PARAMETER IDENTIFICATION OF SERVO-PNEUMATIC POSITION CONTROL SYSTEM UTILIZING LEAST SQUARE ESTIMATE (LSE) APPROACH

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Electronics)

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Signature : ______________________________

Author : NUR’IFFAH BINTI MOHAMED AZMI

Date : 23 NOVEMBER 2009

Specially dedicated to my beloved mother, father

Mrs. Ros Lindawati binti Md Nadzir

Mr. Mohamed Azmi bin Ramli

and

my brothers & sisters

ACKNOWLEDGEMENTS

In the name of Allah S.W.T, the Most Gracious, the Ever Merciful. Praise is to Allah, Lord of the Universe and Peace and Prayers be upon His final Prophet and Messenger Muhammad s.a.w.

This thesis has only been made possible with the help of many parties. Above all, I would like to express my appreciation to my supervisor, Mr. Mohd. Syakirin bin Ramli for his guidance, ideas, advice and patience in supervising this project.

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ABSTRACT

This project focused on the parameter identification of Servo-Pneumatic Position Control System (SPPCS) utilizing Least Square Estimate (LSE) approach. The obtained mathematical is analyzed in terms of transient and steady-state response. Presented method is based on the transfer function estimation, these were identified in calculation of the collection of the input and output data by using the LSE method approach. The mathematical model's parameter is estimated from the calculation. The mathematical model estimation is implemented using the MATLAB's simulation. The output performance from both MATLAB and Visual Basic (VB) will be compared and if the result is similar and the average error, e is smaller, then the results are accepted. The result obtained is a mathematical model that will be used as parameter identification for SPPCS. In the future, this parameter identification can be used to represent the whole of SPPCS in the MATLAB's simulation to replace the actual hardware.

ABSTRAK

Kertas kerja ini bertujuan untuk mengenalpasti satu model matematik (persamaan matematik) untuk *Servo-Pneumatic Position Control System* (SPPCS) melalui kaedah *Least Square Estimate (LSE)* dan juga menganalisis bentuk graf bagi aktiviti system ini dalam bentuk *transient* and *steady-state response*. Kaedah yang digunakan adalah berasaskan pengiraan *transfer function.* Bagi melaksanakan kaedah ini matlumat daripada *input dan output* sistem ini perlu direkodkan. Persamaan matematik untuk sistem ini dapat dikenalpasti daripada kaedah LSE. Dalam mengenalpasti persamaan matematik ini, perisian MATLAB dan perisian Visual Basic digunakan. Keluaran output bagi sistem ini dibandingkan dengan menggunakan MATLAB's simulation. Berdasarkan model simulasi dan model sebenar SPPCS, persamaan matematik dapat dibuktikan dan dapat diaplikasikan dalam kehidupan sebenar. Diakhir projek ini, sistem ini berupaya menunjukkan model matematik (persamaan) untuk SPPCS dengan kaedah LSE dan keluaran output bagi system dapat ditunjukkan dalam bentuk *transient* and *steady-state response*. Model metametik ini boleh digunakan bagi mewakili keseluruhan SPPCS dalam bentuk simulasi MATLAB untuk masa hadapan.

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LIST OF SYMBOL

$u(k)$ - Input Data Sequences

$y(k)$ - Output Data Sequences

p - Parameter Vector

M - Vector of Regression Variables

mv - Manipulated Variables

cv - Controlled Variable

LIST OF ABBREVIATION

I/P - Input
O/P - Output
PLC - Programmable Logic Controller
SPPCP - Servo-Pneumatic Position Control System
LSE - Least Square Estimate

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CHAPTER 1

INTRODUCTION

1.1 Introduction

1.1.1 Parameter Identification

There is a mathematical model for just about everything. Computer programs have been written to describe the flow of water in channels, the flow of electricity in conductors of strange shape, the growth of plants, the population dynamics of ants, the distribution of stress in the hulls of ships and on and on. Modeling programs generally require data of four main types.

These are:

- Fixed data
- Parameters
- Excitations
- Control data

The purpose of a mathematical model is to produce numbers. These numbers are the model's predictions of what a natural or man-made system will do under a certain excitation regime. It is for the sake of these numbers that the model was built, be it a ten line program involving a few additions and subtractions, or a complex numerical procedure for the solution of coupled sets of nonlinear partial differential equations.

Where a model simulates reality it often happens that the model-user does not know what reality is; in fact models are often used to obtain reality by comparing the numbers that they produce with numbers obtained from some kind of measurement. Thus if a model’s parameter or excitation data are “tweaked”, or adjusted, until the model produces numbers that compare well with those yielded by measurement, then perhaps it can be assumed that the excitations or parameters so obtained have actually told us something which we could not obtain by direct observation.

1.1.2 Least Square Estimate (LSE)

The least square method is widely used to find or estimate the numerical values of the parameters to fit a function to a set of data and to characterize the statistical properties of estimates. It exists with several variations: Its simpler version is called ordinary least squares (OLS), a more sophisticated version is called weighted least squares (WLS), which often performs better than OLS because it can modulate the importance of each observation in the final solution. Recent variations of the least square method are alternating least squares (ALS) and partial least squares (PLS).

The biggest advantage of nonlinear least squares regression over many other techniques is the broad range of functions that can be fit. Although many scientific and engineering processes can be described well using linear models, or other relatively simple types of models, there are many other processes that are inherently nonlinear. There are many types of nonlinear models, on the other hand, that describe the asymptotic behavior of a process well. Like the asymptotic behavior of some processes, other features of physical processes can often be expressed more easily using nonlinear models than with simpler model types.

Being a "least squares" procedure, nonlinear least squares has some of the same advantages (and disadvantages) that linear least squares regression has over other methods. One common advantage is efficient use of data. Nonlinear regression can produce good estimates of the unknown parameters in the model with relatively small data sets. Another advantage that nonlinear least squares shares with linear least squares is a fairly well-developed theory for computing confidence, prediction and calibration intervals to answer scientific and engineering questions. It is perhaps the most widely used technique in geophysical data analysis, which can be applied to any problem. In least squares the parameters to be estimated must arise in expressions for the means of the observations. When the parameters appear linearly in these expressions then the least squares estimation problem can be solved in closed form, and it is relatively straightforward to derive the statistical properties for the resulting parameter estimates.

1.1.3 Servo -Pneumatic Position Control System

Modern servo-pneumatic positioning technology has made significant inroads in the automated manufacturing environment. The advantages cited by end users include the speed of motion, low cost of installation and maintenance, cleanliness, and the simplicity of operation of these systems relative to other similar hydraulic and electro-mechanical technologies. The robustness of servo-pneumatic technology solutions is limited by the positioning accuracy of current system controllers. Servo-pneumatic controllers typically rely on sophisticated control algorithms that accommodate the highly non-linear nature of pneumatic actuator operation.

Advantages cited by end users of these systems include the speed of motion, low cost of installation and maintenance, cleanliness, and the simplicity of operation of these systems relative to other similar hydraulic and electro-mechanical technologies. These characteristics have a very positive impact on the use of these systems in the educational laboratory environment. The robustness of these servo-pneumatic actuator systems is typically limited only by the positioning accuracy of system controller.

The servo-pneumatic system consists of the following components:

- PLC (CJ1M-CPU 12)
    - A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or lighting fixtures.

- Cylinder Positioner
    - Cylinder positioner using pneumatic system is mechanical devices which produce force, often in combination with movement, and are powered by compressed gas.

- Electro-Pneumatic Regulator
  - An electro-pneumatic regulator system for controlling a pressure and a current that supplied from a source on the basis of a level of an input electric signal
- LVDT Transducer
  - The linear variable differential transformer (LVDT) is a type of electrical transformer used for measuring linear displacement.

1.2 Problem Statement

In this project, the major statement consists of Parameter Identification and Servo-Pneumatic Position Control System. Pneumatic actuators provide solutions through motion technology in many applications. A wide range of industries now rely on pneumatics since pneumatic actuators have distinct advantages: clean for environment, rapid point-to-point positioning, high load-carrying capacity-to-size ratio, mechanical simplicity, low cost, and ease in maintenance. For Parameter Identification, it is useful for computer simulation, mechatronic design and also for control algorithm design.

1.3 Objective

The main objectives of this project are:

- To identify and obtain the mathematical characteristic of the Servo-Pneumatic Position Control system using a suitable parameter identification and estimation techniques.
- To analyze the performance in terms transient and steady-state response

1.4 Scope of Project

This project is to identify a mathematical model for Servo-Pneumatic Position Control using Least Square Estimate that can be used by implement the parameter equation in MATLAB’s Simulation. As a machine’s performance is a vital factor for a big production line, this project will examine the efficiency and performance of a pneumatic cylinder by comparing the experimental model with real model . Then, the performance of the system will show in term of transient and steady state respond using GUI software. Thus, the focuses of this project are as stated below:

- To set up OMRON CJ1M-CPU 12 Programmable Logic Control and the PLC card.
- To develop the GUI that will analyze the experimental performance in terms of graph.
- To determine a mathematical characteristic that similar with model of the servo-pneumatic system by using parameter identification.
- To perform the simulation of this project by using MATLAB’s Simulink.
- To compare the simulation and experimental in term of the output response.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focused on the literature review for each component in this project. All the component is described in details based on the finding during the completion of this project. The device and method that will be discussed about application in this chapter are:

- Servo-Pneumatic Position Control System
- Parameter Identification
- Programmable Logic Controller
- Least Square Estimate
- MATLAB’s Simulation
- Graphical User Interface (GUI)

2.2 Servo -Pneumatic Position Control System Application

Modern servo-pneumatic positioning technology has made significant inroads in the automated manufacturing environment. Pneumatic actuators can move large loads and can move those loads at rapid speeds if desired. Pneumatic drives can be a cheaper alternative to electric and hydraulic systems, especially for relatively light loads. Pneumatic systems are used for the applications where the required power level is up to 3 kW and required dynamics is up to 70 Hz [1]. Pneumatic actuators also tend to be more durable. The Positioning Cylinder operates on the same principles as the typical valve positioner widely used in the process industries. A precisely regulated air pressure known as "instrument air" is piped to the positioner.

The pneumatic actuator is very common in industrial application because it is less expensive and simpler when compared with electro mechanical servo drives with equal power density. Applications with pneumatic actuators are limited when precision and versatility are needed. Pneumatic actuators have many control difficulties that are caused by their highly non linear system behavior characterized by the compressibility of air, low inherent damping, dead zone, position dependent stiffness, time-dependent frictional effects in the actuator and non linear control valve behavior with discontinuities, which result in instability, unsatisfactory transient response, large positioning errors and limit cycles. [2].

This research is more on the determination of the parameter identification of servo-pneumatic system using fuzzy logic as the controller. The method that been use in this research is more on the parameters that depend on the cylinder being used, and can be estimated from step input responses of the system. The Festo rodless cylinder will be used to illustrate the estimation technique.

The disadvantages of the pneumatic servo positioning systems are that, they are inherently nonlinear, that the compressibility of air results in very low stiffness (compared with the hydraulic system) leading to low natural frequency, and that low damping of the actuator system makes it difficult to control, especially with the presence of nonlinearities, time varying effects and position dependence. The pneumatic servo positioning system contains several nonlinearities such as the air flow-pressure relationship through the variable area orifice of the valve, the compressibility of air, and the (nonlinear) friction between the contacting surfaces of the slider-piston system. To overcome the disadvantages of a pneumatic servo positioning system and for the purpose of control and simulation, all the nonlinearities of the system must be modeled: this is the aim of this paper [3].

The pneumatic components as well as the mechanical components of the test facility are described by linear and by nonlinear mathematical models. These model equations are used as identification hypotheses in the identification process. A comparison of time histories obtained by computer simulations of the nonlinear test facility model and by laboratory experiments shows that this nonlinear test facility model provides a realistic identification hypothesis for the estimation experiments. Based on different model hypotheses the inertia parameters of the test table and of the payload have been successfully identified from laboratory experiments [4].

This article/journal is about the servo-pneumatic that apply on a robot and this research is based on developing the servo-pneumatic cylinder as actuator that will be manipulating by the sensor. The performance for this system is more on the behavior of the robot. The objective on this research is more on the application of servo-pneumatic on a robot and sensor as manipulator then the low-cost and high-performance as a result.

2.3 Parameter Identification Application

A parametric dynamic model of a pneumatic servo system is useful for computer simulation, mechatronic design and control algorithm design. Parameter identification is known as the equation that will represent the behaviour/movement for the system that applies. The mathematical model can be applied on many systems such as induction machine, power system, inverted pendulum, and etc.

Parameter estimation or system identification of continuous-time systems is an important subject which has numerous applications ranging from control and signal processing, to astrophysics and economics. This is because most physical systems or phenomena are continuous time in nature, for example in many control applications in astrophysics, and in economics. Due to the advent of digital computers, research for control and identification of these continuous-time systems and processes has concentrated on their discretized models with samples from the underlying continuous-time system inputs and outputs. Recently, interest in identification of continuous-time systems and processes has arisen. One particularly interesting and practical scenario is the identification of continuous-time systems using discrete data [5].

Design of high-performance control and monitoring algorithms for induction machines (IM) assumes availability of reasonably accurate mathematical models describing their electrical and mechanical properties. Since the differential equations governing the dynamics of the IM are well known, the modeling problem is reduced to parameter estimation. It is recognized that parameter estimation, or identification as it is called in Control Engineering, of the induction machine (IM) is a difficult task.

Power system planning and operation studies rely heavily on the correctness of power system simulation results, which, in turn, are dependent greatly on the accuracy of the system model parameters. In many cases, the dynamic parameters from the manufacturer are unavailable or they may be inaccurate. Thus, the estimation and periodic verification of the synchronous machine parameters and control parameters are necessary for guaranteeing reliable simulations of a power system model [6].

