Fuzzy logic based control design for active dancer closed loop web tension control

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Abstract
Active dancers are used to control web tension in roll-to-roll (R2R) based printing systems. In this paper the control system for a compact active dancer system has been designed using fuzzy logic. The dancer system has a proportional pressure regulator as actuator and a potentiometer to measure the displacement of the system. Controller is designed without using a system model. In this case the problem is broken down into two. First the problem is interpreted as a position control problem. A fuzzy logic based controller is designed to achieve accurate position control. Finally tension feedback is introduced using a simple proportional control.
***Keywords*: Roll-to-roll system, active dancer system, tension control, fuzzy logic.**

1. Introduction

Roll-to-roll (R2R), also known as web handling system is a popular tool to process material in the form of thin strips. It finds application in the fields of textile, paper, film, printing industry etc. The R2R system utilized in this paper is shown in figure 1(a). Schematic representation of the system is shown in figure 1(b). Its role is to first unwind the material in the form of roll at the un-winder section, transport web through the process span 2, and finally wind it in the re-winder section. During this movement the web has to be maintained at constant tension and velocity. This system has a total of 3 spans. Each span is a section of web in the web handling system that is maintained at a certain tension based on the process requirement. Typically some form of closed loop tension control system is applied to maintain the tension. As shown in fig 1(c), the tension of a given span is measured with the aid of load cells and fed back to a controller which may be PID, fuzzy or others. The controller based on error in the tension sends control output to the servo pack which applies the appropriate torque to the driven rolles. A dancer is a prime mover driven mechanical system that is often used to control tension in a span in which the tension cannot be controlled using the conventional model in 1(c). Such as, when running a sequential multi-color printing operation, the gravure rolls at the entry and exit of a span are electronically geared to

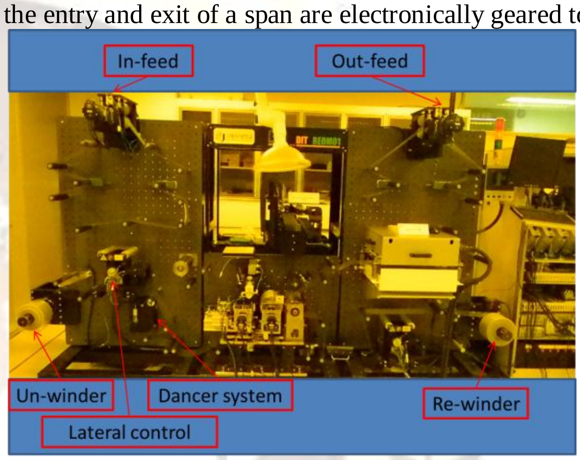

Figure 1(a) R2R system

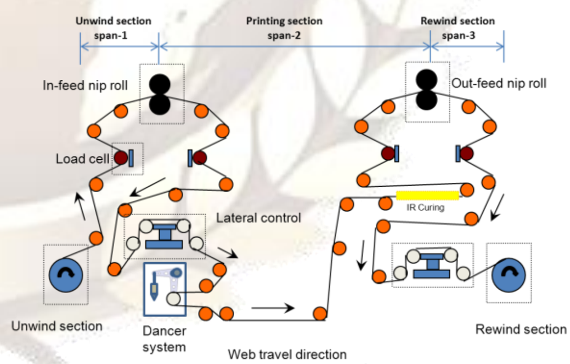

Figure 1(b) Schematic representation of R2R system

each other to operate at the same speed. Under these conditions a dancer system releases or withdraws web into the web span, thus controlling the tension. The dancer system can be seen in figs1 (a) and (b).

The converting industry has utilized web handling systems for a long time and hence there have been a variety of methods to implement web velocity and tension control. [1-6] is an example of a few of these methods. [1] uses a neural net to learn the web dynamics and [3] have applied fuzzy logic. [5] has summarized all different control approaches and has offered a reference tension guideline. Observer system has been developed in [2] thus avoiding load cells. [2] and [6] have modeled the inertia of the un-wind and re-wind sections. [7] and [8] have used active dancer systems to control web tension. While [7] has compared active and passive dancers, [8] has compared three different controller applied to an active dancer system. [8] and [9] emphasize the importance of tension control. [8] correlates the web tension with respect to the quality of patterns printed using an offset printer and [9] has described the relation between web tension and the lateral control, specifically that there is a minimum tension below which lateral control will become difficult due to slip phenomenon between the web and the lateral control system.

