Roughness Tuning Techniques for Improved Soft Optical Shape and Contact Sensing

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Introduction

Background:

Soft robots provide an alternative to traditional surgical instruments that offers less trauma and greater access to confined regions. However, these novel robots lack sensing devices and previously used sensors such as cameras or standard force detectors are not viable due to their rigidity and size.

Solution: Soft optical sensing

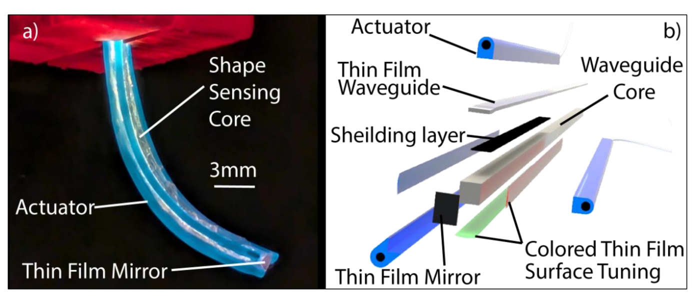

Figure 1: (a) bending of sensor in 3d space (b) exploded view of sensor

Using pneumatic actuators and a soft optical waveguide, this sensor can not only shape and contact sense but also adjust its orientation as needed.

Function:

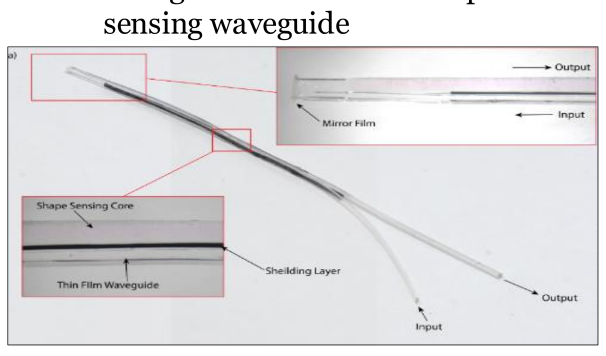

Figure 2: View of thin film waveguide transition to shape sensing waveguide

Light is inputted through the sensor and the output is recorded. Both shape and contact sensing rely on this transfer of light to function.

Shape sensing

For every possible bend or tip position of the sensor, there exists a unique RGB value that is transmitted through the sensor.

Figure 3: Close-up of shape sensing core tip (what RGB sensor detects)

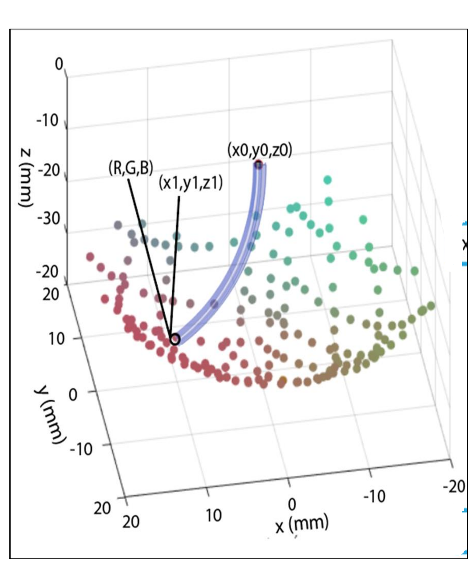

Figure 4: 3D mapping of sensor color values

Contact sensing

These contact detection protrusions lie on the thin film waveguide. When contact is applied to one of these locations, the signal output is altered.

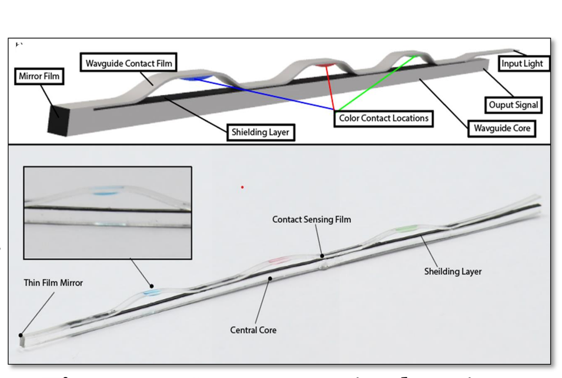

Figure 5: Contact sensing locations on thin film waveguide

My Goal: discover if and how these shape and contact sensing abilities can be improved through waveguide roughening techniques

