Implementation of PID Controller and Pre-Filter to Control Non-Linear Ball and Plate System

Agung Adiprasetya/Telkom University
Electrical Engineering Faculty
Bandung, Indonesia
agungadiprasetya@gmail.com

Agung Surya Wibowo/Telkom University
Electrical Engineering Faculty
Bandung, Indonesia
agungsw@telkomuniversity.ac.id

***Abstract*—In this paper, the authors try to make PID controller with Pre-filter that is implemented at ball and plate system. Ball and plate system will control the position of ball's axis in pixels value by using servo motor as its actuator and webcam as its sensor of position. PID controller with Pre-filter will have a better response than conventional PID controller. Eventhough the response of PID with Pre-filter is slower than conventional PID, the effect of Pre-filter in the system will give the less overshoot response.**

Keywords—PID, Pre-filter, Ball and Plate system

I. INTRODUCTION

The ball and plate system is very interesting to be designed. The open loop system has instability and nonlinearity and it is hard to be controlled. Ball is placed on the plate and its coordinate or position can be set as a set point in pixels value. The actuator of this sistem is servo motor. The actuator will be used to set how much the plate angle is. There are two motor servo built in plate in order to move the ball in x and y direction. The sensor of this sistem is webcam. It will sense where the ball's position is. The ball and plate system is showed in Fig.1.

Fig. 1. Ball and Plate System

The research of the control of ball and plate system has been done by some researcher. The previous research about ball and plate system can be seen in some papers with title such as [1], [2], and [5]. In here, the authors want to begin from the basic and simple controller (PID Controller).

The organization of this paper is as follows: the present Section provides a brief introduction and literature review on the Ball and Plate System, Section II gives more detail about ball and plate system, Section III gives the methodology to design the system, Section IV gives some experiment result and analysis that has been done, finally Section V gives conclusion and suggestion for the future work in ball and plate system.

II. BALL AND PLATE SYSTEM

The block diagram and hardware of system will be showed below. The sistem use a single feedback to track the desired ball position.

A. *Block Diagram of System*

The block diagram of the ball and plate system can be showed in Fig.2 and Fig.3. In Fig.2 It uses PID controller to control ball position on plate. Because there are two variables that must be controlled, so the system must have two PID. The first PID is used to control position in X axis, and another PID is used to control position in Y axis. In Fig.3 the sistem is complemented by pre-filter block in order to reduce the overshoot of the response.

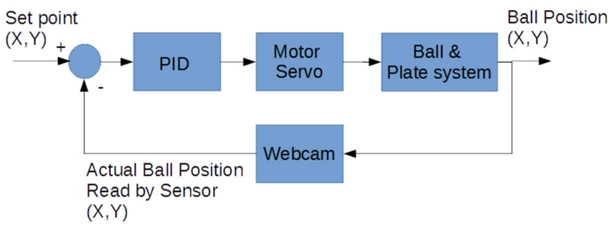

Fig. 2. Block Diagram of Ball and Plate Control System without Pre-filter

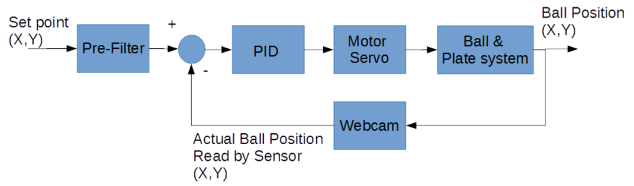

Fig. 3. Block Diagram of Ball and Plate Control System with Pre-filter

B. *Hardware of System*

The system consist of three main devices. The first device is PC that have multiple task such as to make the setpoint, compute position error, process Pre filter and PID controller, and send serial data PWM to Arduino. The second device is Arduino. The Arduino receives serial data from PC to move or set the angle of servomotor. The last device is webcam as a ball position sensor. Fig. 4 show the hardware of system.

