Imperfect Roll Arrangement Compensation Control based on Neural Network for Web Handling Systems

Dinh Nguyen Duc
School of Electrical Engineering
Hanoi University of Science and Technology
Hanoi, Vietnam
dinh.nguyenduc201297@gmail.com

Ly Tong Thi
Hanoi University of Science and Technology and
Hanoi University of Industry
Hanoi, Vietnam
ttly.haui@gmail.com

Tung Lam Nguyen
School of Electrical Engineering
Hanoi University of Science and Technology
Hanoi, Vietnam
lam.nguyentung@hust.edu.vn

Abstract—**The speed and tension control problem of a web handling system is investigated in this paper. From the system equations of motion, we developed a backstepping-sliding mode control for web speed and tension regulation tasks. It is obvious that the designed control depends heavily on roll inertia information. Dissimilar to other researches that were based on the assumptions of rolls with perfect cylindrical form with the rotating shafts of the rolls considered properly aligned, the novelty of this paper is the presentation of a neural network to compensate the effects of imperfect roll arrangement. The neural network design is based on the Radial Basis Function (RBF) network estimating the uncertainty of roll inertia. The information on estimated inertia is fed into a backstepping-sliding mode controller that ensures tension and velocity tracking. The control design is presented in a systematical approach. Closed loop system stability is proven mathematically. The tracking performance is shown through several simulation scenarios.**

Keywords-roll-to-roll; web handling system; backstepping; sliding mode control; radial basis function (RBF); adaptive control

I. INTRODUCTION

Numerous practical applications associated with web handling systems such as flexible displays, color-shifting, lighting, solar cells, etc. utilizing Roll-to-Roll (R2R) systems are becoming prevalent in industry [1-5]. Several papers have been published to enhance speed and tension control with various control algorithms based on the system dynamic modeling illustrated in [2, 3]. Sliding Mode Control (SMC) [6] is employed in [7], in which tension observers are introduced to eliminate the requirement of loadcells. Backstepping control is applied in [8–11] to counter the nonlinearity effects in R2R systems. An indirect tension control is proposed in [12], where the web tension is manipulated indirectly via distance information between two consecutive rolls. The experimental results show a moderate level of tension while tracking performance and high position control accuracy. Authors in [13] designed a tension coupling compensator based on active disturbance rejection control. The main advantage of this method was its simple approach. The elasticity of the web material is the most challenging problem in tension control. In [14], the phenomenon is tackled by a H-infinity robust control with varying gains. The control shows robustness against varying roll radius and inertia. Some effects of the transmission system such as backlash and flexible motor-roll coupling are considered in [15, 16].

It is evident that roll inertia information is essential for control system design [17–19]. Conventionally, the roll inertia depends on roll shape and web thickness. In practice, roll eccentricity and deformation exist and lead to false estimations. The robustness of the closed loop system against roll eccentricity is presented in [20]. However, when the parameters of the system are accompanied by system uncertainties, the proposed controllers can hardly guarantee efficiency and quality control in production. Hence, it is strictly essential to develop an adaptive controller that deals with the problem of varying roll inertia for the control of the R2R systems. A neural network is a powerful tool which can address the complex requirements of the system, requirements that other techniques could hardly solve. In this paper, by taking the advantages of Backstepping and Sliding Mode Control (BSMC) [21], a new control approach which uses BSMC integrated with an RBF neural network [22] (RBFN-BSMC) is proposed for the building of an R2R adaptive control system considering the presence of imperfection roll arrangements. The contribution of this paper can be summarized as: i) the proposal of a nonlinear backstepping-sliding mode control for web handling systems, ii) the realization of an RBF based adaptive mechanism for compensating roll inertia uncertainty.

