Modeling and Tracking of Deformable Cloth for Textile Automation

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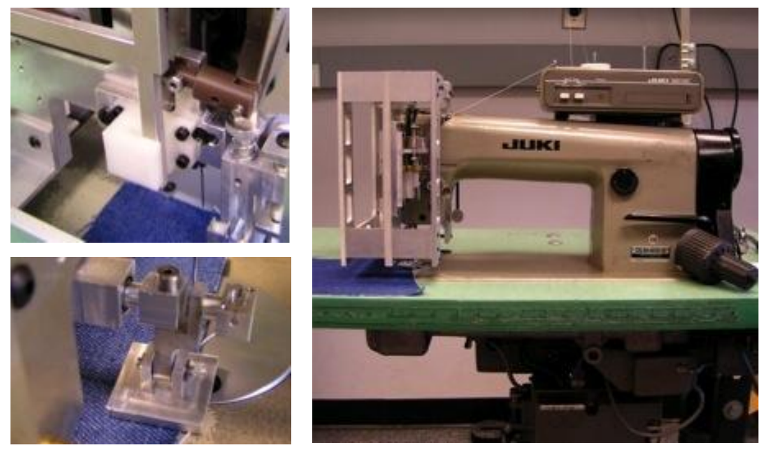
Research Questions:

Is real-time modeling and tracking of non-rigid cloth possible with current computer vision techniques and computer processor power?

If state estimation of cloth is possible, will it allow for large-scale control of cloth on an assembly line and integration with an automated sewing machine?

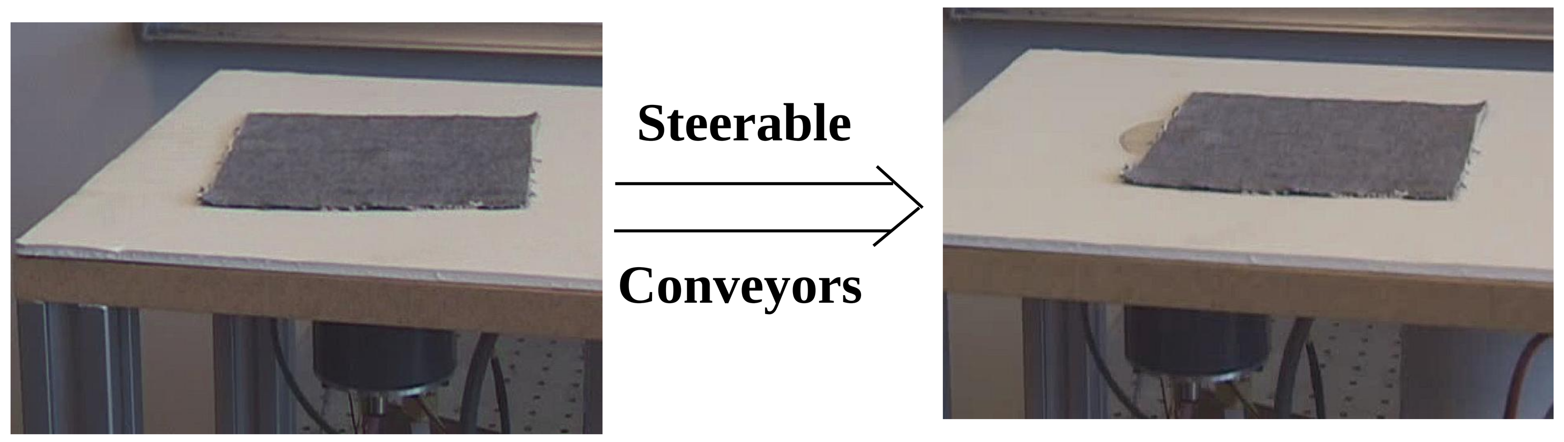
Background and Testbed:

- An automated sewing machine using servo controllers to position cloth with respect to the sewing needle has been completed
- A "steerable conveyor" which consists of a ball actuator with two angular degrees of freedom and a vacuum system is prototyped and allows for a small patch of cloth to be positioned arbitrarily in-plane



