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Instructions for Assembling a 3D Printed Force Sensor

Pre-printing

- The sensor is printed from 2 components: an outer shell and an inner rod.
- The outer shell provides the packaging for the sensor, holds the fiber optics and the EM tracker, and supports one side of the flexures.
- The inner rod is the component that actually receives the applied load and holds the other side of the flexures.
- The solid model parts and assembly can be viewed using Solidworks or other compatible software packages.

Printing

- The components are printing using the .STL format.
- These parts have been successfully printed out of Veroblack material on an Objet Connex500 3D printer (Objet Geometries Ltd, Billerica, MA, USA).
- Printing accuracy and resolution varies greatly, so test these designs on your printer and modify the models as necessary.
- Print extra components in case you have an assembly issue or there is variation in print quality.

Cleaning

- Complete and thorough cleaning is essentially for good bonding and assembly.
- In the case of the Objet printer, the support material can be removed by rubbing the part in a warm water bath, using wire and rods to clean out the different diameter openings, and polished with a clean rag.
- Take extra time to inspect the parts under a microscope and make sure it was properly printed and that the cleaning has not damaged any of smaller features or structures.

Assembly: Flexures

- The flexures (in this case, 0.25 mm diameter superelastic Nitinol wire) should be pressed into the central rod. This can be very challenging because of the small size of the hole. Two helpful methods are using a microscope or feeling the raised features and grooves printed into the piece.
- Each flexure needs to be inserted and independently but they can be affixed at the same time.
- Do not worry if the flexures are much too long at this point, they will be trimmed later.
- Repeat this process with the 2nd flexure, positioned perpendicular to the first flexure and either above or below on the central rod.
- Once the flexures are loaded into the price, a very small drop of Cyanoacrylate (CA) is place on either of the flexure and worked into the groves by either sliding the flexure in and out of the piece or with a small length of wire.

- The CA should lock the flexure in place in a few seconds

Assembly: Fibers

- 500 micron plastic fibers are used with this design. The jacket should be removed and they should be freshly cleaved prior to insertion.
- The fibers are installed by first ensuring the holes at the base of the outer shell are clear from any support material.
- A single fiber is then inserted from the bottom of the shell through to the interior of the shell and out of the body of the shell.
- Once the fiber is exposed, it should be checked to ensure if is clean and not damaged.
- At this point, the fiber is ready to be affixed into the shell. This is accomplished by painting a small amount of CA onto the outside of the fiber inside the shell.
- The fiber should then be quickly retracted so that the CA is pulled into the shell and the fiber tip is flush with the bottom of the shell interior. This can be assisted by pushing down with a clean cylindrical rod that fits into the interior of shell, like the dull end of a drill bit.
- After insuring that the fiber is strongly affixed in place, repeat this operation with the 2nd fiber.

Final Assembly

- The final step is to attach the flexures and central rod to the outer shell
- This is accomplished by sliding the flexures into the slots in the top of the outer shell.
- The positioning of the flexures in the slots should ensure that the central rod is centered in the shell, but this may not be the case if the assembly process deformed the 3D printed components in any way. Before proceeding, check to make sure that the components seem to be properly aligned (refer to the solid model assembly for validation)
- Once the components are positioned correctly, CA the flexures in place on the outer surface of the shell. Extra CA can be used here as it will be trimmed later.
- Once the CA has tried, trim off the excess CA and any length of the flexure wire that is outside of the outer shell.

Calibration

- The calibration step depends on the fiber optic transducer and force sensor you have available. I used a commercial fiber optic signal amplifier package (E3X-DA21-N, Omron Electronics LLC Industrial Automation, Schaumburg, IL, USA) and a 6 degree of freedom Force torque sensor (Mini40, ATI Industrial Automation, Apex, NC, USA).
- If no force sensor is available, weights can also be used to calibrate against static forces and step changes (quickly removing the weights).
- Make sure to properly support the sensor during the calibration process. The sensor is designed to fit on the end of a catheter guidewire, but it can also be supported on a metal tube with a similar outer diameter (~2.4mm) if the fibers are able to fit inside the tube.
- To test the system, apply forces to the tip of the sensor while recording both the force signal from the calibration sensor and the fiber optic transducer.
- The data can then be used to find a calibration law (linear, quadratic, etc.) using a least squares estimation.