# PLC BASED SPEED CONTROL OF DC BELT CONVEYOR SYSTEM

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*To my mother, father, wife and son, Ainon, Mohd Shah , Siti Arfah and Aqeel Khusaini for their encouragement and blessing, support and caring…*

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In The Name of God.

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# ABSTRACT

Conveyor belt system is one of the most common transfer system used in industry to transfer goods from one point to another in a limited distance. It is used in industries like the electro-mechanical/mechanical assembly manufacturing to transfer work piece from one station to another or one process to another in food industries. Belt conveyor system is also used in coal mining industries but a number of conveyor modules needs to be attached together to achieve long distance transfer. The belt conveyor system used in this project is driven by a DC motor and the model of the system will be determined using fundamental laws. The parameter of the model will then be estimated offline using System Identification toolbox in Matlab. For this reason, an open loop experiment will be done by injecting Sine Wave signal to the DC motor driver to obtain the experimental data for estimation process. This model is then used in Matlab for simulation purpose. In this project, two controllers will be designed. The PID controllers will be designed to provide comparison to the main controller which is the Adaptive Fuzzy PID controller. Both controllers will be simulated in Matlab's environment and will also be implemented on real hardware where the algorithm will be written in PLC using SCL language. Both simulation and experimental results shows that Adaptive Fuzzy PID controller performs better and adapted to the changes in load much faster than the PID controller. This project has also proved that PLC is capable of performing high level control system tasks.

# ABSTRAK

Sistem penghantar tali sawat merupakan salah satu sistem pemindahan yang paling biasa digunakan dalam industri untuk memindahkan barangan dari satu tempat ke satu tempat yang lain dalam jarak yang terhad. Sistem penghantar tersebut juga boleh diguna pakai untuk jarak yang jauh tetapi beberapa modul penghantar perlu disambung untuk tujuan tersebut. Sistem penghantar tali sawat yang digunakan dalam projek ini adalah didorong oleh motor pacuan arus terus (DC) dan model sistem tersebut akan diungkapkan dengan menggunakan persamaan asas matematik. Parameter bagi model tersebut kemudiannya akan dianggarkan menggunakan "*System Identification Toolbox"* yang terkandung dalam perisian Matlab. Untuk tujuan itu, satu eksperimen gelung terbuka akan dilakukan dengan menyuntik isyarat "*Sine"* kepada pemandu motor tersebut untuk mendapatkan data eksperimen bagi proses anggaran. Model yang diperolehi akan digunakan untuk tujuan simulasi. Di dalam projek ini, dua pengawal akan direka. Pengawal PID akan direka untuk memberikan perbandingan kepada pengawal utama iaitu pengawal Kabur Suaian PID. Kedua-dua pengawal yang direka akan disimulasi menggunakan perisian Matlab dan juga akan dilaksanakan pada perkakasan sebenar di mana algoritmanya akan ditulis dalam Pengawal Logik Boleh-aturcara (PLC) menggunakan pengaturcaraan Bahasa Kawalan Berstruktur (SCL). Kedua-dua keputusan simulasi dan eksperimen menunujukkan pengawal Kabur Suaian PID mempunyai prestatsi yang lebih baik dan dapat menyesuaikan dengan perubahan beban lebih pantas berbanding pengawal PID. Projek ini juga telah membuktikan bahawa Pengawal Logik Boleh-aturcara mampu melaksanakan aplikasi sistem kawalan tahap tinggi.

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| | |
|---|---|
| AFPID | - Adaptive Fuzzy PID |
| ARX | - Auto-Regressive with Exogenous |
| ARMAX | - Auto-Regressive Moving Average with Exogenous |
| BJ | - Box-Jenkins |
| DC | - Direct Current |
| FB | - Function Block |
| FC | - Function |
| LAD | -Ladder Logic |
| OB | - Organization Block |
| OE | - Output Error |
| PID | - Proportional Integral Derivative |
| PLC | - Programmable Logic Cntroller |
| SI | - System Identification |
| SIDT | - System Identification Toolbox |
| STL | - Structured Text Language |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project background

This project focused on the implementation of speed control of DC Belt Conveyor System on the real hardware. The experimental setup consists of 3 main components which is the DC Belt Conveyor System with Tachogenerator, a PLC and an Oscilloscope for measurement and data acquisition.