The ultrasonic motor is a new type of motor. In recent years, some mathematical models for the ultrasonic motor have been reported. However, these models are very complex to apply to control of the motor, and therefore speed or position controllers for this type of motor have been designed based on proportional and integral controllers or fuzzy controllers. Since these controllers cannot take account of the motor’s dynamics, a simple and convenient mathematical model of the ultrasonic motor is necessary in order to achieve high control performance [7].

Parameter identification is identifying the close model by analyzing the input data and the output data. There are many method of the system identification, including non-parameter identification, parameter identification (levy method, least square method, accessorial variable method, NN non-linear identification). Parameter identification is simply and the model of identification is universal, so we decide to use the parameter identification to identify the model of the system [8].

As we can see, every machine/system has its own parameter identification. Also it does easily can be applied on software/MATLAB as simulation that will represent the actual system.

2.4 Programmable Logic Controller Application

A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of electromechanical processes, such as control of machinery on factory assembly lines, control of amusement rides, or control of lighting fixtures. PLCs are used in many different industries and machines such as packaging and semiconductor machines. Programmable logic controllers are widely used in industry and process control. Programmable logic controllers are used in a wide spectrum of applications from factory automation to waste water treatment plant controls and from chemical process plant control to engine management systems. PLCs are used throughout industry to control and monitor a wide range of machines and other movable components and systems.

The uses of programmable logic controllers are equipment status, process control, chemical processing, equipment interlocks, machine protection, smoke detection, envelope monitoring, gas monitoring, and personnel safety. As a part of process control, a PLC is used to monitor input signals from a variety of input points (input sensors) which report events and conditions occurring in a controlled process. PLCs are well-adapted to a range of automation tasks. These are typically industrial processes in manufacturing where the cost of developing and maintaining the automation system is high relative to the total cost of the automation, and where changes to the system would be expected during its operational life. PLCs contain input and output devices compatible with industrial pilot devices and controls, then need a little electrical design and the design problem centers on expressing the desired sequence of operations in ladder logic notation.

For example, a PLC can monitor such input conditions as motor speed, positioning, temperature, pressure and volumetric flow. Its associated peripherals are designed so that they can be easily integrated into an industrial control system and easily used in all their functions. The functions of PLC are same at difference operation system, by changing the electrical design and the sequence of operation in term of ladder diagram.

2.5 Least Square Estimate (LSE)

The least square methods (LSM) are probably the most popular technique in statistics. This is due to several factors. First, most common estimators can be casted within this framework. For example, the mean of a distribution is the value that minimizes the sum of squared deviations of the scores. Second, using squares makes LSM mathematically very tractable because the Pythagorean Theorem indicates that, when the error is independent of an estimated quantity, one can add the *squared* error and the *squared* estimated quantity. Third, the mathematical tools and algorithms involved in LSM have been well studied for a relatively long time.

LSM is one of the oldest techniques of modern statistics, and even though ancestors of LSM can be traced up to Greek mathematics, the first modern precursor is probably Galileo. The modern approach was first exposed in 1805 by the French mathematician Legendre in a now classic memoir, but this method is somewhat older because it turned out that, after the publication of Legendre's memoir, Gauss (the famous German mathematician) contested Legendre's priority. Gauss often did not publish ideas when he thought that they could be controversial or not yet ripe, but would mention his discoveries when others would publish them (the way he did, for example for the discovery of Non-Euclidean geometry). And in 1809, Gauss published another memoir in which he mentioned that he had previously discovered LSM and used it as early as 1795 in estimating the orbit of an asteroid.

A dynamic model and a design method for an accurate self-tuning pressure regulator for pneumatic-pressure–load systems have some special characteristics such as being nonlinear and time-varying. A mathematical model is derived, which consists of a chamber continuity equation, an orifice flow equation and a force balance equation of the spool. Based on a theoretical analysis of the system dynamics, a three-order controlled auto-regressive moving average (CARMA) model is used to describe the practical pressure–load systems. Then a linear quadratic Gaussian self-tuning pressure regulator is designed to realize an adaptive control of pressure in the chamber. Because the system parameters are time-varying and the system states are difficult to detect, the recursive forgetting factor least-squares algorithm and the Kalman filtering method are adopted to estimate the system parameters and the system states [9].

A somewhat bitter anteriority dispute followed (a bit reminiscent of the Leibniz-Newton controversy about the invention of Calculus), which, however, did not diminish the popularity of this technique. The use of LSM in a modern statistical framework can be traced to Galton who used it in his work on the heritability of size which laid down the foundations of correlation and (also gave the name to) regression analysis. The two antagonistic giants of statistics Pearson and Fisher, who did so much in the early development of statistics, used and developed it in different contexts (factor analysis for Pearson and experimental design for Fisher).

The quantization of LS estimates and tracking the loss of performance due to quantization is a generic problem which can be encountered in all areas of engineering and science. We consider the application of least squares linear prediction for asymmetrical lossless audio compression, where the prediction coefficients are transmitted as side information, making decoding very fast. The study of quantization of linear prediction coefficients (LPC) has a long history and we can distinguish two distinct areas of applications: the first is lossy compression (including the important application to speech coding) and second is frame-wise (or forward) lossless compression [10].

CHAPTER 3

METHODOLOGY

3.1 Introduction

This project is to identify the parameter identification of Servo-Pneumatic Position Control System utilizing Least Square Estimate (LSE) approach and also analyzed the performance in terms of transient and steady-state response.

This project can be separated into 2 main parts there is:

- Hardware Development
- Software Development

3.2 Flow Chart

Figure 3.1 below shows structure flow chart of the overall project.

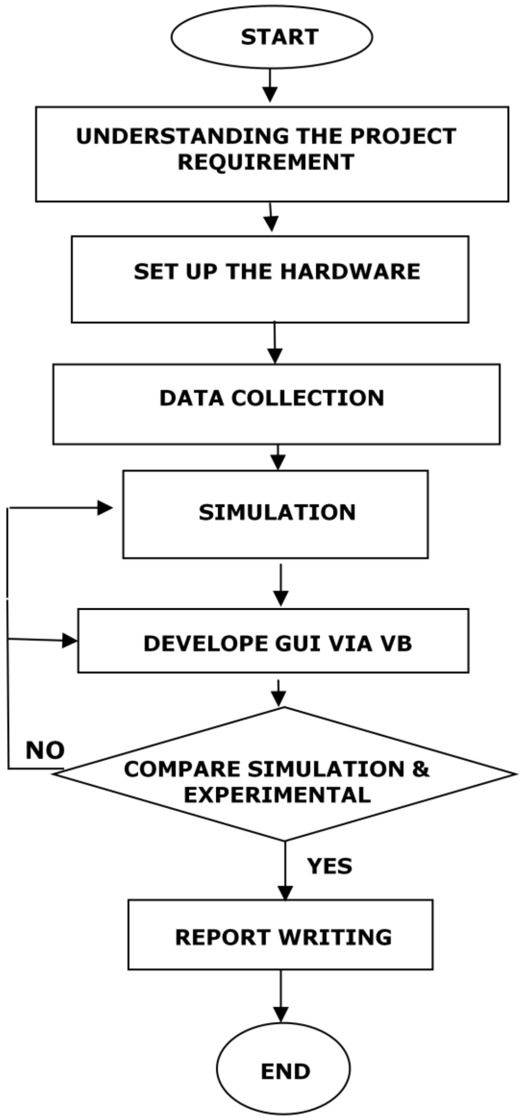


Figure 3.1: Flow chart of overall project

3.3 Hardware Development

3.3.1 CJ1M CPU12 Programmable Logic Controller (PLC)

In this chapter, the PLC has been set up by following the instruction from development done by previous researcher. CJ1M CPU12 is the type of PLC that used in this project. The CJ1M extends the CJ1 series to meet reduces requirements of more compact machine design; greater functional, less memory and build-in I/O. The CJ1M provides a low- cost solution for applications with lower I/O counts and shorter programs compared to the more powerful CJ1G/H CPUs. A common memory area and powerful serial link among nine CJ1M CPUs can help integrate processes or coordinate activities.

The components that have used to set up the PLC including the PLC card (input and output unit) are listed below:

1. OMRON CJ1M-CPU12
2. Digital Input Card (ID211)
3. Digital Output Card (OC211)
4. Analog Input Card (AD081-V1)
5. Analog Output Card (DA08C)
6. Power supply (24 Volt, 2A)
7. Fuse
8. Cable
9. Selected switch
10. PLC panel box
11. Trunking
12. Terminal lock
13. Power indicator lamp (240V)
14. 2 Light (Yellow and Red-24V)
15. 2 Push button (Normally Close and Normally Open)

Following a few steps during the construction of this PLC, the first step is calculating the current consumption of the system. This is important in choosing the suitable power supply for the system. It is to make sure that the current of the power supply can support the current that was desired by the system. In this project, the classification of the power supply that use is 24V and 2A because the current desired by the system is less than 2A. Figure 3.2 below shows the total power consumption of the whole system.

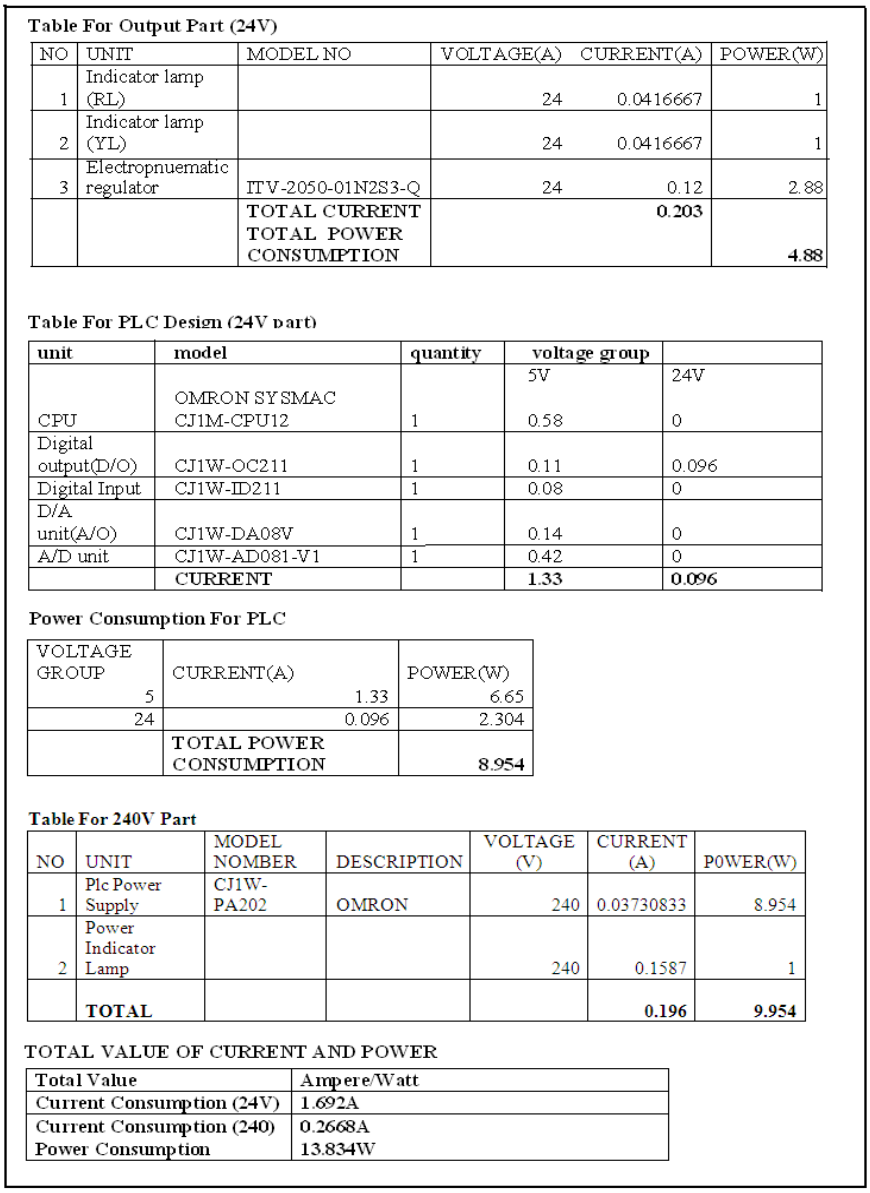


Table For Output Part (24V)

NO	UNIT	MODEL NO	VOLTAGE(A)	CURRENT(A)	POWER(W)
1	Indicator lamp (RL)		24	0.0416667	1
2	Indicator lamp (YL)		24	0.0416667	1
3	Electropnuematic regulator	ITV-2050-01N2S3-Q	24	0.12	2.88
		TOTAL CURRENT		**0.203**	
		TOTAL POWER CONSUMPTION			**4.88**

Table For PLC Design (24V part)

unit	model	quantity	voltage group	
			5V	24V
CPU	OMRON SYSMAC CJ1M-CPU12	1	0.58	0
Digital output(D/O)	CJ1W-OC211	1	0.11	0.096
Digital Input	CJ1W-ID211	1	0.08	0
D/A unit(A/O)	CJ1W-DA08V	1	0.14	0
A/D unit	CJ1W-AD081-V1	1	0.42	0
	CURRENT		**1.33**	**0.096**

Power Consumption For PLC

VOLTAGE GROUP	CURRENT(A)	POWER(W)
5	1.33	6.65
24	0.096	2.304
	TOTAL POWER CONSUMPTION	**8.954**

Table For 240V Part

NO	UNIT	MODEL NOMBER	DESCRIPTION	VOLTAGE (V)	CURRENT (A)	P0WER(W)
1	Plc Power Supply	CJ1W-PA202	OMRON	240	0.03730833	8.954
2	Power Indicator Lamp			240	0.1587	1
	TOTAL				**0.196**	**9.954**

TOTAL VALUE OF CURRENT AND POWER

Total Value	Ampere/Watt
Current Consumption (24V)	1.692A
Current Consumption (240) Power Consumption	0.2668A 13.834W

Figure 3.2: Table of Power and Current Consumption

The second step in PLC wiring part is to design the layout and the circuit connection of the PLC with all input and output. The circuit connection of power circuit, Digital I/O circuit and Analog I/O circuit was shown Figure 3.3, Figure 3.4 and 3.5 below.

