Real Time Implementation of PID and Fuzzy PD Controllers for DC-Servo Motor Based on Lab View Environment

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Abstract

This paper presents an implementation of conventional PID (CPID) controller using Ziegler-Nichols rules and fuzzy PD (FPD) controller for position servo motor control based on Lab View (Laboratory Virtual Instrument Engineering Workbench Environment) through Data Acquisition (DAQ) Device PCI- 6521 of National Instrument's and Data Acquisition Accessory Board Model (CB-68LP).CPID controller is perhaps the most well-known and most widely used in industrial applications. However, it has been known that CPID controller generally don't work well for non-linear systems, higher order and time-delayed linear system and particularly complex and vague system. To overcome these difficulties, this paper proposes to use the FPD controller for a servo motor system instead of CPID. The parameters of servo motor used are completely unknown. The FPD structure has two-input single-output and fairly similar characteristic to its conventional counterpart and provides good performance. Simple rules base are used for FPD (nine rules only). Performance evaluation was carried out via a comparison study for the proposed control scheme and other existing control scheme, such as CPID controller. The critical point for this experiment on position system is a steady state error and settling time. The performance showing that the FPD has less settling time and zero steady state error over its CPID. The algorithms of FPD and CPID controllers are implemented using PID, Fuzzy Logic and simulation toolkits of the Lab View environment.

Keywords: Fuzzy Logic Control, Conventional PID Control, Servo Motor System, Fuzzy PD, Lab View Environment, Ziegler-Nichols Rules.

تطبيق الوقتِ الحقيقيِ لزمن العينة PID وأجهزة السيطرة الضبابية PD لمحركات التيار المستمر مستندة على برامج المحاكاة المختبرِية

الخلاصة

في هذا البحث تم تنفيذ وحدة التحكم التقليدية PID (CPID) باستخدام قواعد زيلفر– نيكولز ومتحكم FPD لأجهزة التحكم في المحركات الموضعية استناداً الى عرض المختبر الافتراضي للآلات الهندسية وكذلك من خلال جهاز اكتساب البيانات (DAC) بواسطة الالة PCI-6521 ونموذجِ لوحة جمعِ البيانات المُساعدِ (CB-68 LP). يعتبر جهاز السيطرة CPID ربما الاكثر شهرة والاكثر استخداماً على نطاق واسع في التطبيقات الصناعية. ومع ذلك ، فقد كان معروفاً ان جهاز CPID عموماً لا يعمل بشكل جيد للأنظمة غير الخطية ، وارتفاع الطلب وزمن التأخير للأنظمة الخطية وخاصة النظام المعقد والغامض. للتغلب على هذه الصعوبات ، تم في هذا البحث اقتراح استعمال جهاز سيطرة FPD لنظام محركات servo بدلا من CPID . ان خصائص محركات ال servo المستخدمة هي مجهولة تماما. وان تركيب FPD له ادخالين واخراج واحد وخصائصه مماثلة جدا لنظيره التقليدي

ويقدم اداءً جيدا. تم استخدام قواعد بسيطة ل FPD (تسع قواعد فقط). واجري تقييم الاداء من خلال دراسة مقارنة لنظام الرقابة المقترح وغيرها من مخطط السيطرة القائمة، مثل وحدة تحكم CPID . ان النقطة الحرجة لهذه التجربة على نظام الموقع هو خطأ ثابت ويحل وقتيا. من خلال اداء النظام نلاحظ بان FPD لديه وقت اقل والخطأ للحالة المستقرة تساوي صفر بالنسبة ل CPID. وتم تطبيق خوارزميات FPD و اجهزة السيطرة CPID باستخدام PID , المنطق الضبابي و برامج المحاكاة المختبرية.

الكلمات الدالة: التحكم المنطقي الضبابي ، وحدة التحكم التقليدية PID، نظام محركات التيار ، الاجهزة الضبابية PD، برامج المحاكاة المختبرِية ، قواعد زيلفر– نيكولز.

Introduction

A special subset of continuous motors is the servo motor, which in ty99pical cases combines a continuous dc motor with feedback loop to ensure the accurate positioning of the motor [1]. Servo motor are generally controlled by conventional Proportional – Integral – Derivative (PID) controller [2].