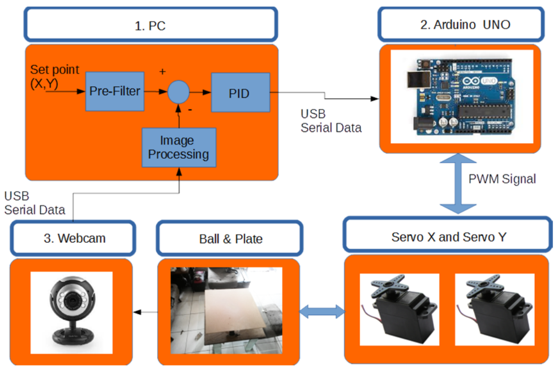

Fig. 4. The Harware of System

C. *Mathematical Modelling.*

The model of system can be simply derived like the model of ball and beam system or we can use detail modelling. Detail modelling has been derived in [6]. Modelling of this system is not effective when we use PID method for its controller. In this paper we will not find mathematical modelling for designing the PID controller. Modelling in system is sensed by intuition that the sistem is type-I, because of the same characteristic with the position control system. We have known that the position control system of DC motor that is unstable system is system type-I. When the system type is known as system type-I, then the control strategy is chosen to focus on the Kp gain constant and Kd gain constant. It has purpose to make the system more stable. Finally, if there is still some error steady state, we can put a little Ki gain constant to our controller.

III. BALL AND PLATE SYSTEM DESIGN METHOD

A. *PID Design*

The parameter of the PID controller in the system is found by trial and error method. Firstly, we focus on proportional gain. Proportional gain must be big enough so that the ball on plate can move freely. Proportional gain cannot big too much, because it will cause very high fluctuation and make the response is hard to achieve steady state. Then, we add derivative gain to reduce the response fluctuation. The ratio between proportional gain and derivative gain usually has value about eight or ten times. Finally, we add a little integral gain to reduce the error steady state.

The transfer function of digital PID can be written in (1) .

$$OutputPID(z) = P(z) + I(z) + D(z)$$

$$P(z) = KpE(z)$$

$$I(z) = \frac{Ki}{1 - z^{-1}}.E(z)$$

$$D(z) = Kd(1 - z^{-1}).E(z) \tag{1}$$

From (1) can be derived the difference equation in (2)

$$OutputPID[n] = P[n] + I[n] + D[n]$$

$$P[n] = Kp.e[n]$$

$$I[n] = Ki.e[n] + I[n-1]$$

$$D[n] = Kd.(e[n] - e[n-1]) \tag{2}$$

Finally, we have code in C++ for digital PID controller implementation from (2). The parameter of PID can be show in the table below. Both X and Y have the same parameter of PIC.

TABLE I. THE PARAMETER OF PID

The axis of image	**Parameter of PID**		
	Kp	***Ki***	***Kd***
X	1.5	0.005	10
Y	1.5	0.005	10

B. *Pre-Filter Design*

Pre-filter used in the system is the 1st order low pass filter. The purpose of pre-filter in here, is to reduce high overshoot of the response. Example of the pre-filter that is used in continuous system can be shown in (3)

$$P(s) = \frac{a}{s+a} \tag{3}$$

The transfer function of pre-filter must have dc-gain equal to one. We want to make the output of the pre-filter will have the same value with the setpoint at the steady state. The idea is to give the setpoint to system little by little so that the error in the system is not so big.

Implementation of pre-filter is done by software as a digital low pass filter. Digital low pass filter that have a dc gain equal to one will have a transfer function like (4). The variable 'a' must have a value |a|<1 so that we have a stable pre-filter system.

$$P(z) = \frac{(1-a)z}{z-a}, \tag{4}$$

From (4), the difference equation can be derived to be (5)

$$P(z) = \frac{OP(z)}{SP(z)} = \frac{1-a}{(1-az^{-1})}$$

$$OP[n] - a.OP[n-1] = (1-a).SP[n] \tag{5}$$

Then, we can make the implementation of digital pre-filter from (5) by code in C++. Sampling time that we used in pre-filter is different from sampling time in PID. We want to make the transition in pre-filter is moving slowly. The sampling time in pre-filter is slower than the digital PID sampling time. The sampling time of pre-filter is about ten times of the PID sampling time.

C. Ball's Position Sensing Method

Fig. 5 and Fig. 6 below explain about how the camera can detect and track the ball.