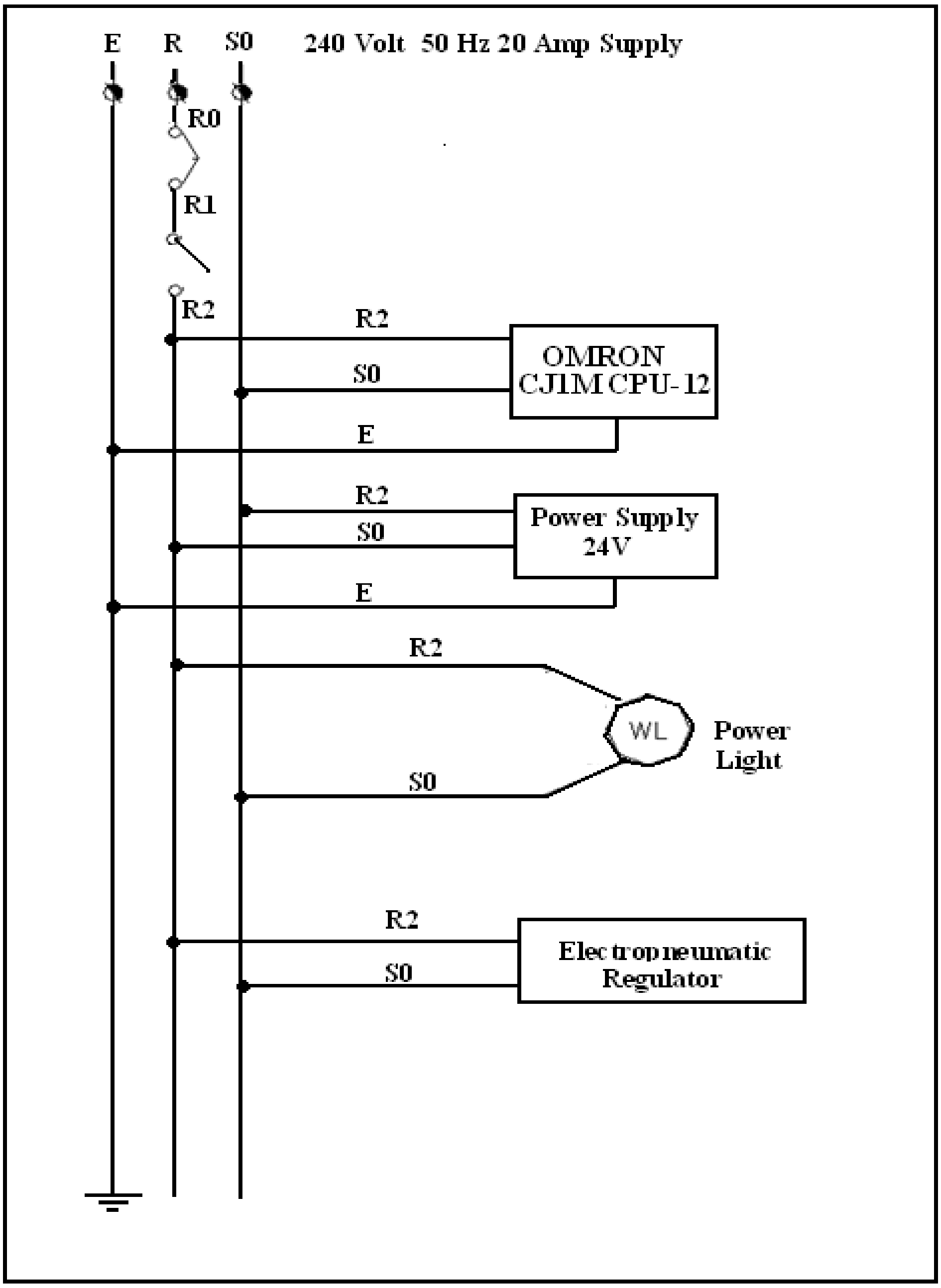


Figure 3.3: Power Circuit on the PLC

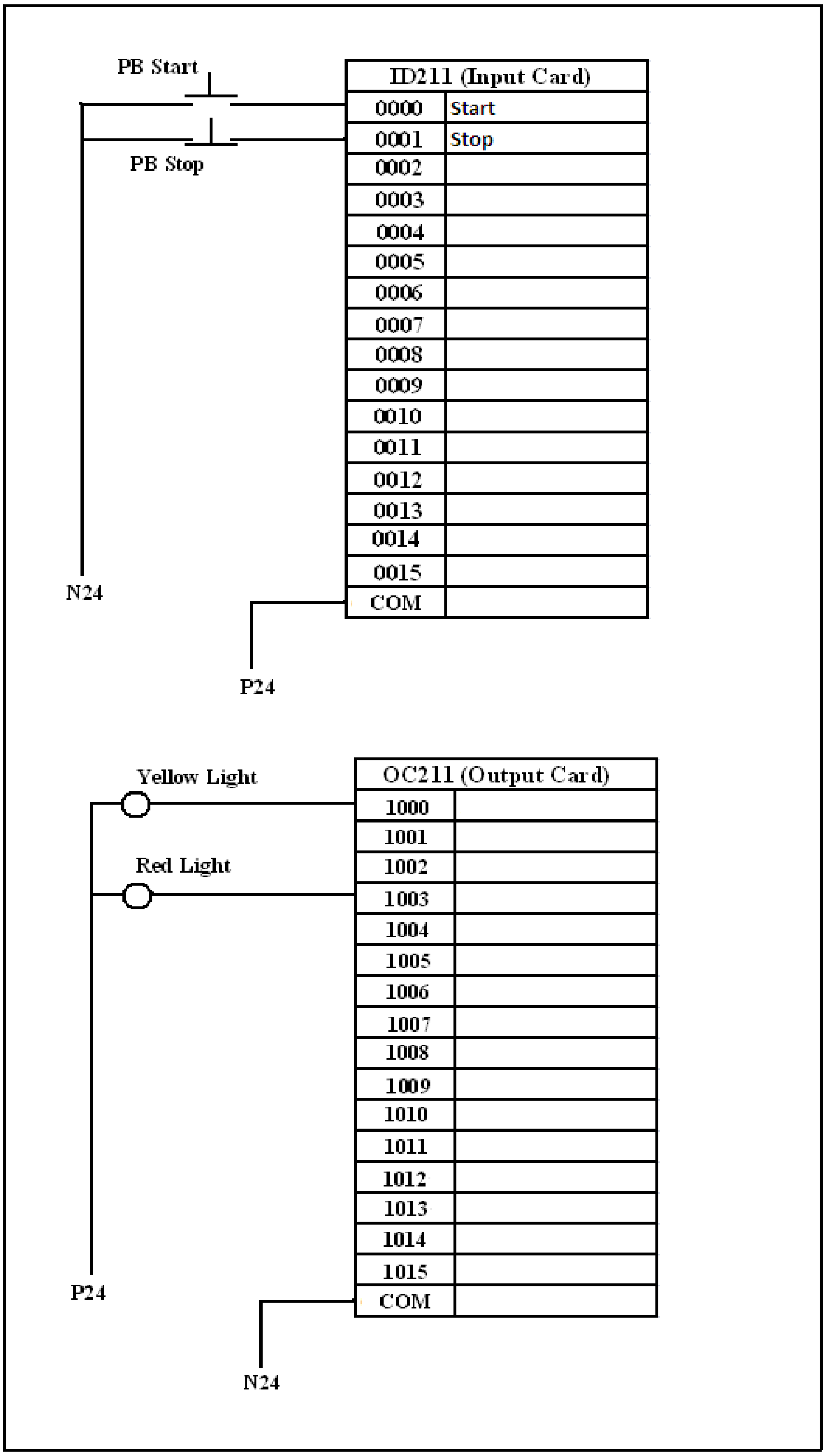


Figure 3.4: Digital Input / Output Circuit

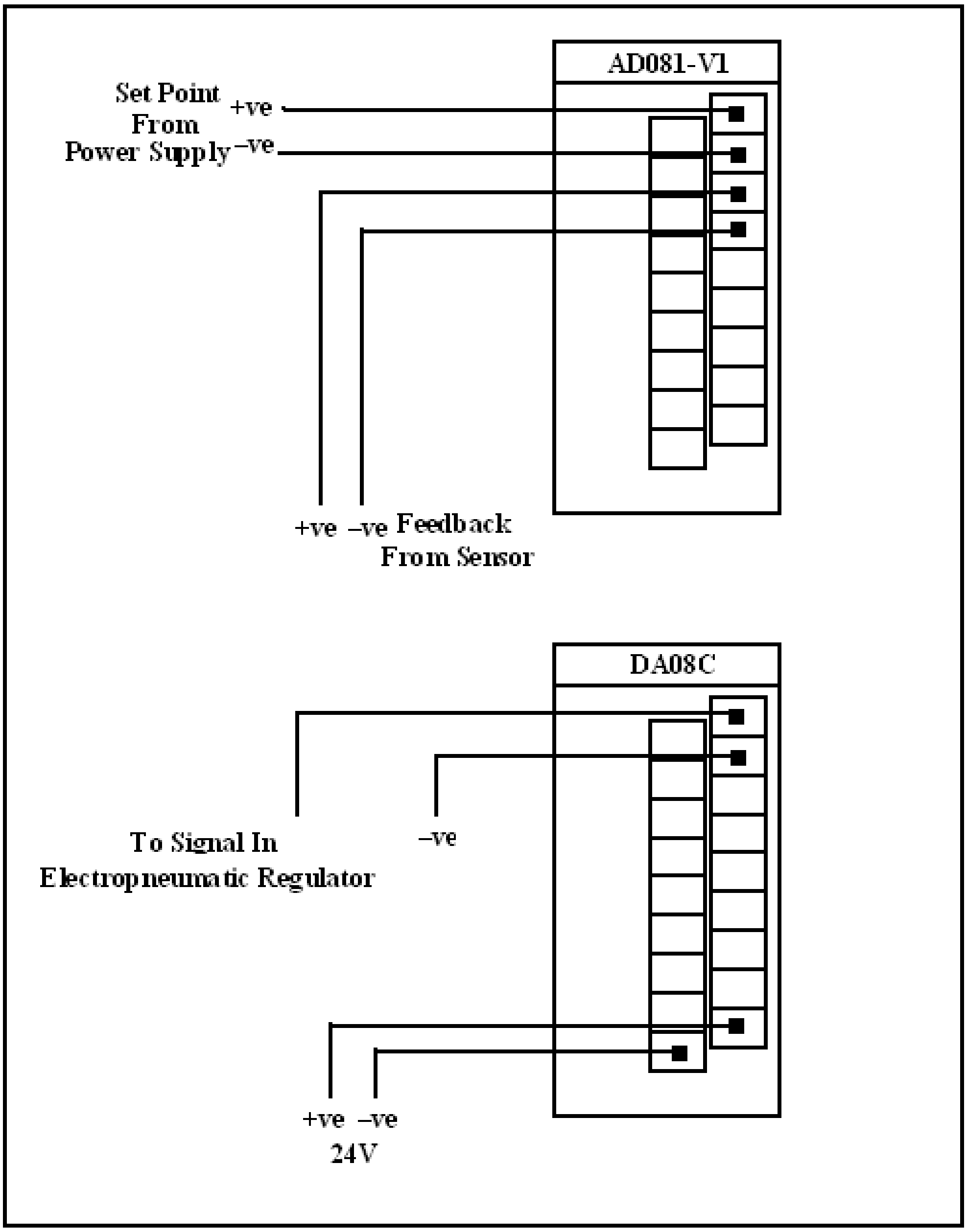


Figure 3.5: Analog Input / output Circuit

3.3.2 The connector RS232

Figure 3.6 below shows connection of DB9 RS232. It is used to interface the software (CX-Programmer) with PLC using laptop. Other than using desktop, this system can use laptop to develop program (CX-Programmer) for the system.