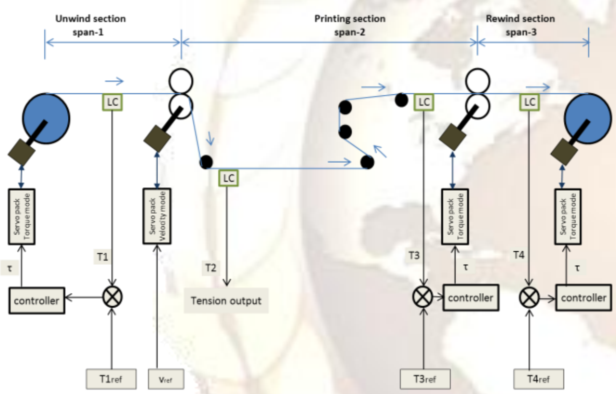

Figure 1(c) Conventional control architecture without dancer

In this paper a dancer system has been introduced into the R2R system and has been used to control web tension. The key feature of this work that distinguishes it from existing literature is that it does not use a system model to develop the control system. A fuzzy controller has been used. First the problem is turned into a position control problem and then the appropriate fuzzy logic based accurate position control system is developed. Then based on the correlation between the position of dancer and tension of web a simple proportional control law is developed and used to achieve tension control.

2. Methods and materials

2.1. R2R system

The R2R system is composed of 4 servo-motors. Servo pack used is Mitsubishi-MRJ2S70A. Tension feed-back is given by load cells (Magpowr-cantilever load cell). Interface with R2R system is done using National Instruments hardware. Entire algorithm has been written in the graphical programming environment, LabVIEW.

2.2. Dancer system

Dancer system is built specifically for R2R system as can be seen in fig 2(a). It has a pneumatic cylinder for prime mover and a potentiometer-Copal (J50S 20K) to sense angular rotation as seen in fig 2(b). The potentiometer measures angular position of the dancer in terms of 0-5 Volts. Although range of potentiometer is 0-5Volts the true range of rotation of the dancer is only 5.6° and hence correspond to 3-3.25V. For convenience angle is measured in Volts in this paper. The force is transmitted from the pneumatic cylinder-Fujikura BF cylinder (FCS-25-26-S1) - to the idle roller of the dancer system via an "L" shaped dancer link shown in fig 2(b). Pneumatic pressure is applied to the cylinder through a proportional pressure regulator-Norgren VP12-which is capable of producing a pressure from 0-8bar proportional to the applied analog signal ranging from 0-10V. The free body diagram of the forces acting on the dancer is shown in fig 2(c). F is the force exerted by the cylinder and F' is the total force exerted by the web tension T on the dancer link.

3. Control system design

Control system for the given system already exists as shown in fig 1(c). But it can be seen that span-2 is quite long and there are two load cells on it. It was found that the tension in the load cell on span-2 closest to span-1 showed a significantly lower tension than that used in feed-back loop of span-2 tension controller. The tension control loop for span-2 is on the downstream end of the span. The large length of the span and the low tension used may be the reason for this phenomenon. The goal is to control the tension in the initial portion of span-2 using the dancer system. Although tension in a moving web is a very complex process it can be simplified as follows:

Young's modulus

$E=\sigma/\varepsilon$

Where, σ= Stress on web

ε=Strain in web

$\sigma=T/A$

$\varepsilon=\delta l/l$

where,

T=web tension

A=area of cross section of web

L=length of span

Therefore,

$T \propto \varepsilon$ ……………………….(1)

The dancer system operates by controlling this strain. And strain control is simply a matter of positioning the dancer arm. Although the relation is not this simple, as the material property of the web is not linear as shown, but equation (1) is assumed to be true. There are other sources of non-linearity such as the motion of the dancer system. The idle roller in the dancer travels along an arc but it is assumed to travel along a straight line as the angle moved is small. Similarly, the force exerted by the cylinder is non-linear especially when the signal is varying, as with all physical systems it will have delays in response.

