# Web-Based Software Tool for Roll-to-Roll Cyber manufacturing (CM) System


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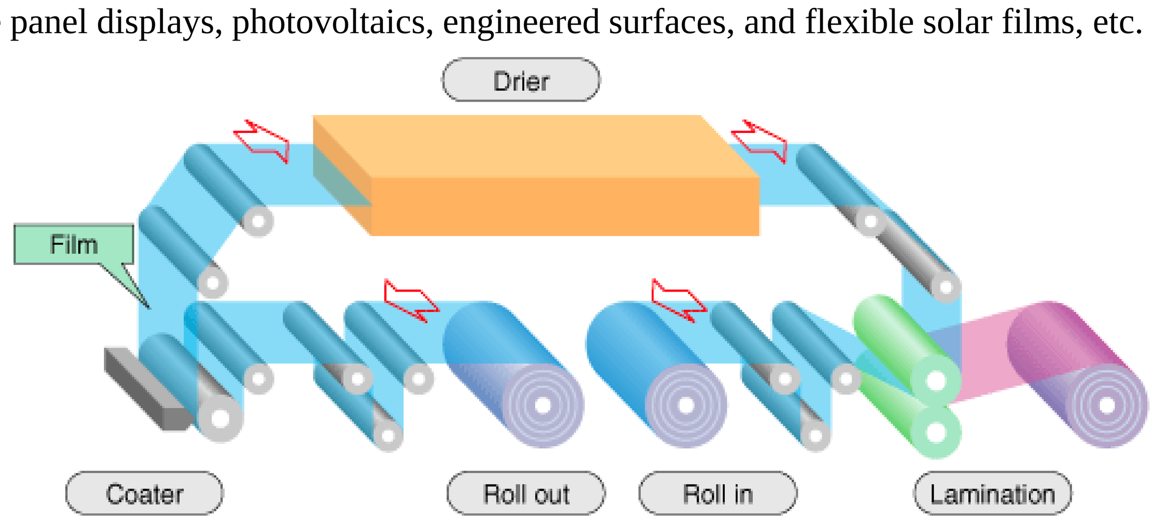
## ABSTRACT


The making of an application to simulate lateral position in Roll-to-Roll(R2R) processing at any given point within a web span is discussed in this paper. R2R manufacturing is the application of different processes such as coating, printing, heating, etc. to flexible materials called webs while being transported on rolls. The existing methods only give the web lateral position on rollers. This paper uses the equation derived in [1] which provides the web lateral position at any location within the span. Based on these equations, a web-based software tool is made through a MATLAB script function to simulate the lateral position for a single web span. Afterward an application (App) is made through App Designer with user interface (UI) that allows the user to interact with the software to predict and visualize the web lateral motion for different web path configurations. A huge advantage of this App is it can simulate the lateral position not just for a single span but also for multiple web spans in the system. The App lets the user see where the oscillations may occur, which will provide guidelines for the location of web guide mechanism to eliminate those oscillations to tremendously improve the required precision in R2R manufacturing. This application can save time, cost and provide clean energy in the manufacturing industry.


## WHAT IS ROLL-TO-ROLL (R2R) ?

Roll-to-Roll (R2R) processing is a web handling technology of flexible materials on rolls. R2R manufacturing could be used to create electronic devices including thin-film batteries, flexible panel displays, photovoltaics, engineered surfaces, and flexible solar films, etc.





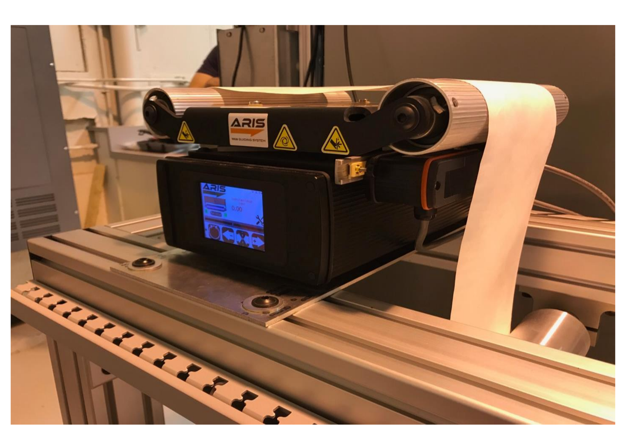



Figure 1: Web guide used in lab (ARIS Web Guide System)