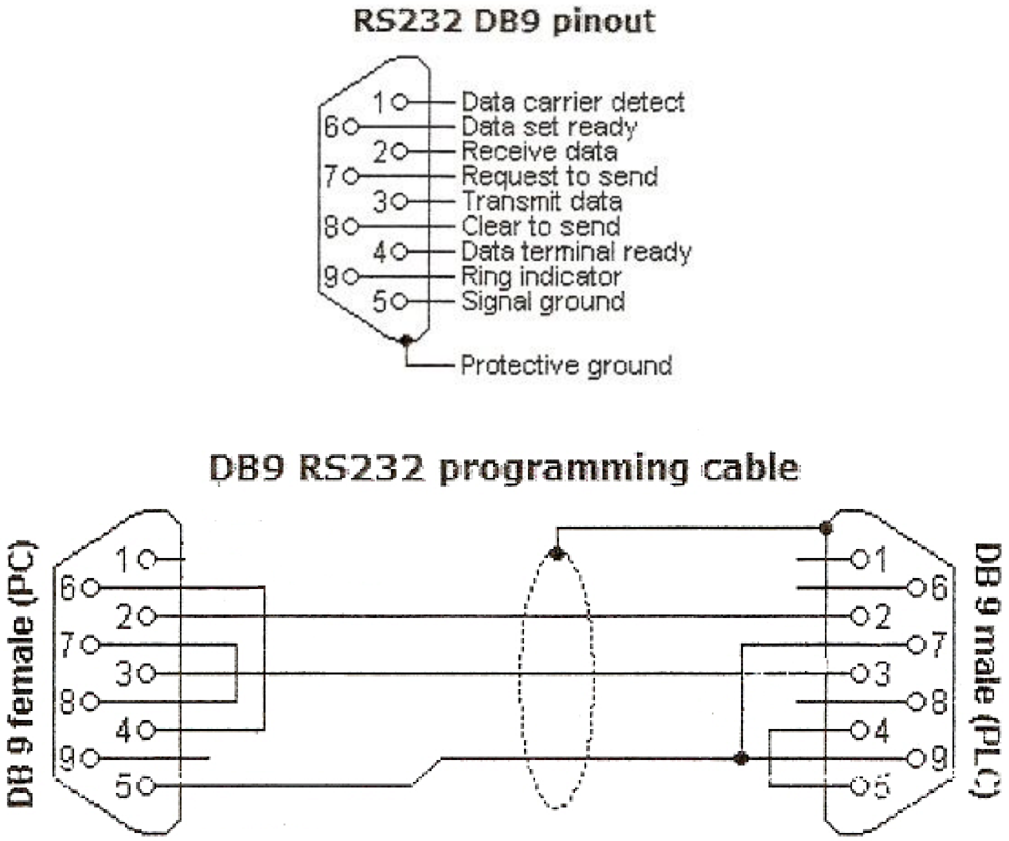
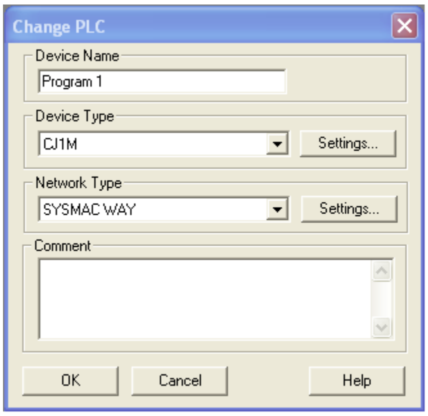


Figure 3.6: The connection of DB9 RS232

3.3.3 Setting the PLC

There are some step and procedure needs to be followed in order to setup the computer (software) before the Ladder Diagram can be RUN successfully without any problem. Below are the steps that need to be considered before using this CX-Programmer:

Step 1: Figure 3.7 & 3.8 below shows the Start up 1 & 2 for the first step to the user to select the appropriate term based on the PLC that use. For this project, PLC CJ1M CPU12 type was chosen to interface with CX-Programmer and other hardware (input & output).



Change PLC

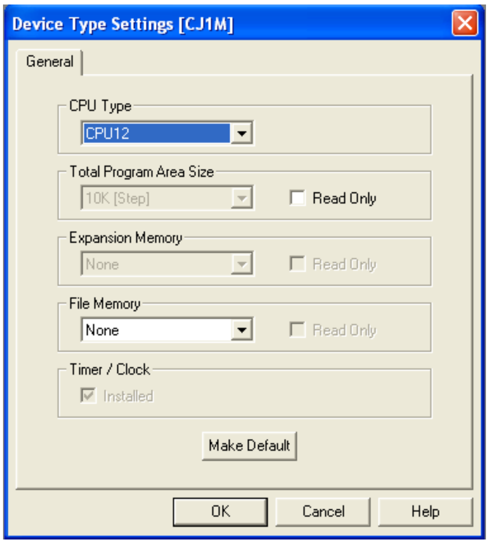
Device Name: Program 1

Device Type: CJ1M

Network Type: SYSMAC WAY

Comment:

Figure 3.7: Start up setting 1



Device Type Settings [CJ1M]

General

CPU Type: CPU12

Total Program Area Size: 10K [Step] ☐ Read Only

Expansion Memory: None ☐ Read Only

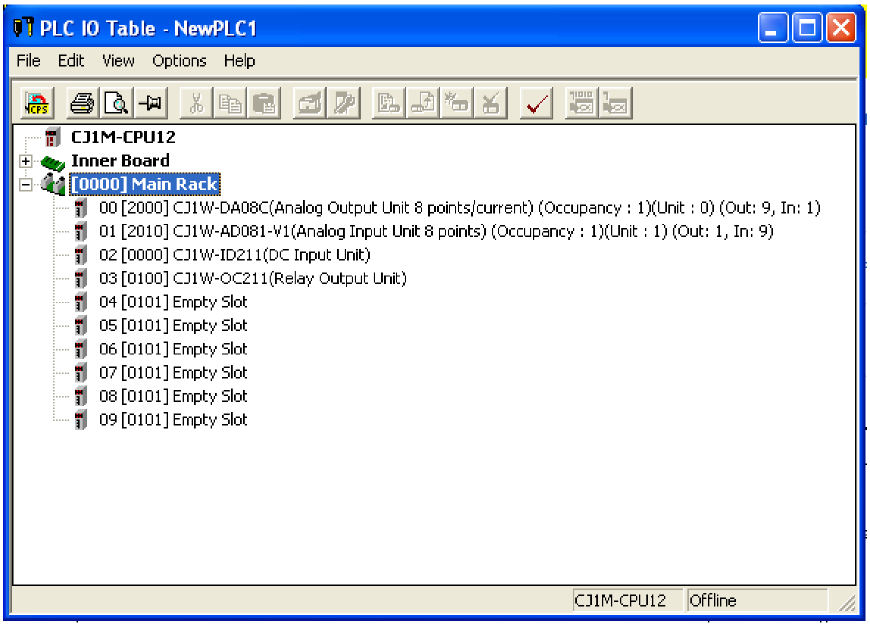
File Memory: None ☐ Read Only

Timer / Clock: ☑ Installed

Figure 3.8: Start up setting 2

Step 2: For this PLC type (CJ1M), each rack that use for this project need to be initialized first in I/O table unit setup like Figure 3.9 below. It is very important step to make sure the software (CX-Programmer) can be interfaced with PLC CJ1M type. The I/O table unit should consist:

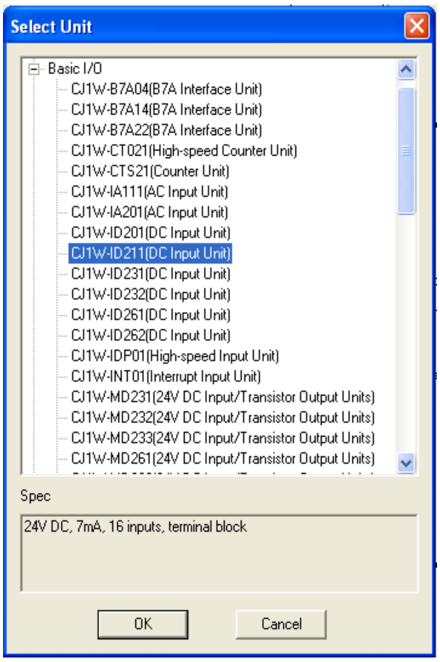
a. CJ1W-DA08C
b. CJ1W-AD081-V1 } Analog card
c. CJ1W-ID211
d. CJ1W-OC211 } Digital card



```
CJ1M-CPU12
Inner Board
[0000] Main Rack
    00 [2000] CJ1W-DA08C(Analog Output Unit 8 points/current) (Occupancy : 1)(Unit : 0) (Out: 9, In: 1)
    01 [2010] CJ1W-AD081-V1(Analog Input Unit 8 points) (Occupancy : 1)(Unit : 1) (Out: 1, In: 9)
    02 [0000] CJ1W-ID211(DC Input Unit)
    03 [0100] CJ1W-OC211(Relay Output Unit)
    04 [0101] Empty Slot
    05 [0101] Empty Slot
    06 [0101] Empty Slot
    07 [0101] Empty Slot
    08 [0101] Empty Slot
    09 [0101] Empty Slot
```

Figure 3.9: I/O table unit setup

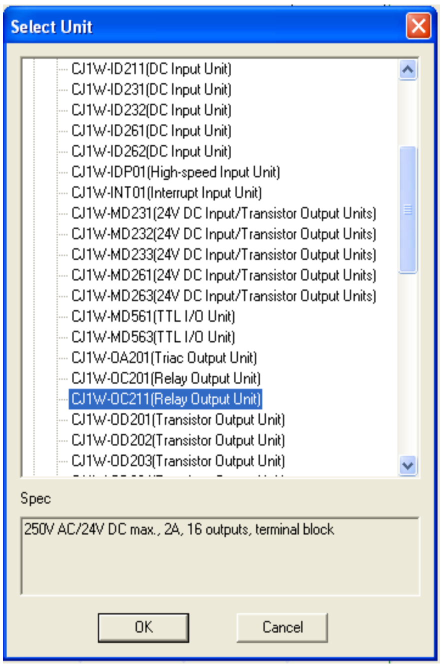
Step 3: Figure 3.10 & Figure 3.11 below shows how to select digital input and digital output. Usually digital I/P and digital O/P control the Push ON/OFF button and indicator light on PLC panel. The analog I/P and analog O/P card also need to be set first before in can be recognized by CX-Programmer.



Basic I/O
- CJ1W-B7A04(B7A Interface Unit)
- CJ1W-B7A14(B7A Interface Unit)
- CJ1W-B7A22(B7A Interface Unit)
- CJ1W-CT021(High-speed Counter Unit)
- CJ1W-CTS21(Counter Unit)
- CJ1W-IA111(AC Input Unit)
- CJ1W-IA201(AC Input Unit)
- CJ1W-ID201(DC Input Unit)
- CJ1W-ID211(DC Input Unit)
- CJ1W-ID231(DC Input Unit)
- CJ1W-ID232(DC Input Unit)
- CJ1W-ID261(DC Input Unit)
- CJ1W-ID262(DC Input Unit)
- CJ1W-IDP01(High-speed Input Unit)
- CJ1W-INT01(Interrupt Input Unit)
- CJ1W-MD231(24V DC Input/Transistor Output Units)
- CJ1W-MD232(24V DC Input/Transistor Output Units)
- CJ1W-MD233(24V DC Input/Transistor Output Units)
- CJ1W-MD261(24V DC Input/Transistor Output Units)

Spec

24V DC, 7mA, 16 inputs, terminal block



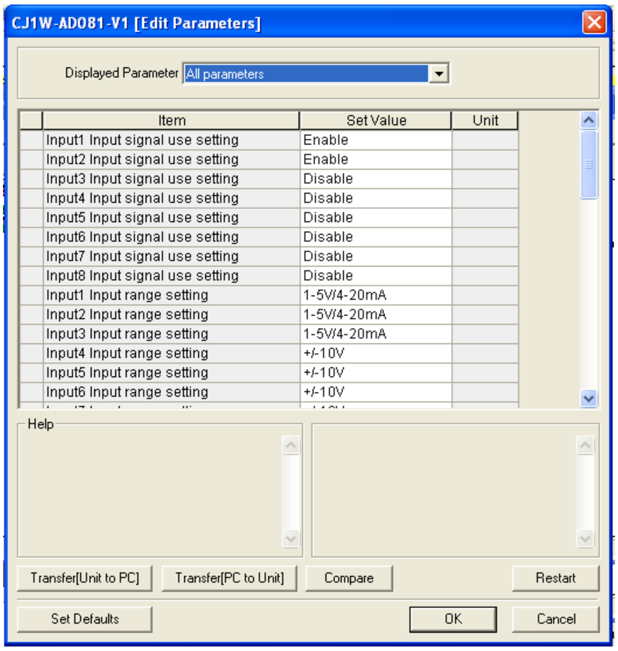
- CJ1W-ID211(DC Input Unit)
- CJ1W-ID231(DC Input Unit)
- CJ1W-ID232(DC Input Unit)
- CJ1W-ID261(DC Input Unit)
- CJ1W-ID262(DC Input Unit)
- CJ1W-IDP01(High-speed Input Unit)
- CJ1W-INT01(Interrupt Input Unit)
- CJ1W-MD231(24V DC Input/Transistor Output Units)
- CJ1W-MD232(24V DC Input/Transistor Output Units)
- CJ1W-MD233(24V DC Input/Transistor Output Units)
- CJ1W-MD261(24V DC Input/Transistor Output Units)
- CJ1W-MD263(24V DC Input/Transistor Output Units)
- CJ1W-MD561(TTL I/O Unit)
- CJ1W-MD563(TTL I/O Unit)
- CJ1W-OA201(Triac Output Unit)
- CJ1W-OC201(Relay Output Unit)
- CJ1W-OC211(Relay Output Unit)
- CJ1W-OD201(Transistor Output Unit)
- CJ1W-OD202(Transistor Output Unit)
- CJ1W-OD203(Transistor Output Unit)

Spec

250V AC/24V DC max., 2A, 16 outputs, terminal block

Figure 3.10: Digital input select unit **Figure 3.11:** Digital output select unit

Step 4: Figure 3.12 below shows the analog I/P setting procedure, also almost same with analog O/P setting procedure. The setting is depend on the input/output that been used at the analog card.