The simplicity in the design and implementation, the robustness of the system, and flexibility, make the conventional PID controller (CPID) as a most controller used in the industry, where it estimated that, 90% of the controllers employed in the industry are PID controller [3]. However, if the model (transfer function) of the controlled system (plant) is not available or is difficult to estimate, therefore, a complex design steps may be involved in the controller designing, as well as the final control target is not guarantee [3]. For that reason, other strategies should be employed to control uncertain system knowledge. One example, expert systems strategies can be used, since accurate models are not essential in this type of controller [3]. Nowadays, fuzzy controller is one successful methods of expert system and it is widely used in different application; one example is unknown system model.

Generally, fuzzy control has number of advantages, compare with conventional controller, such as PID controller, that make it a particularly attractive choice for number of applications [4]. Summaries some this advantages as flow:

1. Fuzzy logic is inherently robust, where, it can be programmed to fail safely if a feedback signal quits or lost.
2. It is development the user-defined rules, and it can be modified change easily to improve system performance.
3. It can be developed for multi-input-multi-output system, since it is operation, depend on rule-based. However, the system becomes complicated and more complex if many inputs and outputs are chosen.
4. Fuzzy controller can be employed for non-linear systems that would be difficult or impossible to model mathematically.

This paper presents the FPD scheme instead of the conventional PID controller for a dc servo motor system through DAQ device PCI- 6521 of National Instrument's. The control algorithm of FPD and CPID controllers were implemented using Lab View Environment.

Lab View is a graphical program designed to make interfacing with any measurement hardware. Lab View provides assistances which make data acquisition quite simple [5]. As well as, Lab View provides functions those are designed to extract useful information from the acquired data to analyze measurements and processing signals. Lab View environment can be used for data visualization, user interface design, and software connectivity. Thus, Lab View can create applications which can be used to collect, analyze and share data with ease and with higher accuracy. Lab View makes it easier to connect to I/O and integrate with software which makes easier to compare data from a process with the theoretical models [5].

Conventional PID Controller

The transfer function of a PID controller is often expressed in the ideal form [6]:

$$G_{PID} = K_P(1 + \frac{1}{T_I S} + T_D s \text{ ....(1)}$$

Where $G_{PID}(s)$ is the control signal acting on error signal E(s), K_P is the proportional gain, T_I is the integral time constant, T_D is the derivative time constant, and s is the argument of the Laplace transform. The control signal can also be expressed in three terms as:

$$U(s) = K_P E(s) + K_I \frac{1}{s} + K_D sE(s) \text{....(2)}$$

Where $K_I = K_P / T_I$ is the integral gain and K_D is the derivative gain. The three-term functionalities include [6]:

1) The proportional term provides an overall control action proportional to the error signal through the all pass gain factor.
2) The integral term reduces steady-state errors through low-frequency compensation.
3) The derivative term improves transient response through high-frequency compensation.

Ziegler – Nichols Tuning Methods [7]

Again, the mathematical model of a controlled is essential to design the controller and tune the gains. On the other hand, if the system model cannot be modeled, systematic and analytical design methods cannot be used. Therefore, well known Ziegler-Nichols tuning methods can be used to find the optimal gains and design the overall controllers. The procedure to tune the PID controller in (1) is pretty easy using Ziegler approach. Firstly, the derivative and integral coefficients are set to zero; and the proportional gain is increased from zero to critical gain value ($K_{c)}$ where the system exhibits sustained oscillations. Then, based on oscillation period of oscillation (P_c) and critical gain (K_c) value the parameters K_P, T_I, T_D can be determined according to the formulas given in Table (1):

Fuzzy Logic Control Design

Fuzzy logic control developed here as shown in Fig.1.a is a two- input single- output controller. The two inputs are derivation from set point error (e) and change of error (Δe).The error is defined as:

$$e(t) = \theta_r(t) + \theta_c(t) \text{ ....(3)}$$

Change of error as follows:

$$\Delta e(t) = \frac{d}{dt} e(t) \text{ ....(4)}$$

Where $\theta_r(t)$ is the reference input signal, $\theta_c(t)$ is the output signal.

The tracking error signal (position) and change of the error signal (velocity) are converted into information that the rule based mechanism can easily use to activate.