Automated Sewing Machine

- An array of "steerable conveyors" would allow an entire sheet of cloth to be positioned and fed into the automated sewing machine if state estimation of the cloth was possible



Collaborators:

Georgia Institute of Technology

Robotics@GT & Intelligent Machines

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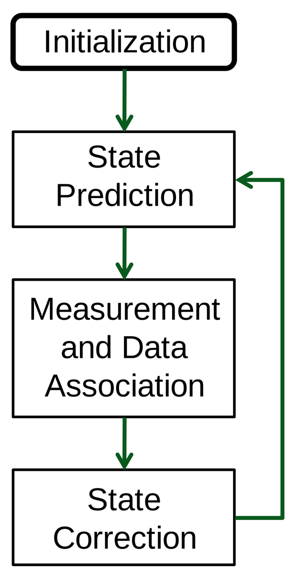
Proposed Algorithm (Extended Kalman Filter):



1)Initialize
 -Extract cloth perimeter using background subtraction
 -Fix location of cloth in space
  -Extract initial image features on cloth to track

2)Predict current states given previous states and approximate input forces
 -Use the Nvidia PhysX engine to predict motion of cloth

3)Correct the state predictions
 -"Measure" using 2D feature tracker to resolve data association problem
 -Weight the difference or "residual" to give current state estimate
  -Use shape functions to predict measurements given predicted states

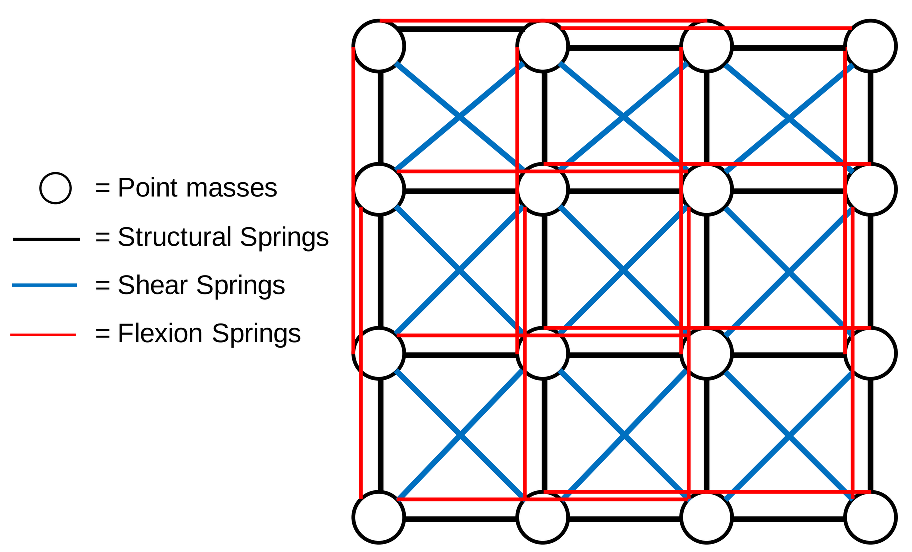
4)Repeat steps 2) and 3)

Cloth Modeling/Prediction:

The majority of cloth simulation/modeling is based on equations of motion describing a representative network of mass particles connected by springs. The image below shows the general form of the mass-spring network that is used. The different springs are allowed to have different spring constants in order to accurately model a given type of cloth.

Using a commercial physics engine:

- The point mass or state node locations are simulated
  - Assuming input from steerable conveyors is available
- Parameters for spring constants, friction, damping and cloth density are some of the variables defined in the model



State Measurement:

The measurement step is done by tracking the image features from frame to frame that were intitially extracted on the cloth during the initialization sequence. This can be done using various methods of feature tracking in computer vision that resolve the data association problem between each frame.