### 1.1.1 DC Belt Conveyor System

Belt conveyor system is a belt driven transfer or transport system used to transfer or transport goods or material from one point to another within a limited distance. It is used widely in industries like in the electro-mechanical assembly, food manufacturing, coal mining and etcetera. Belt conveyor is a preferred transfer system in industry compared to the robotic arm and pneumatic or hydraulic pick and place system because of its simple design, light weight, cost effective, requires less maintenance and the potential to achieve high efficiency. However, this system is inherently difficult to control due to belt flexibility, vibration, friction, system uncertainty and other nonlinearities [1]. Furthermore, the characteristic of the system might also be varies with different load applied to the system.

One of the demands for the modern conveyor is the operation with variable speed. Speed control of conveyors is justified, since most of the time conveyors operate with less than the maximum capacity [2]. The belt can only be partially filled when the material flow transported by the conveyor is smaller than the nominal conveying capacity. The conveying capacity and material loading rate of the belt conveyor can be adapted to the actual material flow by lowering the belt speed [3].

Figure 1.1 and 1.2 shows the belt conveyor system used in this project. This conveyor system is driven by a DC motor equipped with the driver for direction and speed control supplied by Elabo Training Systeme for German Malaysian Institute. Although the system is used mainly for training purpose, it was designed such that it has similar performance and robustness as the one used in industry. The speed of the belt can be varies by applying 0 – 10VDC signal to the driver.

**Figure 1.1** DC Belt Conveyor System


**Figure 1.2** Driver Unit for DC Belt Conveyor System

### 1.1.2 DC Tachogenerator

In this project, the speed of the system is measured by the angular velocity of the pulley attached directly to the belt. This is done using DC Tachometer Generator which usually called as Tachogenerator. The tachogenerator shaft turned as the pulley turned producing a voltage signal proportional to the rotational velocity of the input shaft. Reverse voltage will be produced if the direction of the shaft is changed making direction control possible for this device. Figure 1.3 shows the principle of operation of DC Tachogenerator [4].

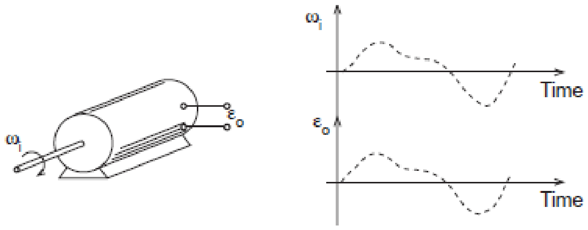


**Figure 1.3** DC Tachogenerator

The advantage of using this device for speed measurement is that it's more precise and additional circuits or devices like high speed counter or digital encoder are not required compared to any optical sensor. However, permanent magnet is used in tachogenerator to maintain the strength of magnetic field constantly. The miss-contact between the commutator and carbon brush can happened due to wear and tear resulting an abnormal waveform produced. Filter is required to reduce or remove the abnormal waveform. The tachogenerator used in this project have the capability to measure speed up to 3000rpm and can produce maximum 20VDC output.

### 1.1.3 Programmable Logic Controller

Programmable Logic Controller (PLC) can be defined as a microprocessor-based control device with the original purpose of supplementing relay logic. In the early days, PLC can only perform logical operations [5]. PLC has been used extensively in industrial applications for control for decades due to their high reliability and robust architecture. The newest PLCs have moved past just a robust platform into a new realm of high computational power and processor speed. These, along with the PLC's highly expandable layout, make it an ideal platform for far beyond the classical applications. These new applications include implementing computational intelligence based modeling, optimization and control techniques that require fast processing power to be executed in real-time [6].