The fuzzy controller is composed of the following three-elements as shown in Fig.1.b [8]:

1) Fuzzification: This converts input data into suitable linguistic values. The third triangular input and output member ship functions of the fuzzy logic control are shown in the Fig. (2). For the system under study the universe of discourse for both e(t), Δe(t) and for output may be normalized from [-1 , 1], and the linguistic labels are{ Negative, Zero , Positive}, and are referred to in the rules base as {N, Z, P }.

2) Rule base: A decision making logic which is, simulating a human decision process, inters fuzzy control action from the knowledge of the control rules and linguistic variable definitions. For given input and output linguistic label table (2) shows the control rules base that used for FPD.

$$U_f = \frac{\sum_{i=1}^{n} \mu(\mu_i)\mu_i}{\sum_{i=1}^{n} (\mu_i)\mu_i} \quad \ldots\ldots\ldots\ldots(5)$$

Where μ(u_j) member ship grad of the element u_j, U_f is the fuzzy control output, n is the number of discrete values on the universe of discourse.

Derivative of the Fuzzy PD Structure

Derivative controller is an intelligent part of PID controller, where it can predict the changes in the error signal and it can improve closed-loop stability, where the phase margin of the system may be increased by aid of derivative gain. The basic structure of a PD controller is can be present as [9]:

$$u_n = K_P(e_n + T_d \frac{e_n - e_{n-1}}{T_S}) \ldots\ldots\ldots(6)$$

As describe in (6), the control action of derivative part is relative to the prediction of the error signal. Now, for T_d= 0, the control action is conversional proportional gain, and when T_d is gradually increased, the system start to

The computation of the fuzzy control action signal composed many steps. These steps can be all combined together in what is called control surface because the system has two inputs and one output. The shape of this surface shows how the output value varies with different combination of the two inputs values. Fig (3) shows the rule surface viewer of the FPD [8].

3) Defuzzification: The input for defuzzification is the member ship (certainty) μ(u_i) from implied fuzzy sets resulted from premise rules and the output is a crisp number. The most popular method, center of gravity or center of area is used for defuzzification [8]:

damply oscillations. If T_d becomes too large the system becomes over damped [9] and it will start to oscillate again. Input to the FPD controller is the error and derivative of error [8]:

$$\Delta e(n) = \left(\frac{e_n - e_{n-1}}{T_S} \right) \ldots\ldots\ldots\ldots\ldots(7)$$

This is a discrete approximation to the differential quotient using a backward difference. Other approximations are possible. The controller output is a nonlinear function of error and change of error [9]:

$$U_f(n) = f(K_e * e_n + K_{\Delta e} * \Delta e(n))K_f \ldots(8)$$

Where f is input-output map of fuzzy controller, using the linear approximation K_e* e_n + $K_{\Delta e}$* Δe(n), then[9]:

$$U_f(n) = (K_e * e_n + K_{\Delta e} * \Delta e(n))K_f \quad \ldots(9)$$

$$U_f(n) = K_e * K_f * \left(en + \frac{K_{\Delta e}}{K_e} \Delta e(n) \right) \ldots(10)$$

By comparison, the gain in (4) and (7) are related the following way:

$$K_e * K_f = K_R \qquad \ldots\ldots\ldots\ldots\ldots(11)$$

$$\frac{K\Delta_e}{K_e} = T_d \qquad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

The FPD controller may be applied when the performance of the system is not enhanced using proportional part only. Finally, derivative term improves response; and it can reduce overshoot, however, it is more sensitive to noise [9]; in addition, fast changes in the system, such as abrupt change in target signal; can be leads to derivative kick in control action. However, number of method can be apply to overcome this limitation, for instance output signal can be used in derivative part instead of the error [9].

Hardware, Software Setup and System Description

The experiment part can be divided into two levels:

Hardware Level Design

The apparatus of the servo control system shown in Fig (4) consists of an internal A/D and D/A conversions based computer by using NI PCI-6251 DAQ device, which is connected to the plant (servo motor). The positing was sensing by using a potentiometer. The potentiometer and gear box are embedded into a dc motor. The parameters of this dc motor are completely unknown.

The feedback signal will pass to the A/D converter of a DAQ device, and into the computer, where will be used to control the position of the servo motor. Upon the software design of control algorithm in Lab View, The output signal will sent to the plant (servo motor) from the computer through D/A converter of the DAQ device.