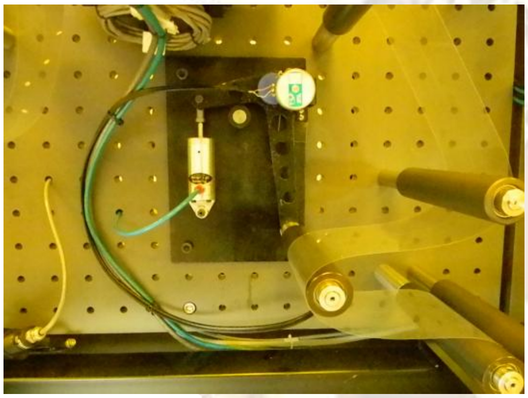

Figure 2(a). Dancer system

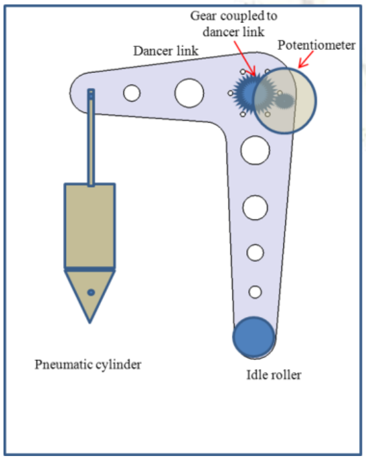

Figure 2(b). Components of dancer system

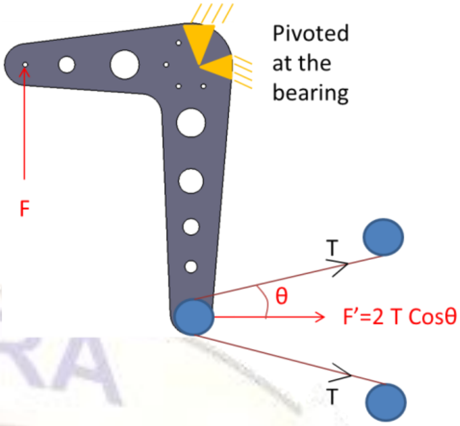

Figure 2(c) free body diagram of dancer link

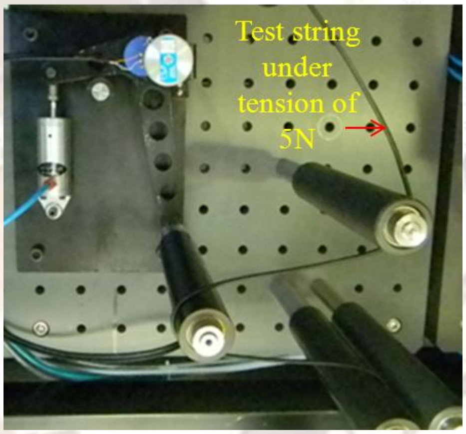

Figure 3 Test rig with standard tension of 5N

3.1. Fuzzy position control

A test rig is set up as shown in figure 3. The web is replaced with a string that maintained a constant tension. This tension is also the reference tension. This is achieved by hanging a weight equivalent to 5 N, i.e. 500gms at the end of the string that traces the path followed by the web in the dancer system. As mentioned earlier the whole dancer system is highly non-linear and we need to achieve perfect position control. Again for convenience we shall refer to position in volts as given by potentiometer, and the pressure is also expressed in volts. First the voltage is slowly increased until the pressure in the cylinder just begins to pull and move the string under tension. This is found to be 2.75volts. Now the tension is slowly decreased until the string is able to pull the dancer system, this value was found to be 1volt. Ideally both of these values have to the same, but due to inertia, friction and a host of other reasons they are distinct. These two values form the basis for a fuzzy control system. The fuzzy controller takes error in position, given in volts as input and computes an output voltage for proportional pressure regulator in the range (1, 2.75). The overall fuzzy controller is given in fig 4. The output from the output scaling function is given as,

$$\eta = K1*(\text{output of fuzzy inference system}) + K2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

