control signal produce from pneumatic valve. If the cross section of pressure 1 and pressure 2 below 3pa, the significant data will be verified. The data will be use in designing the compensator for dead zone.

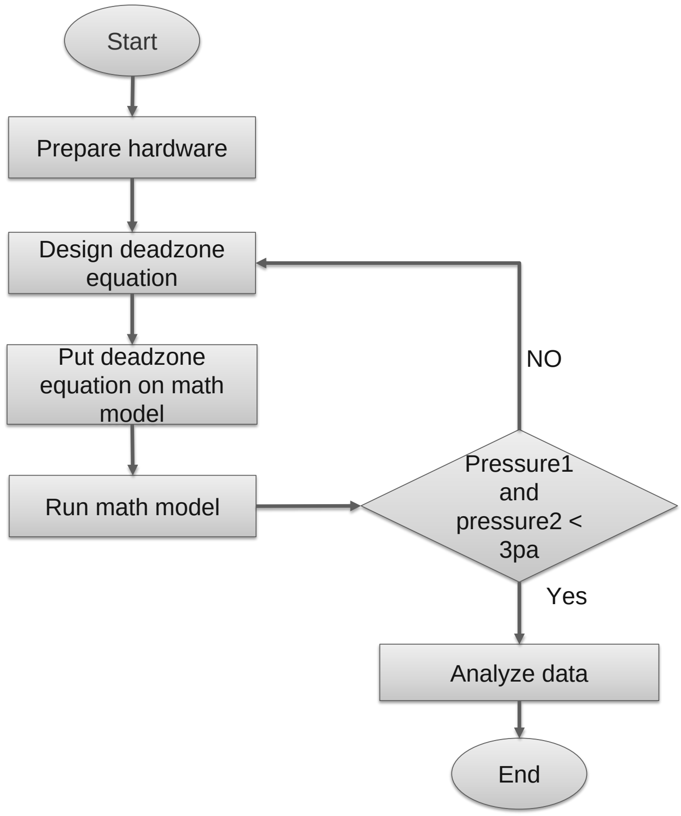

Figure 3.3: Flowchart of Dead zone Identification

3.4 DEAD ZONE COMPENSATOR DESIGN

Dead zone can be defined a static state of input-output relationship where there is no output for the range of input value. The mathematical model for dead zone in pneumatic servo system has been derived as below: [19]

$$u_{zm} = \begin{cases} md(U(t) - zmd & if\ U(t) \geq zmd \\ 0 & if\ zme < U(t) < zmd \\ me(U(t) - zme & if\ U(t) \leq zme \end{cases} \quad 3.1$$

where, Uzm is the output and U is the input in general, zmd is right limit, zme is left limit of dead zone, md right slope, me left slope are not equal. [19] Figure 3.4 shows a graphical representation of the dead zone.

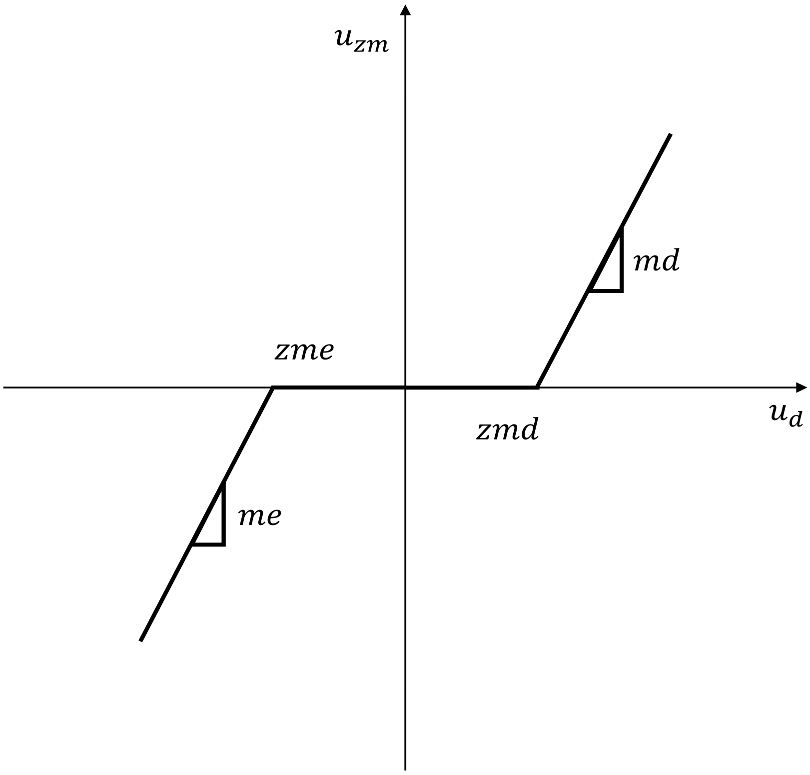

Figure 3.4: Graphical representation of Dead Zone [19]

The use of a dead zone compensation improves the control signal and reduces position inaccuracies and lag. To correct the dead zone non-linearity, an inverse of the dead zone function is added to the controller output to cancel or compensate the dead band effect in the system. If the dead zone is known (zme,zmd,me and md) and the valve dynamics are rapid enough to ignore, this method can be employed.

