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Development of a 2 Degrees of Freedom Tracking System Part II: Controller Design and Implementation

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Abstract

Platform stabilization and control problems are a major field of study in control systems. For a long period of time, analog control schemes using op-amps for gain, as differentiators and as integrators were used and are still used but they require complex circuitry even for simple PI controllers. With the advent of the digital era this approach has changed. Now even complex closed loop control schemes are easily achievable using programmable gains and adjustable parameters. Different scenarios require different control schemes that optimize different parameters of the systems closed loop response. Object tracking requires a highly stable platform capable of tracking high speed moving targets. This paper is the continuation of our previous paper in which we discussed the design and construction of a real time target tracker, a 2 DOF platform with emphasis on its stability and balanced weight distribution. In this paper we discuss the digital control scheme for the closed loop control of the designed platform.

Keywords: 2DOF platform, Tracking control, PID controller.

1. Introduction

The problem of controlling a two degrees of freedom (DOF) platform has been a bench-mark problem in demonstrating and motivating various control design techniques. Controlling the 2DOF platform is always a crucial task as it not only requires complex analog and digital circuitries but also it needs robust controller for better stabilization and control dynamics. The most important and challenging task is the design of controller, which affects the plant performance directly. A PID controller is the most widely used controller in this regard. This is a type of feedback controller whose output, a control variable, is generally based on the error between some user-defined set point and some measured process variable. Each element of the PID controller refers to a particular action taken on the error. Tuning of a PID involves the adjustment of its gains to achieve some user-defined "optimal" character of system response. Although much architecture exists for control systems, the PID controller is mature and well understood by practitioners. For these reasons, it is often the first choice for new controller design. In most modern control systems, the controller is implemented in a digital computer whereas the process itself evolves in continuous time. So in this paper, in order to have proper control on the platform, a digital PID controller has been designed and its gains adjusted for a minimum steady state error and high performance factors.
Before going into the details of the control scheme let us have a brief insight into the mechanical structure of the platform.

1.1 Mechanical Structure of the Platform

The mechanical platform shown in figure 1, is constructed using worm gears whose locking capability ensured that there is no need to keep the motors powered up to retain achieved position. The platform constructed has the following specs [1].

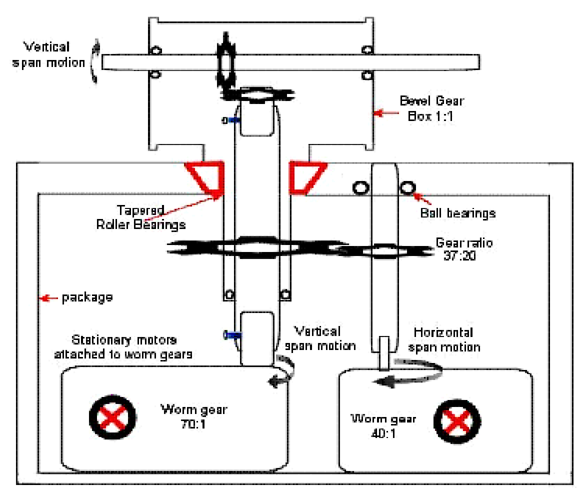

Fig. 1. Mechanical structure of the platform

The structure shown in figure 1 is constructed having gear ratios of 70:1 in both the elevation and the azimuth, two DC servo motors with a torque of 0.91Nm and speed of 2100rpm, having encoders of high resolution 1250 counts/rev are used to drive the platform. This construction enabled us to achieve a large open loop torque of 62Nm to drive the platform, enabling acceleration up to 1400rad/sec^2 at the rated current. By keeping the motors at the static base the dynamic part of the platform was kept light to meet the specs, however cost was paid in the form of mechanical coupling between the joints. Hence the kinematics of the platform are not straight forward. However this problem can be resolved with a proper control algorithm.

1.2 Platform Kinematics

Since the elevation shaft passes through the azimuth shaft so a rotation in azimuth introduces relative motion in the elevation shaft in the opposite direction. Hence open loop input to azimuth causes motion at the output in both the axis, thereby introducing coupling between the output elevation and the input to the azimuth. Taking this fact into account the kinematics of the system can be given by the following equation.

$$\begin{bmatrix}\theta_E\\ \theta_A\end{bmatrix}=\begin{bmatrix}1/N_1 & N_2/N_1\\ 0 & 1/N_2\end{bmatrix}\begin{bmatrix}\tau_E\\ \tau_A\end{bmatrix}$$

N_1 = Gear ratio for Elevation

N_2 = Gear ratio for Azimuth

τ_E = Torque applied to elevation platform

τ_A = Torque applied to azimuth platform

Where θ_E and θ_A are the outputs angles for elevation and azimuth respectively.

