Dynamic Matrix Control Algorithm with Data Packet Dropout in Networked Control Systems

Tao WU, Chen DIAO, Yong-sheng XU and Hong-tao LIU
College of Electrical Engineering, Northwest University for Nationalities, Lanzhou, Gansu 730000, China

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Abstract. A new control strategy based on dynamic matrix control algorithm is proposed in the paper to deal with data packet dropout which universally exists in networked control systems. Proper output value of the system is selected by comparing time stamp of the data packet in controller and actuator, consequently the worsen system performance due to data packet dropout is overcome by the strategy. The simulation results show that the new strategy is effective.

Introduction

With the wide application of computer network and the continuous development of network technology, the structure of control system is being changed, and networked control systems (NCSs) have become a research hotspot of control field in recent years. NCSs are to introduce network into control system and are of distributed control system rather than independent control system, to connect main functional parts of sensor, executor, controller and other systems via network and transmit and exchange relevant signal and data through communication network. Although NCSs have many advantages over traditional control system, inevitably, they also have some frequently-seen problems of computer network due to the involvement of network, such as network delay, data packet dropout, messy code and disordering, leading to severe impacts on the performance of control system. Prediction control is a widely used new control algorithm in current industrial process control field. Due to the utilization of multistep prediction, rolling optimization and feedback compensation, it is of better control effect and applicable for the industrial processes less prone to establishing precise mathematic model. By the application of the design philosophy of prediction control to NCSs, a network forecast design method compensating network delay and data packet dropout to some extent is developed[1~4]. In the paper, dynamic matrix control algorithm (DMC) is used to compensate data packet dropout to a certain extent, and the simulation results show that the system performance is improved.

PC-based Control Design of Networked Control Systems

The network based on TCP protocol is mainly used for ensuring the reliability of data transmission, and the data failing to arrive at the receiving end is usually sent in a repeated way. However, NCSs are of higher real-time demand of system data. Therefore, the repeated sending of old data is not applicable to NCSs. In actual NCSs, when new sampling data or control data arrives, the unsent old data will be deleted. In addition, network congestion or data destroy may cause misfit between the data finally arriving at the end and the data sent at the transmission end. Such phenomena are deemed as loss of network data. Figure 1 shows a typical NCS. NCSs are usually composed of
network module, controller, actuator, controlled object, sensor and other nodes. The switching on/off of the switch simulates data transmission and loss in network. From Figure 1, it is not difficult to find that two processes are vulnerable to encountering such data loss, i.e. data transmission from sensor to controller and data transmission from controller to actuator. Due to such two processes, the controller and actuator cannot timely update the measured output value of the controlled object and output value of actuator, thus seriously impacting the system performance.

**Dynamic Matrix Control Algorithm**

Dynamic matrix control is a prediction control algorithm based on object step response module. With this algorithm, the optimized control of system is realized through module prediction, rolling optimization and feedback compensation. [5]

The amplitude $a_k$ of response curve at the sampling moment $k = 1, 2, \ldots$ can be measured through applying unit step signal to the system. The output of such an object at moment $k$ is caused by all the previous input increments. The prediction module in DMC is of the said step response expression, i.e.

$$y_m(k) = \sum_{i=0}^{\infty} a_i \Delta u(k-i)$$

If the current moment is $k$; the control step is $L$; the current and future control increment sequences are $\Delta u(k), \Delta u(k+1), \ldots, \Delta u(k+L-1)$, then the output prediction value at future moment shall be

$$Y_m = A\Delta U + S$$

Where, $S$ represents the output generated by the former control.

$$Y_m = [y_m(k+1), y_m(k+2), \ldots, y_m(k+p)]^T$$

$$\Delta U = [\Delta u(k), \Delta u(k+1), \ldots, \Delta u(k+L-1)]^T$$

![Matrix A](image)

In consideration of model error and interruption, the output prediction shall be corrected to be closer to the actual output of the system.