Therefore, this study has taken the inverse equation of dead zone which described from the equation 3.2 to apply it in the system.[10] Where, desired signal input ($u_d(t)$), smoothness width used in compensation (lc) and compensated output signal (u_{cm}).[20]

$$u_{cm} = \begin{cases} \dfrac{u_d(t)}{md} + zmd & if\ u_d(t) \geq lc \\ \dfrac{u_d(t)}{me} + zme & if\ \ u_d(t) \leq -lc \\ \left(\dfrac{zmd + \dfrac{lc}{md}}{lc}\right) u_d(t) & if\ 0 \leq u_d(t) \leq lc \\ \left(\dfrac{zme + \dfrac{lc}{me}}{lc}\right) u_d(t) & if -lc \leq u_d(t) \leq 0 \end{cases} \qquad 3.2$$

This method is useful in order to avoid the discontinuity near to the zero position and also suddenly switching between zmd and zme. Figure 3-5 show the graphical of the dead-zone compensation.

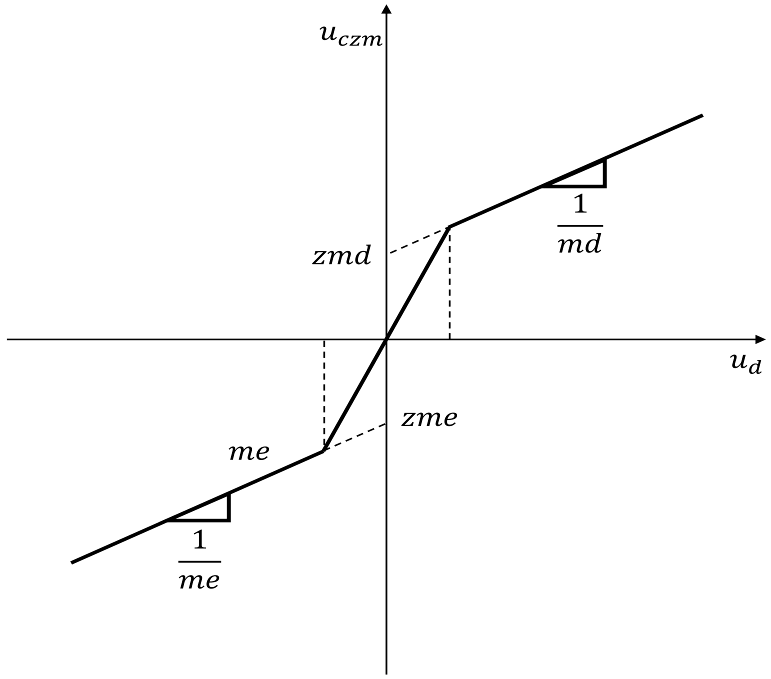

Figure 3.5: Graphical representation of Inverse Dead Zone [19]

This compensator equation applied to the control system, as PID control is chosen as controller as shown in Figure 3.6. This compensator was designed and put before the plant that consists of proportional valve pneumatic actuator. It will act as filter to remove the dead zone effect in the system.