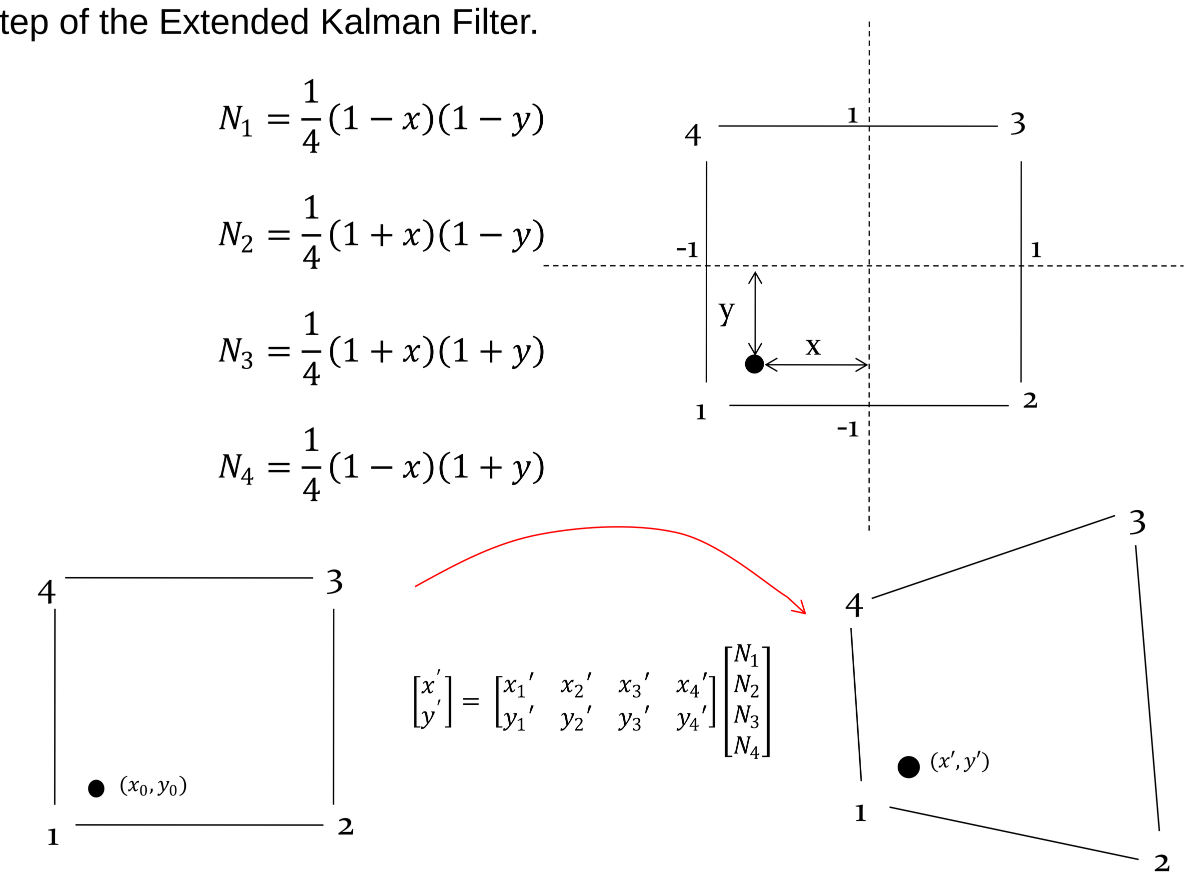
The "measurements" are then related to the mesh of representative state nodes from the prediction step using shape functions from finite element theory. The method describes a mapping of any point within an undeformed grid to a new point in a deformed grid. This results in a relationship between the measured points and the state node locations of the mass-spring network which can be used in the correction step of the Extended Kalman Filter.