DAQ Device Specifications

To create a communication between the process and the computer National Instruments provides different input/output cards which are further supported by DAQ assistance. DAQ assistance is a simulation of data acquisition device. The DAQ assistance creates different channels for measurement and transfer signals from one form to other so that a computer can process [5]. In this experiment the National Instrument PCI-6251DAQ device is used.

This device has the following specifications:

1- 16 Channels Analog Input.
2- 1.25 MS/s Sample Rate.
3- 16 Bits Resolution.
4- (-10V to 10V) Maximum I/O Voltage Range.
5- (-100 to 100 mV) Minimum Input Voltage Ranges.
6- Two Channels Analog Output.
7- (-5V to 5V) Minimum Output Voltage Ranges.
8- 24 Digital I/O Channels.
9- Two Counter/ Timers.
10- 80 MHz Maximum Source Frequency.

Positing Sensor Calibration

The sensing signal for feedback is a potentiometer. The signal was calibrated to convert the voltage signal to position. The feedback rang (voltage input) from -2 V to 2 V and it was digitized by a DAQ device. 2V corresponding to 20 degree and -2 V to 340 degree. Regression equation was derived as follows:

$$\text{Position} = (V_{feedback} - 2) * \frac{340 - 20}{-4} + 20 \qquad \ldots..(13)$$

Where **V *feedback*** is a potentiometer signal.

Software Level Design

Lab View Environment was used in order to develop the system software and I/O signal process[5]. Lab View programs are called virtual instruments or VI because their appearance and operation imitate physical instruments, such as oscilloscopes and multi meters. A Lab View VI contains three main components[5]:

- Front panel.
- Block diagram.
- Icon/connector panel.

The front panel is the user interface for the VI. Front panel contains the interactive input and output terminals of the VI. The block diagram contains graphical source codes. These codes are added using the graphical presentation of functions to control the front panel objects. Icon/connector panel is used to use a VI inside the other VI, which is called a sub VI .The upper right corner of the front panel and block diagram displays an icon, which can contain both texts and images. An icon identifies a sub VI on the front panel of a VI. To use a VI as a sub VI there is a need of a connector panel. Connector panel is a set of terminals that corresponds to controls and indicators of that VI [5].

Control experiment to the servo motor can be achieved by implementing CPID and FPD using PID, Fuzzy Logic and simulation toolkits of the Lab View Environment. The software level of this experiment consisted of two front panel VI parts: one for CPID controller as shown in Fig.5 and other for FPD controller as shown in Fig.(6).

The user enters desired position of the servo motor from the front panel (manual or automatic). And when executed the program, the sub VI reads the user specified desired position of the motor, and apply the control algorithm (FPD or CPID) also the front panel of the VI display the real current position of the motor by gauge indicator and graph the position response. The desired position may be changes on line. The graphical presentation of function to control the front panel objects are shown in Figs. (7,8) for CPID and FPD Controllers respectively.

Experimental Results

Real time comparison between FPD and CPID controllers are designed and implemented for dc servo motor based on Lab View Environment through Data Acquisition (DAQ) Device PCI-6521 of National Instrument's and Data Acquisition Accessory Board Model (CB-68LP) .

Initially, the CPID controller is designed and the PID gains are optimally tuned using Ziegler Nichols rules. Again, the parameters of this motor are completely unknown. For this reason Ziegler Nichols rules is employed in this paper. CPID parameters are founded as follow: K_c = 3.5, T_I = 0.08, and T_D = 0.02. Flowing that, the FPD gains are tuned several times till to get the best possible results for fair comparison with CPID. Where, FPD controller gains are K_e = 1, $K_{\Delta e}$ = 0.3, K_f = 6.

The aims of the controller designed are: minimum of overshoot and oscillation, and minimum steady state error.

Now, to evaluate the robustness of the system and asses the overall dynamic behavior of the system for both type of controller (CPID and FPD); the reference signal (desired angular position) has been changing abruptly in both direction (clockwise and antilock wise). Initially, the reference signal was set to 20^o and then moved quickly to 180^o in clockwise direction; as shows in Fig. (9, and 11) for both controller (CPID and FPD). Then, we assumed that the controller will change abruptly again as depicts in Fig. (10, and 12) in opposite direction (anti clockwise). Therefore, those results clearly demonstrated that, both controllers are robust against change in the system and they have the ability to track the sudden changes in the system, in both directions. However, the overshoot and the steady state error using FPD are better than CPID. However, the integral part that leads to zero error is not included in FPD.