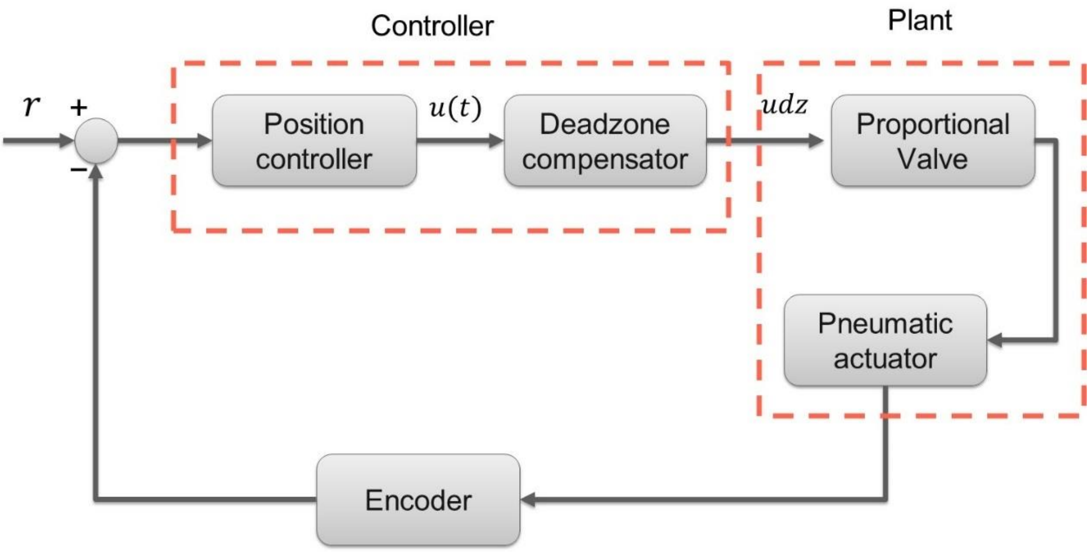

Figure 3.6: Dead zone compensator in control system

In dead zone compensation, value was use me = md = 1 and lc = 0.05. The lc value is a balance between control signal quality and dead zone compensating effectiveness. Dead zone compensation is inadequate if lc is too large, for example. Oscillations in the control signal can arise near the origin if lc is too small. While the value for right limit (zmd) and left limit of dead zone (zme) are same.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter will be focusing the current result obtained during the project period. This project is to verify and analyze the effectiveness of the dead zone compensator with implemented controller. An experiment was done to identify and analysis the dead zone value in the system. The designed compensator was verified by compared the generated signal with system without dead zone compensator.

4.2 EXPERIMENTAL SETUP

In this project, the arrangement of the experimental from the input (air compressor) to output (pneumatic actuator) as shown in Figure 4.1. The 5/3-way proportional valve choose as the control element of this experiment. This experiment will focus on the transient response of the proportional valve.

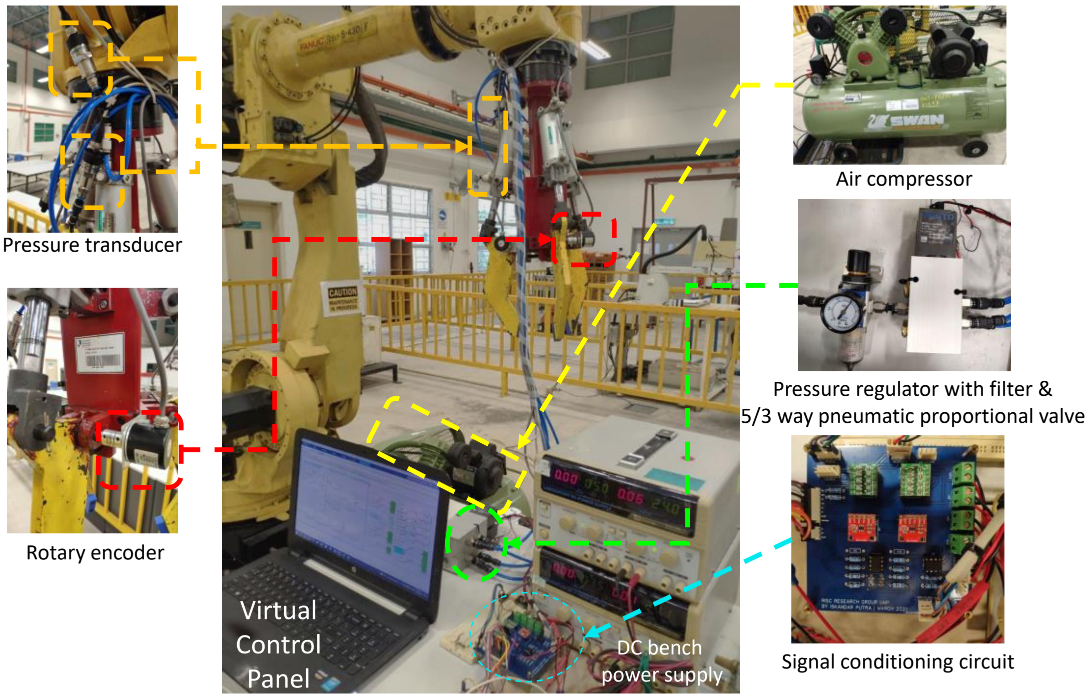

Figure 4.1: Actual experimental setup

4.3 DEAD ZONE ANALYSIS

In order to identified the dead zone, an experiment open loop test need to be done to get the significant value of the dead zone before design the compensator. Figure 4.2 show the dead zone analysis for left pressure and right pressure.