2. Digital Control Scheme

The control loop can be divided into two parts. One portion of the control loop is in digital domain, which is comprised of a computer and microcontroller section. The other part of the loop is in continuous domain, which comprises the H-Bridge for motor drives and the platform itself.

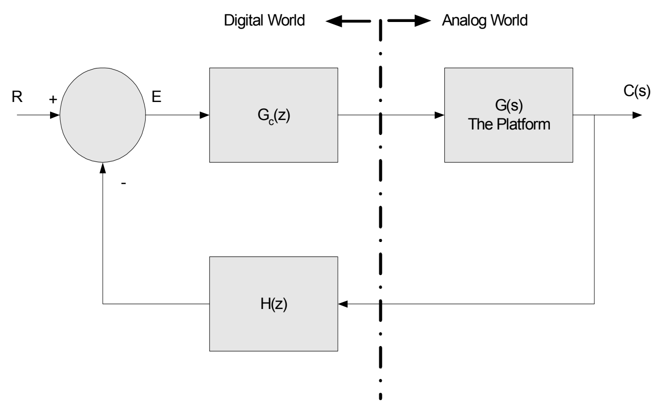

Fig. 2. Elementary Feedback Control System

As shown in figure 3, the reference input applied to the control scheme is the applied torque, which is applied to platform using the RS 232 Serial port command to the microcontroller. The input is applied in terms of the desired angle [2]. The desired input in turn actuates the plant. The output from the plant is fed back, the output and the reference input are used to calculate the error. This error drives the plant. As the plant output approaches the desired output the error reduces thereby reducing the platform drive, eventually the platform comes to rest close to the desired position.

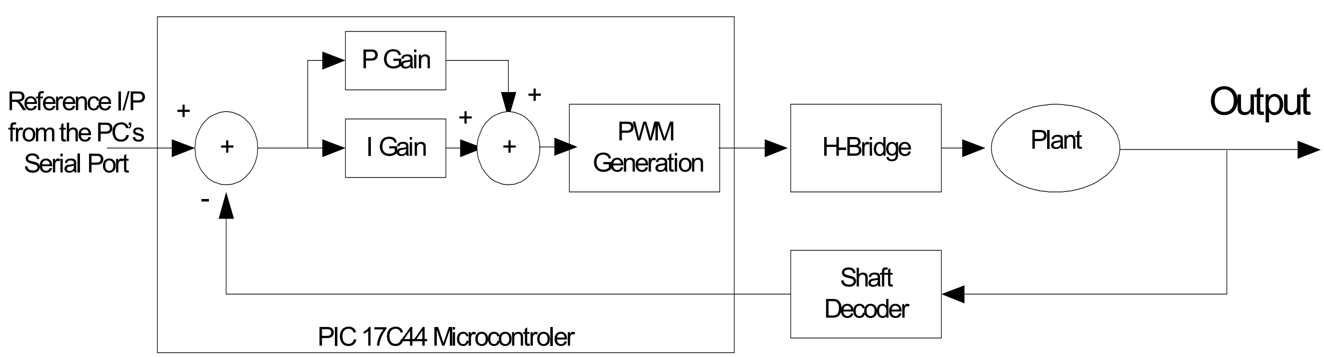

Fig. 3. Control scheme for the 2DOF Platform

The microcontroller communicates with the PC through its serial port, similarly all the error and drive calculations are performed in the microcontroller; the resulting PWM drives the motors of the platform. The shaft decoder ICs reads the readings of the shaft encoders mounted on the motors. The microcontroller uses the output of the shaft decoder ICs to calculate the respective error that drives the motors.

