The Application of PID-DMC Algorithm with Feedforward Compensation in the PTZ Platform

Y H Zhao*, L Chai and L Z Jin
Four Pai Lou campus of Southeast University, Nanjing, China
*Zhaoyahan0926@163.com

Abstract. According to the characteristics of PTZ camera itself pure delay of measurement and control, discontinuity of control system and unknown model, a new PID-DMC control algorithm with feedforward compensation is proposed. When using the conventional PID algorithm to control, due to the discontinuity of the control amount of the PTZ camera, the serious control jitter when the closed-loop system operating, the stability of the system is affected critically, and even the equipment will be damaged. For this reason, feedforward compensation is added on the basis of conventional PID control to alleviate the problem of increasing of the overshoot caused by the integral action. Meanwhile, DMC control is introduced to effectively reduce the fluctuation of the system, which makes the follow-up tracking of the system more stable and effective.

1. Introduction
In the application of intelligent video surveillance, PTZ (Pan/Tilt/Zoom) cameras can realize full-range (horizontal, vertical) rotation of intelligent cloud platform and zoom control, and are considered to be one of the most useful sensors[1]. In the monitoring system, the main task of the PTZ camera is to perform target detection and target tracking [2].

In the moving target tracking system, the rotation of the camera will cause changes in the background of the monitor screen, which brings great challenge to the recognition and tracking of the target in the image processing[3]. Therefore, this paper uses joint tracking scheme of PTZ camera platform and static camera. Under this scheme, the main task of the PTZ camera rotation control is to control the rotation of the camera in the both horizontal and the vertical direction, so that the given target angle position is tracked by the horizontal and vertical angle of the camera cloud.

This paper first discusses the characteristics of PTZ camera control, and then designs the PID-DMC predictive controller with feedforward compensation to control the horizontal and vertical axis of the PTZ camera separately according to the characteristic of the pure lag of the camera. Compared with the traditional PID controller from simulation results, the PID-DMC predictive controller with feedforward compensation can effectively prevent the large fluctuation of the system control and make the tracking of the control system more stable.

2. The features of the PTZ camera

2.1. Pure lag of measurement and control
The PTZ camera used in this paper is BRC-Z330 of Sony Corp, and its control communication adopts VISCA protocol based on RS-232C/RS-422. The command sequence of the VISCA protocol is shown...
in Figure 1. V represents the command processing cycle of the VISCA protocol and under the PAL system 1V represents 20ms[4]. As shown in Figure 1, the VISCA protocol command sequence specifies that the two adjacent command sending intervals must be at least 1V, and the response packet of the command should be return within the 4V interval. According to the actual measurement data, the command of the angle measurement generally returns the measured data 16ms or 32ms after command, while the speed control command will need 47ms or even longer time to return the response packet and the completion package, thus bringing the pure lag and uncertainty of the angle measurement and control of the PTZ camera.

![Figure 1. Sequence diagram of VISCA protocol command](image)

2.2. Discontinuity of control system

The command group that controls the rotation of the PTZ camera in the VISCA protocol is Pan-tilt Drive, which is divided into the speed rotation control and angle rotation control. But the execution of angle control command is not suitable for the follow-up tracking system where the target position rapidly changes. In applications, because of this command, the next instruction won’t be read until the systems reaches specified position. Therefore, the rotation control of the PTZ camera is achieved through its speed control command here. The speed control command is divided into the direction domain and the speed domain. The speed word domain is composed of two 4 bits. The allowable transmission speed is divided into 24 levels of 01H-18H from low to high. The PTZ camera has a minimum panning speed of 0.25°/s and a maximum panning speed of 60°/s. The actual running speed corresponding to the 24 speed levels of horizontal axis is shown in Figure 2.

![Figure 2. Actual speed curve of horizontal axis](image)
As shown in Figure 2, the effective speed control of the PTZ camera is only a limited number of discrete point, and it is unevenly distributed throughout the entire speed range, which will inevitably cause a great difficulty for the continuous smooth operation of the system.