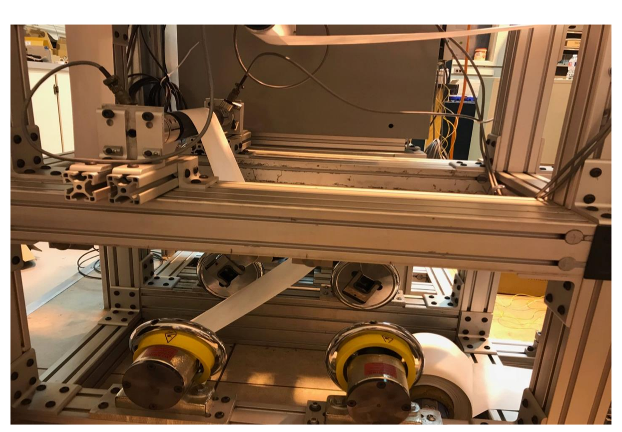


Figure 3: Unwinding and Rewinding motors

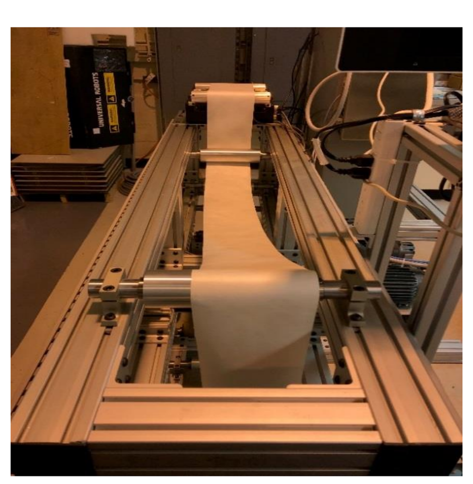


Figure 2: R2R system set up for tests run

Figure 4: Load cell attached to roller

## METHODS

**Euler-Bernoulli Beam Equation**

$$EI\frac{\partial^4 y(x,t)}{\partial x^4} - T\frac{\partial^2 y(x,t)}{\partial x^2} = 0.$$

where E: Modulus of elasticity of web material
I: Web span moment area of inertia
x: Transport direction distance
y: Web lateral displacement
t: Time
T: Web tension

**and the four boundary conditions are**

$$y(0,t) = y_0(t);$$
$$\frac{\partial y(0,t)}{\partial x} = \theta_0(t);$$
$$\frac{\partial y(L,t)}{\partial x} = \theta_L(t) + \frac{1}{v}\frac{\partial z(t)}{\partial t} - \frac{1}{v}\frac{\partial y(L,t)}{\partial t};$$
$$\frac{\partial^2 y(L,t)}{\partial x^2} = \frac{1}{v^2}\left(\frac{\partial^2 y(L,t)}{\partial t^2} - \frac{\partial^2 z(t)}{\partial t^2}\right).$$

where subscripts 0 and L denotes variables at the entry and exit rollers
θ: Roller angle
v: Web transport velocity

**and the spatially dependent Laplace transform of the lateral position**

$$\hat{y}(x,s) = \frac{P_4(x,s)}{D_b(s)}\hat{z}_L(s) + \frac{P_3(x,s)}{D_b(s)}\hat{\theta}_L(s) + \frac{P_1(x,s)}{D_b(s)}\hat{\theta}_0(s) + \frac{P_2(x,s)}{D_b(s)}\hat{y}_0(s)$$

