Multimode Sensing for Roll-to-Roll Flexible Electronics Print Process Control

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Microcontact printing holds the promise of large-scale, high rate surface micro-patterning. We address the real time monitoring, metrology and control issues for the scale-up process using a roll-to-roll (R2R) continuous printing method. The first key factor is precise web handling, including high accuracy measurement and control of speed, tension, and registration of the moving web in real time. The second key factor in scale-up is always the ability to image the quality of the printing in real time to provide for feedback regulation of the printing process to ensure pattern integrity.

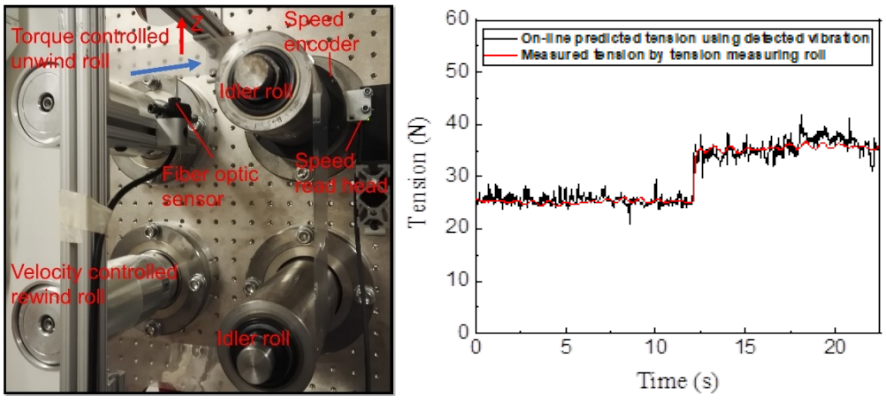

Figure 1. (left) Experimental setup for vibration measurement and (right) comparison of the web tension calculated using the proposed method and the tension measured by tension measuring roll when the web tension suddenly changes from 25N to 35N.

Web handling [1]: The tension in a moving web ultimately determines the efficacy of a R2R printing process. Calculating web tension by measuring the out-of-plane vibration offers a non-contacting and cost-effective method of tension measurement during the R2R process, which is suitable for situations where contact-based web tension measurement cannot be applied. We developed a real-time learning-based prediction approach for prediction of web tension based on contactless sensing of out-of-plane web vibration and web moving speed. We designed and tested a real-time frequency estimation algorithm based on Fourier series. The real time performance of the proposed algorithm was tested on our lab R2R testbed (**Figure 1**), performance markers included accuracy, robustness and computation speed. The experimental results show that the proposed method can predict the web tension with an error of less than 10% for various setup of tension values and track the tension changes within one analysis window of 50ms.

Pattern metrology [2]: Printing of Hexadecanethiol (HDT) on thin gold substrates is the most common form of microcontact printing (μCP) using self-assembled monolayers (SAMs). The ability to visualize the HDT-gold on a continuous moving web prior to subsequent steps – such as etching – is necessary to achieve any acceptable in-process quality control. We present a real-time imaging technique for inspecting the online print pattern in a roll-to-roll (R2R) process by condensation figures (CFs). The real-time desirable CFs are achieved through controlled consistent condensation of water vapor and a synchronous imaging process (**Figures 2**). The distribution of droplets of water recorded by high-speed camera on an HDT-gold surface can be clustered and segmented for determining pre-etch pattern locations and geometries, as well as print pattern evaluation (**Figure 3**). Our imaging system can achieve pattern resolution up to 0.7 μm, web moving speed of 3 in/s, given a low-cost camera with the frame rate up to 1500 fps. We demonstrate that the method can be promisingly used in combination with a pattern "truth table" for online quality monitoring and in-process control.

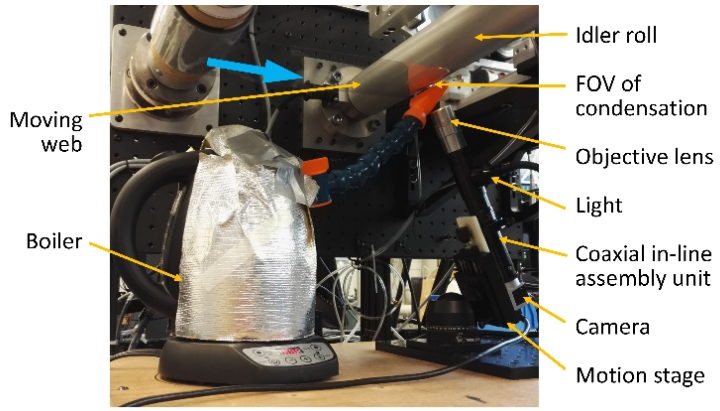

Figure 2. Experimental setup for imaging condensation.

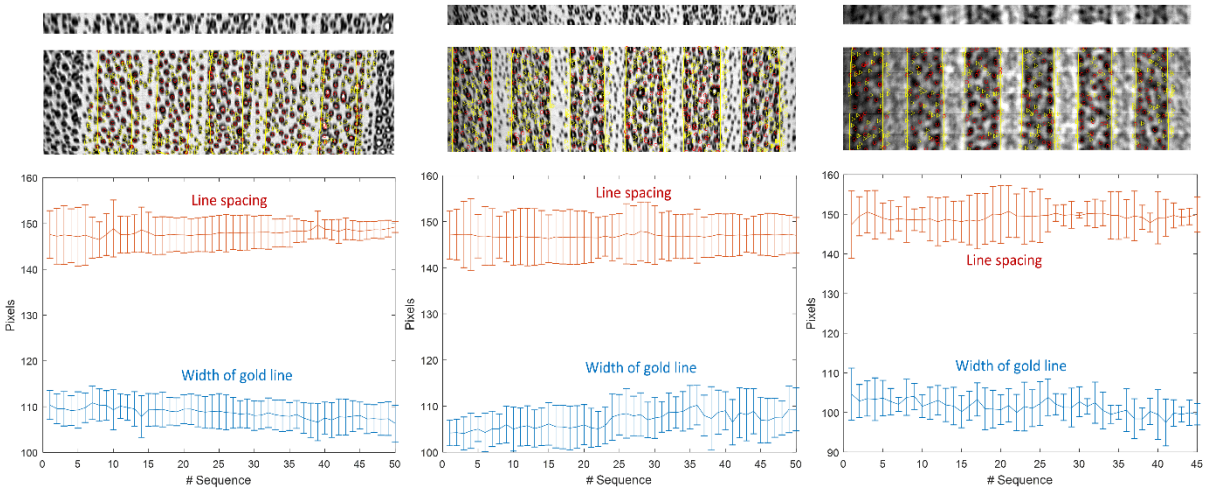

Figure 3. Metrology of print pattern with clustering results for various web-moving speeds: (a) 0.3 In/s; (b) 1.5 in/s; (c) 3 in/s. Row 1 – single frame; row 2 – line pattern (yellow contour) recognized from droplet clustering (circle for larger droplet and triangle for small droplet) of stitched images; row 3 – average width and standard deviation of hydrophilic pattern (gold) and pitch of print lines.

Acknowledgements:

This work is supported in part by the National Science Foundation (grant no. CMMI1916866). Any opinions, findings and conclusions or recommendations expressed in

this material are those of the authors and do not necessarily reflect the views of National Science Foundation.

Reference:

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2. Xian Du, David Hardt, Brian Anthony, “Real time imaging of invisible micron-scale monolayer patterns on a moving web using condensation figure." IEEE Transactions on Industrial Electronics, DOI: 10.1109/TIE.2019.2914632, 2019.