II. BSMC FOR ROLL TO ROLL WEB SYSTEMS

A. R2R Web System Modeling

The single-span R2R web control system shown in Figure 1 contains an unwinder, a rewinder and a loadcell subsystem with idle rollers. Input torqueses are applied on the unwinder and rewinder. The following assumptions are made:

- Web slippage and deformation are totally ignored.
- Loadcell dynamics and friction are not taken into account.
- The web obeys Hook’s law.

Corresponding author: Tung Lam Nguyen

- Actuator dynamics are ignored.

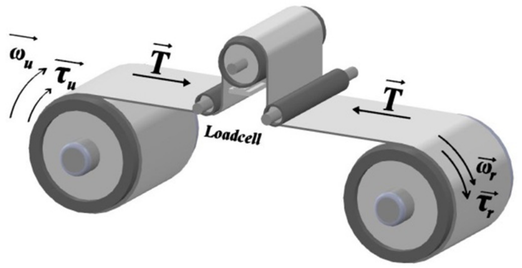

Fig. 1. Single-span web control system

The non-linear dynamic equations of the single-span R2R web control system are [3]:

$$\dot{\omega}_u = c_1\omega_u + c_2T + c_3\tau_u \quad (1)$$

$$\dot{T} = c_4\omega_u + c_5T\omega_r + c_6\omega_r \quad (2)$$

$$\dot{\omega}_r = c_7T + c_8\omega_r + c_9\tau_r \quad (3)$$

where $c_1 = \frac{B_u}{J_u}$, $c_2 = \frac{R_u}{J_u}$, $c_3 = -\frac{1}{J_u}$, $c_4 = -KR_u$, $c_5 = -\frac{Rr}{L}$, $c_6 = KR_r$, $c_7 = \frac{R_r}{J_r}$, $c_8 = -\frac{B_r}{J_r}$, $c_9 = \frac{1}{J_r}$.

In the above equations of motion, (1) and (2) present the dynamics of unwinding and rewinding section, and (3) describes tension dynamics between the two rolls. The relations between the total moment of inertia, operating radius, web thicknes, and roll speed are described by:

$$R_u(t) = R_{u0} - \frac{\theta_u h}{2\pi}$$

$$J_u = J_{u0} + \pi\rho\omega\frac{\left(R_u^4 - R_{u0}^4\right)}{2}$$

$$R_r(t) = R_{r0} + \frac{\theta_r h}{2\pi}$$

$$J_r = J_{r0} + \pi\rho\omega\frac{\left(R_r^4 - R_{r0}^4\right)}{2}$$

where T is web tension, J_u and J_r are the moments of inertia of the unwind and rewind rolls, R_u and R_r are radii of the unwind and rewind rolls, B_u and B_r are the coefficients of vicious friction of the unwind and rewind rolls, K is the spring constant of the web, L is the total web length, h is web thickness, ρ is web density, ω_u, ω_r are the unwinding and rewinding roll speeds, and θ_u, θ_r, are unwinding and rewinding roll positions.

B. Backstepping Sliding Mode Control

The controller's purpose is keeping web tension and web speed at the desired values. Web speed is controlled through tracking the angular velocity. This section uses the sliding algorithm based on backstepping technique to design the controller. The design steps are:

Step 1: The tracking error variables are defined as bellow:

$$\bar{T} = T - T_d \quad (4)$$

$$\bar{\omega}_u = \omega_u - \omega_{ud} \quad (5)$$

$$\bar{\omega}_r = \omega_r - \omega_{rd} \quad (6)$$

where T_d and ω_{rd} are the desired web tension and the desired rewind web angular velocity respectively, ω_{ud} is an unknown function serving as a virtual control that will be designed in such a way that T tends to T_d.