In order to perform such applications, a high level language programming is needed, thus the traditional Ladder Diagram (LAD) has become powerless in the face of increasingly complex control requirements. One programming language that can be used to perform high level task in PLC environment is the PASCAL oriented Structured Control Language (SCL) [7]. In addition to high-level language elements, SCL also includes language elements typical of PLCs such as inputs, outputs, timers, bit memory, block calls, etcetera. In other words, SCL complements and extends the traditional LAD programming.

The PLC used in this project is a highly modular Siemens S7-300 equipped with 24V, 5A power supply, 315F-2PN/DP CPU module, 4 analog channel input and 2 channel analog output module, 32 digital input channel, 16 digital output channel, an AS-I communication processor and an Ethernet switch which used to load the program in programming station into PLC as shown in figure 1.4.

**Figure 1.4** Siemens S7-300 PLC

## 1.2 Project Objectives

The project objectives are;

i. To develop an Adaptive Fuzzy PID Speed Controller for DC Belt Conveyor System
ii. To implement the Adaptive Fuzzy PID Controller using Siemens S7-300 PLC on a real DC Belt Conveyor System

iii. To analyzed the performance of Adaptive Fuzzy PID Controller
iv. To enhance the usage of PLC to advance control technique

## 1.3 Project scopes

The scope of work in fulfilling the project objectives are;

i. To determine the dynamic model of DC Belt Conveyor System using fundamental laws and system identification.
ii. To simulate the PID Speed Controller for DC Belt Conveyor System in Matlab's environment.
iii. To implement the PID Speed Controller for DC Belt Conveyor System using PLC on the real hardware.
iv. To simulate the Adaptive Fuzzy PID Speed Controller for DC Belt Conveyor System in Matlab's environment.
v. To implement the Adaptive Fuzzy PID Speed Controller for DC Belt Conveyor System using PLC on the real hardware.
vi. To compare the performance of PID Speed Controller and Adaptive Fuzzy PID Speed Controller.

## 1.4 Project Report Outline

This project report is divided into five chapters. The first chapter explains briefly on the system and hardware used in this project along with the objectives and scopes of the project. Some literatures and previous researches with similar title have been reviewed in Chapter 2. Chapter 3 explained details on the method and implementation procedure of this project. All the findings and results of this project are discussed in Chapter 4. And finally on Chapter 5 summary of conclusion and recommendations are presented.

# CHAPTER 2

# LITERATURE REVIEW

This chapter discussed some overviews of previous works that have been carried out with similar interests related to this project. All related literature is discussed according to three main interests as follows;

i. Modeling of DC Belt Conveyor System.
ii. Design and implementation of Speed Controller for DC Belt Conveyor System.
iii. Implementation of advance control technique using PLC.

## 2.1 System Model

There were many researches have focused on the modeling of belt conveyor system. Mitsantisuk *et al*, in [1] shows how a conveyor with twin belt-drive which consists of two motors, two driving wheels and a belt drive is modeled. The complicated mechanism of the system has been divided into two simplified model which are the belt deflections model and the driving wheel of the belt system. Mathematical equation of the belt deflections model is constructed by taking into considerations of the Youngs modulus of the belt material, the moment inertia of the circular cross section, the belt tension force, radius of the belt cross section, distance from the belt take off point to the center of the belt span and the radius of driving wheels. Precise model of the belt conveyor system can be obtained using the method discussed however, it has also proved to be time consuming as a lot of parameter of the model requires measurement and experiment.

Sabanovic *et al,* in [8] and Hace *et al,* in [9] and [10] used modal analysis technique in modeling their belt conveyor system. In this approach, the resonance ratio of anti-resonant frequency and resonant frequency of the system is considered. The descriprion of the motor-belt mass system is simplified and modeled as a two-mass system with nonlinear spring connection. The mathematical model obtained was a $4^{th}$ order dynamical system which is nonlinear system with torque of the motor as a control input and two exogenous disturbances entering in the different points to the system. This approach is difficult and expensive as experiments must be carried out by exciting input signal to the system and suitable measurement tool is needed to estimate the elasticity force and the belt damping force.