3. Gain Selection Procedure

Due to the coupled joints of the system the elevation output had to be decoupled from the azimuth input, hence the elevation gains were adjusted first.
A simple digital implementation of a PID controller, is as follows [3]:

$$P_k = K_P e_k$$

$$I_k = K_i T \sum_{t=0}^{k} e_t$$

$$D_k = (K_d / T)(e_k - e_{k-1})$$

$$CV_k = P_k + I_k + D_k$$

Where $e_k = SP_k - PV_k$, , CV is the control variable, SP is user defined set point, PV is measured process variable and T is the sampling interval. Another important aspect in sampled data control systems is the choice of sampling intervals. With electronic controllers that emulate continuous time algorithms, this choice is simple: sample as fast as possible. This is because of the approximations that are used to generate the difference equations describing the controllers. Smaller sampling intervals mean that the properties of the underlying controller design will be less distorted, hence more predictable and better performances.
Extensive experimentation was carried out with different gains so as to achieve the desired closed loop response. First keeping I and D gains zero, the P gain was adjusted to a point where it resulted in minimum steady state error. Increasing the P gain further would induce oscillations, which is undesirable.
Keeping this P gain, the I gain was adjusted to eliminate the steady state error.
With these gains we achieved the desired results.
Similarly for the azimuth the same procedure resulted in these gains.

3.1. Controller gains for Elevation

As described above the proportional gain is applied first. A step input is given to the system and the output response is examined. The following figures show the results of experimentation:
Figure 4 shows that the steady state error is very low and settling time is fast. This type of gain can be used in tracking purposes.

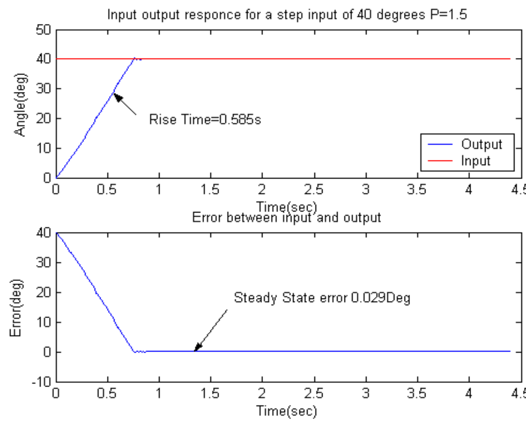

Fig. 4. Input output plot for P=1.5

Increasing the gain to 1.8 have almost same steady state error but high rise time and also low settling time.

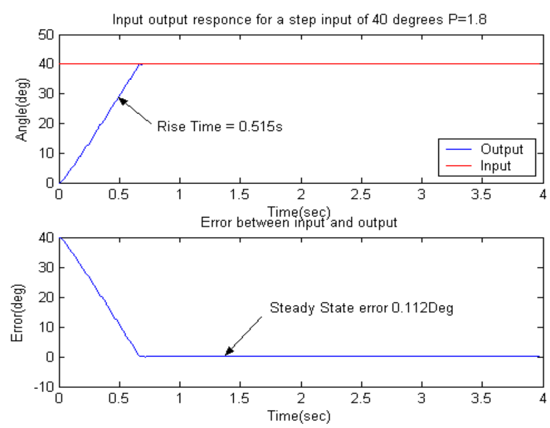

Fig. 5. Input output plot for P=1.8

Increasing gain causes oscillations as can be seen from figure 6. If gain is further increased the oscillations continue to increase in the output so this is the ending point for the proportional gain. Since the platform is used for tracking purpose, therefore oscillations will cause error to grow up.

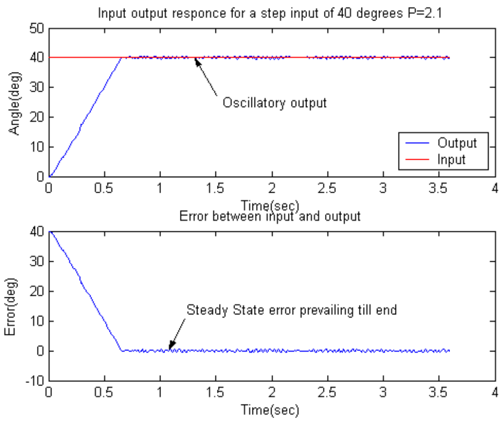

Fig. 6. Input output plot for P=2

By applying proportional gain with the integral gain, rise time is high but there appears an overshoot of 1.2 degrees but steady state error is almost zero as shown in figure 7.