2.3. Unknown model properties

BRC-Z330 as a mature commercial product, the internal implementation details are well packaged, only leaving user with the necessary interface, which is convenient for installation, connection and use of the system. But that also brings difficulties for the real-time control of the PTZ camera.

Because it is impossible to understand the specific implementation details such as motor type, driving method and speed control algorithm, the establishment of accurate dynamic model of the PTZ camera becomes very difficult or even impossible, which brings great difficulties for not only the design of control algorithm but also the tuning of the controller parameters.

In summary, PTZ camera has the characteristics of unfavourable control, such as pure delay in measurement and control, discontinuous control and unknown model characteristics. In order to analyze and attempt to overcome the influence of the above characteristics on control during the design of the controller, the following discussion is made on how to carry out the controller design of PID-DMC predictive control with feedforward compensation. Through its result of tracking control, it can be seen that compared with the classic PID controller, the PID-DMC controller with feedforward compensation has smaller operating error and runs smoothly.

3. Design of PTZ camera controller

3.1. Feedforward control

The PID control algorithm is composed of three parts including Proportion, Integration and Differentiation[5]. Because the cloud platform controller generally uses the discrete control system implemented by the embedded computer or the industrial control computer, we use its discrete form for computer implementation[6]. However, integral action must be introduced in the control of PID, and the integral effect makes the overshoot and adjusting time of the system increase, which is not conducive to the rapid response of the system. Therefore, in order to ensure that the system can still track without static error, the feedforward compensation of target speed is introduced to the control system, as shown in Figure 3.

![Figure 3. Forward compensation PID controller structure diagram](image)

The control algorithm of PID controller with feedforward compensation is shown in the following expressions:

\[
\begin{align*}
\{u(k) &= u_p(k) + u_v(k) \\
u_p(k) &= K_p e(k) + K_i \sum_{i=0}^{k} e(i) + K_d [e(k) - e(k - 1)] \\
u_v(k) &= K_v \times [r(k) - y(k - 1)]/T \\
e(k) &= r(k) - (y(k) + u(k - 1) \times D)
\end{align*}
\]

(1)

\(K_p, K_i, K_d, K_v\) represent proportional coefficient, integral time constant, differential time parameter and feedforward coefficient respectively.

3.2. DMC control
DMC control is a kind of advanced control algorithm which is first developed in the field of process industry in the 1970s and 1980s. It is based on the “three major principles” such as prediction model, rolling optimization and feedback correction, which overcomes the shortcomings of modern control theory which relies on the precise model of the system, and has been successfully applied [7] in the practical engineering.

1) The predictive model  DMC control only focuses on the predictive function of the model rather than the specific form of the model [8]. The system uses a step response model as a prediction model for DMC controller. The unit step response curve of the PTZ camera measured by experiment is shown in Figure 4:

![Unit step curve](image)

**Figure 4.** Unit step curve

$a_s$ is steady state value; $N$ is truncated step length. Once a constant control increment $\Delta u(k)$ is applied at $k$ time, the system step response model can be used to predict the output value of the system for the next $N$ time in the future, as shown by formula 2.

$$y_m(k+i) = y_0(k+i) + a_i \Delta u(k), \quad i = 1,2, \ldots, N$$  \hfill (2)

$y_0(k+i)$ is the output of the system without $\Delta u(k)$ at $k$ time.

According to formula 2, the relationship between predictive output vector and control increment vector can be expressed as:

$$Y_m(k+1) = Y_0(k+1) + A \Delta U(k)$$  \hfill (3)

$Y_m, Y_0, \Delta U$ are respectively the vector of time sequence of future sampling, and $A$ is the dimensional matrix $P \times M$ composed of step response coefficients.

\[
\begin{align*}
Y_m(k+1) &= [y_m(k+1) \ldots y_m(k+P)]^T \\
Y_0(k+1) &= [y_0(k+1) \ldots y_0(k+P)]^T \\
\Delta U(k) &= [\Delta u(k) \ldots \Delta u(k+M-1)]^T
\end{align*}
\]

$$A = \begin{bmatrix}
a_1 & \cdots & 0 \\
\vdots & \ddots & \vdots \\
a_p & \cdots & a_{p-u+1}
\end{bmatrix}_{P \times M}$$  \hfill (5)