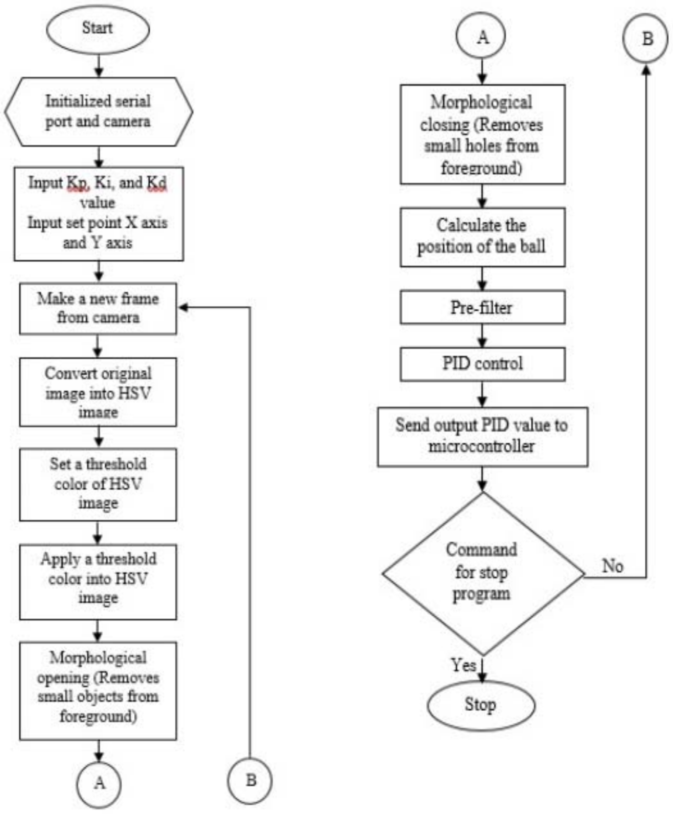

Fig. 5. Personal Computer Flowchart (Without Pre-Filter)

From Fig.5 and Fig.6, it is explained that the ball is detected by its color. The captured image from camera is converted into HSV image. After we have an HSV image then it is converted into black and white image by applying the threshold value. At this step, we have had an image of the white ball and another is outside the ball is black.

Finally, software will find the coordinate of the ball by detecting white color in the black and white image. The coordinate is in pixels value. This coordinate is used for the error calculation. Error is calculated by subtracting between the setpoint coordinate and the actual coordinate. Signal error will be excited to PID controller. The PID controller's output then is sent to Arduino via serial communication.

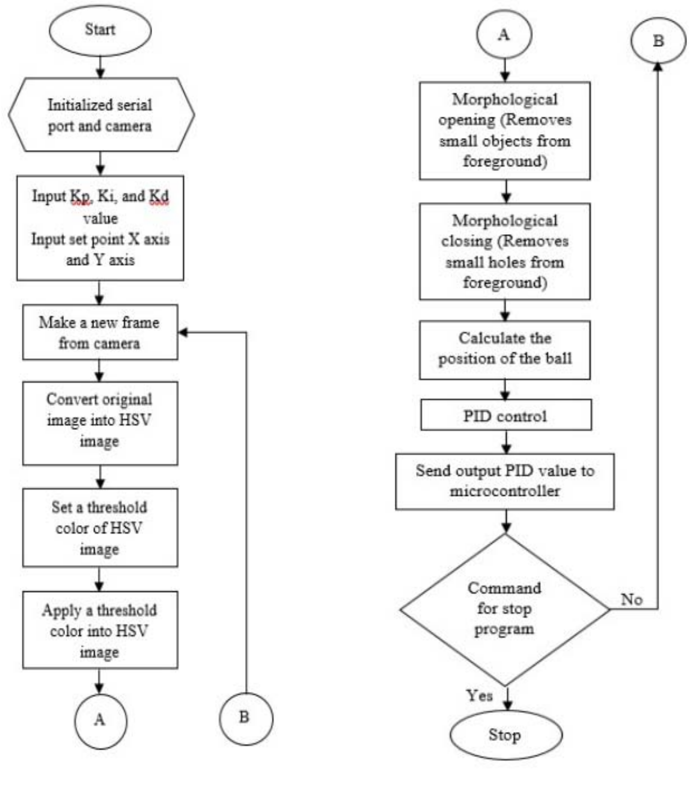

Fig. 6. Personal Computer Flowchart (With Pre-Filter)

Fig.7 explains how the servo motor can move. The output of PID from the PC's software calculation, is received by Arduino UNO. The type of receiced data is a string type. The Arduino must convert this data into number so that it can be used to move the desired angle's position of servo motor. Then the servo motor will stabilize the ball on the plate.