More validation is carried out for FPD and CPID as presents in FIG. (13, 14, 15, and 16), with different angular position; and again it demonstrates that, FPD have a zero steady state error in a short time, less settling time, and no overshot while in the CPID, if zooming the figures we can see that the steady state error is not equal to zero and it has a small overshoot.

Finally, the tracking performance for FPD and CPID controller has been evaluated as well by varying the desired angular positions into different location; as shows a fast tracking can be achieved with both controllers, however in FPD is faster and accurate.

Conclusions

In this paper, servo motor system was controlled the using two control methods. CPID and FPD controllers; a FPD and CPID controller were designed and implemented using Lab View Environment for automatic position control system, through DAQ device PCI- 6521 of National Instrument's. The FPD structure has two-input single-output and fairly similar characteristic to its conventional counterpart and provides good performance. Simple rules base are used for FPD (nine rules only) to make the position response faster. The investigated scheme has been tested depending on different position by running the servo motor to forward and backward directions. According to the results; it could be concluded that the FPD controller as compared with the CPID controller, has no overshoot, zero steady state error and less settling time.

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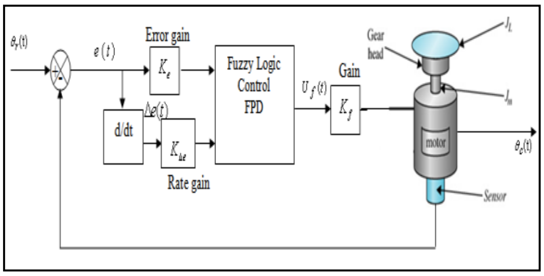