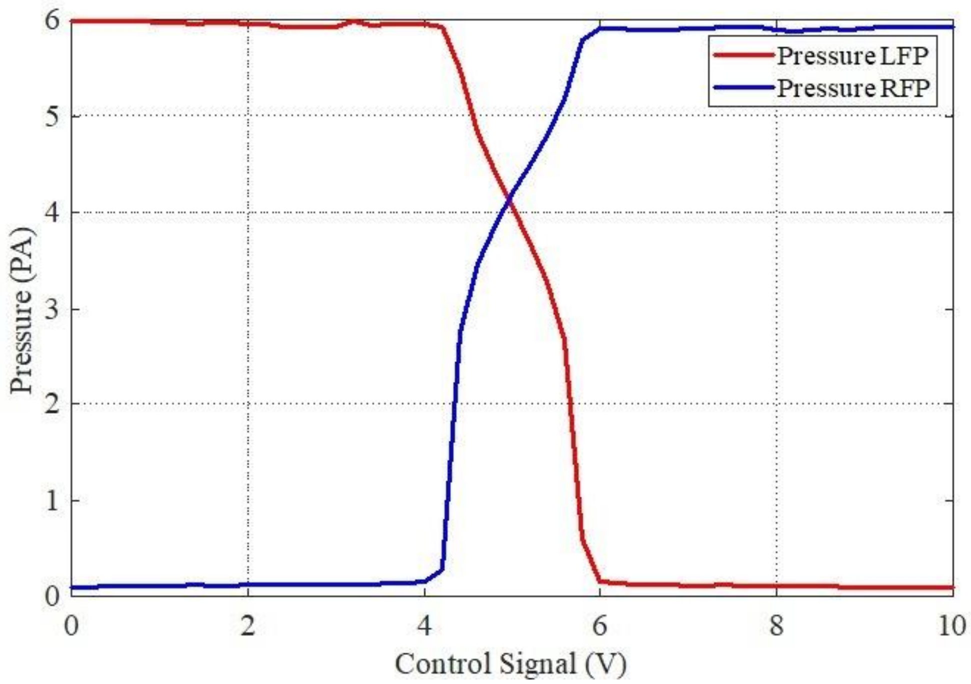

Figure 4.2: Result of identified dead-zone for single ppvdc on TPG's finger

In the figure 4.2, two data need to be taken to get intersecting points from left pressure and right pressure. From this result, we can get the value of left dead zone (zme) and right dead zone (zmd). The values achieved were left dead zone zme = 0.88 V and right dead zone zmd = 0.88V. The offset value was 5 V and it near to the center. When the control signal crosses the left or right limits of the dead zone for the pressure right and left, the pressure changes abruptly. The offset identification of the proportional valve is determined by the midpoint of the pressure change owing to internal leaks [9].

4.4 DEAD ZONE IMPLIMENTATION & VALIDATION

In this section are shown the conditions that experimental tests were carried out in position control which PID controller was implemented to comparison between controller without and with dead zone compensator in TPG system. Experimental results obtained from dead zone compensation to trajectory tracking control tests to sinusoidal trajectory are shown in Figure 4.3.

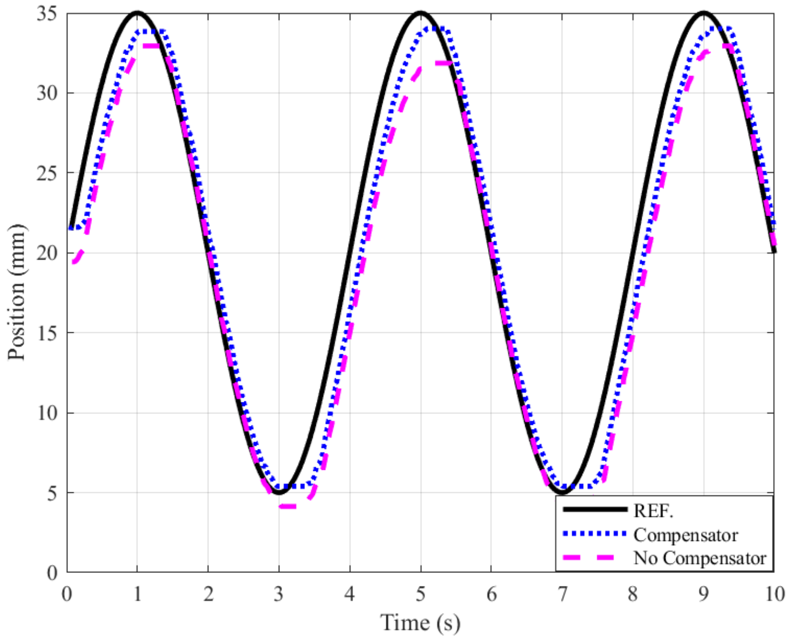

Figure 4.3: Sample of TPG's displacement tracking control with angular input trajectory

The expressiveness of control performance is limited by nonlinearity. The signal has a large position lag without the compensator. After adjusting the dead zone compensator, the latency is reduced, and the executed trajectories are close to the desired trajectories. So, there is improvement on transient response for TPG system than system without compensator.