**where**

$$g_1(L) = \frac{KL\cosh(KL) - \sinh(KL)}{K[\cosh(KL) - 1]}$$
$$g_2(L) = \frac{KL\sinh(KL) + 2[1 - \cosh(KL)]}{K^2[\cosh(KL) - 1]}$$

$$g_1(x) = \frac{\sinh(KL)[\cosh(Kx) - 1] - \cosh(KL)[\sinh(Kx) - Kx]}{K[\cosh(KL) - 1]}$$
$$g_2(x) = \frac{[\cosh(KL) - 1][\cosh(Kx) - 1] - \sinh(KL)[\sinh(Kx) - Kx]}{K^2[\cosh(KL) - 1]}$$

**and various inputs**

$$P_1(x,s) = \frac{1}{g_2(L)}\Big[\big((x - g_1(x))g_2(L) - (L - g_1(L))g_2(x)\big)s^2 + v\big(xg_1(L) - Lg_1(x)\big)s + (x - g_1(x))v^2\Big]$$
$$P_2(x,s) = \frac{1}{g_2(L)}\Big[(g_2(L) - g_2(x))s^2 + v(g_1(L) - g_1(x))s + v^2\Big]$$
$$P_3(x,s) = \frac{1}{g_2(L)}\Big[(g_1(x)g_2(L) - g_1(L)g_2(x))s^2 + v^2 g_1(x)\Big]$$
$$P_4(x,s) = \frac{1}{g_2(L)}\big[g_2(x)s^2 + vg_1(x)s\big]$$

where variables with the hat represent the transfer functions
s: Laplace variable
L = Web span length
$g_l(x)$: Defined functions, l = 1,2,3
$g_l(L)$: Defined functions, l = 1,2,3 when x = L
K: Constant parameter, $K^2 = T / EI$
$z_i$: Roller lateral displacement
*i*: position in span, 0 (upstream roller) or *L* (downstream roller)

## MATLAB/ APP DESIGNER

MATLAB is a computing program that is used to create the web-based software tool. It integrates computation, visualization, and programming in an environment where problems and solutions are expressed in familiar mathematical notation.

A MATLAB code is developed to calculate the lateral position for any points within the web span.

$$\textit{Length of web } (L) = \sqrt{(x_2 - x_1)^2 + (w - w_1)^2}$$

$$\textit{Web angle } (\theta_{rad}) = \tan^{-1}\frac{w_2 - w_1}{x_2 - x_1} \quad \textit{in radians}$$

$$\textit{Web angle } (\theta) = \theta_{rad} * \frac{180}{\pi} \quad \textit{in degree}$$