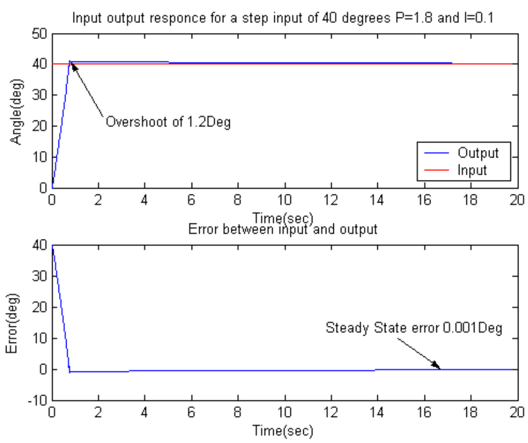

Fig. 7. Input output plot for P=1.8 and I=0.1

Increasing I gain causes the overshoot to rise more

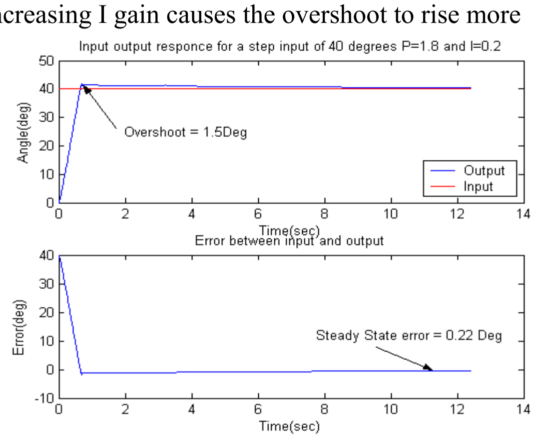

Fig. 8. Input output plot for P=1.8 and I=0.2

3.2. Controller Gains for Azimuth

Same step input applied to azimuth platform shows following results: A very small ideal steady state error and low settling time is observed for a proportional gain of 1.5 as shown in figure 9.

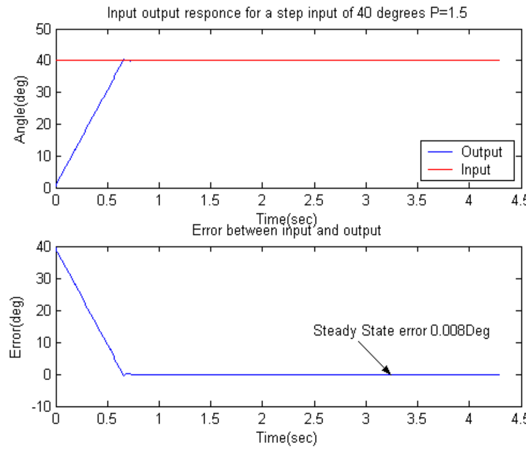

Fig. 9. Input output plot for P=1.5

Increasing gain increases steady state error

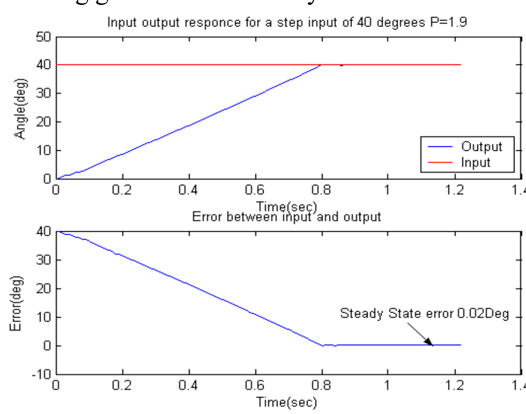

Fig. 10. Input output plot for P=1.9

Increasing more proportional gain causes oscillations

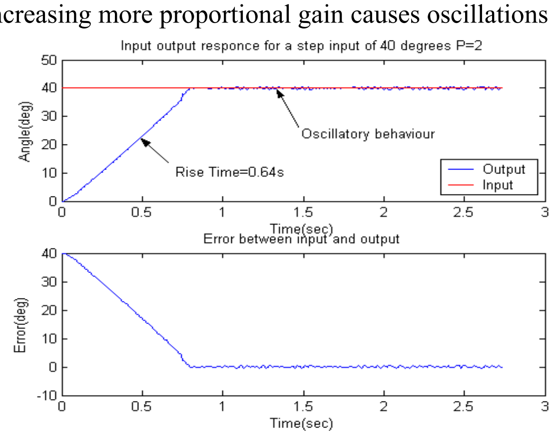

Fig. 11. Input output plot for P=2

Increasing more proportional gain causes oscillations

I and P gains for azimuth don't cause a suitable output as overshoot becomes high and steady state error does not settle to a value.