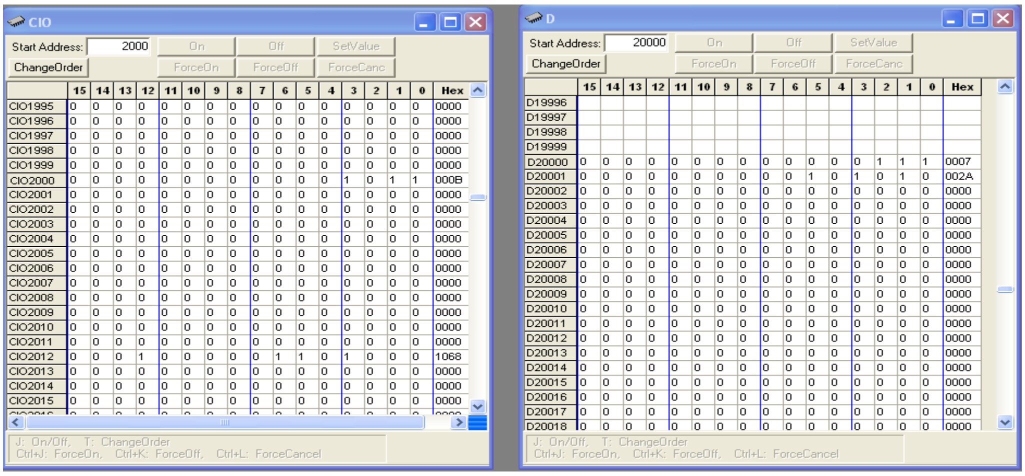


Displayed Parameter: All parameters

Item	Set Value	Unit
Input1 Input signal use setting	Enable	
Input2 Input signal use setting	Enable	
Input3 Input signal use setting	Disable	
Input4 Input signal use setting	Disable	
Input5 Input signal use setting	Disable	
Input6 Input signal use setting	Disable	
Input7 Input signal use setting	Disable	
Input8 Input signal use setting	Disable	
Input1 Input range setting	1-5V/4-20mA	
Input2 Input range setting	1-5V/4-20mA	
Input3 Input range setting	1-5V/4-20mA	
Input4 Input range setting	+/-10V	
Input5 Input range setting	+/-10V	
Input6 Input range setting	+/-10V	

Figure 3.12: Analog I/P setting

Figure 3.13 below shows the setting of the memory in PLC. The address for I/O memory in D and CIO need to be setup first.



CIO — Start Address: 2000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Hex
CIO1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO1999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2000	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	000B
CIO2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2012	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	1068
CIO2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
CIO2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000

D — Start Address: 20000

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	Hex
D19996																	
D19997																	
D19998																	
D19999																	
D20000	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0007
D20001	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	002A
D20002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20004	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20005	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000
D20018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0000

Figure 3.13: Setting on CIO and D memory

Analog input card (CJ1W-AD081-V1):

Set the unit number switch to (0) and (1) like Figure 3.14 below. The Special I/O Unit Area and Special I/O Unit DM Area word addresses that each Analog Input Unit occupies are set by the unit number switch on the front panel of the PLC Unit.

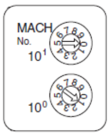
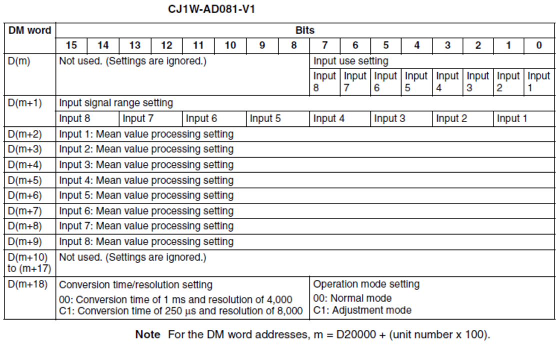


Figure 3.14: Unit Number Switch

Then set the memory for D(m) and CIO. First, determine the input that been used in this system. Two inputs are used in this project and the input signal range is 1-5V/4-20mA. So the memory should been set at D(20100) = $000F_8$, D(20101) = $00AA_8$ and CIO(2010) = $00FF_8$. Figure 3.15 below shows the table of the allocation of DM words and set values for the analog card. The allocation of words and bits in the CIO Area is shown in Figure 3.16 below.

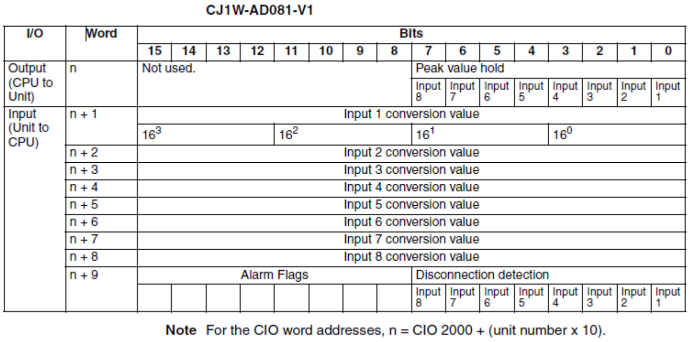


CJ1W-AD081-V1

DM word	Bits															
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
D(m)	Not used. (Settings are ignored.)								Input use setting							
									Input 8	Input 7	Input 6	Input 5	Input 4	Input 3	Input 2	Input 1
D(m+1)	Input signal range setting															
	Input 8		Input 7		Input 6		Input 5		Input 4		Input 3		Input 2		Input 1	
D(m+2)	Input 1: Mean value processing setting															
D(m+3)	Input 2: Mean value processing setting															
D(m+4)	Input 3: Mean value processing setting															
D(m+5)	Input 4: Mean value processing setting															
D(m+6)	Input 5: Mean value processing setting															
D(m+7)	Input 6: Mean value processing setting															
D(m+8)	Input 7: Mean value processing setting															
D(m+9)	Input 8: Mean value processing setting															
D(m+10) to (m+17)	Not used. (Settings are ignored.)															
D(m+18)	Conversion time/resolution setting 00: Conversion time of 1 ms and resolution of 4,000 C1: Conversion time of 250 μs and resolution of 8,000								Operation mode setting 00: Normal mode C1: Adjustment mode							

Note For the DM word addresses, m = D20000 + (unit number x 100).

Figure 3.15: Table of the allocation of DM words



CJ1W-AD081-V1

I/O	Word	Bits															
		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Output (CPU to Unit)	n	Not used.								Peak value hold							
										Input 8	Input 7	Input 6	Input 5	Input 4	Input 3	Input 2	Input 1
Input (Unit to CPU)	n + 1	Input 1 conversion value															
		16^3				16^2				16^1				16^0			
	n + 2	Input 2 conversion value															
	n + 3	Input 3 conversion value															
	n + 4	Input 4 conversion value															
	n + 5	Input 5 conversion value															
	n + 6	Input 6 conversion value															
	n + 7	Input 7 conversion value															
	n + 8	Input 8 conversion value															
	n + 9	Alarm Flags								Disconnection detection							
										Input 8	Input 7	Input 6	Input 5	Input 4	Input 3	Input 2	Input 1

Note For the CIO word addresses, n = CIO 2000 + (unit number x 10).

Figure 3.16: Table of the allocation of CIO words

Analog output card (CJ1W-DA08C):

Set the unit number switch to (0) and (0) like Figure 3.17 below. The Special I/O Unit Area and Special I/O Unit DM Area word addresses that each Analog Input Unit occupies are set by the unit number switch on the front panel of the PLC Unit.

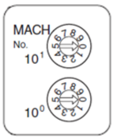
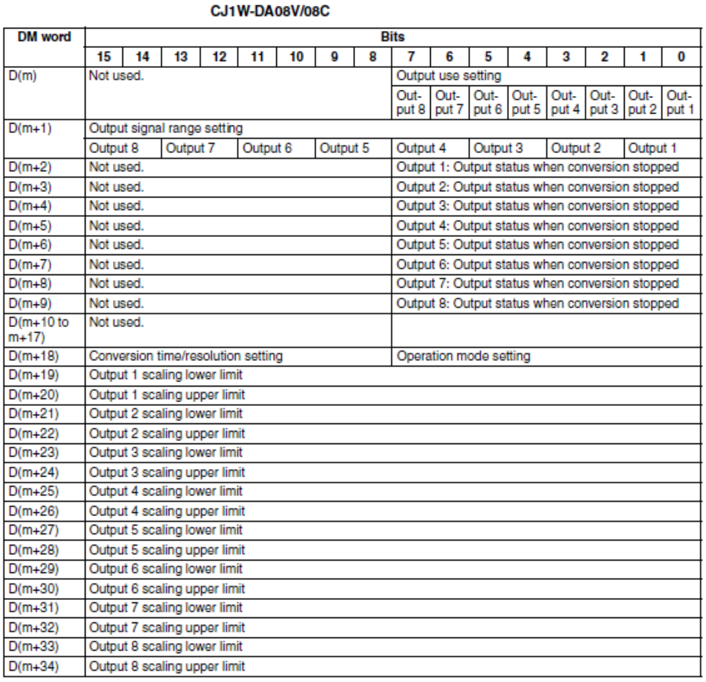


Figure 3.17: Unit Number Switch

Then set the memory for D(m) and CIO. First, determine the input that been used in this system. Two inputs are used in this project and the input signal range is 1-5V/4-20mA. So the memory should been set at D(20000) = 000F$_8$, D(20001) = 00AA$_8$ and CIO(2000) = 000F$_8$. Figure 3.18 and 3.19 below shows the table of the allocation of DM words and set values for the analog card. The allocation of words and bits in the CIO Area is shown in Figure 3.20. Figure 3.21 below shows the set values for CIO Area.

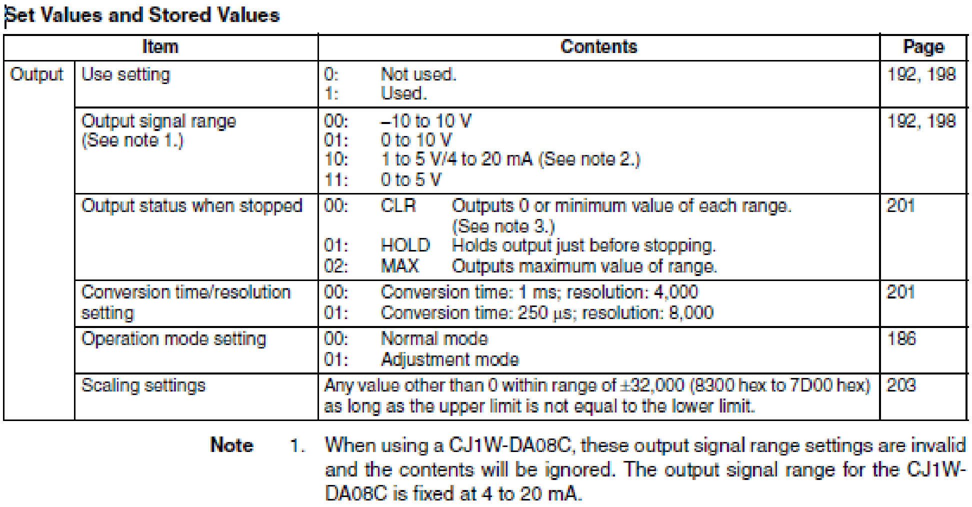


CJ1W-DA08V/08C

DM word	Bits															
	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
D(m)	Not used.								Output use setting							
									Out-put 8	Out-put 7	Out-put 6	Out-put 5	Out-put 4	Out-put 3	Out-put 2	Out-put 1
D(m+1)	Output signal range setting															
	Output 8		Output 7		Output 6		Output 5		Output 4		Output 3		Output 2		Output 1	
D(m+2)	Not used.								Output 1: Output status when conversion stopped							
D(m+3)	Not used.								Output 2: Output status when conversion stopped							
D(m+4)	Not used.								Output 3: Output status when conversion stopped							
D(m+5)	Not used.								Output 4: Output status when conversion stopped							
D(m+6)	Not used.								Output 5: Output status when conversion stopped							
D(m+7)	Not used.								Output 6: Output status when conversion stopped							
D(m+8)	Not used.								Output 7: Output status when conversion stopped							
D(m+9)	Not used.								Output 8: Output status when conversion stopped							
D(m+10 to m+17)	Not used.															
D(m+18)	Conversion time/resolution setting								Operation mode setting							
D(m+19)	Output 1 scaling lower limit															
D(m+20)	Output 1 scaling upper limit															
D(m+21)	Output 2 scaling lower limit															
D(m+22)	Output 2 scaling upper limit															
D(m+23)	Output 3 scaling lower limit															
D(m+24)	Output 3 scaling upper limit															
D(m+25)	Output 4 scaling lower limit															
D(m+26)	Output 4 scaling upper limit															
D(m+27)	Output 5 scaling lower limit															
D(m+28)	Output 5 scaling upper limit															
D(m+29)	Output 6 scaling lower limit															
D(m+30)	Output 6 scaling upper limit															
D(m+31)	Output 7 scaling lower limit															
D(m+32)	Output 7 scaling upper limit															
D(m+33)	Output 8 scaling lower limit															
D(m+34)	Output 8 scaling upper limit															

Note For the DM word addresses, m = D20000 + (unit number x 100).