In modeling their belt conveyor system, Jeftenic *et al,* in [2] and Vijayakumar *et al,* in [11] paid special attention to the dynamics of the rubber belt. The belt is divided in a number of equal segments, with the length of each segment is modeled as a single Kelvin-Voigt element. Kelvin-Voigt element which is also called the Voigt model representing the characteristic of the belt as a purely viscous damper and purely elastic spring connected in parallel. The equations of the element requires certain parameters to be known which includes the length of the belt segment, viscosity, cross section of the belt, Young’s modulus of elasticity and the elongation of the belt. This approach is more suitable to be used to model long belt conveyor system with numbers of carrier drums which is not the case of the system used in this project.

Wahyudie and Kawabe in [12] have modeled a short DC Belt Conveyor System which is much similar to the one used in this project. The conveyor model discussed in [2] and [11] have been simplified by representing the conveyor load model with a single spring-mass system. The spring represents the tension or elasticity of the belt and the mass consists of the belt mass and the material mass carried by the system. This modeling approach has been adopted in this project and will be discussed in greater details in Chapter 3.

## 2.2 Control Stratergies

Most of the literatures found on speed control of belt conveyor system were focusing on energy efficiency in transfer system used in coal mining industries. Pang and Lodewijks in [3] implement Fuzzy Speed Control to adjust the belt speed at the occasion when the loading rate reaches certain point. The loading rate is obtained by dividing the actual material flow by the nominal capacity of the belt conveyor. Simulation results show that 4% energy efficiency improvement was estimated. Practical measurement of the belt conveyors at a large bulk material terminal verified the simulation results.

Ristic and Jeftenic in [13] discussed in more details on the implementation of fuzzy control to improve the efficiency of the belt conveyor used in coal mining industry. The fuzzy logic controller developed based on Mamdani's reasoning method with two inputs, the change of reference speed and drive torque, and one output which is the reference output speed. The fuzzy rules developed based on the three main rules. If the drive torque approaches zero, the reference output speed increment must converge to zero to avoid activation of electrical braking. If the required change of reference speed is small, then no change of the output value is needed. And if incoming material on the belt is increasing, the belt conveyor drive must achieve proper acceleration to avoid spillage of material over belt. This control strategy have been implemented on a real open-pit mine with investment value of more than U.S. $40 Million and eight month of observation shows that the energy consumption has been reduced.

Yilmaz *et al*, in [14] implements fuzzy control to control two conveyors used in product packaging. The control objective is to synchronize the arrival of the products to assemble area by controlling the speed of the second conveyor. The inputs to the FLC are the product offset and offset rate of change while the output is the speed adjustment of the second conveyor. The product offset were obtained by measuring the distance of the product from the assemble area using digital encoder attached to the motor. The experimental results have shown that the fuzzy control can be applied in real industrial machines.

Controlling the speed of conveyor can be achieved by controlling the speed of its drives unit, in this case the DC motor. Therefore, literatures that implement speed control on DC motor with similar control objectives have also been reviewed. Arrofiq and Saad in [15] simulate PI Fuzzy Logic Controller in speed control of DC motor. The controller consists of two fuzzy logic block where the main block acts as a speed controller while the other is used for scaling the main fuzzy output. Mamdani type of fuzzy inference is used with the inputs for both fuzzy logic blocks are the output error and the change of error. The centroid defuzzification method is used with the output membership functions for both blocks are singleton. Comparison performance of the Self Tuning PI Fuzzy Logic Controller (STPIFLC) with PI Fuzzy Logic Controller (PIFLC) is presented. The results shows that although STPIFLC produced higher overshoot, the response is much faster compared to the PIFLC.

Ji and Li in [16] have integrated the neural network and the traditional PID to constitute DC motor speed control system based on Back Propagation neural network self-tuning parameters PID control. The neural network is trained by first using the parameter of PID from the traditional PID controller. The parameter is then changed to the self-tuned parameter after few seconds of training. Simulation results show that the self-tuning controller has better performance compared to the traditional PID controller in terms of lower overshoot, faster rise time and settling time under steady load. It has also shown that the self-tuning controller adapted to the change in load faster.