2) Predictive error feedback correction

Predictive error detection is as follows:

$$e(k) = y(k) - \hat{y}(k|k-1) = y(k) - y_0(k)$$  \hfill (6)

After introducing the prediction error feedback, the recursive update $Y_0$ is changed into formula 7.
\[
\begin{align*}
Y_0(0) &= [0 \ldots 0]^T \\
e(k) &= y(k) - y_0(k) \\
Y_0(k) &= Y_0(k) + He(k) \\
Y_0(k) &= [y_0(k + 1) \ldots y_0(k + P - 1)]^T \\
Y_0(k + 1) &= Y_0(k) + \sum_{i=1}^{P} a_i \Delta u(k)
\end{align*}
\]

\( H \) is an error feedback gain matrix of \( P \)-dimensional vectors. Due to the lack of sufficient understanding of the inherent mechanism of model mismatch and external disturbance, the dynamic characteristic of prediction error is generally described by step model that the prediction error remains unchanged at the future P time, and the typical \( H \) values of each component are taken as formula 8.

\[
H = [h \ldots h]^T
\]

3) The rolling optimization and control quantity solving
At the time \( k \), the optimal performance index of DMC is:

\[
\min J(k) = \sum_{i=1}^{P} q_i |y_r(k + i) - y_m(k + i)|^2 + \sum_{j=1}^{M} \eta_j \Delta u^2(k + j - 1)
\]

\( y_r \) is the target trajectory; \( y_m \) is the \( p \) step prediction output under the \( M \) step control increment \( \Delta u \); \( q_i \) represents the tracking error weighting coefficient. And \( \eta_j \) represents the control function weighting coefficient.

After the upper expression is transformed into vector form, get the following formula:

\[
\min J(k) = \|Y_r(k + 1) - Y_0(k + 1) - A\Delta U(k)\|_Q^2 + \|\Delta U(k)\|_R^2
\]

\( Q, R \) are respectively weights of the weights of the sampling points in the optimal time domain.

The optimal performance index can be obtained when \( \partial J(k)/\partial \Delta U(k) = 0 \) and it shows as following:

\[
\Delta U(k) = (A^T QA + R)^{-1}A^T Q[Y_r(k + 1) - Y_0(k + 1)]
\]

In this experiment, the flow chart of DMC controller method is shown in Figure 5.

![Flow chart of DMC speed loop correction control algorithm](image)

**Figure 5.** Flow chart of DMC speed loop correction control algorithm.

In summary, the structure of PID-DMC control algorithm with feedforward compensation is shown in Figure 6.
4. Simulation experiment
Taking sampling period $T = 62 \text{ms}$, the PID controller and PID-DMC controller with feedforward compensation are respectively used to track the superimposed signals of step signal and ramp signal. By simulating the read-back operation data, target trajectory and control quantity curve as shown in figure 7, 8, 9, 10. The compared result of statistics of the IAE (Integrated Absolute Error) and PAE (Peak of Absolute Error) of the operation data is shown in Table 1.
**Table 1. Comparison of simulation experiment results of pan tilt servo control algorithm**

| Algorithm          | IAE/° | PAE/° |
|--------------------|-------|-------|
| PID controller     | 283.2 | 35.7  |
| PID-DMC controller | 112.3 | 18.5  |

From the Figure 7 and Figure 8, it can be seen that the speed control amount under the PID controller fluctuates greatly, and there is a clear overshoot during the step motion, and the system operation is unstable. While in the Figure 9 and Figure 10, under the control of the PID-DMC controller with feedforward compensation, the fluctuation of speed control is significantly reduced and the overshoot was further reduced. The operation was also very smooth.

5. Conclusion

In this paper, a PID-DMC controller with feedforward compensation is designed in the case that the PTZ camera has the characteristics of the pure time delay of measurement and control, the discontinuous control quantity and the unknown model characteristics. The experimental results show that the algorithm prevents the large fluctuation of the system and improves the stability of the system effectively.

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