Figure 3.18: Table of the allocation of DM words

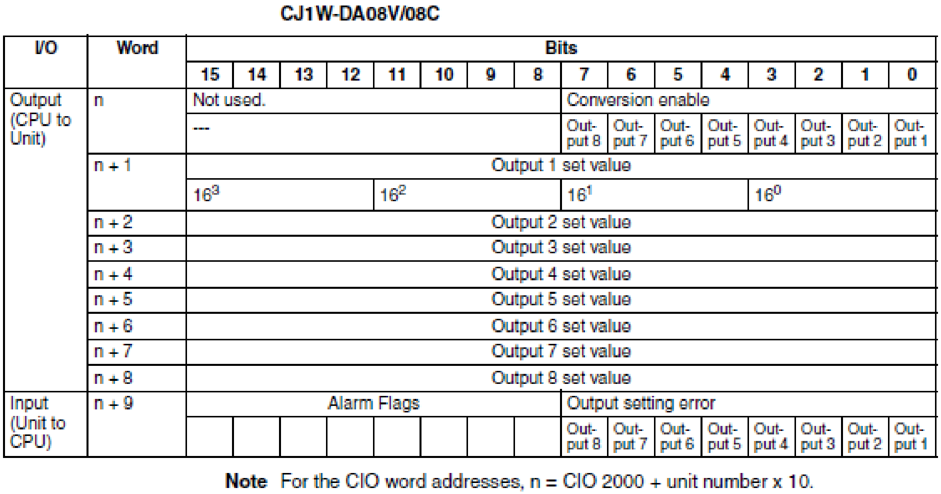


Set Values and Stored Values

Item		Contents	Page
Output	Use setting	0: Not used. 1: Used.	192, 198
	Output signal range (See note 1.)	00: –10 to 10 V 01: 0 to 10 V 10: 1 to 5 V/4 to 20 mA (See note 2.) 11: 0 to 5 V	192, 198
	Output status when stopped	00: CLR Outputs 0 or minimum value of each range. (See note 3.) 01: HOLD Holds output just before stopping. 02: MAX Outputs maximum value of range.	201
	Conversion time/resolution setting	00: Conversion time: 1 ms; resolution: 4,000 01: Conversion time: 250 μs; resolution: 8,000	201
	Operation mode setting	00: Normal mode 01: Adjustment mode	186
	Scaling settings	Any value other than 0 within range of ±32,000 (8300 hex to 7D00 hex) as long as the upper limit is not equal to the lower limit.	203

Note 1. When using a CJ1W-DA08C, these output signal range settings are invalid and the contents will be ignored. The output signal range for the CJ1W-DA08C is fixed at 4 to 20 mA.

Figure 3.19: Set Values and Stored Values for DM

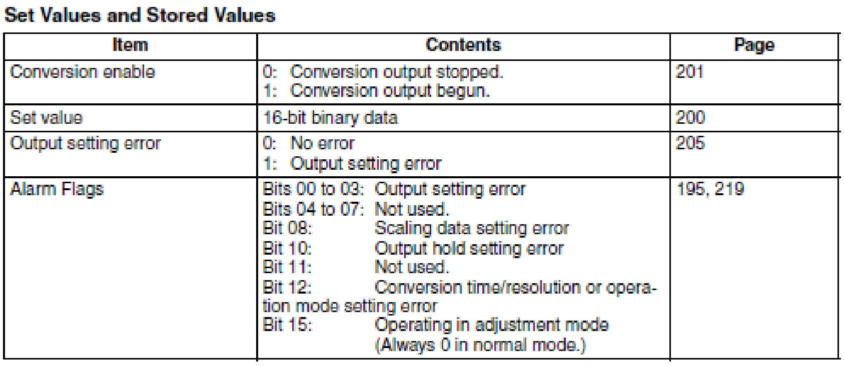


CJ1W-DA08V/08C

I/O	Word	Bits															
		15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Output (CPU to Unit)	n	Not used.								Conversion enable							
		---								Out-put 8	Out-put 7	Out-put 6	Out-put 5	Out-put 4	Out-put 3	Out-put 2	Out-put 1
	n + 1	Output 1 set value															
		16^3				16^2				16^1				16^0			
	n + 2	Output 2 set value															
	n + 3	Output 3 set value															
	n + 4	Output 4 set value															
	n + 5	Output 5 set value															
	n + 6	Output 6 set value															
	n + 7	Output 7 set value															
	n + 8	Output 8 set value															
Input (Unit to CPU)	n + 9	Alarm Flags								Output setting error							
										Out-put 8	Out-put 7	Out-put 6	Out-put 5	Out-put 4	Out-put 3	Out-put 2	Out-put 1

Note For the CIO word addresses, n = CIO 2000 + unit number x 10.

Figure 3.20: Table of the allocation of CIO words

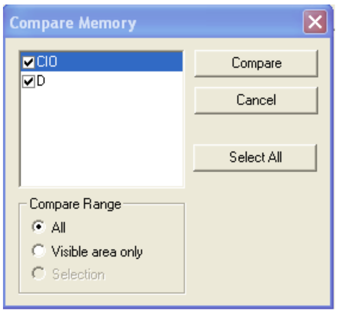


Set Values and Stored Values

Item	Contents	Page
Conversion enable	0: Conversion output stopped. 1: Conversion output begun.	201
Set value	16-bit binary data	200
Output setting error	0: No error 1: Output setting error	205
Alarm Flags	Bits 00 to 03: Output setting error Bits 04 to 07: Not used. Bit 08: Scaling data setting error Bit 10: Output hold setting error Bit 11: Not used. Bit 12: Conversion time/resolution or operation mode setting error Bit 15: Operating in adjustment mode (Always 0 in normal mode.)	195, 219

Figure 3.21: Set Values and Stored Values for CIO

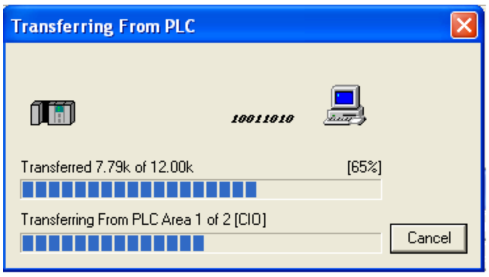
Figure 3.22 below show the memory will be compared and transfer the memory to PLC after comparing process such as in Figure 3.23 below.



☑ CIO
☑ D

Compare Range
● All
○ Visible area only
○ Selection

Figure 3.22: Comparing the data in memory

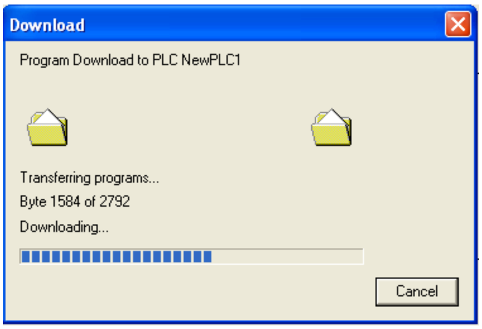


Transferred 7.79k of 12.00k [65%]

Transferring From PLC Area 1 of 2 [CIO]

Figure 3.23: Transfer data after comparing to PLC

Step 5 : Finally, after designing the ladder diagram, the program need to be downloaded to the PLC like Figure 3.24 below.



Program Download to PLC NewPLC1

Transferring programs...

Byte 1584 of 2792

Downloading...

Figure 3.24: Program download to PLC

After the installation of the hardware is completed, the work on the software part continues. For the software part, it consists of CX-Programmer, Visual Basic (VB) and MATLAB.

3.4 Software Development

3.4.1 Ladder Diagram for CX-Programmer

Figure 3.25 and 3.26 below shows the ladder diagram of the overall SPPCS. The flow of SPPCS is when push start button, timer1 on for 5 second. After 5 second, the system is running and the timer2 also on. It is run for 5 second. This system will keep looping until stop button is pushed.

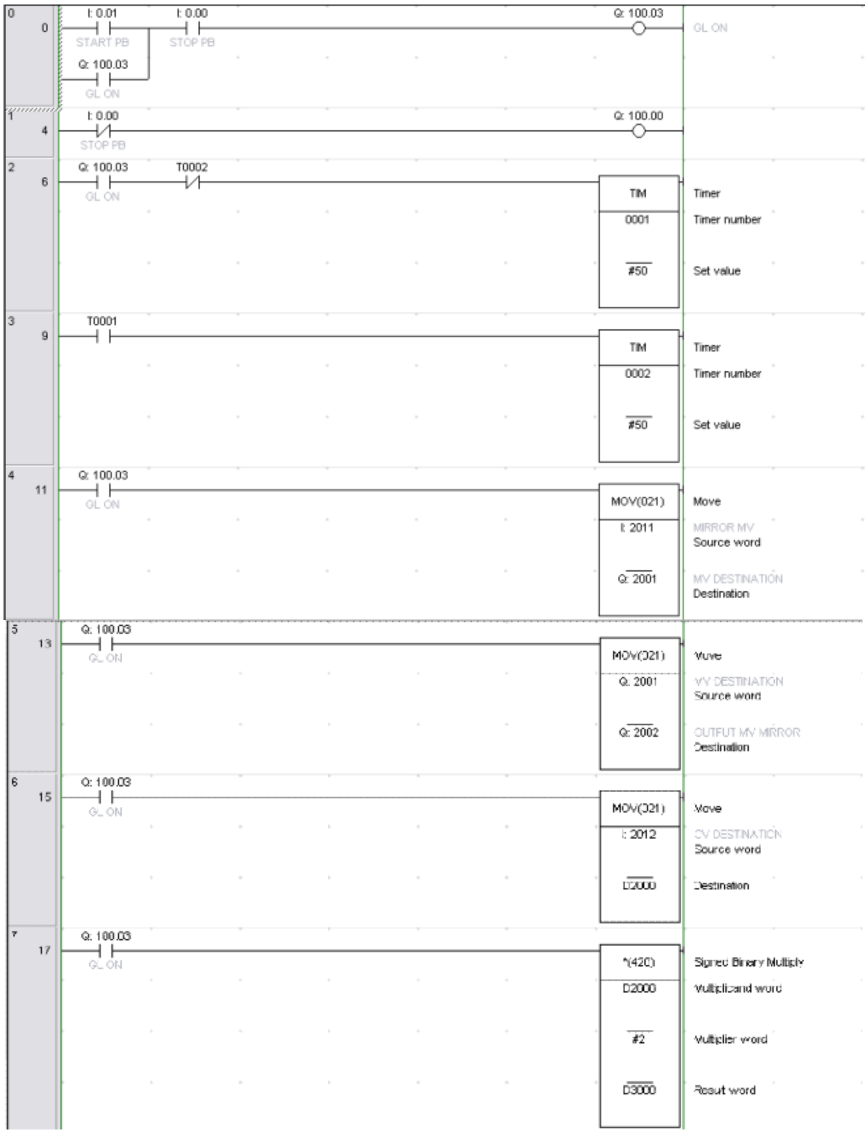


Figure 3.25: Ladder Diagram 1

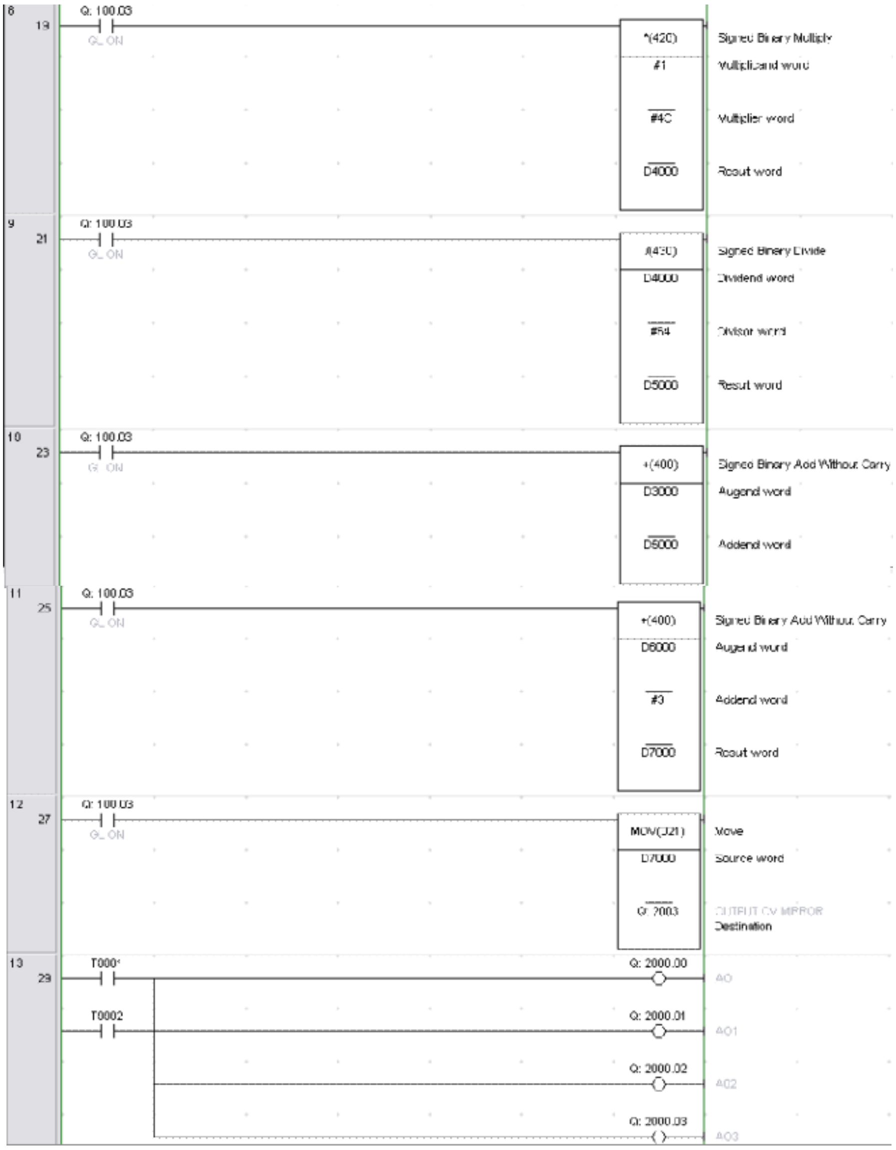
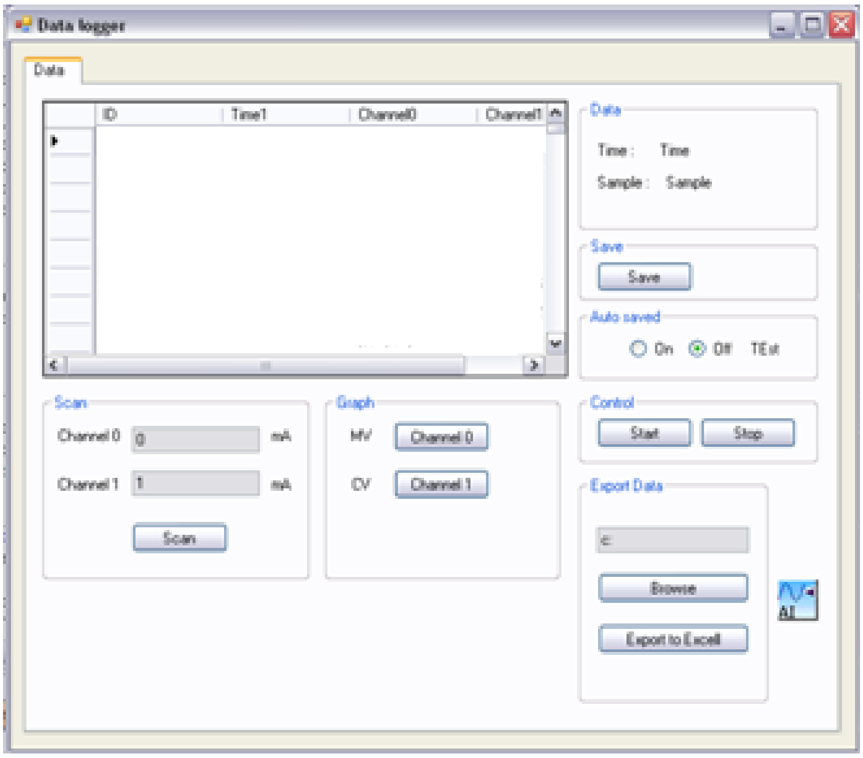