$$\textit{Wrap angle } (\beta) = \theta_1 - \theta_2 \quad \textit{in degree}$$

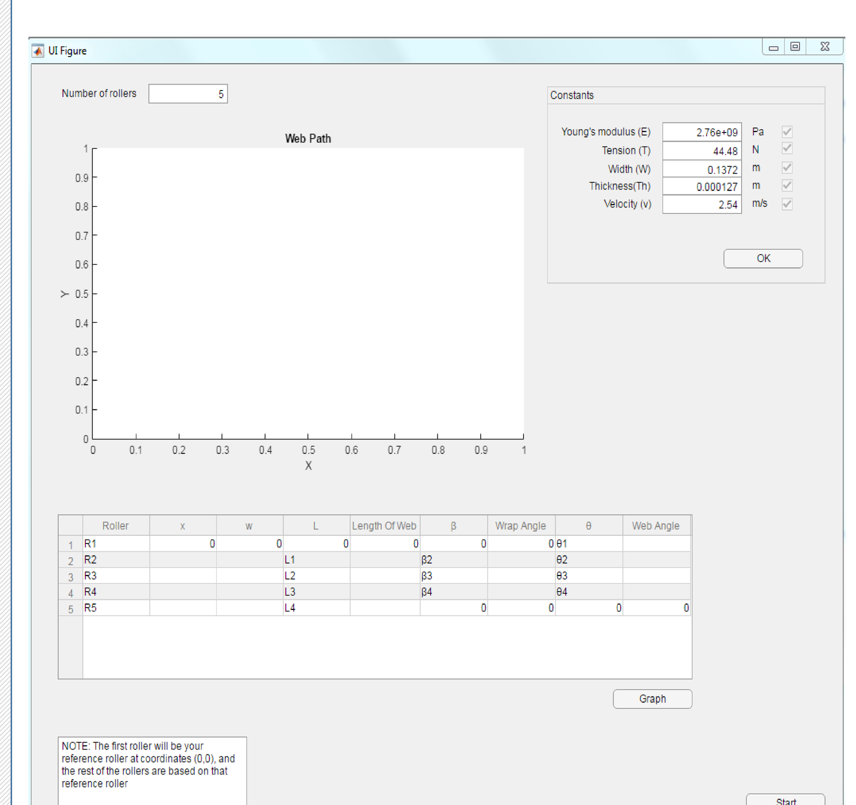


Figure 5: App Designer Design View

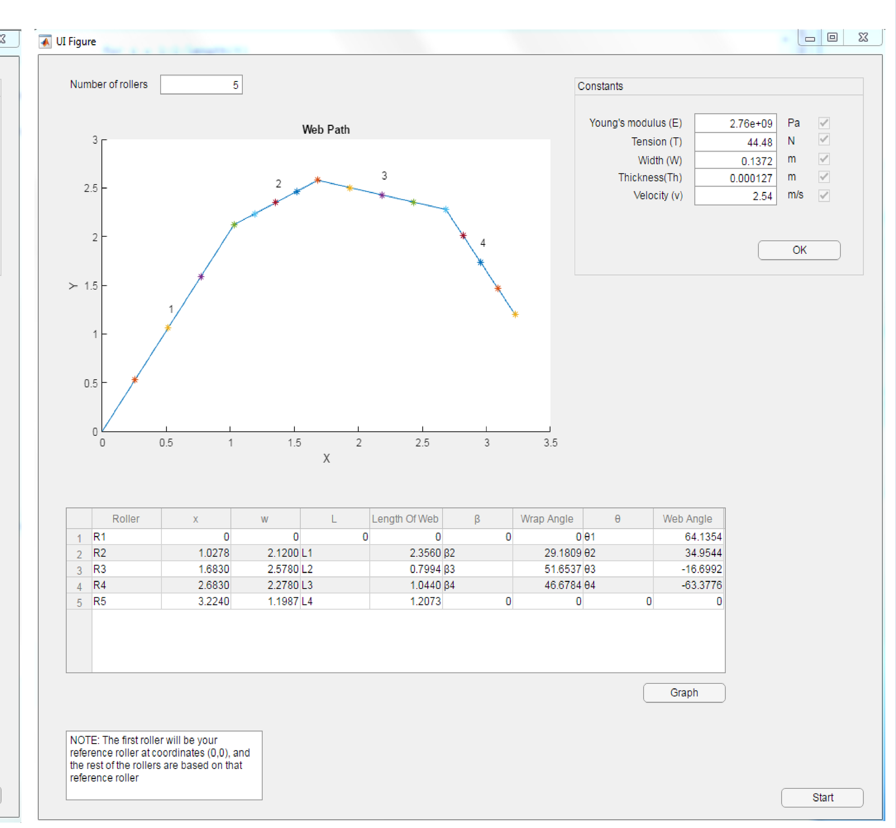


Figure 6: Design View when the app runs with calculated data for 5 rollers

## RESULTS

Numerical simulations were performed, and the results are compared with [1] results for validations for a single web span system