Figure 4.4 shows the result of position obtained to step trajectory, for situation without and with dead zone compensator. The analysis of these performances permits to see the improvement of compensator for step response. These experimental results for this section confirm the importance of dead zone compensator in TPG system.

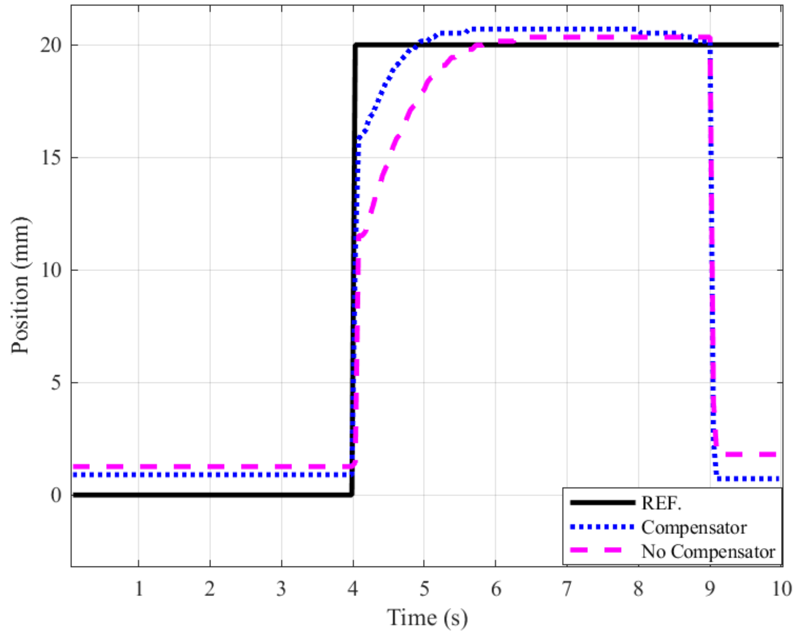

Figure 4.4:Step tracking control with angular input trajectory

The reference step trajectory position from 0mm to 20mm. For controller without compensator, the position of trajectory reacts slowly follow the reference signal and has a lag effect from 4 seconds until 6 seconds. On the other hand, controller with compensator show the improvement of response where signal follow closer to the reference signal and the lag is minimized.

Table 4.1 show the controller performance of step response trajectories with compensator and without compensator in rise time, settling time and overshoot.

Table 4.1: Controller Performance With and Without Compensator

Controller	**Compensator**	**Without Compensator**
Rise Time	4.2ms	35.3ms
Settling Time	9.0864s	9.0904s
Overshoot	2.775mm	1.03mm

From Figure 4.5, it shows that there is position shift in control signal between the Compensator and the Control Signal without Compensator. The controller generates a control signal that allows the actuator to continue moving despite reduced position error.

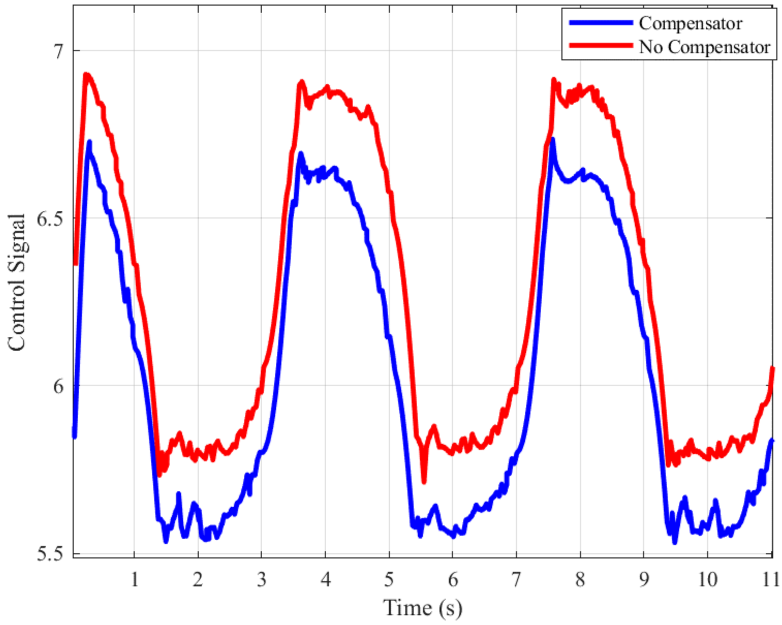

Figure 4.5: Result for Control Signal to sinusoidal trajectory

Table 4.2 show the control parameters for the PID control are based on random tuned to get the best signal response.