Figure (1.a): Closed loop fuzzy PD Structure Proposed

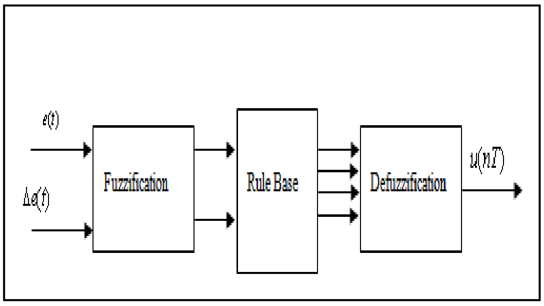

Figure (1.b): Fuzzy logic control

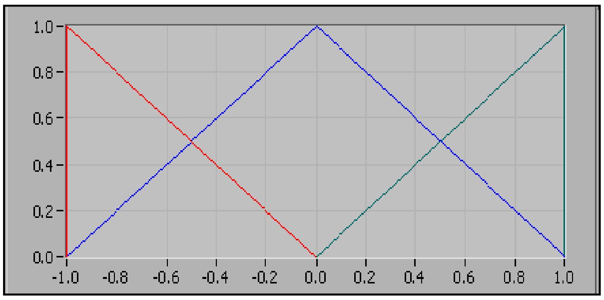

Figure (2): The input and output membership function for FPD controller

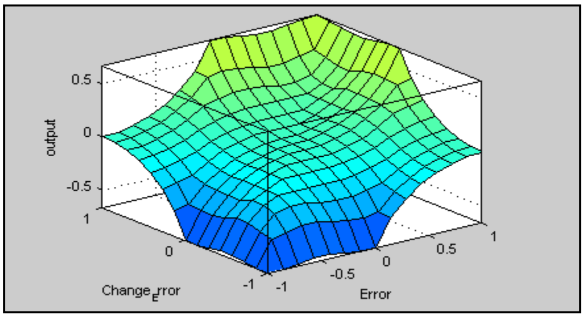

Figure (3): Rule Surface viewer of the FPD controller

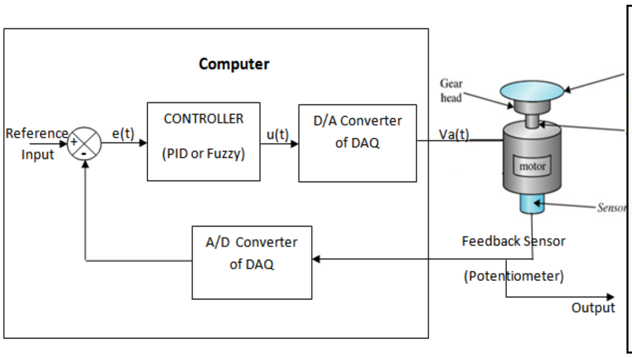

Figure 4: Hardware level block

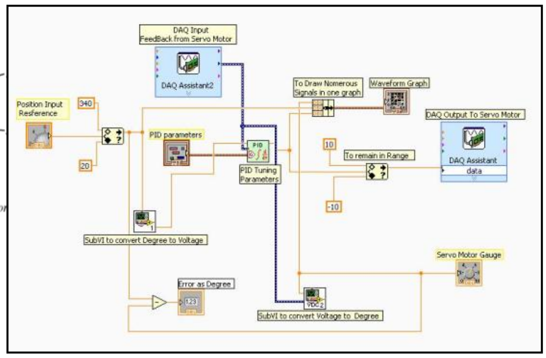

Figure 7: Circuit diagram of Lab View (sub VI) for CPID Controller

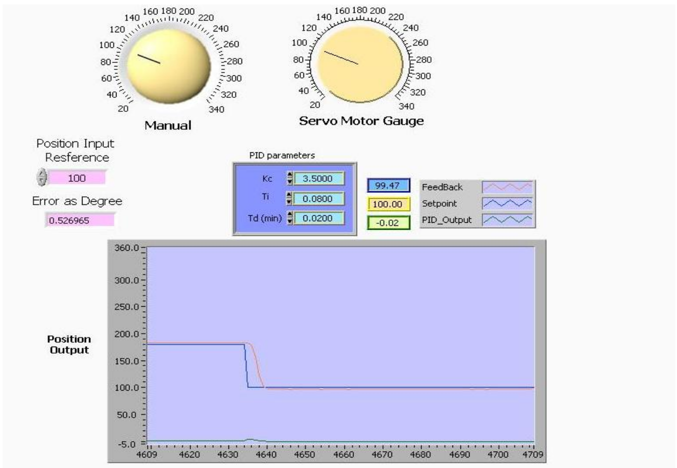

Figure 5: Front panel of Lab View (Vi) for CPID controller