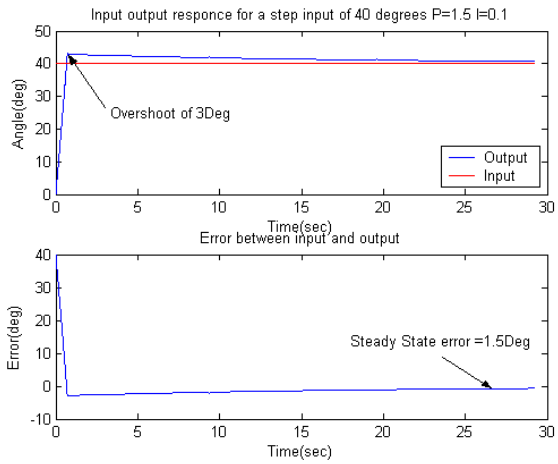

Fig. 12. Input output plot for P=1.5 I=0.1

4. Mode of Operation

For the control of the platform in different scenarios two modes of operation were selected. The information of the mode was conveyed to the microcontroller through the serial port for which a secure communication protocol was used. This protocol transmits the mode of operation, the reference input for the azimuth and elevation, the parity for alignment of the data packet and a checksum in the last bytes to ensure error free transmission. The following modes were programmed in the microcontroller.

4.1. Static Target Tracking

In this mode the aim was to achieve a desired position from the starting positions the reference with minimum steady state error so the following gains were fixed in the microcontroller using above experimentation for this mode.
Elevation: P=1.8 and I=0.1
Azimuth : P=1.5

4.2. Moving Target Tracking

In this mode the aim was to track a target in the next frame, taking center of the screen as a reference. The image processing algorithms running on the computer calculated the future position of the target which served as the reference to the control scheme. The platform had to achieve the specified position before the next frame was captured. This required a small rise time for the system however any over shoot or oscillation in the platform output will make the net system unstable as the next reference will be based on the image captured. If it was captured on the overshoot the next reference might be faulty thereby causing a loss of target. The following gains were selected.
Elevation : P=1.5
Azimuth : P=1.5

5. Conclusions and Recommendations

Excellent results were achieved for the static target tracking. For the moving target tracking, little oscillations were observed in the azimuth, this was due to backlash in the gears driving the platform. This effect is not visible in the elevation as the gravitational force ensured that the output and the input remained in contact.

5.1. Experimental verification

To verify the results and to confirm the effect of backlash, the following experiment was carried out. Placing two objects exactly apart 90^0, the platform was placed facing the first object and a reference of 90^0 was applied to the platform. The platform achieved the reference with a very little error i.e. 89.5^0 instead of the reference 90^0.

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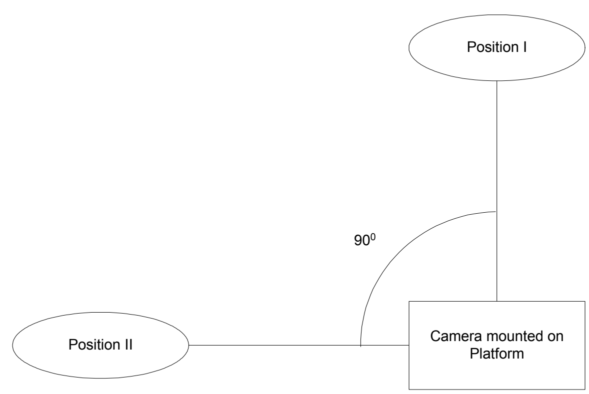

Fig. 13. Position sensing experiment

This effect is also prominent in the PI graph of figure 14. As at the point of directional reversal the driving and the driven gears are decoupled so the motor is running free. There is a sharp direction reversal as there is no load on the motor, instead of the expected smooth settling of the curve.

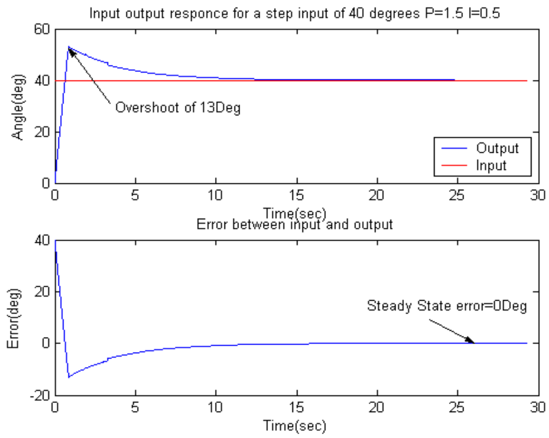

Fig. 14. Input output plot for a step input and PI gains

As evident from the preceding discussion there is backlash in the system that is causing jittery tracking in the azimuth therefore some backlash compensation should be used for the azimuth drive. To achieve better tracking the shaft encoder should be mounted on the final output.

A model-based controller accommodating intermediate states would be a better choice as compared to the PID.

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