비선형 장력 제어 시스템 설계

The design of web tension control system using nonlinear feedback

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Abstract – We consider a web transport system. The objective of this paper is to design the controller such that desired tension and processing on web transport system. We propose the new design method which is independent with operating condition. The proposed method used a nonlinear feedback to transform to linear system. We show a performance of controller via the simulation.

Key Words : web transport system, nonlinear feedback, tension control

1. Introduction

The precise control of web tension is very important to improve the quality of product such as a textile industry. There has been some works to control the tension and processing speed[1,2]. The work[1] used the gain scheduling method to handle a difficulty of nonlinearity on the system. The work fixed the processing speed with some operating condition. After fixing the processing speed, the system was changed to a linear system. The controller was designed on the linear system. This approach can be cause a problem when the operation condition was changed. To avoid this problem, we propose a new control design method which use the nonlinear feedback to transform to linear system. We calculate the relative degree of the system to check the possibility that the system can be transformed to a linear system using nonlinear feedback. The web transport system considered in this paper can be transformed to a linear system. After transformation to a linear system, we design a controller to achieve the control objectives. The proposed method works on the every operation condition, since we do not assume that processing to be a fixed one. We show that a performance of the controller via a simulation.

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2. System modeling and controller design

2.1 system modeling

The web transport system to be considered in this paper is shown in Fig 1. Motors are used to drive the unwind roller and rewind roller. Idle rollers guide the web to load cell. The load cell is used to measure the tension of web. The tension and velocity control can be done

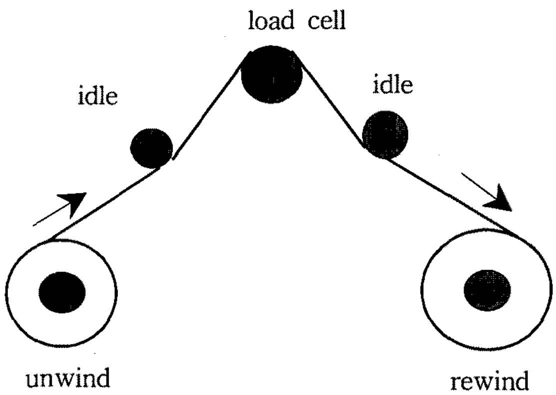

Fig. 1 The web transport system

by controlling the velocity of the unwind roller and rewind roller. The tension of the web can be controlled by torque control of the unwind roller' motor: the unwind roller acts as if a brake against moving web. The speed of web can be controlled by the torque control of the unwind roller' motor. The dynamic equations for the web transport system in Fig. 1. can be described by the following equation[1,3].

$$J_u \frac{dw_u(t)}{dt} = -B_u w_u + r_u T(t) - \tau_u$$
$$\frac{dT(t)}{dt} = -\frac{r_r w_r}{L} T(t) + K[r_r w_r - r_u w_u]$$
$$J_r \frac{dw_r(t)}{dt} = -B_r w_r + r_r T(t) - \tau_r \quad (1)$$

where

$J_u \equiv$ moment of inertia of unwind roll including motor($kg/m/\sec^2$),

$J_r \equiv$ moment of inertia of unwind roll including motor($kg/m/\sec^2$),

$w_u \equiv$ angular velocity of the unwind roll(rad/sec),

$w_r \equiv$ angular velocity of the wind roll(rad/sec),

$B_u \equiv$ coefficient of viscous friction of unwind roll(kg-m-s/rad),

$B_r \equiv$ coefficient of viscous friction of wind roll(kg-m-s/rad)

$r_u \equiv$ radius of the unwind roll(m),

$r_r \equiv$ radius of the unwind roll(m)

$T \equiv$ web tension(kg),

$\tau_u \equiv$ torque generated by unwind motor(kg/m),

$\tau_r \equiv$ torque generated by wind motor(kg/m),

$L \equiv$ total length of web(m),

$K \equiv$ spring constant of web(kg/m).

Note that we neglected the friction and dynamics of idle roller and load cell in the equation (1).

2.2 Feedback Linearization and controller design

The main object of this paper is to design the torques generated by unwind roll and rewind roll enabling a desired angular velocity of rewind roll and tension of moving web. The desired processing speed of web can be achieved by controling the angular velocity of the rewind roll. The term $-\frac{r_r w_r}{L}$ in the equation(1) was fixed at an operating point in the paper[1] because of nonlinearity. After assuming the constant for the term $-\frac{r_r w_r}{L}$, The equation (1) is a linear system and one can designs the desired controller by using a standard controller design technique for linear system. However the design method used in the paper[1] may cause a problem when operating point is changed. There are some progresses in the nonlinear system during the last decade[4,5]. A class of nonlinear system can be transformed to a linear system via change of coordinate. We use the change of coordinate to transformed the equation (1) to a linear system. To check the feedback linearizability, we rewrite the equation (1) as the following equation.

$$\begin{bmatrix} \dot{w}_u \\ \dot{T} \\ w_r \end{bmatrix} = f(w_u, T, w_r) + g \cdot \begin{bmatrix} \tau_u \\ \tau_r \end{bmatrix} \quad (2)$$

where

$$f(w_u, T, w_r) = \begin{bmatrix} k_1 w_u + k_2 T \\ k_4 w_u + k_5 T w_r + k_6 w_r \\ k_7 T + k_8 w_r \end{bmatrix}, \quad g = \begin{bmatrix} k_3 & 0 \\ 0 & 0 \\ 0 & k_9 \end{bmatrix},$$