Payakkawan *et al,* in [17] and El-Gammal and El-Samahy [18] in have used PID controller to control the speed of DC motors. The PID parameter is tuned online using AI-based heuristic optimization techniques based on Particle Swarm Optimization (PSO). Results in both papers shows that the PID controller for speed control of DC motor can be optimized by applying online tuning based on PSO under the load torque disturbances and change of reference speed. Extensive analysis have also been done in [17] to compare the performances of the online tuning of PID via PSO, the offline tuning also using the PSO and the offline tuning via Ziegler-Nichols. The result shows that the auto-tuning via PSO have the lowest overshoot and fastest settling time but no significant improvement on the rise time.

Another control strategy that has gained popularity for speed control of DC motor is the Adaptive Fuzzy PID (AFPID) controller. Kandiban and Arulmozhiyal in [19], Yu *et al,* in [20] and Feng and Qian in [21] have all developed the said controller to control the speed of DC motor. The initial PID parameter is obtained offline while the fuzzy inference system will change the parameter online based from the information of the error and the change of error. Simulation results in [19] and [21] shows that the AFPID has better performance compared to the traditional PID controller. This is proved by the lower overshoot, faster settling and rise time.

## 2.3 Implementation of Advance Control Technique in PLC

Several literatures have been found to have used PLC as a medium to implements their control strategies. Ghandakly *et al*, in [22] have implemented an adaptive controller for DC motor on Allen Bradley PLC5 system. The adaptive controller is based on an intelligent parallel regulator and a Parameter Optimization technique. Simple least square algorithm was used which only requires basic arithmetic operation. Therefore the programming language, the traditional ladder logic have enough capability to perform that algorithm. However, the programming language was useless if one requires high level instruction such as *if else* to be used for example in programming the fuzzy knowledge base like the one used in following literature.

Yilmaz *et al*, in [14] have used different type of PLC to implement fuzzy control to control the speed of belt conveyor system. The PLC used was OMRON PLC which requires additional Fuzzy logic unit, C200H-FZ001 to implement the fuzzy logic control. A special software was also required to program the knowledge base and a subprogram for ladder diagram must be prepared for transferring data between the PLC and the Fuzzy Logic unit. The programming language used for the fuzzy knowledge base was not discussed.

Structured Text Language (STL) is standard PLC programming language that has the capability to perform high level operation. Ferdinando in [23] has used that programming language in PLC TSX 37-21 medium to control the speed of DC motor using fuzzy logic. The program was made easy by additional plugin PL7 FUZZ installed. With this plugin, the shape of the membership function can be specified in graphical form.

Yulin in [24] and Velagic *et al,* in [25] have implement PI controller for the Permanent Magnet DC Motor using the same type of PLC which is Siemens S7-200. In both literatures, a standard, pre-programmed PID subroutine was used. The used of this subroutine was easy as there was no need to program the control algorithm. They only need to assign PID parameter to the ladder block generated and specifying the address of set-point and output.

Junjie *et al,* in [7] shows how PID algorithm can be written in higher range of Siemens PLC which is S7-300 without using the standard pre-programmed block. This was achieved by using the Structured Control Language (SCL), a high level programming language for PLC similar to PASCAL. Although PID is considered as traditional controller, the usage of SCL has provided the base for more advance control technique which is why the same language will be used in this project.

## 2.4 Summary

All the literatures reviewed in previous sections were to help in deciding the best applicable methodology to be used in this project to achieve the objectives stated in previous chapter. At the end, the modeling approach introduce in [12] was used in this project due to the approach that suits the system used but, since the parameter can't be obtained from the manufacturer, an offline parameter estimation will be employed. The control strategy discussed in [19], [20] and [21] will be adopted in this project because of its popularity and simplicity especially a real industrial hardware will be used. Finally, the control algorithm will be implemented in a PLC S7-300 using the programming language introduced in [7].

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