$$Y_c = A\Delta U + Y + P$$

Where, $A$ is the same with Eq. (1), $Y_c = [y_c(k+1), y_c(k+2), \ldots, y_c(k+p)]^T$  

$$\Delta U = [\Delta u(k), \Delta u(k+1), \ldots, \Delta u(k+L-1)]^T$$

$$Y = [y(k), \ldots, y(k)]^T$$

$$P = [p(k+1), p(k+2), \ldots, p(k+p)]^T$$

The error between the corrected output prediction and the reference input is

$$E = Y_c - Y$$

The optimal control law of DMC is determined by quadratic performance index

$$J = E^T Q E + \Delta U^T R \Delta U$$

Where, $Q = \text{diag}[q_1, q_2, \ldots, q_p]$, $R = \{r_1^2, r_2^2, \ldots, r_p^2\}$

From $\frac{\partial J}{\partial \Delta U} = 0$, the optimal control law is

$$\Delta U = (A^T QA + R)^{-1} A^T Q[a_x, [Y_e - Y(k)] - P]$$

$\alpha_2$ is softness factor
Countermeasures for Data Packet Dropout in Network Control

Before the discussion of countermeasures for data packet dropout, firstly, the following hypotheses are made: (1) sample at sensor, controller and actuator synchronously; (2) add a time stamp behind each sampling signal; (3) for sampling period, the signal processing period of controller and actuator can be ignored.

According to the principle of dynamic matrix control algorithm, the future output and control signal of the system can be obtained through DMC algorithm. With such signal, the problem that the data of controller and actuator cannot be timely updated due to data packet loss can be solved. If data loss occurs at \( k \) moment when the data is sent from sensor to controller, the measured output value of the controlled object, which is required to be used by the controller, cannot be updated timely. In that case, the difference \( \Delta k \) between the time stamp and moment \( k \) of the data packet in use is obtained by the controller through the comparison of the two moments. If \( \Delta k \) is less than the predicted length \( p \), the predicted output value of the controlled object consistent with the moment \( k \) is calculated by the controller according to the data in use; if \( \Delta k \) is more than the predicted length \( p \), the predicted output value of the controlled object nearest to the moment \( k \) is calculated by the controller, and such prediction value will be deemed as the actual measured output value of the controlled object to calculate corresponding control output. If \( \Delta k \) is less than the predicted length \( p \), \( k + p \) is taken as time stamp to be included into a “package” with the control output; if \( \Delta k \) is more than the predicted length \( p \), \( k + p \) is taken as time stamp to be included into a “package” with the control output and finally the “package” is sent to the actuator via network. If data loss occurs at moment \( k \) when the controller is sending data to the actuator, the control quantity output consistent with the moment \( k \) is selected by the actuator through the comparison of the moment \( k \) and the time stamp of data packet in use. If the comparison result is more than the control length, the control quantity output nearest to the current moment is selected by the actuator.

Simulation Example

Let simulated object be:

\[
G_m(s) = \frac{1000}{s^2 + s}
\]

Selected sampling period \( T_s = 0.1 \), sampling length \( N = 10 \), prediction horizon \( P = 8 \), and control horizon \( M = 5 \).

From Figure 5, we can see that \( p = 1 \) and \( p = 0 \) respectively represent the situations that the data
packet loss occurs and doesn’t occur in the transmission process. Response1 in Figure 1 is the step response of the system when the improved algorithm is not used in case of data packet dropout. Response2 is the step response of the system when the improved algorithm is used in case of data packet dropout. Through comparison, we can find that a better tracking performance is seen when the improved algorithm is used.

Conclusion
A networked control system design method based on DMC is presented in the paper to cope with the problem of possible data packet dropout in network transmission of the data of control system in network environment. Through the comparison of the time stamps of different data packets, proper measured output value of the controlled object and the controller output are selected from the controller and actuator to solve the problem that the data of controller and actuator cannot be updated timely due to data packet dropout. The simulation shows that the strategy is effective.

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