From the range of the function which is (1, 2.75) and range of the fuzzy inference system we can compute K1 and K2. Hence

$$\eta = -0.875*(\text{output of fuzzy inference system}) + 1.875 \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The input scaling function is given as

$\mu = ep/K3$

where $ep = Pref - P$ ………………….(4)

where, Pref=reference position or the position where the dancer link should be; and, P=actual position of dancer.

K3 is to be determined experimentally.

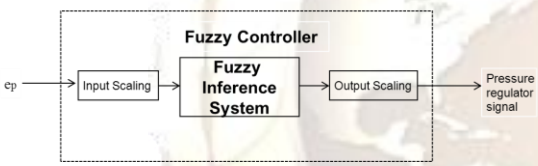

Figure 4 Fuzzy controller

The fuzzy inference mechanism is described by fig 5(a) and (b). Fig 5(a) is used to find member ship value of each of the sets given in it. Fig 5(b) is used to compute the output of individual rule, which are given as follows:

If VL then VH
If L then H
If N then N
If H then L
If VH then VL

The final output of the fuzzy inference mechanism is found using the center of gravity method. The output is given by

$$t = VL(\text{ep})*1 + L(\text{ep})*x + N(\text{ep})*0 + H(\text{ep})*(-x) + VH(\text{ep})*(-1) \quad \ldots\ldots\ldots\ldots(5)$$

This is a very simple fuzzy controller, but non-linearity can be introduced into this controller. The controller has two tuning parameters K3 and x. After iteratively tuning the K3 and x values were found to be 0.07 and 0.85, respectively. The well-tuned fuzzy controller is operated to determine its capability, by giving it step input Pref values of 3.15, 3.2 and 3.25, as shown in fig 6.

3.2. Closed loop fuzzy tension control

Due to the excellent closed loop position control, it is now possible to introduce closed loop tension control. The string is removed from the dancer system and the actual web is introduced into it. The final closed loop tension control is implemented as shown in fig 7. To achieve it the fuzzy controller is slightly modified. The *Pref* in equation (4) is given by

$$Pref = Kp*(Tref - T) \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Equation (6) is actually a proportional control. Where, Kp is experimentally determined to be -15.

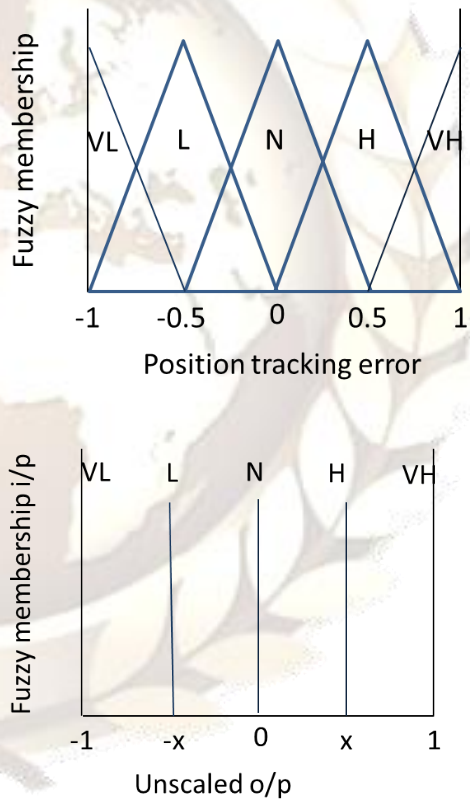

Figure 5 Fuzzy sets; (a) input set (top); (b) output set (bottom).