Step 2: The control signal ω_{ud} is determined such that the web tension tracks the desired value. Equation (2) can be rewritten as:

$$\dot{\bar{T}} = c_4\omega_u + c_5T\omega_r + c_6\omega_r \quad (7)$$

To regulate the tension error $\bar{T} \to 0$, virtual control ω_{ud} is chosen as:

$$\omega_{ud} = -\frac{1}{c_4}\left(c_5T\omega_r + c_6\omega_r + k_1\bar{T}\right) \quad (8)$$

where k_1 is a positive gain. The proposed Lyapunov candidate function is:

$$V_T = \frac{1}{2}\bar{T}^2 \quad (9)$$

Using (7) and taking the time derivative of (9) we obtain:

$$\dot{V}_T = \bar{T}\left(c_4\omega_u + c_5T\omega_r + c_6\omega_r\right) \quad (10)$$

Replacing ω_u by ω_{ud} from (8) results in:

$$\dot{V}_T = -k_1\bar{T}^2 \le 0$$

Step 3: Based on backstepping technique, the control signal τ_u, τ_r will be determined in order to drive ω_u to track ω_{ud}, and ω_r to track ω_{rd} asymptoticaly. From (1), (3), (5), and (6) we obtain the error equations:

$$\dot{\bar{\omega}}_u = c_1\omega_u + c_2T + c_3\tau_u - \dot{\omega}_{ud} \quad (11)$$

$$\dot{\bar{\omega}}_r = c_8\omega_r + c_7T + c_9\tau_r - \dot{\omega}_{rd} \quad (12)$$

The sliding surfaces are defined as:

$$S_u = \bar{\omega}_u \quad (13)$$

$$S_r = \bar{\omega}_r \quad (14)$$

The proposed Lyapunov candidate function is:

$$V_u = \frac{1}{2}S_u{}^2 \quad (15)$$

Differentiating (15) gives:

$$\dot{V}_u = S_u\dot{S}_u \quad (16)$$

The control signal is calculated as:

$$\tau_u = \tau_{ueq} + \tau_{usw} \quad (17)$$

where τ_{ueq} is the control component making $\dot{S}_u = 0$ and τ_{usw} is the control component ensuring $\dot{S}_u \leq 0$. From (11), it is straightforward to get τ_{ueq} as:

$$\tau_{ueq} = -\frac{1}{c_3}\left(c_1\omega_u + c_2T - \dot{\omega}_{ur}\right) \quad (18)$$

In order to guarantee $\dot{S}_u \leq 0$, the signal τ_{usw} is proposed to be:

$$\tau_{usw} = -\frac{k_2}{c_3}\text{sat}\left(S_u\right) \quad (19)$$

where k_2 is a positive gain. From (11), (13), (16)-(19) we get:

$$\dot{V}_u = -k_2 S_u \text{sat}\left(S_u\right) \leq 0$$

Similarly, the control signal τ_r is generated by taking the total τ_{req} and τ_{rsw}, where:

$$\tau_{req} = -\frac{1}{c_9}\left(c_8\omega_r + c_7T - \dot{\omega}_{rr}\right) \quad (20)$$

$$\tau_{rsw} = -\frac{k_3}{c_9}\text{sat}\left(S_r\right) \quad (21)$$

where k_3 is a positive gain. It should be highlighted that the designed controls depend on the calculated roll inertia which is based on the assumption of a perfectly prismatic roll shape and ideal rotating shaft alignment. This assumption does not always hold in practical applications.

III. ADAPTIVE BSMC FOR THE UNCERTAINTIES OF THE ROLL TO ROLL WEB SYSTEM

In practice, roll eccentricity and deformation as demonstrated in Figure 2 might occur [3].

