Liquid Phase Boundary Control for Fabrication of Features in Thermoplastic, Micro-Hair Arrays

EE 291 Final Project
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Background

- Gecko feet:
  - Rows of hairs (~ half a million hairs on each foot)
  - Each hair interacts with surface through Van der Waals forces
  - Excellent adhesive properties, that are not diminished with use
Motivation

- Create adhesion with Thermoplastic Micro-hair arrays:
  - Growth of hair array is fairly straight-forward
  - Adhesion needs to be improved

Basic Idea:
Controlling Solid-Melt boundary location to shape hair tip to increase adhesive forces.
Solving the Stefan Problem

\[ u(x, t) = \text{Temperature along sample} \]

- The following PDE and boundary conditions models the system
  \[ u_t = u_{xx} \]
  \[ u_x(y(t), t) = -k\dot{y}(t) \quad \text{Expresses moving boundary} \]
  \[ u(0, t) = h(t) \geq T_m \quad \text{Control} \]
  \[ u(x, 0) = 25 < T_m \]
- Desired Boundary Position \( y(t) \)

\[ \sum_{n=0}^{\infty} \frac{a_n(t)}{n!} [x - y(t)]^n \]

\[ u(0, t) = \sum_{n=0}^{\infty} \frac{a_n(t)}{n!} [-y(t)]^n \]

\[ u(0, t) = T_m + k\ddot{y} + \frac{k}{2} \dddot{y}^2 + \frac{k}{6} \dddot{y}^3 \]

We solved this problem using differential flatness
Temperature Control Simulations

Reference Temperature

System Temperature

Switch Control

Error

Experimental work
Experimental work

Polymer used: Polycaprolactone
Experimental work

[Diagram showing the flow of experimental work from Computer to Controlled Heater to Sample to Thermocouple]

Results

Target: 10mm
Heating Time: 500 seconds

[Graphs showing Temperature Control and Boundary Trajectory]
Results

Target: 10mm
Heating Time: 500 seconds

Boundary Trajectory

Target: 10mm
Heating Time: 500 seconds
Results

Target: 10mm
Heating Time: 500 seconds
Results

Results vary with target location and heating time

Future Work

- Improve Model to include heat losses or better insulate sample.
- Refine Control System for better reference tracking.
- Perform the experiment on different polymers.