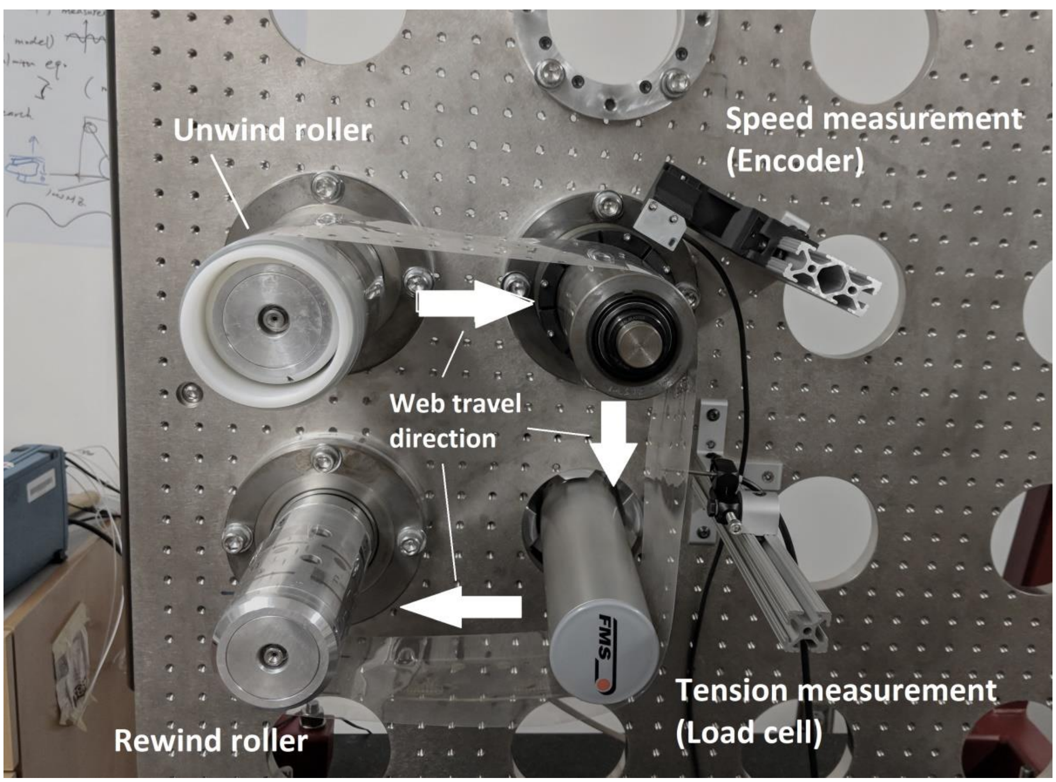
Bhavesh Parkhe **Date: 05/08/2019**
MIE 644; Final Project Report

System identification for web tension control in roll-2-roll printing machine

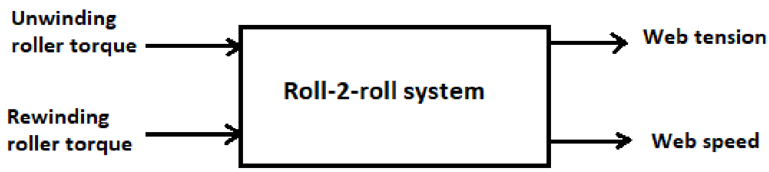
Roll-2-roll printing process is an upcoming technology for mass production of flexible electronics. It involves a flexible substrate which travels over multiple rollers, similar to a printing press. In a roll-to-roll process, precise control of the web (substrate) speed and tension is critical to ensure print quality, since improper web speed and tension would lead to severe damage to the substrates. Multiple ways of controlling these parameters for printing have been tried and tested. Implementation of these controllers require user to have some knowledge about the physical model of the process and then linearizing it to obtain a set of equations which can solved to minimize errors in the calculated value and the actual value in the process.

A black box model of the system can be estimated using a state space method where he sets of equations can be parametrized using state variables. Further permutations of auto regression and moving average are possible after obtaining a state-space output equation.