Table 4.2: Parameter of PID Controller

Parameter	**PID**
K_p	0.3
K_i	0.2
K_d	0.00001

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

This project analyses the dead zone influence in the pneumatic system, design the compensator by establish the inverse equation for the dead zone, and validation by compare the data output for the compensator along with controller. The development of the dead zone compensator with PID controller as the close-loop controller can give effect on the system to improves the performance of trajectory tracking with step and sinusoidal trajectories during pneumatic system operation. The positioning response with compensator show improvement in reducing the lag and trajectories near the desired trajectories. This compensator able filter out the dead zone effect in pneumatic robot grasper unit. The obtained results show that the dead zone is a significant pneumatic non-linearity, whose compensation is essential to achieving precision control.

5.2 RECOMMENDATION FOR FUTURE RESEARCH

For the future research and development on dead zone compensator on pneumatic system can be done by using another method or approach that easier in order improve the system nonlinear. Beside the non-linearity problem, the Pneumatic system has a slow response that need to be improve. So, another controller can be used to make the system more durable and more effective.

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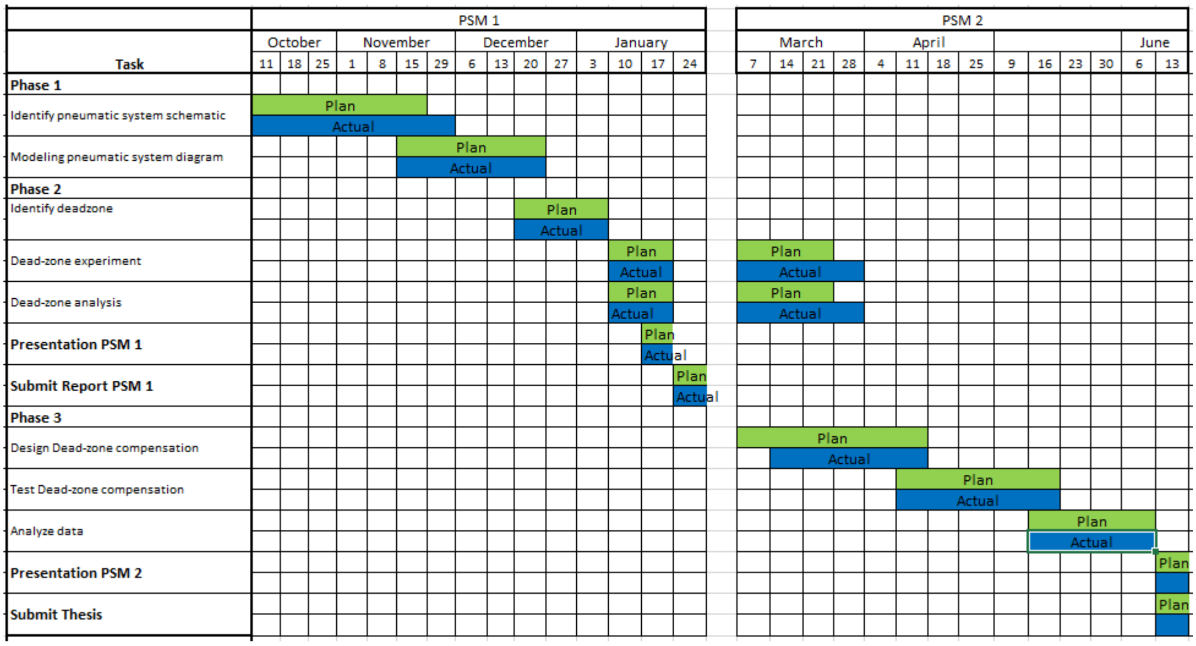
APPENDIX A

