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Design of a GPC-based PID controller for controlling a weigh feeder

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ABSTRACT

Most weigh feeders are controlled by a PID control method, and it is desirable to achieve high performance with this PID control. The present paper discusses the application of a generalized predictive control (GPC)-based PID controller to a weigh feeder. In conventional methods, GPC-based PID controllers are designed using a step-type reference signal, but in control of a weigh feeder, a reference input to be followed by a measured signal is a ramp-type signal because the measured signal is discharged mass. Hence, control of a weigh feeder using a GPC-based PID controller is enhanced for tracking a ramp-type signal. Because GPC can be expressed by PID parameters, the proposed method can be easily adopted in various industries. Experimental results show that a weigh feeder is well controlled using the enhanced GPC-based PID controller.

1. Introduction

Weigh feeders (Hopkins, 2006) have been developed to dispense material at a specified rate, and have been employed in various area, e.g., processing industries (Heinrici, 2000), cement manufacturing (Haefner, 1996), the food industry (Vermylen, 1985), and so on. Most weigh feeders are designed using proportional and integral compensation. Since the control performance is decided by the selection of these adjustable controller parameters, they must be designed to satisfy the required specification. In addition, the dynamic characteristics of a weigh feeder depend on the material to be discharged. Hence, the authors have proposed an adaptive control method for a weigh feeder that minimizes the variance of discharged material (Sato & Kameoka, 2007) using generalized minimum variance control (GMVC) (Clarke, 1984). Because the adaptive controller includes parameter identification, good performance can be obtained even if the dynamic characteristics of the weigh feeder are unknown. However, it is difficult to adopt this control method in industrial fields because GMVC is not as easy to understand intuitively as PID control. GMVC has been extended to generalized predictive control (GPC) (Camacho & Bordons, 2000; Clarke, Mohtadi, & Tuffs, 1987) to evaluate long range prediction. The performance of a weigh feeder is improved by using GPC, but its structure is also more complex than PID control. Therefore, in the present paper, to obtain both performance upgrade and a simple control structure, a PID controller is designed on the basis of GPC. Using the proposed method, GPC can be achieved by a PID controller since GPC is expressed by PID parameters. Consequently, the conventional PID controllers employed in a weigh feeder can be replaced by GPC-based PID controllers, thus improving weigh feeder performance.

In design of a GPC-based PID controller, three problems need to be solved. First, the future reference trajectory of GPC needs future information, but PID control essentially consists of present and past data. Second, the coefficients of a GPC law are generally higher order polynomials than those of a PID control law, so a GPC law cannot be straightforwardly replaced by a PID control law. Third, in design of a controller for a weigh feeder, a reference input to be followed by a measured signal is a ramp-type signal (Usui, 1992) because the measured signal is discharged mass. However, conventional GPC-based PID controllers have been designed to have the plant output follow a step-type reference input. Therefore, to apply a GPC-based PID controller to a weigh feeder, the future reference trajectory employed in the design of GPC is rearranged, and a GPC-based PID controller for a ramp-type signal is newly obtained. Consequently, the future reference trajectory can be expressed without future predictive data, and a high order coefficient polynomial is rewritten as a low order polynomial which can be replaced by PID control. Hence, an upgraded PID controller is obtained for controlling a weigh feeder. Finally, experimental results are shown to confirm the effectiveness of the proposed method.

2. Problem statement

2.1. Weigh feeder

In the weigh feeder that is the control object in this study (Fig. 1), to have discharged mass follow a given reference input, the rotation velocity of the motor that actuates a discharge

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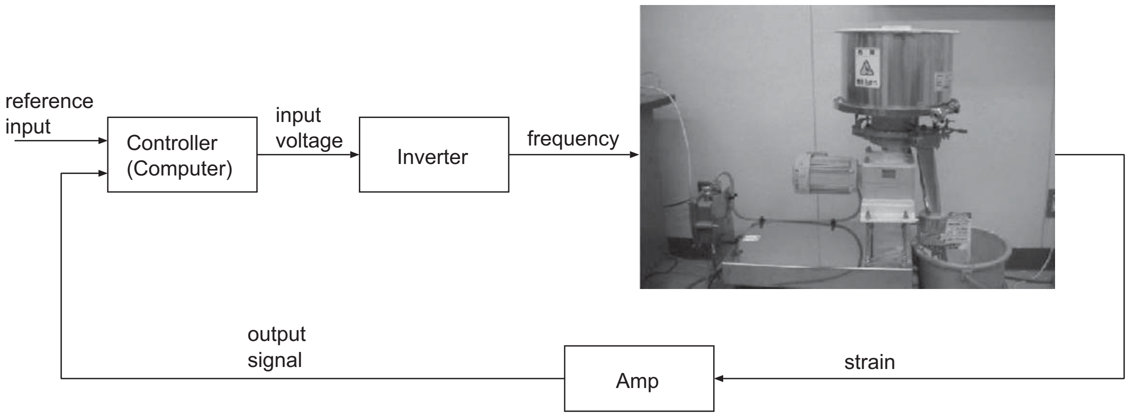

Fig. 1. Weigh feeder control system.