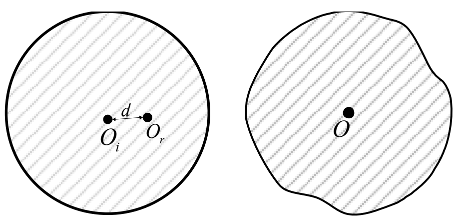

Fig. 2. Roll eccentricity and deformation

This phenomenon leads to miscalculated moments of inertia of the unwind and rewind rolls, hence some system parameters are unknown: c_1, c_2, c_3, c_7, c_8, and c_9. The designed input torques given in (22)-(25) indicate a strong dependence on the accuracy of acquired inertia. Inaccurate information on roll inertia can deteriorate control performance. It is necessary to develop a strategy to retrieve unwinding and rewinding sections. In order to tackle this problem, a mechanism based on the RBF network is proposed to estimate these parameters. The inputs of the neural network are ω_u, ω_r and the outputs are $\hat{J}_u, \hat{J}_r$ which are the estimated inertia values. The neural network is trained online in order to force the error between the actual and the estimated values to approach zero. W is defined as the ideal weight and $\hat{W}$ as its estimation The error of ideal and estimated weights is:

$$\tilde{W} = \hat{W} - W \quad (22)$$

Then, J and $\hat{J}$ can be writen as:

$$J = W^T \underline{h}, \ \hat{J} = \hat{W}^T \underline{h} \qquad \tilde{J} = \hat{J} - J = \tilde{W}^T h \quad (23)$$

where $\underline{h}$ is the vector output of the hidden layer with its transfer function defined as:

$$h_i = \frac{\exp\left(-\frac{\left\|\omega_u - c_{1i}\right\|^2 + \left\|\omega_r - c_{2i}\right\|^2}{b_i^2}\right)}{\sum_{j=1}^{n}\exp\left(-\frac{\left\|\omega_u - c_{1i}\right\|^2 + \left\|\omega_r - c_{2i}\right\|^2}{b_j^2}\right)}$$

where n is the number of neurons of the neural network. Under the condition of uncertain roll inertia, control signals that are derterminded in the above section can be rewritten as:

$$\hat{\tau}_u = -\frac{1}{\hat{c}_3}\left(\hat{c}_1\omega_u + \hat{c}_2T - \dot{\omega}_{ud} + k_2\text{sat}\left(S_u\right)\right) \quad (24)$$

$$\hat{\tau}_r = -\frac{1}{\hat{c}_9}\left(\hat{c}_8\omega_r + \hat{c}_7T - \dot{\omega}_{rd} + k_3\text{sat}\left(S_r\right)\right) \quad (25)$$

where $\hat{c}_1, \hat{c}_2, \hat{c}_3, \hat{c}_7, \hat{c}_8$, and $\hat{c}_9$ are the estimated values of c_1, c_2, c_3, c_7, c_8, and c_9, respectively, since these constants depend on roll inertia. The objective of this control design is to identify the laws for unwinding and rewinding rolls. Replacing τ_u, τ_r with $\hat{\tau}_u$, $\hat{\tau}_r$ in (11) and (12) we obtain:

$$\dot{S}_u = \frac{\tilde{J}_u}{J_u}\dot{\omega}_{ud} - \frac{\hat{J}_u}{J_u}k_2\text{sat}\left(S_u\right) \quad (26)$$

$$\dot{S}_r = \frac{\tilde{J}_r}{J_r}\dot{\omega}_{ur} - \frac{\hat{J}_r}{J_r}k_3\text{sat}\left(S_r\right) \quad (27)$$

The Lyapunov candidate function for S_u becomes:

$$V_u = \frac{1}{2}J_u S_u^{\ 2} + \frac{1}{2}\text{Tr}\left(\tilde{W}_u^{\ T} F_u^{\ -1}\tilde{W}_u\right) \quad (28)$$

where F_u is a fit positive matrix. Taking the time derivative of (28) we get:

$$\dot{V}_u = \frac{1}{2}\dot{J}_u S_u^{\ 2} + J_u S_u \dot{S}_u + \text{Tr}\left(\tilde{W}_u^{\ T} F_u^{\ -1}\dot{\hat{W}}_u\right) \quad (29)$$