Since the state variables matrix actually indicates the state of the system, they can be replaced by variables which have a physical variance and certain know values can be filled in to calculate them. This approach can be termed as gray-box model of the system

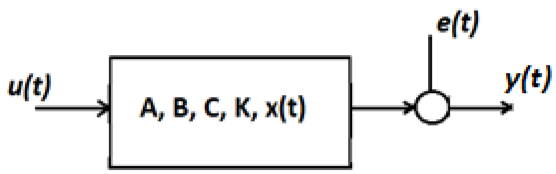


The inputs to this system are the respective torques for the rewinding and unwinding roller. The speed of 2nd roller is measured using a magnetic roller and is converted to the web speed in inches per second. Tension measurement is using the load cell which acts as the 3rd roller. The output speed and tension are interdependent on the torque inputs. However, as common control strategy, the tension is usually controlled using the unwinding roller and speed is assumed to be dependent on the rewinding torque. We however won't be making these assumptions in developing the state space model.



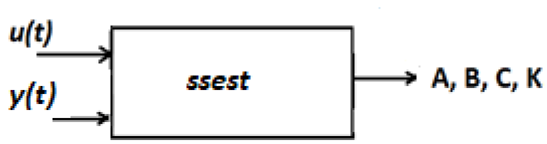
The state variable x(t) which represents the state of the system and can be calculated regressively by estimating the state space form. A discrete form of this equation just requires replacing the time *t* with k^{th} sample value.

$$x(t+1) = A(\theta)x(t) + B(\theta)u(t) + w(t)$$
$$y(t) = C(\theta)x(t) + v(t)$$



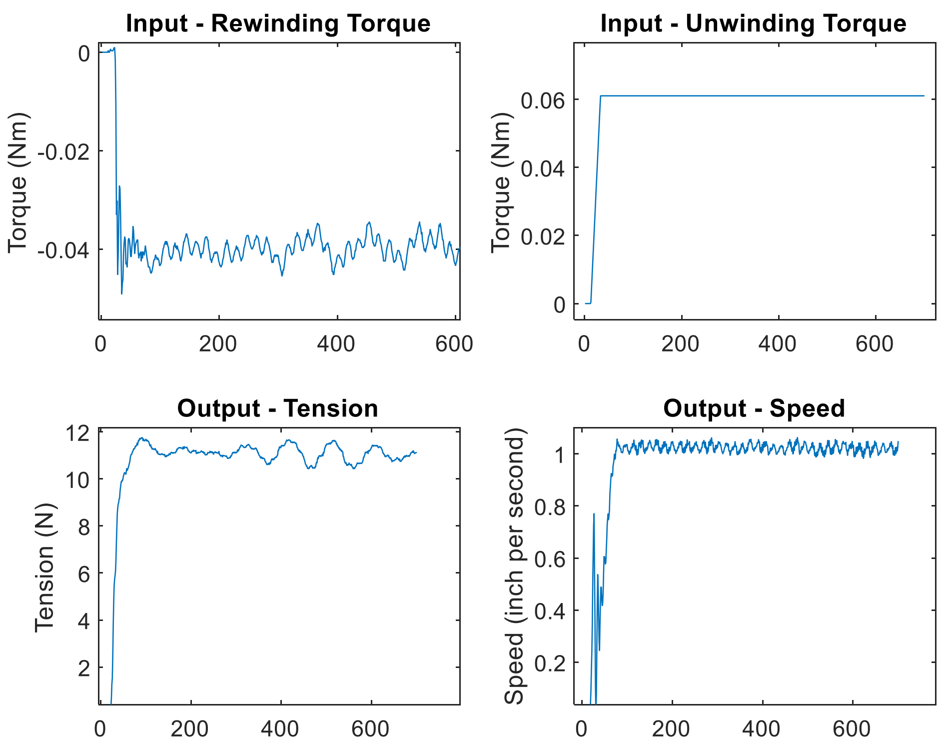
The estimations for the following data have been performed using MATLAB system identification toolbox (ssest)

$$\hat{x}(t+1,\theta) = A(\theta)\hat{x}(t,\theta) + B(\theta)u(t) + K(\theta)e(t)$$
$$y(t) = C(\theta)\hat{x}(t,\theta) + e(t)$$