The App is made successfully that can simulate multiple spans in the system

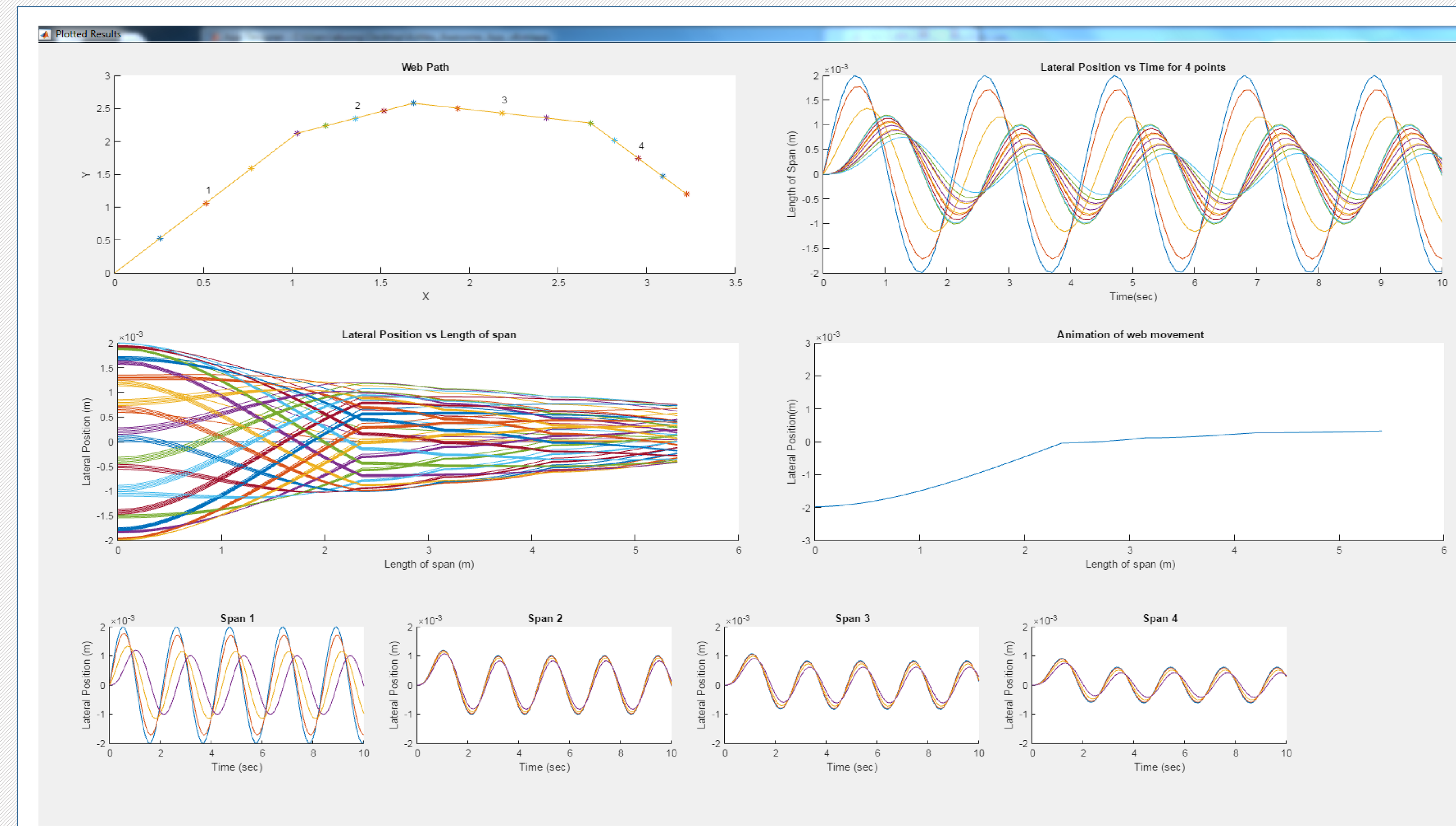



Figure 7: Example results for 5 rollers

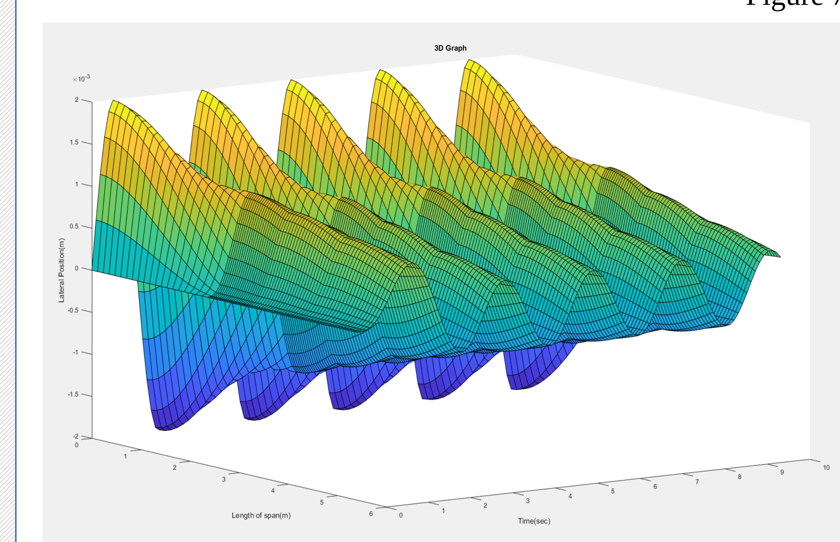


Figure 8: 3D plot for one span

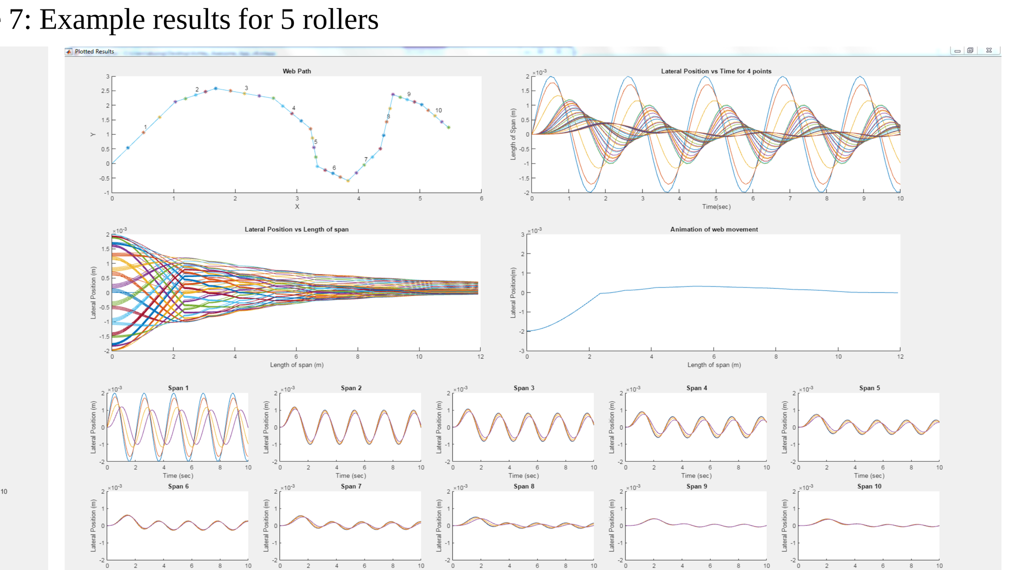


Figure 9: Example results for 10 spans

## CONCLUSION

The contribution of the app to the R2R industry will have a big impact on helping the user visualize how the web moves, how the system will be set up, the location with the most oscillation will occur, and most importantly the lateral positions at any given point within the web span.

The main concept is to visualize the oscillation that is happening through the system, and putting the guide where the major oscillation occurs to eliminate that oscillation is the main purpose of this App.

The app will help the user select the web guide's position to eliminate oscillation to increase the precision, make it possible in the future for R2R manufacturing of electronics in reducing the time and manufacturing costs by reducing waste, provide clean energy and minimizing the environmental impact.

## REFERENCE


[1] E. O. C. Torres and P. R. Pagilla. "Spatially dependent transfer functions for web lateral dynamics in roll-to-roll manufacturing". *Journal of Dynamic Systems, Measurement, and Control*, 2018.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