Substituting (26) into (29) yields:

$$\dot{V}_u = \frac{1}{2}\dot{J}_u S_u^{\,2} + J_u S_u\left(\frac{\tilde{J}_u}{J_u}\dot{\omega}_{ud} - \frac{\hat{J}_u}{J_u}k_2 \text{sat}(S_u)\right) + \text{Tr}\left(\tilde{W}_u^{\,T} F_u^{-1}\dot{\hat{W}}_u\right)$$

After some fundamental operations, it can be shown that:

$$\begin{aligned}\dot{V}_u &= \frac{1}{2}\dot{J}_u S_u^{\,2} - \hat{J}_u k_2 S_u \text{sat}(S_u) \\ &+ \text{Tr}\left(\tilde{W}_u^{\,T}\left(F_u^{-1}\dot{\hat{W}}_u + h\dot{\omega}_{ud} S_u\right)\right)\end{aligned} \qquad (30)$$

Equation (30) suggests that the updated law can be selected as:

$$\dot{\hat{W}}_u = -F_u h_u \dot{\omega}_{ud} S_u \qquad (31)$$

With the selected updated law $\dot{V}_u$ can be rewritten as:

$$\dot{V}_u = \frac{1}{2}\dot{J}_u S_u^{\,2} - \hat{J}_u k_2 S_u \text{sat}(S_u)$$

It is noted that $\dot{J}_u \le 0$, thus $\dot{V}_u \le 0$. The proposed candidate Lyapunov function for S_r is:

$$V_r = \frac{1}{2}S_r^{\,2} + \frac{\text{Tr}\left(\tilde{W}_r^{\,T} F_r^{-1}\tilde{W}_r\right)}{2J_r} \qquad (32)$$

where F_r is a fit positive matrix. Taking the time derivative of (36) yields:

$$\dot{V}_r = -\dot{J}_r \frac{\text{Tr}\left(\tilde{W}_r^{\,T} F_r^{-1}\tilde{W}_r\right)}{2J_r^{\,2}} - \frac{\tilde{J}_r}{J_r}\bar{\omega}_r^{\,2} + \frac{\text{Tr}\left(\tilde{W}_r^{\,T}\left(F_r^{-1}\dot{\hat{W}}_r + h\dot{\omega}_{rd} S_r\right)\right)}{J_r} \qquad (33)$$

Similarly, the updated law for neural network weight is chosen as:

$$\dot{\hat{W}}_r = -F_r h_r \dot{\omega}_{rd} S_r \qquad (34)$$

The update law renders $\dot{V}_r$ becomes:

$$\dot{V}_r = -\frac{\hat{J}_r}{J_r}k_3 S^2{}_r - \frac{\dot{J}_r \text{Tr}\left(\tilde{W}_r^T F^{-1}{}_r \tilde{W}\right)}{2J_r^{\,2}}$$

In addition, $\dot{J}_r \ge 0$, thus rendering $\dot{V}_r \le 0$.

IV. SIMULATION RESULTS

In this section, the performance of the proposed control and estimation mechanism is demonstrated through a numerical simulation. To adequately evaluate the effectiveness of the control system, there will be two simulation cases: with constant inertia and with added disturbance to the inertia. The parameters of the R2R system are utilized as: $R_{u0} = 0.04$m, $B_u = B_r = 0.00002533$kgms/rad, $w = 1$m, $J_{u0} = J_{r0} = 1$kg/m/s, $L = 0.3$m, $R_{r0} = 0.015$m, $h = 0.00002$m, and $K = 200$kg/m. The parameters of the controller are chosen as: k_1=5, k_2=10, k_3=10. In the simulation, the performance of the BSMC controller was compared with the adaptive RBFN-BSM controller's. The reference web speed was 0.2m/s and the desired web tension T_{ref}= 2N. BSMC receives full information of the web transport system while RBFN-BSMC must estimate the information of the model.