$$N_1 = \frac{1}{4}(1-x)(1-y)$$

$$N_2 = \frac{1}{4}(1+x)(1-y)$$

$$N_3 = \frac{1}{4}(1+x)(1+y)$$

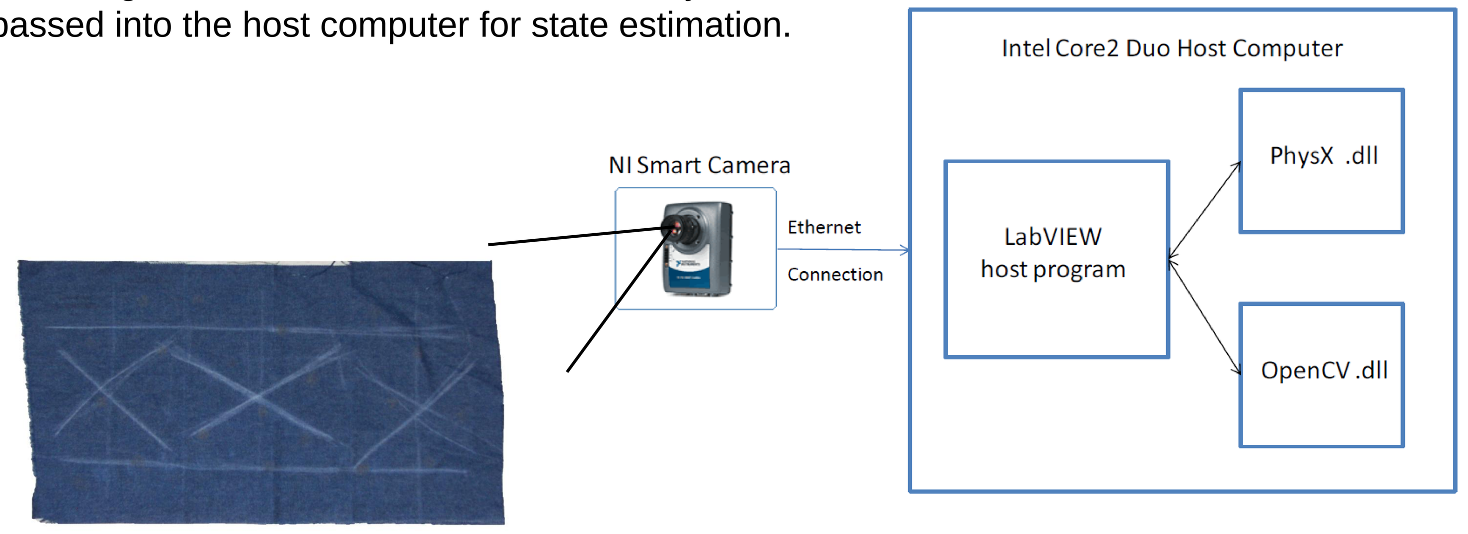
$$N_4 = \frac{1}{4}(1-x)(1+y)$$



$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} x_1' & x_2' & x_3' & x_4' \\ y_1' & y_2' & y_3' & y_4' \end{bmatrix} \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \end{bmatrix}$$

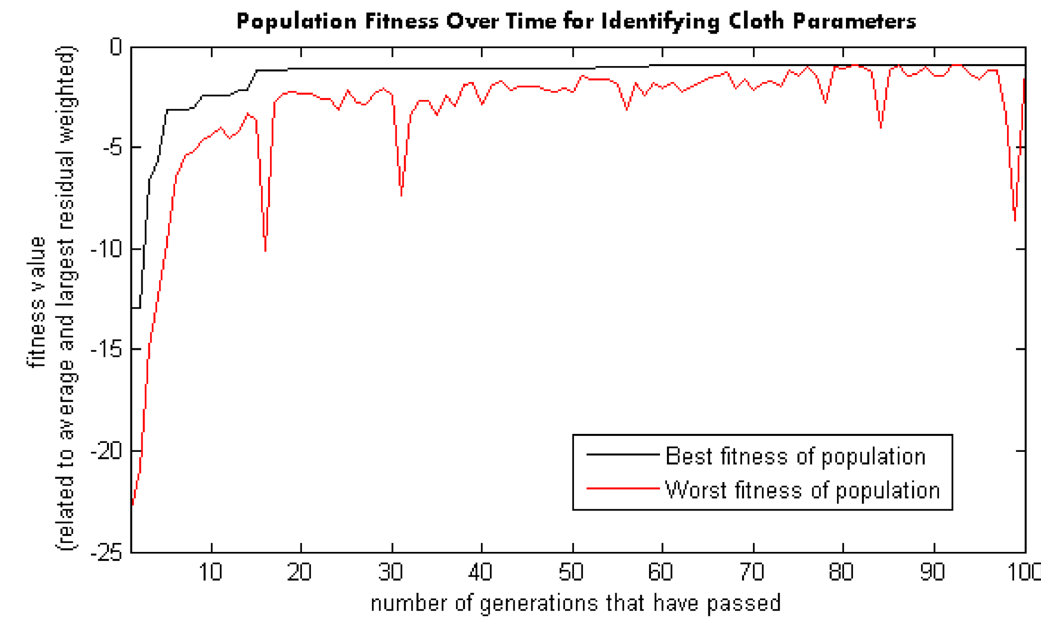
Experimental Setup:

The cloth which is on a surface with steerable conveyors is visible to an NI Smart Camera. The camera grabs frames at a fixed rate and they are passed into the host computer for state estimation.



Cloth Parameter Estimation and Modeling:

Using a set number of video frames that show general cloth motion (translation, rotation, bending), cloth parameters for the physics engine were estimated. Manually extracted feature points were compared to their predicted corresponding points in simulation in order to minimize error between the predicted cloth motion and the actual observed behavior. A real-valued genetic algorithm was used to find the approximate solution. The result of this optimization can be seen on the right.



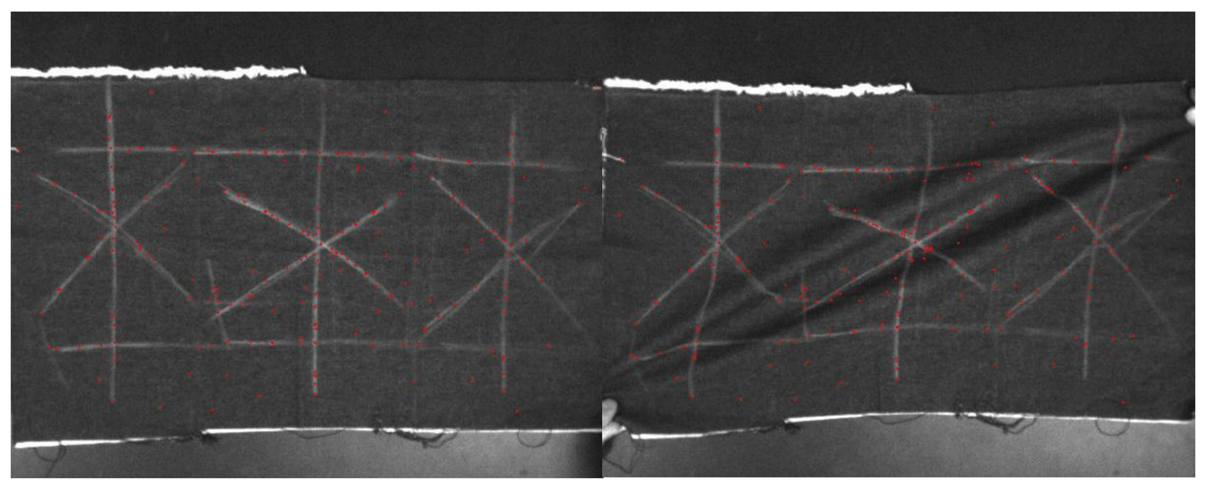
$$max\ \ f(x) = -[(average\ pixel\ error) + 2 \times (worst\ pixel\ error)]$$

$$s.t.\ \ a_i < x_i < b_i\ ,\ \ \forall\, i = 0 \ldots . n,\ \ \ \ for\ n\ variables$$

These images show the result of the cloth parameter estimation. The photos on the right are real deformation of the cloth subject to certain force inputs. The images on the right are the corresponding predictions from the cloth model.

Feature Tracking Using Fiducial Chalk Lines

The images on the right show the ability of the Pyramidal Lucas-Kanade tracker to track features even when the cloth is bending or shearing as long as features are not occluded.



Next Steps

- Complete the LabVIEW-OpenCV interface
- Estimate forces induced by steerable conveyors
- Estimate process and measurement noise
- Complete Extended Kalman Filter
- Develop a simple control law