Figure 3.26: Ladder Diagram 2

3.4.2 GUI via Visual Basic Software (GUI)

This part is the part that the development for the performance in terms transient and steady-state response using the GUI via Visual Basic software. GUI must consist of 2 channels for input and output and 2 graphs to represent the performance of input and output. DAQ’s card device used to obtain data from the system. DAQ's card is used to read the analog voltage from hardware (plant) and then the voltage reading converted into digital signal which will be used as data collection in GUI. DAQ’s card must interface with laptop to get the real time data collecting using GUI in Visual Basic.

Figure 3.27 below shows the basic GUI that consists of two channel of output from DAQ’s card.



Time : Time
Sample : Sample
Channel 0 0 mA
Channel 1 1 mA
c:

Figure 3.27: GUI’s development

Figure 3.28 below shows the graph of performance of input and output, for the x-axis represent time response (second) and y-axis represent current output response (mA).

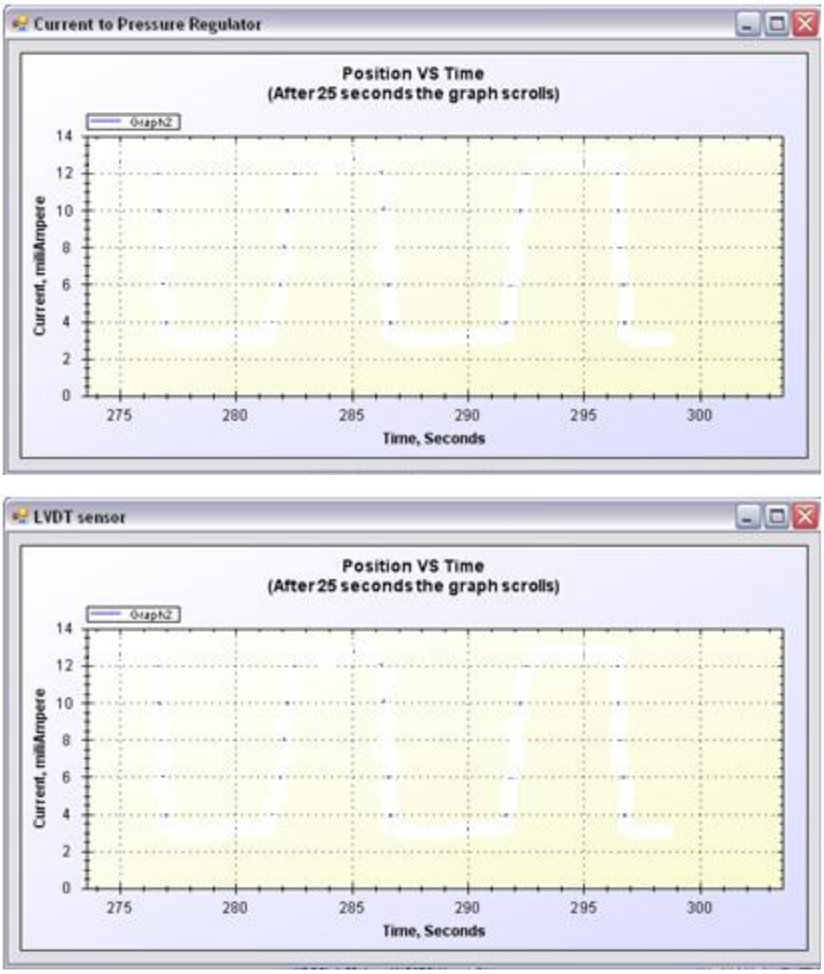


Figure 3.28: Graph's Performance of I/O signals

3.4.3 MATLAB's Software

The MATLAB program has been chosen to simulate the controller design to get the output response in a graphical form. Some of the advantages of using MATLAB are wide variety of modeling method available such as control, system ID, fuzzy logic, neural network, digital signal processing and so on. It is also easy to write and incorporated program as well as can be linked to develop custom applications.

By getting the input and output data from the hardware (plant) the calculation to determine the mathematical model. The mathematical equation that has been determined by the calculation using the Least Square Estimate (LSE) technique will be load in the MATLAB for simulation.

Then, by using the simulation result compares it with the real model from the plant. If the average error, e is small, then the work will proceed to the part where the transfer function will be calculated. The calculation is use the LSE approach to get the value of the transfer function.

Least Square Estimate:

Assume the transfer function model for the system to be identified which is through to be governed by a second order linear difference equation;

$$G_{(z)} = \frac{a}{bz^{-2} + cz^{-1} + d} \tag{3.1}$$

Expand equation 3.1 yields to,

$$\frac{Y_{(k)}}{U_{(k)}} = \frac{a}{bz^{-2} + cz^{-1} + d}$$

$$Y_{(k)}(bz^{-2} + cz^{-1} + d) = aU_{(k)}$$

This problem can be expressed in the form of linear regression model by writing the difference equation of the system as

$$\left.\begin{aligned} dy(k) &= -by(k-2) - cy(k-1) + au(k) \\ y(k) &= -\frac{b}{d}y(k-2) - \frac{c}{d}y(k-1) + \frac{a}{d}u(k) \\ y(k) &= -Ay(k-2) - By(k-1) + Cu(k) \end{aligned}\right\} \tag{3.2}$$

$$A = \frac{b}{d}$$

$$B = \frac{c}{d}$$

$$C = \frac{a}{d}$$

Form a linear regression model:

$$Y = Mp + E \tag{3.3}$$

$$y(k) = \begin{bmatrix} -y(k-2) & -y(k-1) & u(k) \end{bmatrix} \begin{bmatrix} A \\ B \\ C \end{bmatrix} + e(k)$$

$$M = \begin{bmatrix} -y(k-2) & -y(k-1) & u(k) \end{bmatrix}$$

$$p = \begin{bmatrix} A \\ B \\ C \end{bmatrix}$$

$$p = (M^T M)^{-1} M^T Y \tag{3.4}$$

The parameter vector p obtained from (3.4) will satisfy (3.3) only if the system is indeed exactly governed by linear difference equation of the assumed order and if there are no measurement errors.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In order to identify and obtain the mathematical characteristic of the Servo-Pneumatic Position Control system, Least Square Estimate (LSE) approach was utilized. The data from the system was captured using DAQ card and stored in Excel. This chapter also discusses all the result obtained from the simulation, data collection from hardware and the performance in terms transient and steady-state response. The result is based on the experimental and transfer function for the servo-pneumatic system. Also the comparison between the experimental and the modeling (transfer function) result. Table 4.1 shows that the assumption of the relation between current and the position of the piston.

Table 4.1: Table of relation between current and position

%	Current (mA)	Position (mm)
0	4.00	0.00
25	8.00	70.0
50	12.00	140.0
75	16.00	210.0
100	20.00	280.0

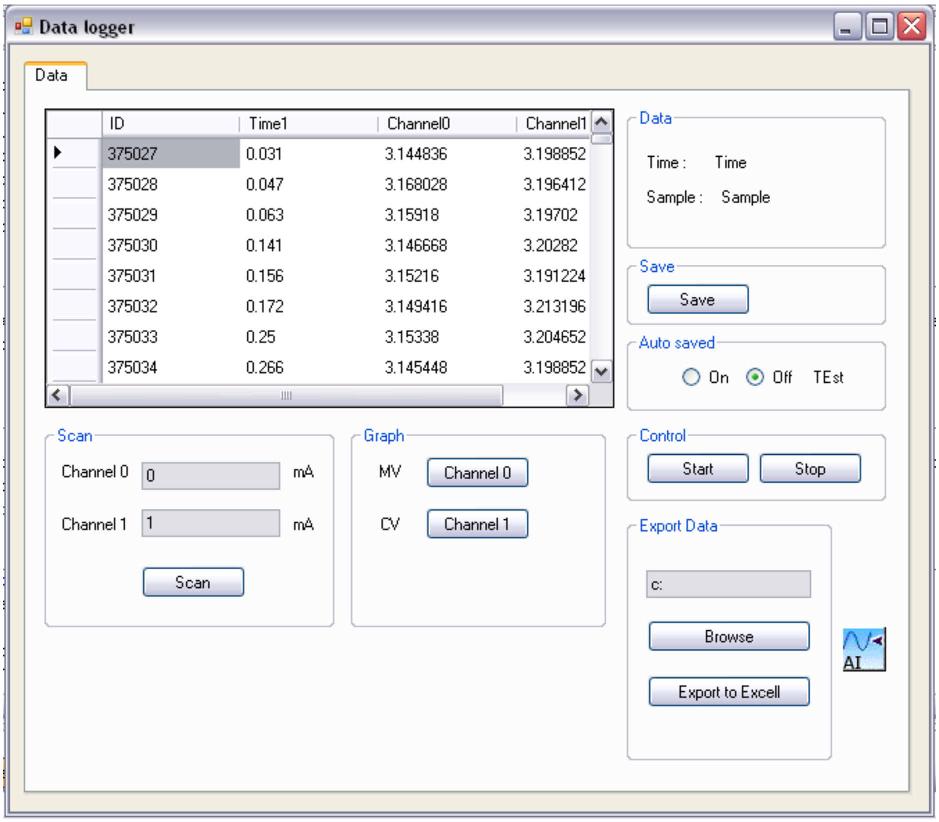
4.2 VB Software

The GUI’s form contains the place to store and display the data from the system. It also contain the graph from both signals, the button for the data to save in term of Excel format, auto save button and button ‘start’ and ‘stop’. The channel 0 column is for input (mv), channel 1 column is for output (cv), ID column is for number of sample and time column is for time.

The function for each buttons of the Data logger form;

- Scan button is to scan voltage value in channel 0 and channel 1 of DAQ Card.
- In data group box, it will display the sampling time and total of sample had taken.
- In auto saved group box, the ON and OFF selection button is for auto save setting. If it is OFF, the collected data will be manually saved by using the Save button.
- Export Data box used to save the data collection based on the selected place in Excel format.
- The data grid view is divided into 4 column which is ID, Time 1, Channel 0 and Channel 1. All data collecting is uploaded into this data grid view.
- Channel 0 button consist a graph of Position Vs Time for mv while Channel 1 button consist a graph of Position Vs Time for cv.
- These two graph display real-time data collecting while the SPPCS behaviour is observed.

The GUI's form is shown in Figure 4.1. This GUI shows how data collection is done. Data is sampled every second and the performance is shown in graph. The Figure 4.2 is for an injected current while Figure 4.3 shows how much distance the piston can extend with injected current but in signal performance.



ID	Time1	Channel0	Channel1
375027	0.031	3.144836	3.198852
375028	0.047	3.168028	3.196412
375029	0.063	3.15918	3.19702
375030	0.141	3.146668	3.20282
375031	0.156	3.15216	3.191224
375032	0.172	3.149416	3.213196
375033	0.25	3.15338	3.204652
375034	0.266	3.145448	3.198852

Time : Time
Sample : Sample

○ On ● Off

Channel 0: 0 mA
Channel 1: 1 mA

c:

Figure 4.1: GUI VB Form

Figure 4.2 and 4.3 below shows the signals that produce by DAQ's card for input Data and output Data from the system. For the input Data, it represented the injection current that can be adjusted based on the distance required. In this experiment, the values current that been injected was 12mA. Output Data represented the values of current after running the system.