Methods

Create → Roughen → Color → Test

Waveguide Creation:

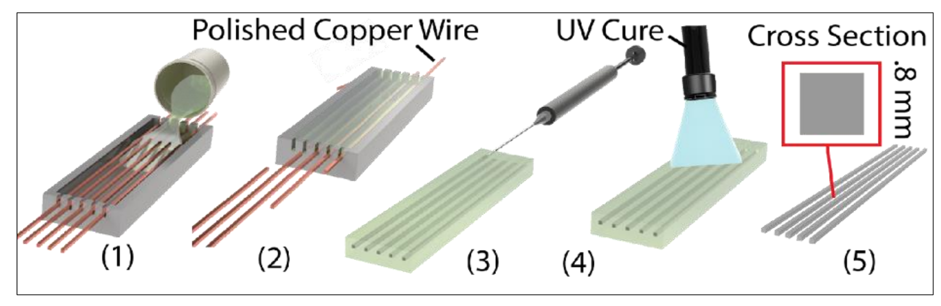

Figure 6: steps for shape sensing waveguide creation

The mold is injected with clear optical adhesive to make the waveguides.

Waveguide Roughening:

Roughened centrally for 30 mm with a CO2 laser cutter. Power of the cuts range from 8-15% and distance between individual cuts (roughening pattern) range from 0.2-0.6 mm.