$k_1 = -\frac{B_u}{J_u}$, $k_2 = \frac{r_u}{J_u}$, $k_3 = -\frac{1}{J_u}$, $k_4 = -Kr_u$,

$k_5 = -\frac{r_{\{r\}}}{J_u}$, $k_6 = Kr_r$, $k_7 = -\frac{r_r}{Jr}$, $k_8 = -\frac{B_r}{J_r}$,

$k_9 = -\frac{1}{J_r}$. Our interesting outputs are T(t) and w_r. Since $L_{g1}L_f^0 T = 0$, $L_{g1}L_f^1 T = k_3 k_4 \neq 0$,, $L_{g2}L_f^0 T = 0$, $L_{g2}L_f^1 T = (k_5 T + k_6) k_9 \neq 0$, $L_{g1}L_f^0 w_r = 0$, and $L_{g2}^1 L_f^0 w_r = k_9 \neq 0$, where $L_f^1 T$ is derivative of T along a vector field f, i.e., $L_f^1 T \equiv \left[\frac{\partial T}{\partial w_u} \ \frac{\partial T}{\partial T} \ \frac{\partial T}{\partial w_r}\right] \cdot f$, $L_f^0 T \equiv T$, and similarly $L_{gi}L_f^1 T$, $L_{gi}L_f^0 w_r$ are defined where g_i is the i th column vector of g. the equation (2) has a vector relative degree of [2,1]. Thus implies that the equation (2) is feedback linearizable system. Define $z_1 = T$, $z_2 = k_4 w_u + k_5 T w_r + k_6 w_r, z_3 = w_r$. It can be shown that

$$\begin{bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \end{bmatrix} = \begin{bmatrix} z_2 \\ b_1(z) + a_{11}(z)\tau_u + a_{12}(z)\tau_r \\ b_2(z) + k_9 \tau_r \end{bmatrix} \quad (3)$$

where $z = [z_1, z_2, z_3]^T$, , $b_2(z) = k_7 z_1 + k_8 z_3$, $a_{11}(z) = k_3 k_4$, and $a_{12}(z) = k_5 k_9 z_1 + k_6 k_9$. After choosing $\tau_u = \frac{1}{a_{11}}[-b_1(z) - a_{12}(z)\tau_r + v_u]$ and $\tau_r = \frac{1}{k_9}[-b_2(z) + v_u]$ where v_u and v_r are to be defined later on, the equation (3) results in the following equations

$$\dot{z} = Az + Bv \quad (4)$$

where $A = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$, $B = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}$, $v = \begin{bmatrix} v_u \\ v_r \end{bmatrix}$.

One can use the standard linear system design method[4] for the design of v_u and v_r. One can verify that $[A, B]$ is controllable pair. Therefore we can choose the control input v to achieve the desired tension and angular velocity of rewind roll. Since [A,B] is controllable pair, one can choose c_i with $v_u = c_1(z_1 - T_d) + c_2 z_2$, $v_r = c_3(z_3 - w_{rd})$ such that the closed loop pole is located in open left half plane. Note that T_d and w_{rd} denote the desired tension value and desired angular velocity respectively.

2.3 Example

We consider the experimental system given in[lin] as an example. The experimental system has the following data:

$J_u = J_r = 1.95 \times 10^{-5} kg - m - s^2$,

$B_u = B_r = 2.533 \times 10^{-5}$kg-m,L=0.3m,K=200 kg/m,

$r_u = 0.04$ m, $r_r = 0.015$ m.

We consider the desired tension $T_d = 0.5kg$ and the desired angular velocity $w_r = 250$rad/sec. We choose control gain c_1=-20, $c_2 = 9$, c_3 =-4. Fig. 2 and Fig. 3 show that we can achieve our control objective. The trajectory of tension of the web is followed 0.5 kg within 0.5 sec and the trajectory of angular velocity of rewind web is followed 250 rad/sec.

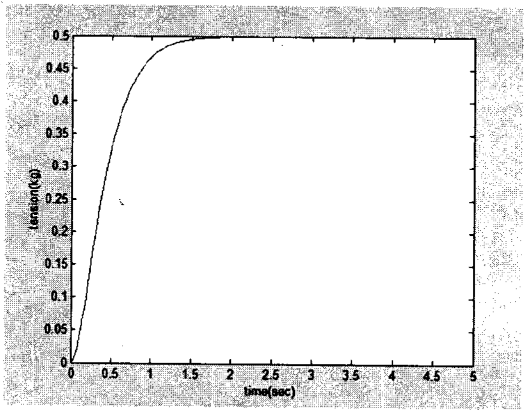

Fig. 2 The plot of tension of web

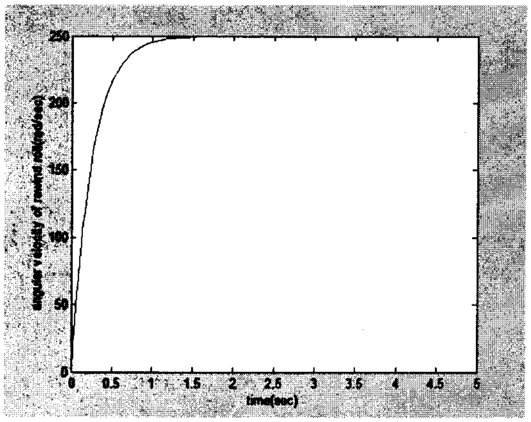

Fig. 3 The plot of angular velocity of rewind roll

3. Conclusion

We consider a web transport system. We propose the new controller design method using nonlinear feedback. The proposed controller can work any operating condition, while the previous work[1] restricted to the certain operation condition.

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