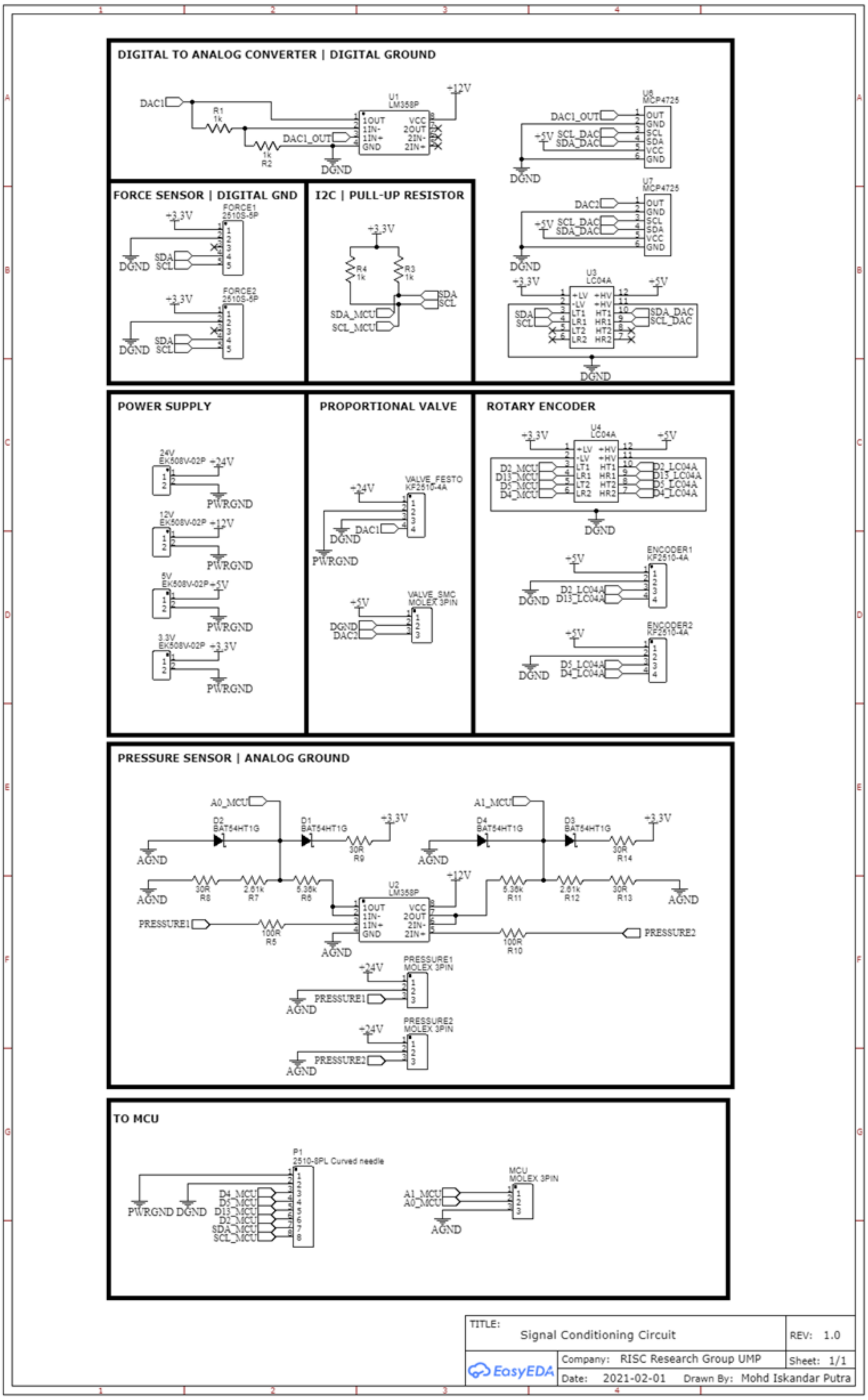
Gant Chart



APPENDIX B

Signal Conditioning Circuit

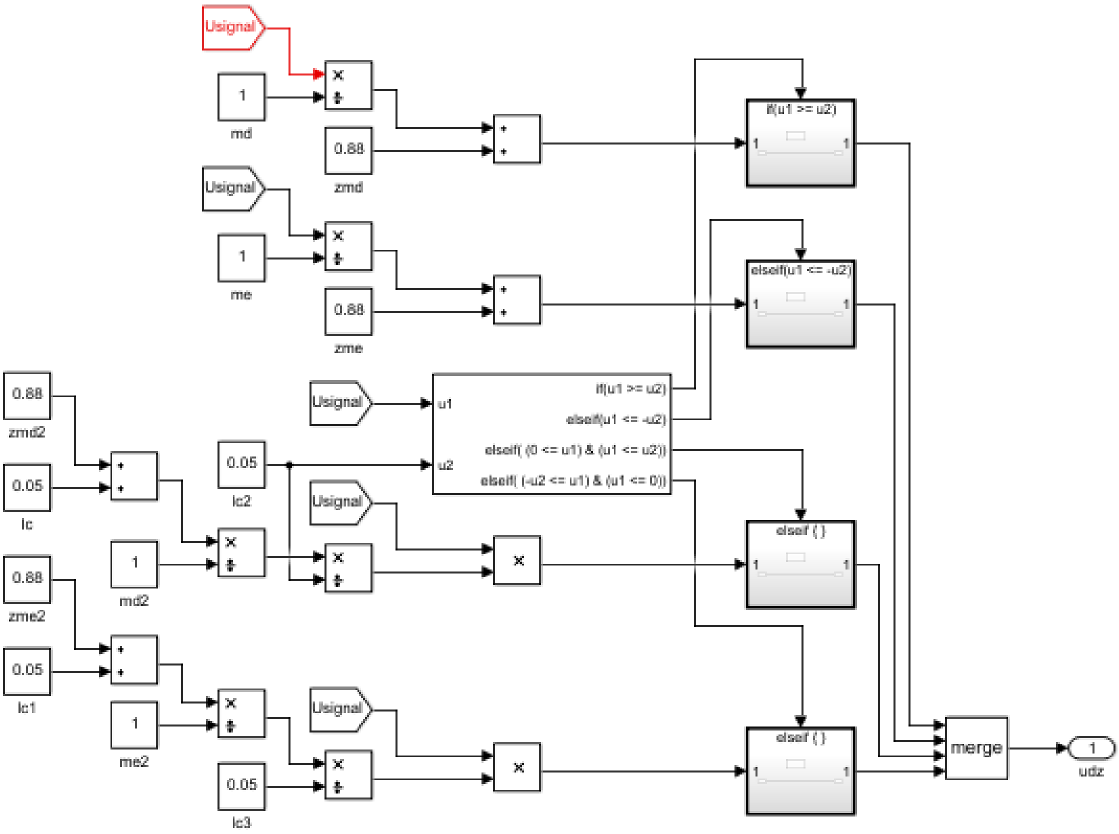
Signal Conditioning System Schematic

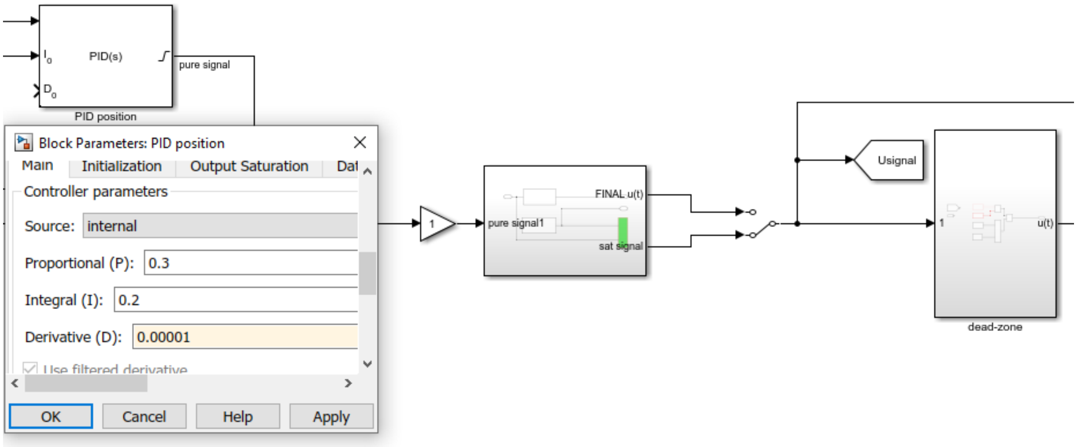


Cost Planning for 1 finger Gripper

BIL	ITEM	QUANTITY	PRICE PER UNIT	TOTAL PRICE
1	Pneumatic proportional valve Model: FESTO MPYE-5-1/4-010-8	1	RM3300.00	RM3300.00
2	Pneumatic pressure transmitter Model : FESTO SPTW-B@R-G14-A-M12	2	RM610.00	RM1220.00
3	Force Transmitter Model : HONEYWELL FSAGPNXX010WC2C3	1	RM705.00	RM705.00
4	Microcontroller	1	RM150.00	RM150.00
5	Pressure regulator & filter	1	RM60.00	RM60.00
6	Fitting: -Valve -Pressure sensor	3 2	RM5.00	RM40.00
7	Signal conditioning circuit PCB	1	RM250.00	RM250.00
8	Rotary encoder	1	RM450.00	RM450.00
9	Silencer/exhaust fitting	2	RM4.00	RM8.00
10	Connecting tube	10meter	RM2.50	RM25.00
11	Air compressor	1	N/A	N/A
			TOTAL	RM6208.00

Dead zone compensator design using SIMULINK




PID(s)
I_0
D_0
pure signal
PID position
Block Parameters: PID position
Main
Initialization
Output Saturation
Controller parameters
Source: internal
Proportional (P): 0.3
Integral (I): 0.2
Derivative (D): 0.00001
Use filtered derivative
OK
Cancel
Help
Apply
1
pure signal1
FINAL u(t)
sat signal
Usignal
u(t)
dead-zone