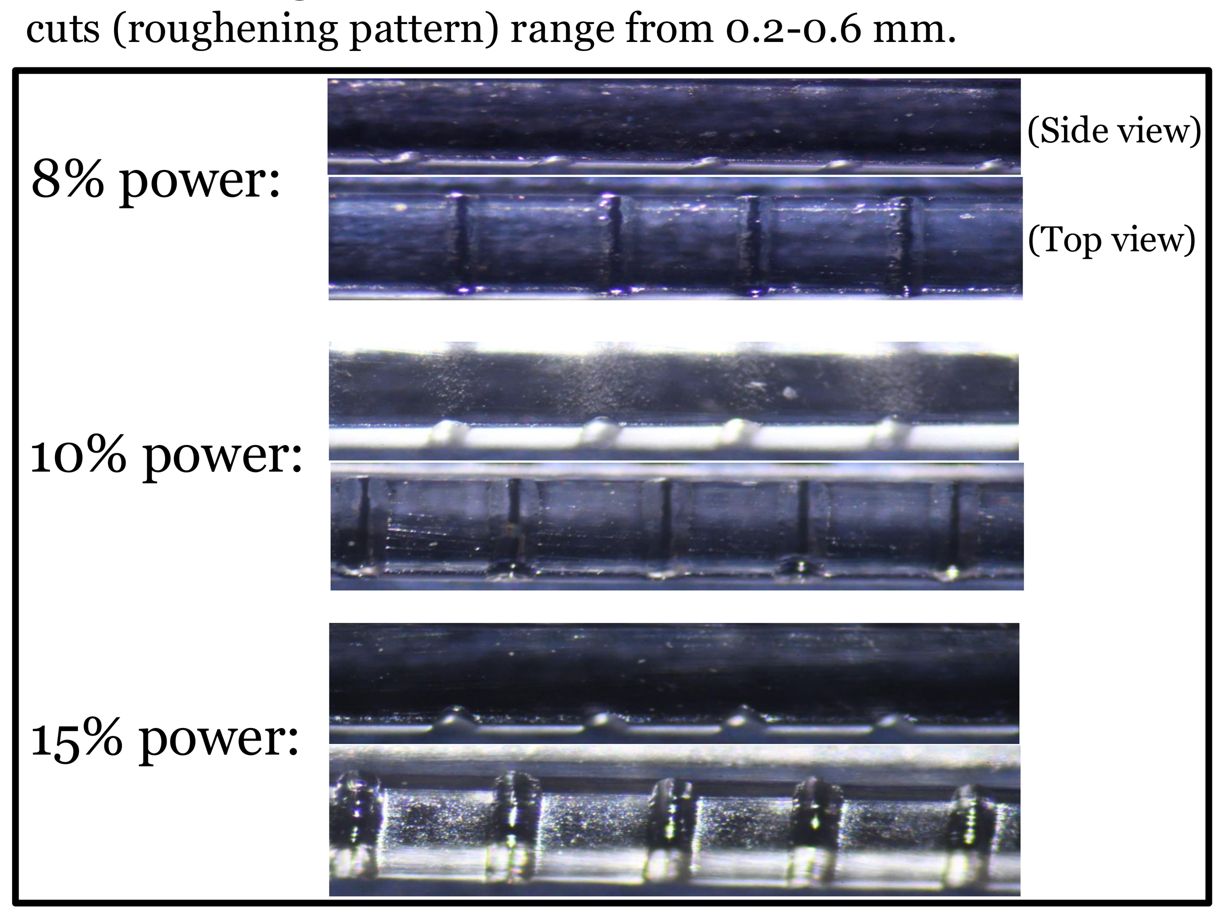

Figure 7: view of laser cuts through microscope

Waveguide Coloring:

For a complete sensor, multiple dyes are used, but for simplicity of testing only one was used - red.

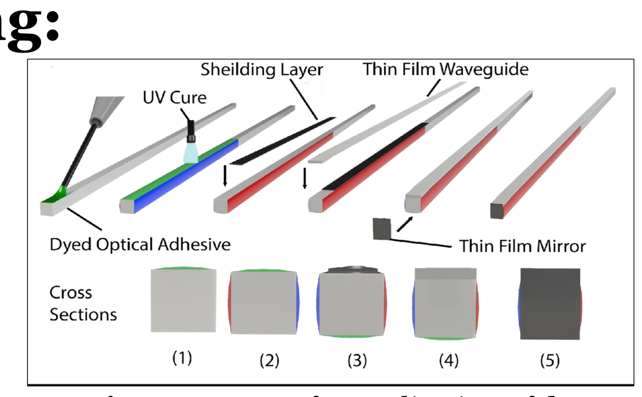

Figure 8: steps for application of dye to shape sensing waveguide

Waveguide Testing:

The waveguides are connected to black optical cords to facilitate light input and output.

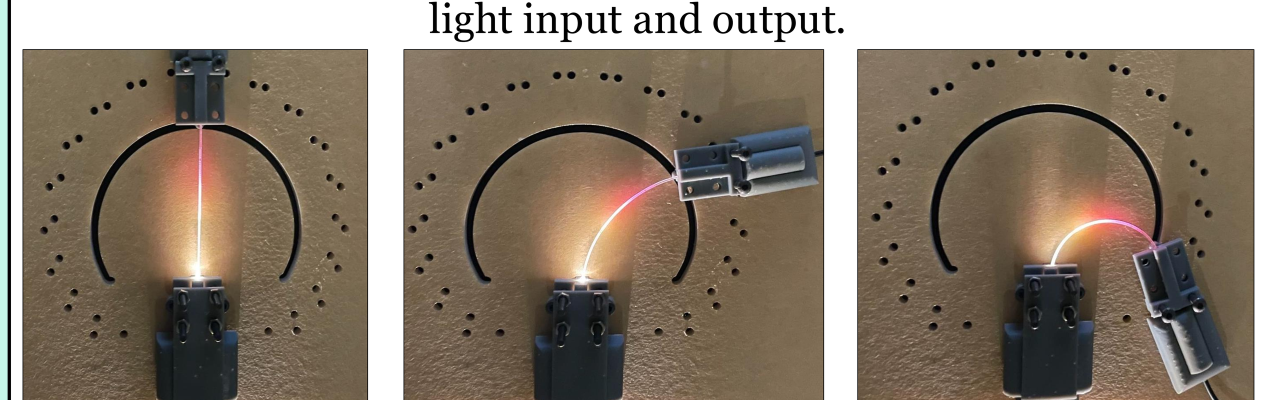

Figure 9: shape sensing waveguide bent in testing set-up

The waveguides are bent *opposite* to the dyed side. An LED powered the set-up and an RGB sensor connected to an Arduino was used to collect data.

Results

The output power loss of a soft waveguide is defined as

$$I_{loss} = 10\log10\,(I_0 / I)$$

where I is the measured intensity and I_o is the baseline intensity with no stretch or compression. The output intensity loss I_{loss} is 0 with no deformation.