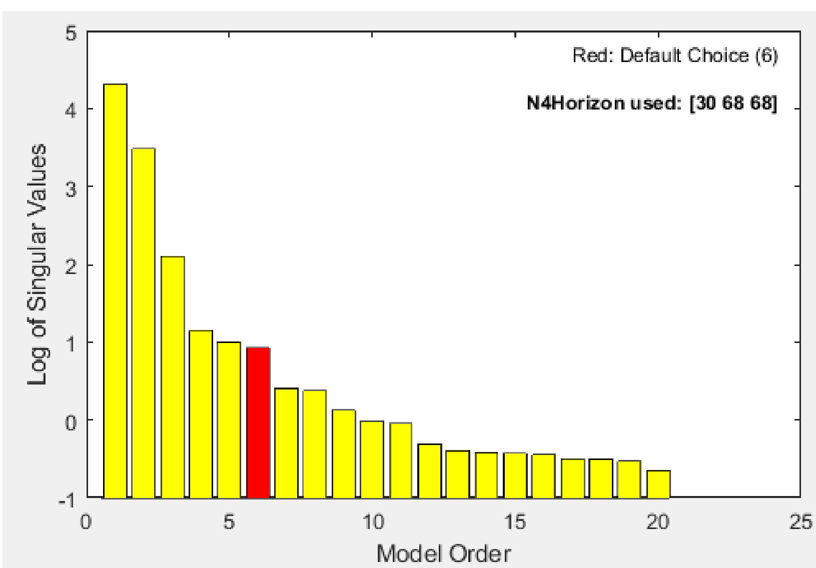


Training data

The initial run of the system with web speed of 1 inch/s was used as a training data. The unwinding torque is held constant and the rewind torque is varied to control the speeds of web travel.



We need to choose the order of the state space matrix i.e. the number of state space variable to define the system. To optimize the order of estimation the singular value decomposition may be performed on the Hankel matrix. Order of the system is a tradeoff between a low singular value and overfitting of the model. Order of matrix has been chosen to be 6 since the physical model as per existing literature have close to these state variables.



A =

-2.1345	-1.2060	3.7400	-1.7572	3.1887	-3.2588
2.7670	0.6175	-3.1180	5.4571	-3.9742	2.7801
0.5045	-0.2695	-73.0489	213.6912	-53.0560	-59.2749
2.3315	-3.8193	-190.2345	24.2368	33.6302	0.9748
2.8526	-0.5553	16.4622	-31.3673	-7.9953	10.7026
5.7503	-1.9938	30.3110	3.3807	-12.6472	-4.6360

B =

1.0e+04 *

0.0040	0.0763
-0.0022	-0.1170
-0.2786	-4.3593
-0.4027	-4.3904
0.0648	0.8912
0.0593	0.6460

C =

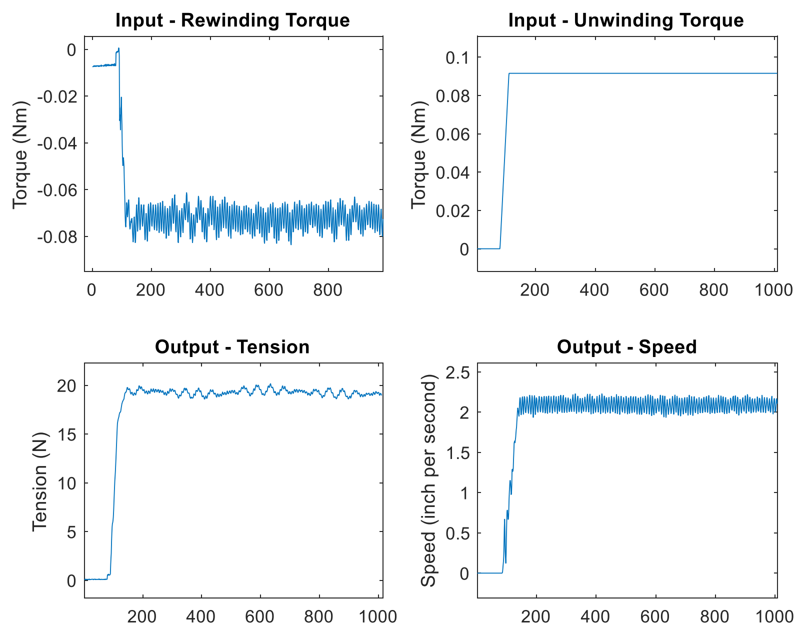
1.5705	2.1000
-1.5740	8.5590
2.4078	181.5160
1.0650	30.3995
-0.3277	-16.3763
-2.5338	-2.9244