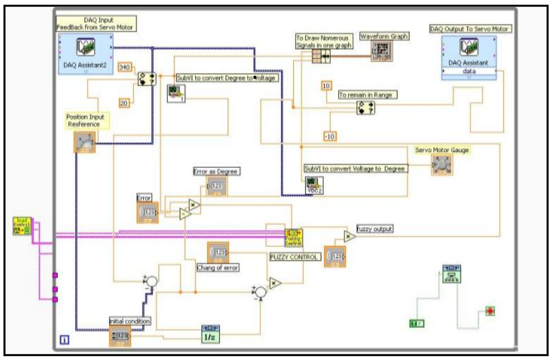

Figure 8: Circuit diagram of Lab View (sub VI) for FPD Controller

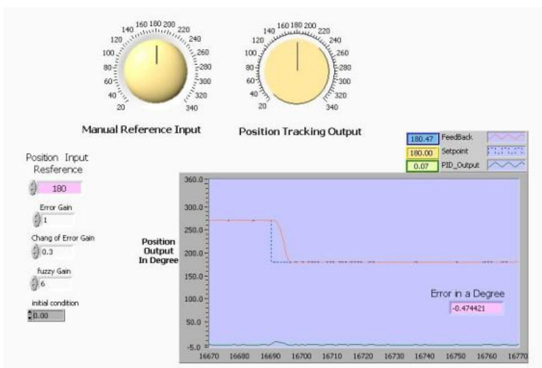

Figure 6: Front panel of Lab View (VI) for FPD controller

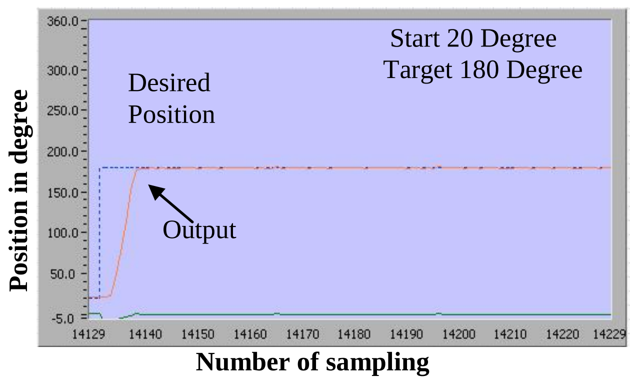

Figure 9: Position response for FPD

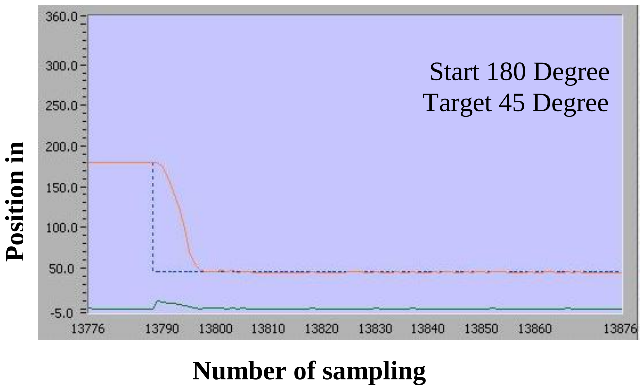

Figure 10: Position response for FPD

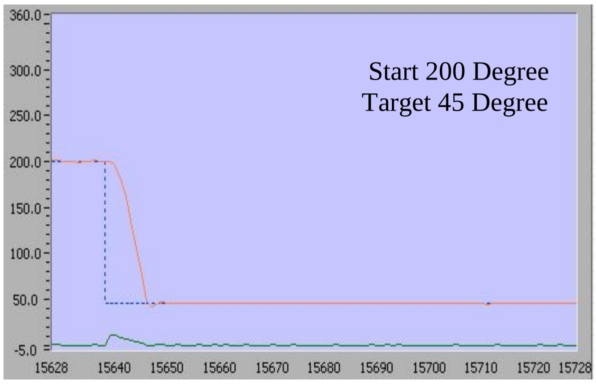

Figure 13: Position response for FPD

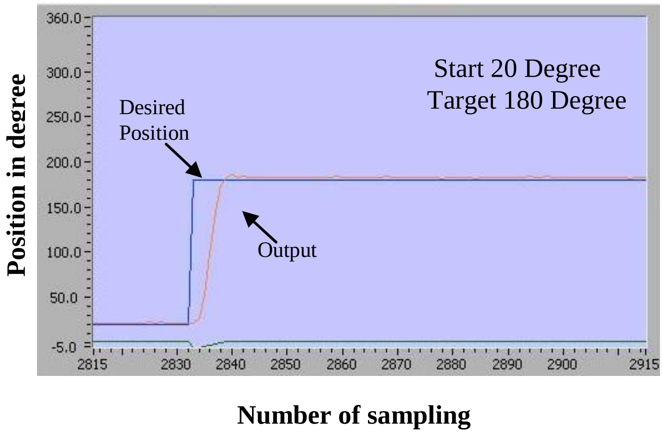

Figure 11: Position response for CPID

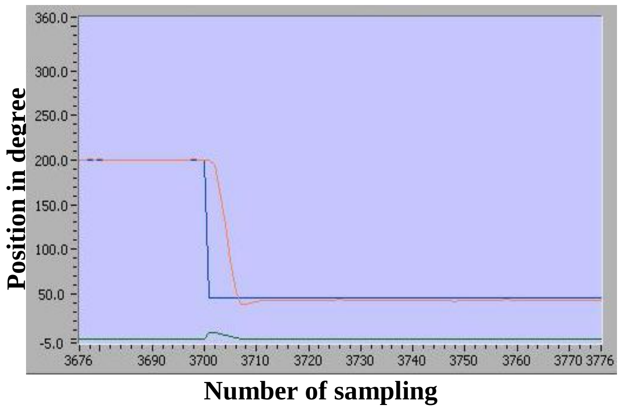

Figure 14: Position response for CPID

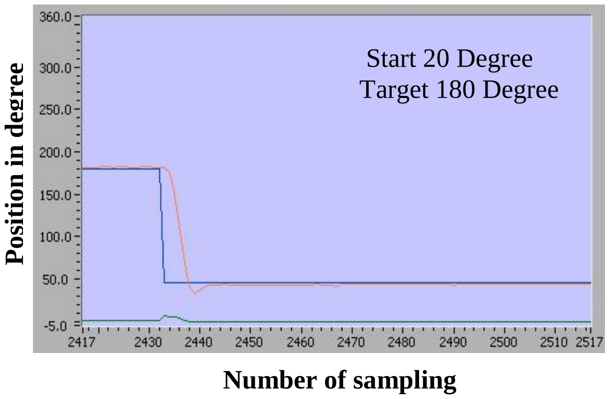