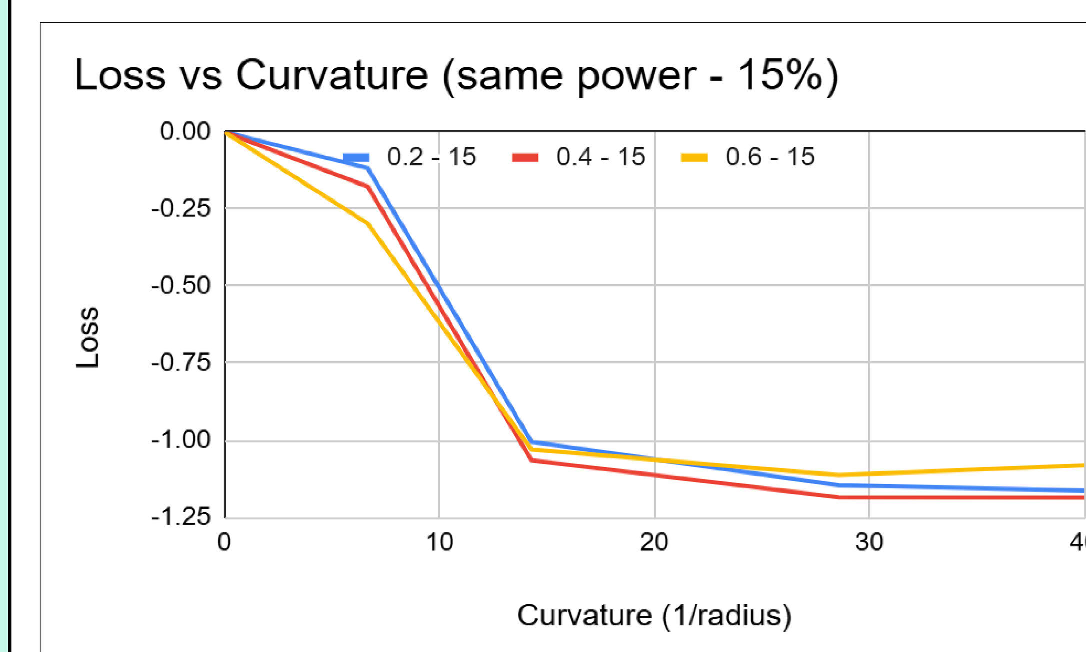

Figure 10: Waveguides cut at the same power, but varying patterns.

Clearly, the roughening pattern (gap between cuts) is insignificant, especially when compared to roughening power (graph below).