K =

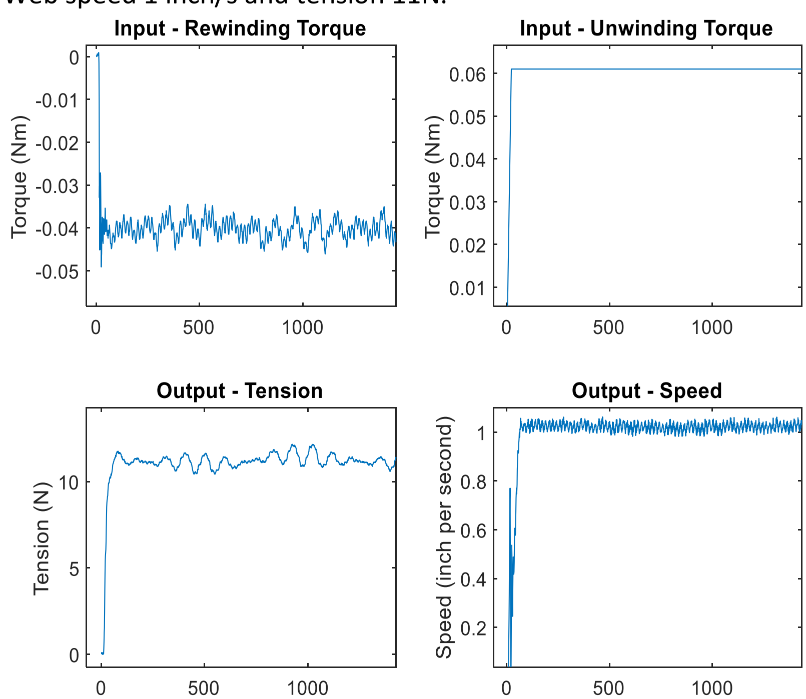
19.9235	-3.3095	0.1662	0.3035	0.0234	0.1272
-0.0433	0.5597	0.3313	0.4913	0.2932	-0.1123

Testing data

Test 1: Web speed 2 inch/s and tension 20N.

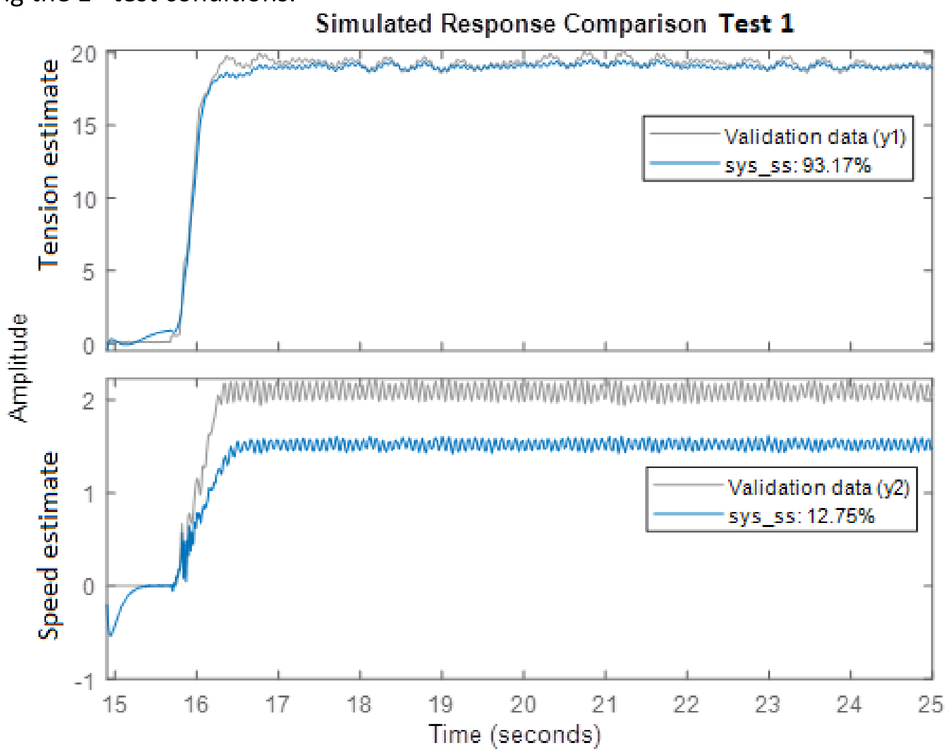


Test 2: Web speed 1 inch/s and tension 11N.



Validation

The state space model estimates the tension quite accurately given that the model was estimated under a separate set of conditions. The normalized root mean square error is at approximately 7%. However, the speed estimates are not that accurate due to the slippage between web and speed measurement roller during the 1st test conditions.



For the 2nd test, where the inputs are same as the training data, the tension and velocity measurements are fairly close to their measure values. The accuracy in both cases can be improved by accounting for slippage and having a better training dataset.