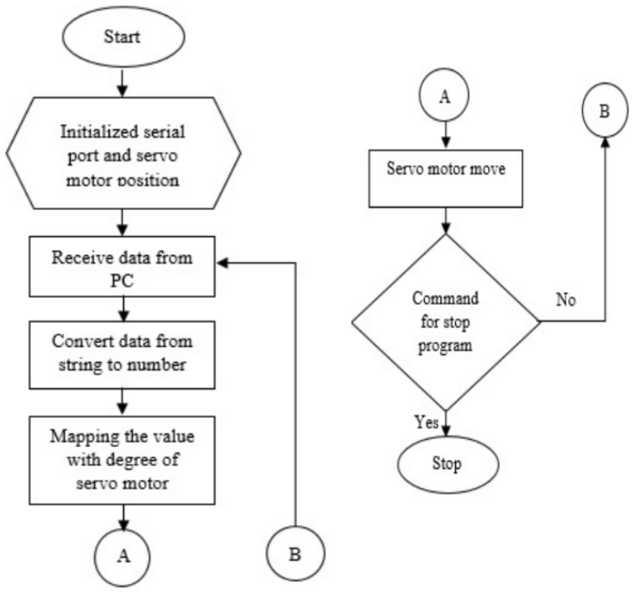

Fig. 7. Arduino Uno Flow Chart

IV. Experiments Result and Analysis

The experiments have been performed on the system that use both pre-filter and without pre-filter. There are two types of experiment that is performed on ball and plate system. The first experiment is using one fixed set point. The set point of coordinate is set at the center of the ball and plate system. The second experiment is using four changed set point. Four coordinate is set to create a square trajectory on the plate.

A. *First Experiment (Using Fixed Set Point at The Center)*

In this experiment, the system use the value of set point in X = 300 pixels and Y = 300 pixels. Based on the ball movement in Fig. 8 and Fig. 9, it is showed that the both sytem will make the actual coordinate is going to reach the set point at the steady state. The overshoot of the system that use pre-filter is less than that of the system without pre-filter. The error of this experiment is about 10 – 20 pixels.

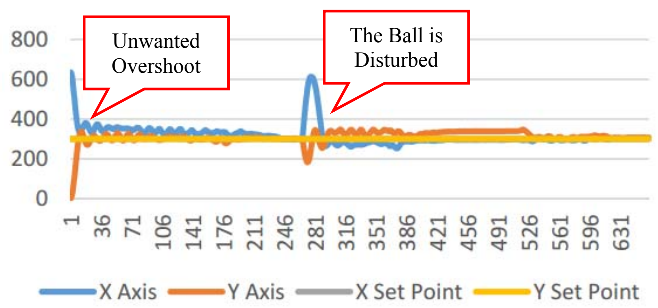

Fig. 8. Response of System Without Pre-filter

Fig. 9. Response of System with Pre-filter

B. *Second Experiment (Using a Square Trajectory)*

In this experiment, the system use four coordinate for its setpoint. The four set point coordinate are set in (x, y) point. There are point (100, 100), (100, 400), (500, 400) and (500, 100). These points will make the square track or trajectory. The response of the system will be showed at Fig. 10 and Fig. 11. Based on the response graph, there are some differences.

The response of the system without pre-filter has a higher overshoot but it has a less rise time. The system without pre-filter is faster and it can be seen clearly at the graph that it has a bigger gradient than that of the system with pre-filter. On the opposite, the system with pre-filter will have a less overshoot but this system has slower response.

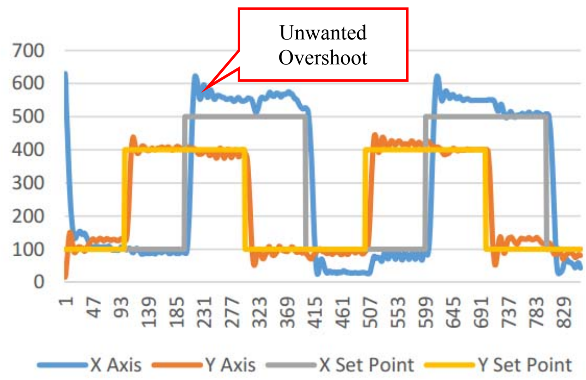

Fig. 10. Responses Of System Without Pre-Filter (4 Different Setpoint)

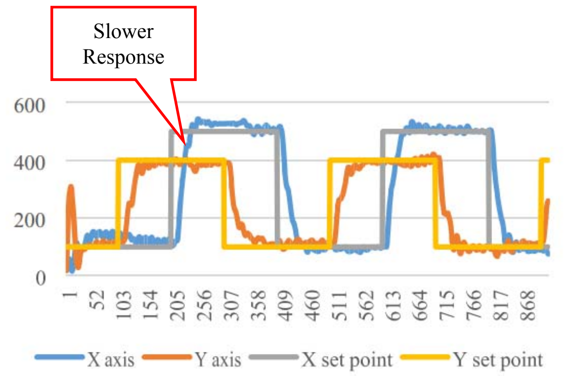

Fig. 11. Responses of System With Pre-Filter (4 Different Setpoint)

The trajectory of the ball's movement can be shown in Fig.12 and Fig. 13.