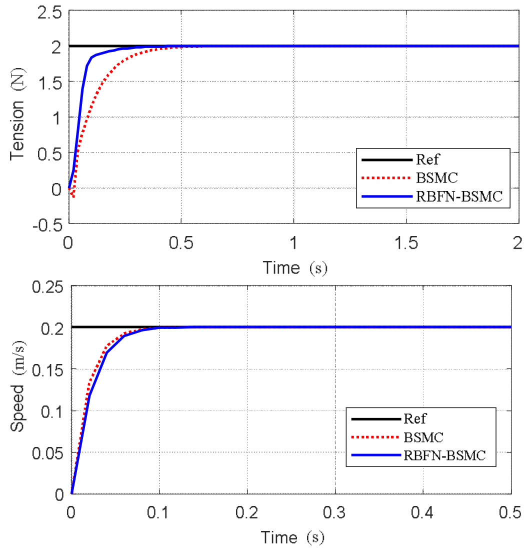

Fig. 3. System response with constant roll inertia. (a) Web tension, (b) web speed

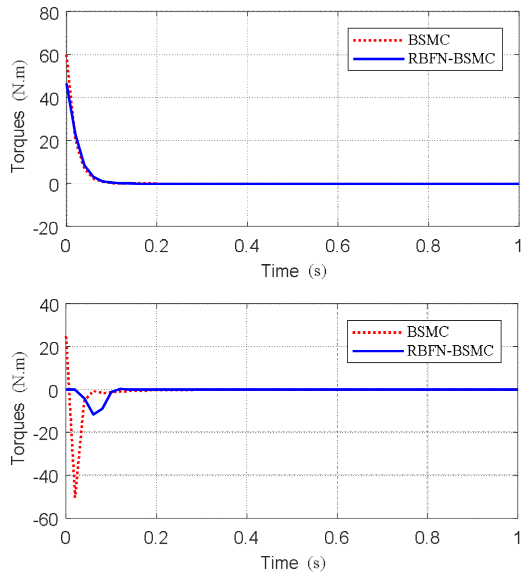

Fig. 4. Input torques with constant roll inertial. (a) Rewinding roll, (b) unwinding roll

When the roll inertia is pre-identified, both BMSC and RBFN-BMSC produce accurate and fast tension and speed responses as shown in Figures 4 and 5.

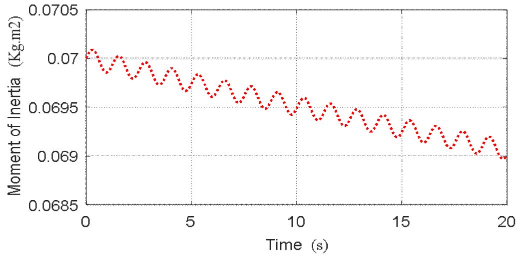

Fig. 5. Roll inertia disturbance

(a)

(b)

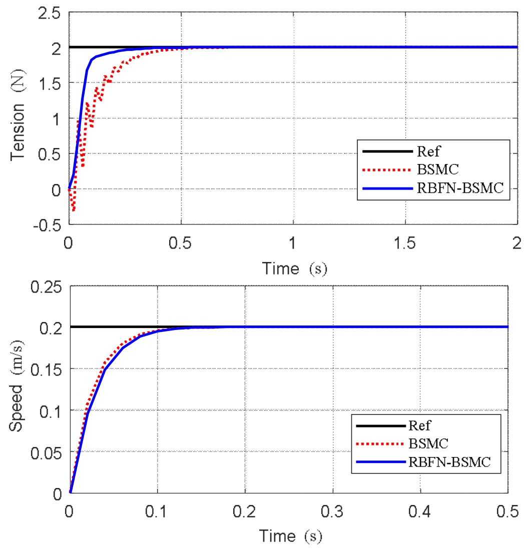

Fig. 6. System response with varying roll inertia. (a) Web tension, (b) web speed

(a)

(b)

