Realization of Ball on Plate Control using PID Controller and Webcam

Dahnur Agus Pahlawan, Agung Surya Wibowo, Erwin Susanto1
School of Electrical Engineering, Telkom University

E-mail: 1erwinelektro@telkomuniversity.ac.id

Abstract. This study aims to apply the PID controller to the ball on plate control realisation to reach a stable position of ball on plate. The ball on plate props adjust the position at the desired coordinates on a flat square plate. The targeted position is set as set point coordinates in the form of X pixels and Y pixels. The input used is in the form of coordinates obtained from the webcam through image processing methods and sent serially to the microcontroller. The output from the microcontroller is fed into the actuator, namely the servo motor. From the experiment results and its implementation, it is shown that ball on plate can move towards to the desired set point. For PWM signal set point, the value referred to centre of plate is 250 and the response of X-Y axes have errors 3.64% and 8%, respectively.

1. Introduction
Ball on plate control instruments are popular props in many basic control system laboratories. They were used for education purposes and showing how a kind control method can be applied. However, to provide these instruments and others is often constrained by cost problem. Building a simple ball and plate control instrument using low cost electronics and mechanics parts is an alternative solution for providing aid learning or trainer module in laboratory.

This research aims to build a simple and inexpensive ball on plate control system for the benefit of providing a control system learning model using PID control. In addition, this research also uses a camera to detect the position of the ball on the plate. Therefore, image processing is needed to apply control strategies.

Ball on Plate control is a tool that adjusts the position of a ball on plate so that it is located at a certain point and stable. Some researches on ball and plate control with any kind control methods can be found in some manuscripts, [1][2] for instances. The control system is designed in the form of a closed loop control whereas the feedback sensor is fed to reference, providing measured output information.

Ball on Plate system is a mechanical system in which a ball is placed on a flat plane that can move freely and can be noised by disturbances from its environment, such as wind or shocks. Mechanical construction of this system can be shown in Figure 1.

In references [1], [2], the ball position data is detected using the touch panel so that it is mechanically contacted. In this research, the ball position data is detected using a web camera so that it is not physically touching and avoiding measurement noise caused by friction between the ball and the plate. They used the MPC (Model Predictive Control) and SMC (Sliding Mode Control) method which required a fairly mathematical model. It led to complex computations and advanced control. In this
research, a simple PID control is applied with intuitively adjusted gains so that it has the advantage, once a suitable gain is obtained it can be used for further works with lighter computations.

Figure 1. Mechanical Structure of a Ball on Plate

2. Control Method
Different from that was done by [1] they used the touch panel sensor to obtain position data of ball, in this research, the ball on plate system uses a camera as a sensor to determine the position of the ball. The captured image will be processed using image processing and fed to PID controller which is built in Personal Computer. The controller actuates servomotor to regulate slope of plate. This condition led a ball move to set point or targeted position, on the centre of plate for instance. Servomotor is an actuator designed as closed loop system along with some parts such as servo motor, a series of gear, control circuit and potentiometer. Because it is a closed loop system then it can be adjusted to determine the angular position of the motor output shaft.

The servo motor is controlled by providing a pulse width modulation (PWM) signal. PID controller was used to regulate PWM signal as given control signal that determine the rotational angle position of the servo motor shaft.

2.1. PID Control
PID (Proportional-Integral-Derivative) control is a classical controller that often used to determine the control action for system the feedback [3]. The PID controller yields a control action by comparing the error signal which is the difference between the process variable and set point. This controller is represented by the following equation:

\[
\begin{align*}
    u(t) &= K_p e(t) + \frac{K_i}{T_i} \int_0^t e(t) dt + K_p T_d \frac{de(t)}{dt} \\
    u(t) &= K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{de(t)}{dt}
\end{align*}
\]

where:
- \( u(t) \) = PID controller output signal
- \( K_p \) = proportional constant
- \( T_i \) = integral time constant
- \( T_d \) = derivative time constant
- \( K_i \) = integral constant (Kp/Ti)
- \( K_d \) = derivative constant (Kp.Td)
- \( e(t) \) = error signal = reference – plant output = set point – sensor signal

The figure 2 is a block diagram of the generalized PID control.

2.2. Image Processing
Webcam has promised low cost for detecting motion and position of the objects thus supporting the development of computer vision, including eye movement sensing [4]. The webcam functions as a
sensor that is used to detect the X and Y coordinates of the ball, the direction of movement of the ball on a plate is read as an input signal.

![Generalized PID Control](image)

**Figure 2.** Generalized PID Control

Image processing is a signal processing of a set of image input. The output can be in the form of an image or a set of characteristics or parameters related to the image. The term of digital image processing is generally defined as two-dimensional image processing with a series of real or complex numbers represented by certain bits. Digital images are formed by a collection of image dots called pixels.