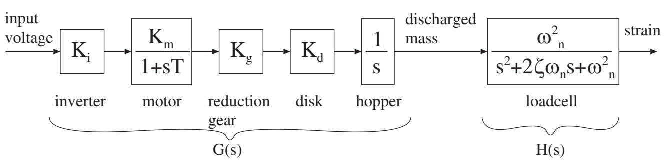

Fig. 2. Block diagram of weigh feeder.

mechanism is controlled by adjusting the control input, which is the input voltage supplied to the inverter. Discharged mass, which is the output signal of a weigh feeder, is obtained by a loss-in-weight method, and is measured using a loadcell. The dynamic characteristics of this weigh feeder can be approximated as a first order system, an integrator and a second-order system, and a block diagram of it is illustrated in Fig. 2. The dynamic characteristics of the motor and the loadcell are approximated as a first-order system and a second-order system, respectively. Since the input voltage is limited due to the specification of the inverter, if the sampling interval is set small, the control input is saturated. Hence, the sampling interval is selected as long enough to ignore the dynamic characteristics of the loadcell, so the first-order system and the integrator are dominant (Sato & Kameoka, 2007). Hence, the dynamics characteristics of the control object are described as

$$G(s)=\frac{1}{s}\frac{K_m}{1+Ts} \tag{1}$$

where K_m is gain and T is assumed to be the time-constant of the motor. Because (1) is employed as the dynamic characteristics of this weigh feeder, control performance is influenced by the choice of the plant parameter. Therefore, the proposed controller is designed using a self-tuning controller that recursively estimates unknown parameters.

2.2. Discrete-time model and controller

A controller for a weigh feeder is designed by the following discrete-time model:

$$A[q^{-1}]y[k]=B[q^{-1}]u[k-1]+\xi[k] \tag{2}$$

$$A[q^{-1}]=(1-q^{-1})(1+\alpha_1 q^{-1})=1+a_1q^{-1}+a_2q^{-2} \tag{3}$$

$$B[q^{-1}]=b_0 \tag{4}$$

where q^{-1} is the backward shift operator. $y[k]$ is the plant output or the measured output signal, $u[k]$ is the control input or the input voltage supplied to the inverter, and $\xi[k]$ is the noise that

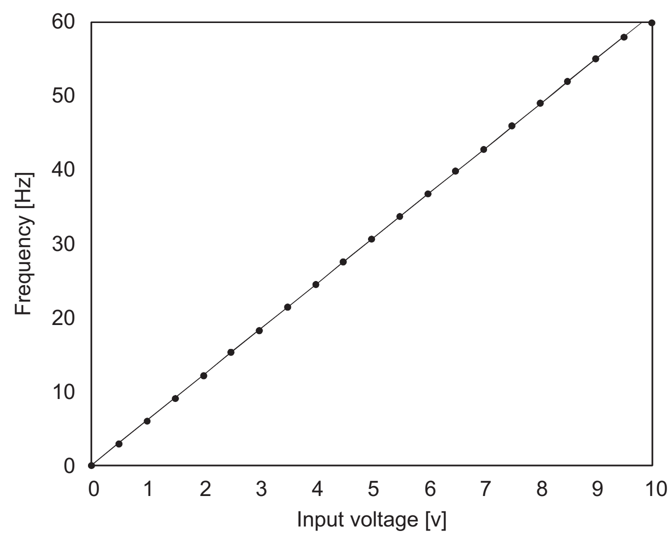

Fig. 3. Relationship between input voltage and output frequency of inverter.

disturbs the output signal. Polynomial $B[q^{-1}]$ is generally first-order but it is assumed to be 0-th in the present paper. This is because the difference between the experimental results of 0-th and 1-st is small, and the description of the proposed method can be simplified by restricting the order of $B[q^{-1}]$. Consequently, the precise dynamic characteristics of the weigh feeder might be not obtained, but because the proposed PID control is based on GPC, control performance deterioration caused by the approximation error between a GPC law with a PID control law can be prevented.

Due to the specification of the inverter built into the weigh feeder, the control input is limited, where the specification of the inverter comprises the range of the input voltage: 0−10 V and the range of the output frequency: 0−60 Hz. The experimental results for the inverter are shown in Fig. 3 (Sato & Kameoka, 2007), where the horizontal axis is the input voltage, the vertical axis is the output frequency, and the voltage supplied to the inverter is set from 0 to 10 in 0.5 increments. Using the least square method, the gradient of the experimental data except for 10 V is obtained as $K_i=6.11$. Hence, the range of the valid control input is given as

$$0\le u[k]\le 9.82 \tag{5}$$

In this study, the weigh feeder is controlled by the following PID control law:

$$\Delta u[k]=C_1[q^{-1}]r[k]-C_2[q^{-1}]y[k] \tag{6}$$