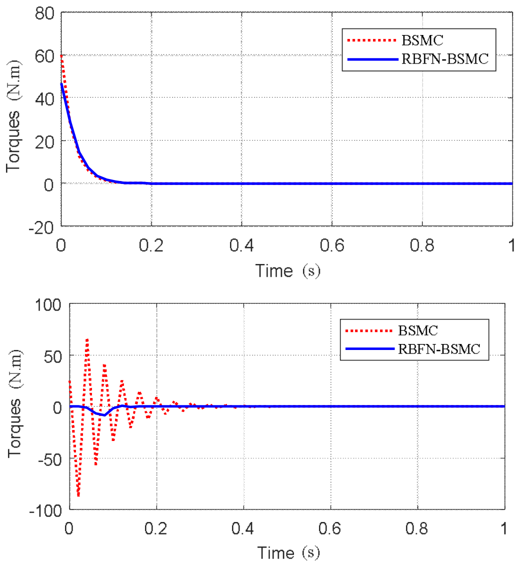

Fig. 7. Input torques with varying roll inertia. (a) Rewinding roll, (b) unwinding roll

However, the required input torque for RBFN-BMSC is lower than BMSC's. It is interesting to note that in this situation, RBFN-BMSC provides better tension tracking performance. The effectiveness of the proposed RBFN-BMSC is validated when the system is subject to unknown varying inertia. It is assumed that the roll inertia disturbance is the one given in Figure 5. As can be seen in Figure 6, the tracking result of RBFN-BMSC is still guaranteed. Without precise information of roll inertia, the BMCS shows its weakness in following the reference. Figure 7 indicates that under varying roll inertia, BMSC input torque fluctuates with high amplitude. Keeping in mind that full information of the roll to roll model is difficult to be obtained in real conditions, thus RBFN-BSMC law is more suitable for industrial applications than BSMC.

V. CONCLUSION

In this paper, a controller which combines the backstepping method with sliding mode control was proposed for web transport systems. In the proposed controller the estimator based on the RBF neural network was utilized for approximating system uncertainties. Simulation results show that the control system achieves both tracking and adaptation. Furthermore, when using RBF neural network, the controller does not require the precise description of the plant, thus the proposed controller is highly capable to be used in industrial applications. Future research focus on system generalization to multi-section web tension and a tension sensorless control will be proposed along with the experimental work.

ACKNOWLEDGEMENTS

This research is supported by the Hanoi University of Science and Technology under the research grant T2018-PC-053.

REFERENCES

[1] K. Okada, T. Sakamoto, "Adaptive fuzzy control for web tension control system", 24th Annual Conference of the IEEE Industrial Electronics Society, Aachen, Germany, August 31-September 4, 1998

[2] K. M. Chang, C. P. Weng, "Modeling and control for a coating machine", JSME International Journal Series C Mechanical Systems, Machine Elements and Manufacturing, Vol. 44, No. 3. pp. 656–661, 2001

[3] C. G. Kang, B. J. Lee, "Stability analysis for design parameters of a roll-to-roll printing machine", International Conference on Control, Automation and Systems, Seoul, South Korea, October 17-20, 2007

[4] C. G. Kang, B. J. Lee, "MIMO tension modelling and control for roll-to-roll converting machines", IFAC Proceedings Volumes, Vol. 41, No. 2, pp. 11877-11882, 2008

[5] T. Sakamoto, Y. Fujino, "Modelling and analysis of a web tension control system", IEEE International Symposium on Industrial Electronics, Dubrovnik, Croatia, July 10-14, 1995

[6] S. Drakunov, V. Utkin, "Sliding mode observers. Tutorial", 34th IEEE Conference on Decision and Control, New Orleans, USA, December 13-15, 1995

[7] N. R. Abjadi, J. Soltani, J. Askari, G. R. A. Markadeh, "Nonlinear sliding-mode control of a multi-motor web-winding system without tension sensor", IET Control Theory and Applications, Vol. 3, No. 4, pp. 419–427, 2009