Pixel is the smallest part of a digital image. The monitor displays the image by dividing the screen into thousands (even millions) of pixels. These pixels are so close together that they appear to be connected to one another.

The number of bits is used to represent each pixel determines how many colours of the pixel can be displayed. This is commonly referred to colour depth. For example, if the monitor uses 8 bits for each pixel, then each pixel is capable of displaying 256 different colours. Each pixel is represented as one small square. Each pixel has a position coordinate. Row and column index (x, y) in a pixel are represented by integers. Pixel (0,0) is located in the upper left corner of the image, index x moves to the right and index y moves down. Figure 3 shows a top of view from captured web camera.

![Webcam top view of Ball on Plate](image)

**Figure 3.** Webcam top view of Ball on Plate

3. **System Design**

Figure 4 shows the developed ball on plate control system. Computers provide extensive image processing due to the large capacity, software and algorithms that are embedded. For this reason, detection of the position of the ball on the plate uses a camera connected to a computer as a processor.
Moreover, development of computer vision itself began in the early 1970s[5], so the use of cameras and computers in this research is a potential option.

Figure 4. System Design of Ball on Plate Control

Figure 4 also displays entire work process flow. This process is conducted by algorithm and programming using a PC. The results of the programming is processed and sent serially into the Arduino microcontroller. This microcontroller actuates servo motor, and the servo motor drives the plate movement such that the ball move to desired position. The position of the ball is captured by camera to determine whether the ball's position is around desired position. The specifications of designed instruments listed here:

- The plates are 45 cm x 45 cm square.
- The webcam has 720p high quality
- Microcontroller that can control servo motor rotation
- Servo motor can rotate 180 degrees.
- PC is used for image processing and PID control actuating.

Realization of Ball on Plate Control is built to provide the advantage of PID control method in physical implementation. The system output is the ball on the plate in desired position according to user setting. The coordinates of the ball are known after the data from the webcam is processed by the image processing and PID control, forwarded to the microcontroller and sent to the servo motor.

| No | Set Point (PWM signal value) | X-axis Coordinate | Y-axis Coordinate | Error on X-axis | Error on Y-axis | Disturbance | Time |
|----|-----------------------------|-------------------|------------------|-----------------|----------------|-------------|------|
| 1  | 250                         | 244               | 220              | 6               | 30             | No          | 110  |
| 2  | 250                         | 249               | 287              | 1               | 37             | Yes         | 310  |
| 3  | 250                         | 274               | 260              | 24              | 10             | Yes         | 780  |
| 4  | 250                         | 233               | 234              | 17              | 16             | Yes         | 1050 |
| 5  | 250                         | 238               | 242              | 12              | 8              | Yes         | 1400 |
| 6  | 250                         | 234               | 235              | 16              | 15             | Yes         | 1810 |
| 7  | 250                         | 243               | 277              | 7               | 27             | Yes         | 2500 |
| 8  | 250                         | 248               | 204              | 2               | 46             | Yes         | 2550 |
| 9  | 250                         | 253               | 242              | 3               | 8              | Yes         | 3000 |
| 10 | 250                         | 247               | 247              | 3               | 3              | Yes         | 3500 |

4. Results and Analysis
The purpose of this testing is to find out the error between set point and actual position. The test is carried out by giving interference to the ball. The ball is stopped at the specified set point. The error is
calculated from the difference between the set point and the obtained coordinates of the ball. Measurement of PWM signal value according to set point and X-Y coordinate is provided in Table 1 and Figure 5. PID gain constants are given, $K_p = 0.3$, $K_d = 4.5$ and $K_i = 0.003$.

Disturbance is given by touching the ball randomly with finger when the ball has stopped around the centre of the plate.

![Figure 5. Response of X-Y coordinates at desired point in PWM signal](image)

The measurement results show that the average error of X-Y coordinates are 3.64% and 8%, respectively. The final position of the ball depends on initial ball location processed by web camera image processing. The size of the plate is 45 cm x 45 cm square, it means that if the error between the average distance of the ball to the centre point is 3.64% and 8%, then it will be about 1.64 cm and 3.6 cm. Dynamic system with PID control usually has maximum error of 5%, see [3]. It means that PID can work well to control ball position in x coordinate. However, it still needs to be corrected for ball position in y coordinate which can be done by adjusting the gain control.

5. Conclusion
This research had built a simple and inexpensive ball on plate control system for the benefit of providing a control system learning model using PID control. To verify the result, some points of conclusion are provided here:

1. Based on the measurement of set point and actual position for realization of ball on plate control system, the testing leads to errors on X-Y coordinates: 3.64% on the x-axis and 8% error on the y-axis.
2. To reach around set point position at centre of plate, ball on plate system needs 94.46 seconds.
3. Interface of object detection using web camera and PID control action is handled by personal computer and embedded software.

From the analysis, simulation and experimentation, it can be shown in student learning that PID control can be applied to control of the ball position on the plate in the x and y coordinates.

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