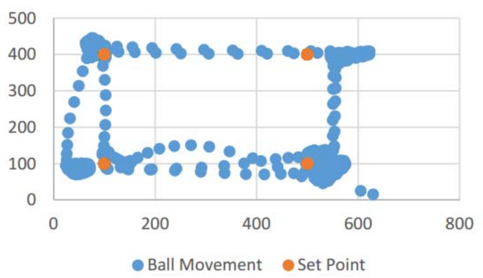

Fig. 12. Trajectory Of System Without Pre-Filter (4 Different Setpoint)

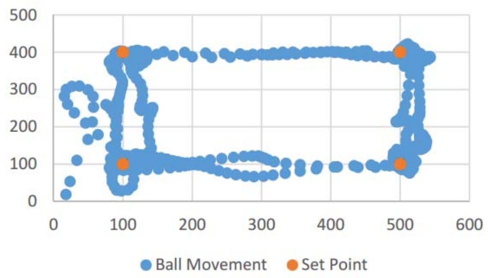

Fig. 13. Trajectory Of System With Pre-Filter (4 Different Setpoint)

V. Conclusion and Future Works

In this paper , implementation of PID controller with pre-filter to control nonlinear ball and plate system has been done successfully. Actually, we propose two design method for controlling the ball and plate system, there are the system with conventional PID controller and PID controller with Pre-filter. The result show that PID controller with Pre-filter will have a better response for tracking position of the ball in square trajectory or balancing position of the ball in the center of the plate.

The overshoot of the system with pre –filter is about 5 – 10 pixels. It is very different from the overshoot of the system without pre–filter. The overshoot of the system without pre – filter is about 50 – 100 pixels.

For the future works, we suggest for another method design for controller design. Other method that can be proposed for better result such as FLC Fuzzy Logic Controller, or adaptive control for nonlinear system because in fact the ball and plate system is nonlinear system.

References

[1] Miad Moarref, Mohsen Saadat, and Gholamreza Vossoughi, "Mechatronic Design and Position Control of a Novel Ball and Plate System," 16th Mediterranean Conference Control and Automation, Congress Center, Ajjacio, France, June 25-27, 2008

[2] Diego Col´on , Jos´e M. Balthazar , C´elia A. dos Reis, Atila M. Bueno ´ ,Ivando S. Diniz and Su´elia de S. R. F. Rosa, "Control Design and Robustness Analysis of A Ball and Plate System By Using Polynomial Chaos", Conference Paper, July 2014.

[3] M. Amjad, KashifM.I., S.S Abdullah, Z.Shareef,"A Simplified Intelligent Controller For Ball and Beam System," 2nd International Conference On Education Technology and Computer (ICETC), June 2010.

[4] Muhammad Asif Rana, Zubair Usman, Zeeshan Shareef, "Automatic Control of Ball and Beam System Using Particle Swarm Optimization," 12th IEEE International Symposium on Computational Intelligence and Informatics (CINTI), Budapest Hungary,.21-22 November 2011.

[5] Manashita Borah, Lalbahadur Majhi, P. Roy and B.K.Roy, "Design of a Fractional Order PD Controller Tuned by Firefly Algorithm for Stability Control of the Nonlinear Ball and Plate System," Conference Paper, May 2014.

[6] Mohammad Nokhbeh, Daniel Khashabi," Modelling and Control of Ball-Plate System", Final Project Report, Amirkabir University of Technology 2011.

[7] Putri Mahanani R, Fernando Ardilla S, and Setiawardhana," Tracking Object Menggunakan Metode Counterpropagation", Final Project Report, Institut Teknologi Sepuluh Nopember.

[8] Chan Ham and Mohsin Mohammad Taufiq,"Development of a Ball and Plate System", 122nd ASEE Annual Conference & Exposition, 2015.

[9] Hani Hunud A. Kadouf and Yasir Mohd Mustafah,"Colour – based Object Detection and Tracking for Autonomous Quadrotor UAV", 5th International Conference on Mechatronics (ICOM' 13), 2013.

978-1-5090-0744-8/16/$31.00 ©2016 IEEE