[8] B. Bouchiba, A. Hazzab, H. Glaoui, F. M. Karim, I. K. Bousserhane, P. Sicard, "Backstepping control for multi-machine web winding system", Journal of Electrical Engineering and Technology, Vol. 6, No. 1, pp. 59–66, 2011

[9] T. T. Tran, K. H. Choi, "A backstepping-based control algorithm for multi-span roll-to-roll web system", The International Journal of Advanced Manufacturing Technology, Vol. 70, No. 1–4, pp. 45–61, 2014

[10] T. T. Tran, K. H. Choi, D. E. Chang, D. S. Kim, "Web tension and velocity control of two-span roll-to-roll system for printed electronics", Journal of Advanced Mechanical Design, Systems, and Manufacturing, Vol. 5, No. 4, pp. 329–346, 2011

[11] K. H. Choi, T. T. Thanh, D. S. Kim, "A precise control algorithm for single-span roll-to-roll web system using the back-stepping controller", IEEE International Symposium on Industrial Electronics, Seoul, South Korea, July 5-8, 2009

[12] N. Nevaranta, M. Niemela, J. Pyrhonen, O. Pyrhonen, T. Lindh, "Indirect tension control method for an intermittent web transport system", 15th International Power Electronics and Motion Control Conference, Novi Sad, Serbia, September 4-6, 2012

[13] S. Liu, X. Mei, F. Kong, K. He, "A decoupling control algorithm for unwinding tension system based on active disturbance rejection control", Mathematical Problems in Packaging Engineering, Vol. 2013, Article ID 439797, 2013

[14] H. Koc, D. Knittel, M. D. Mathelin, G. Abba, "Modeling and robust control of winding systems for elastic webs", IEEE Transactions on Control Systems Technology, Vol. 10, No. 2, pp. 197–208, 2002

[15] R. V. Dwivedula, P. R. Pagilla, "Effect of backlash on web tension in roll-to-roll manufacturing systems: Mathematical model, mitigation method and experimental evaluation", IEEE International Conference on Control Applications, Hyderabad, India, August 28-30, 2013

[16] L. T. Thi, L. N. Tung, C. D. Thanh, D. N. Quang, Q. N. Van, "Tension regulation of roll-to-roll systems with flexible couplings", International Conference on System Science and Engineering, Dong Hoi, Vietnam, July 20-21, 2019

[17] F. Mokhtari, P. Sicard, "Decentralized control design using integrator backstepping for controlling web winding systems", 39th Annual Conference of the IEEE Industrial Electronics Society, Vienna, Austria, November 10-13, 2013

[18] J. K. Chen, Z. P. Yin, Y. L. Xiong, J. Z. Quan, "A hybrid control method of tension and position for a discontinuous web transport system", International Conference on Information and Automation, Zhuhai, China, June 22-24, 2009

[19] X. M. Xu, W. X. Zhang, X. L. Ding, M. Zhang, S. H. Wei, "Design and analysis of a novel tension control method for winding machine", Chinese Journal of Mechanical Engineering, Vol. 31, Article ID 101, 2018

[20] K. C. Lin, "Observer-based tension feedback control with friction and inertia compensation", IEEE Transactions on Control Systems Technology, Vol. 11, No. 1, pp. 109–118, 2003

[21] Z. B. Duranay, H. Guldemir, S. Tuncer, "Fuzzy sliding mode control of DC-DC boost converter", Engineering, Technology & Applied Science Research, Vol. 8, No. 3, pp. 3054–3059, 2018

[22] G. S. Fesghandis, A. Pooya, M. Kazemi, Z. N. Azimi, "Comparison of multilayer perceptron and radial basis function neural networks in predicting the success of new product development", Engineering, Technology & Applied Science Research, Vol. 7, No. 1, pp. 1425–1428, 2017