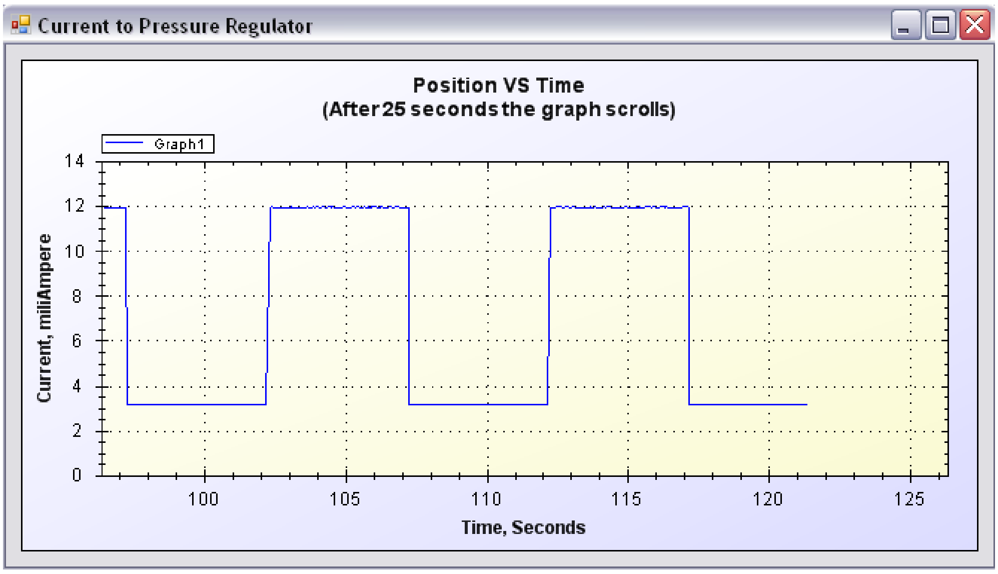


Figure 4.2: Signal response from input (mv)

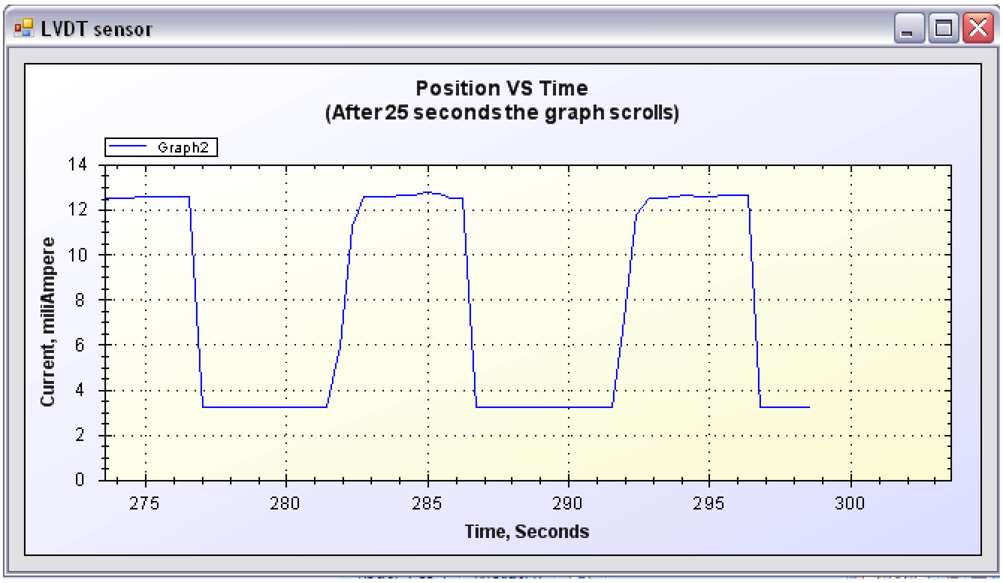


Figure 4.3: Signal response from output (cv)

4.3 MATLAB Simulation

By using MATLAB editor, the result can be determined from the data have been captured from DAQ card. The Figure 4.4 show the input signal (mv) and output signal (cv) from data collection and display using MATLAB graphical form.

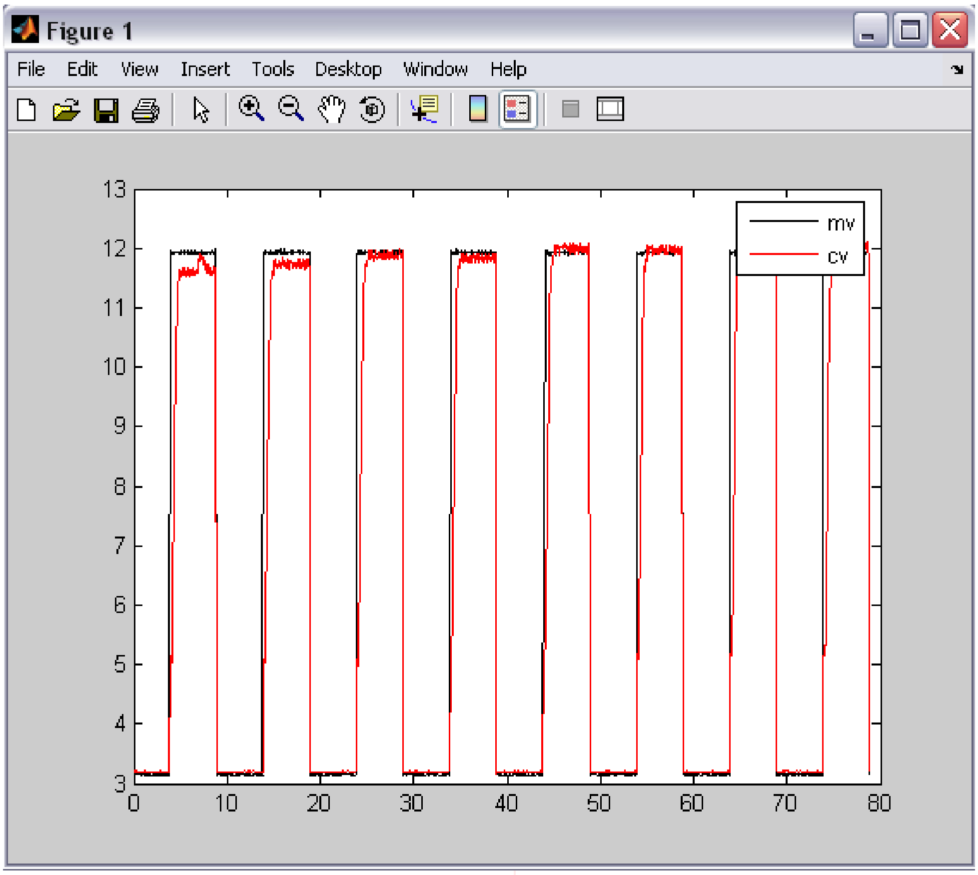


Figure 4.4: I/O signal from data collection

The calculation of parameter identification for the system was completed in MATLAB workspace. Then the result from the calculation was used as the values for the transfer function of the system. Figure 4.5 shows the programming of LSE approach.

```
load datafinal.txt
t = datafinal(:,1);
mv = datafinal(:,2);
cv = datafinal(:,3);

Y=cv(660:925);
M=[-cv(658:923) -cv(659:924) mv(660:925)];
p=(inv(M'*M))*M'*Y;

d = 0.8;
b =p(1) * d;
c = p(2) * d;
a = p(3) * d;

input=[t,mv];
actOutput = [t,cv];

plot(t,mv,'-k',t,cv,'-r')

legend('mv','cv')
```

Figure 4.5: MATLAB calculation

Figure 4.6 below shows the block diagram for the servo-pneumatic system. The input block is function to get the data from the experimental input (mv) result. cvOut diagram is for get the data modeling to send at workspace. actOutput is the place to recalled the output (cv) from the experimental result.

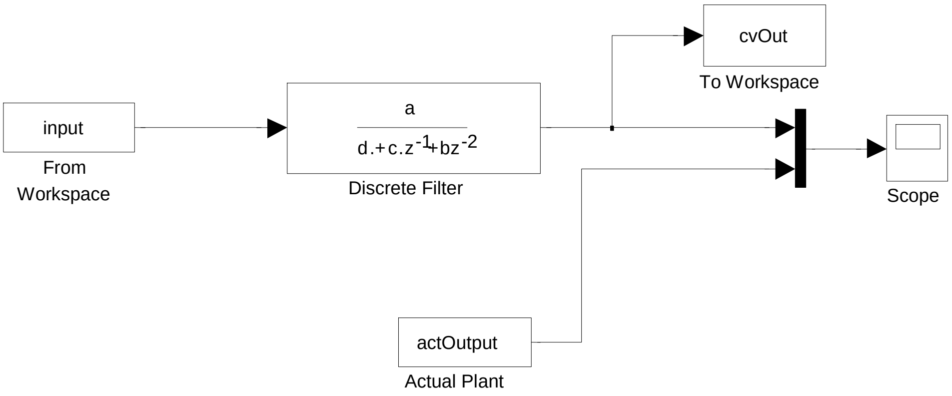


Figure 4.6: Block diagram

The result from both experimental and modeling was shown in Figure 4.7. The signal comparison shows that the signals from both result nearly or similar to each other. The modeling signal result was followed the experimental signal result.

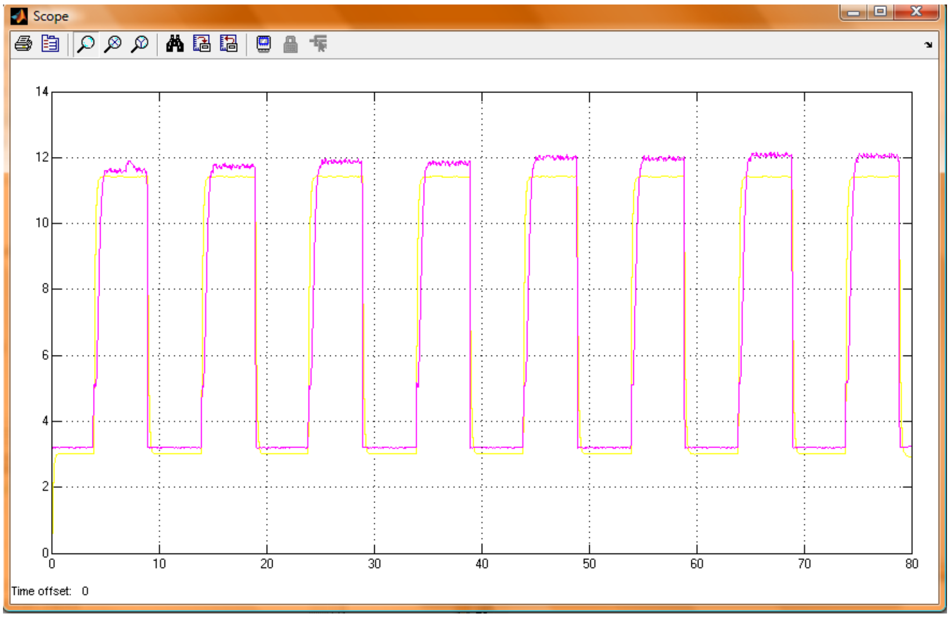


Figure 4.7: Comparison between experimental and modeling

Figure 4.8 shows the identification of a transfer function model in term of block diagram.

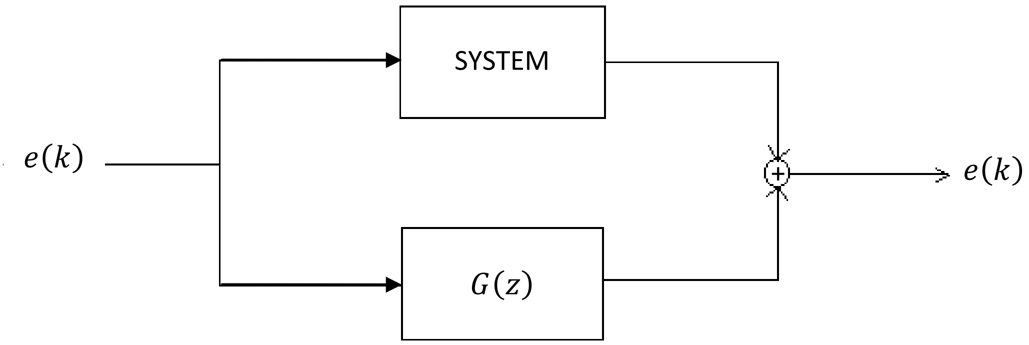


Figure 4.8: Identification of a transfer function model

The transfer function for the servo-pneumatic position control is:

$$G(z) = \frac{0.1819}{1-0.7739z^{-1} - 0.0361z^{-2}} \tag{4.1}$$

The data collected which was then saved in Excel form, to calculate for its average error and mean square error. The values for average error and mean square error (MSE) are summarized in Table 4.2 below.

Table 4.2: Average error and Mean square error

Type of error	Values
Average	0.004894946
MSE	6.859214456

CHAPTER 5

CONCLUSION

5.1 Conclusion

In order to analyze the performances of the system, the signal that had been taken was run in VB software and DAQ is the tool for storing input and output data of the SPPCS. This project also aims to determine the performance and reliability of the designed mathematical model especially in order to get the ideal transfer function of the servo-pneumatic position control system. It is expected that experimental result should tally with the simulation result and this project should come with more research to make sure that the parameter identification of SPPCS can be determined with the exact value that required.

The important part of this project is to truly understand about the project and also its process flow. It is important to study and understand the manual of hardware before work on it. Students gain a new knowledge and can be familiar by working with new hardware and software in finishing this project. By doing this project also, it can develop the critical thinking and problem solving skills and this is the most important criteria for the fresh graduates to grab before enter the work fields. This project also trains the student to work under pressure and prepared them to deal with industrial world.

5.2 Future Recommendation

This project have some weakness, and one of them is the system are not user friendly because their noise from the air compressor and also from the pneumatic cylinder positioner when the system is working. So, the mechanism on how to reduce the noise from the pneumatic cylinder each time their move is needed to solve by doing some kind of research on it.

Introduce the new software such as PLC CJ1M by giving the practical and training class for students and lecturers and so on. It is very important to make sure the student can finish their project without any disturbance that can delay their schedule to finish the project at the due date. Improve the transfer function by using other approach (e.g. PSO).

5.3 Costing & Commercialization

This project come out with the total costing RM 15 000 for all equipment used which are consists of Positioner Cylinder, CJ1M PLC, Air-Pneumatic Regulator, Filter and LVDT Sensor.

The mathematical model of SPPSC can be commercialized and used for future development of the system work and ability of performance.

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