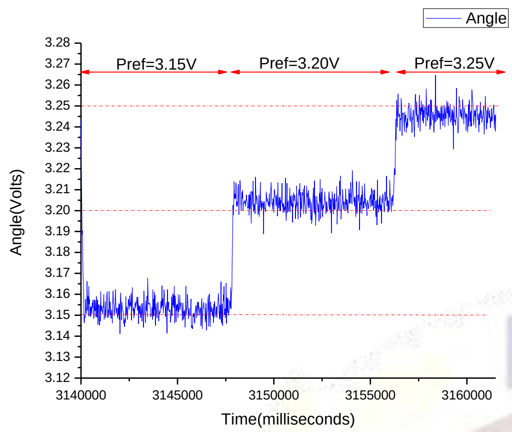

Figure 6 Step response of position control

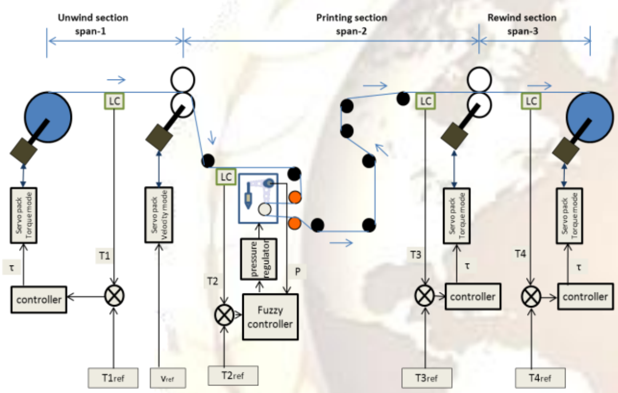

Figure 7 Closed loop tension control using dancer

4. Results and discussion

R2R system is operated at a speed of 0.04 m/s and a reference tension of 5N. Tension span-2 is controlled using the dancer system with fuzzy controller. The results are as shown in fig 8. It can be seen that the assumptions made during the design of control system is valid. The tension fluctuations never exceed amplitude of 1.25N. Also it can be seen that the position control is all that is needed for controlling the tension. Since there is sufficient tension in the span the slip of web at lateral error control system can be minimized, all the while maintaining a reasonably low tension. Thus this method is suitable for controlling web tension while printing functional material for printed electronics.

5. Conclusions

A fuzzy logic based tension control algorithm is developed for an active dancer system. An unconventional approach is presented, which does not use any model. This imparts flexibility to not just to tuning or calibration of dancer system, but also gives flexibility to dancer design. The algorithm will find application in R2R based printed electronics industry as the system is capable of operating at low tensions with only minute fluctuations. In future it also will find use in precise printing registration control.

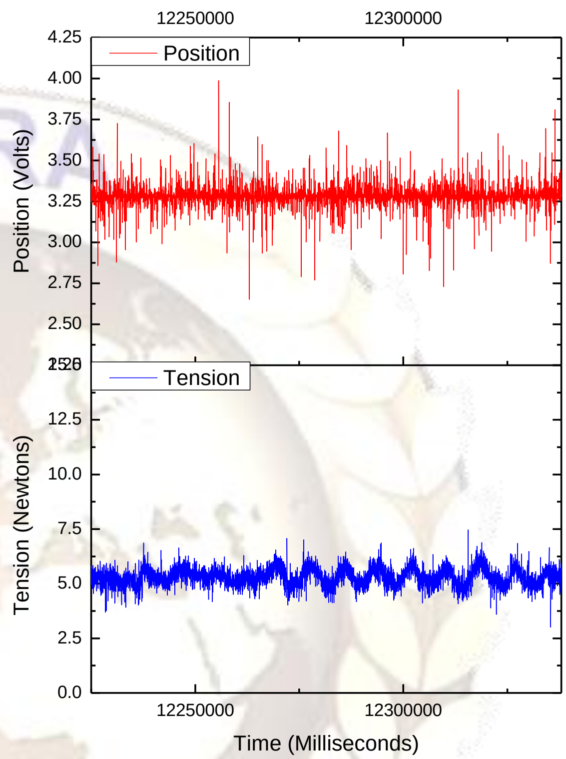

Figure 8 Closed loop tension characteristics of the fuzzy dancer control system

6. Acknowledgement

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