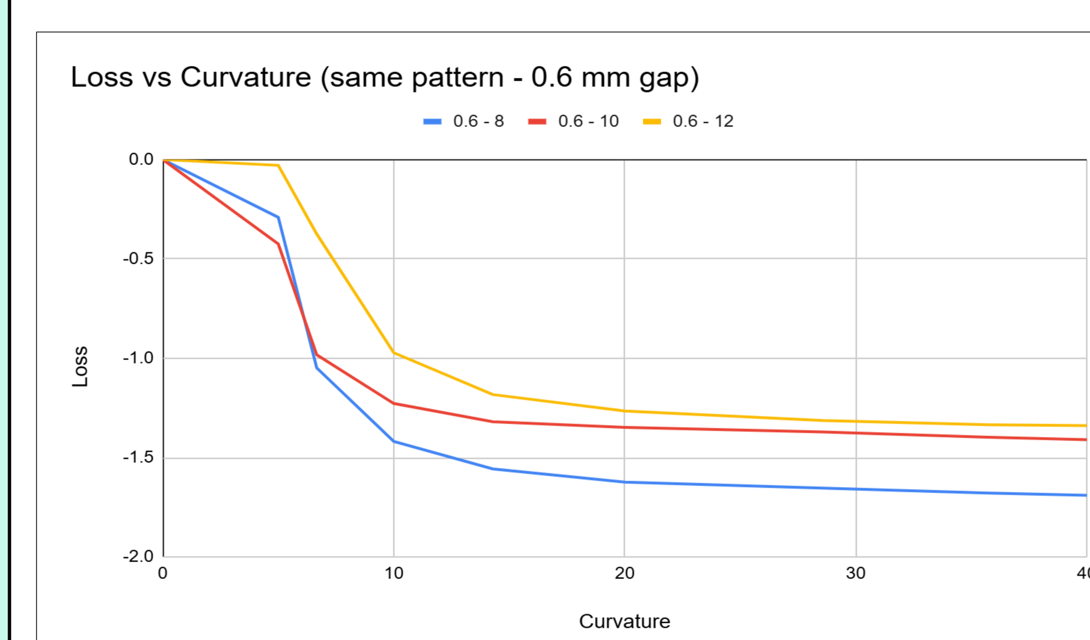

Figure 11: Waveguides cut with the same pattern, but varying powers.

Equal percent increases in power don't necessarily mean equal increase in signal output - likely due to uneven increments of cut depth in spite of even power increments. Cuts of 15% power replaced those of 12% to get even increments in cut depth.

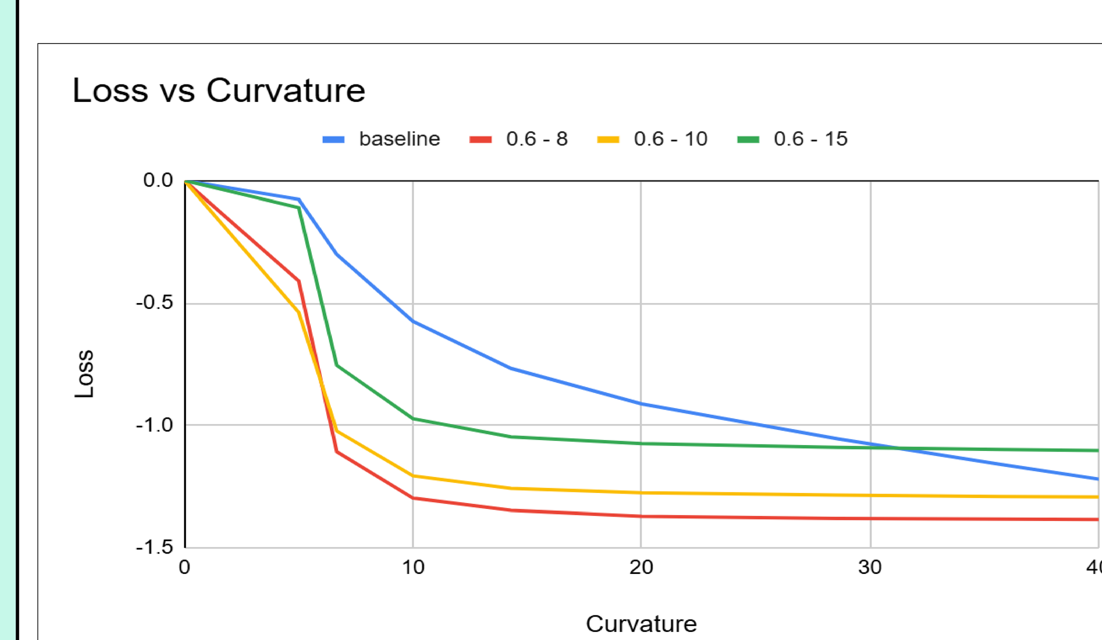

Figure 12: Comparison of roughened waveguides to baseline (no roughening, only the red dye)

Discussion/Conclusions

The baseline waveguide is most apt for shape sensing (roughness does not help) due to the continually linear trend regarding signal output that occurs even during extreme degrees of bending. However, increased roughness does prove to be helpful for contact use by creating a "spike" in the signal because this dramatic increase means that contact is easily distinguishable from bending which allows for more accurate contact detection.

References

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Future Work

Roughness provides a degree of variability so by changing the roughening strength, the signal output can be altered to create a desired trend. For example, greater degrees of roughness create an especially sudden increase in signal whereas minimal levels of roughness create a more prolonged increase. This means that a waveguide containing contact sensing locations of non-uniform roughness can classify the point of contact itself, not only the general presence of contact. Combined with varying dyes, this feature can help create extremely precise contact sensing because the number of possible unique contact detecting nodes expands significantly, meaning they can be placed on the entire waveguide.

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