Figure 12: Position response for CPID

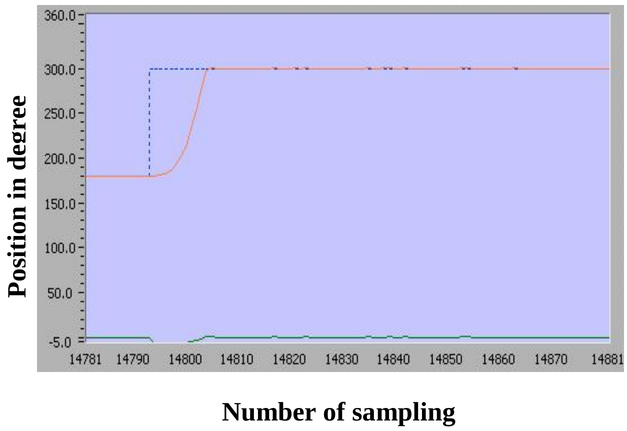

Figure 15: Position response for CPID

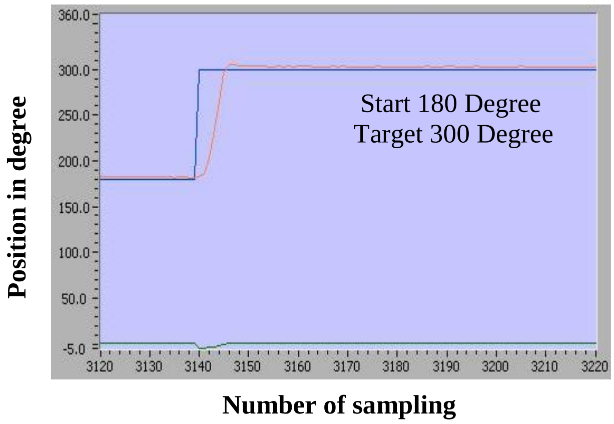

Figure 16: Position response for CPID

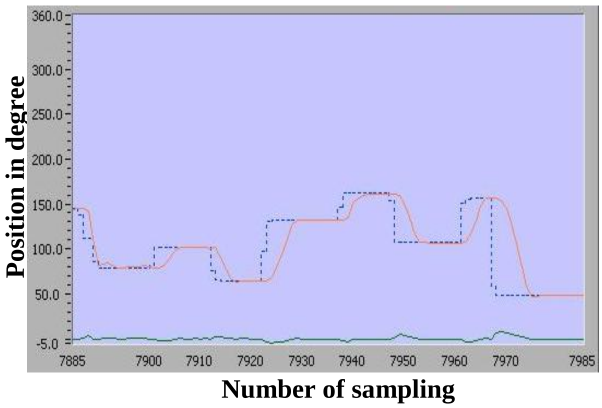

Figure 17: Tracking performance for FPD

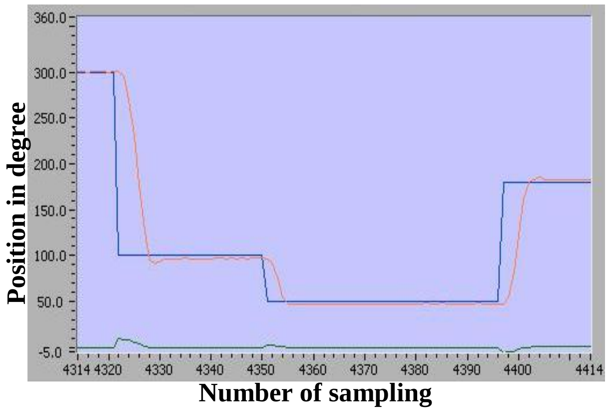

Figure 18: Tracking performance for CPID

Table(1): Ziegler-Nichols tuning rules

Controller	K_P	T_I	T_D
P	0.5 K_c	∞	0
PI	0.45 K_c	1/1.2 P_c	0
PID	0.6 K_c	0.5 P_c	0.125 P_c

Table (2): Rules base for fuzzy PD controller

e(t)/Δe(t)	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P