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Supplementary Materials for

The milliDelta: A high-bandwidth, high-precision, millimeter-scale Delta robot

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The PDF file includes:

Other Supplementary Material for this manuscript includes the following:
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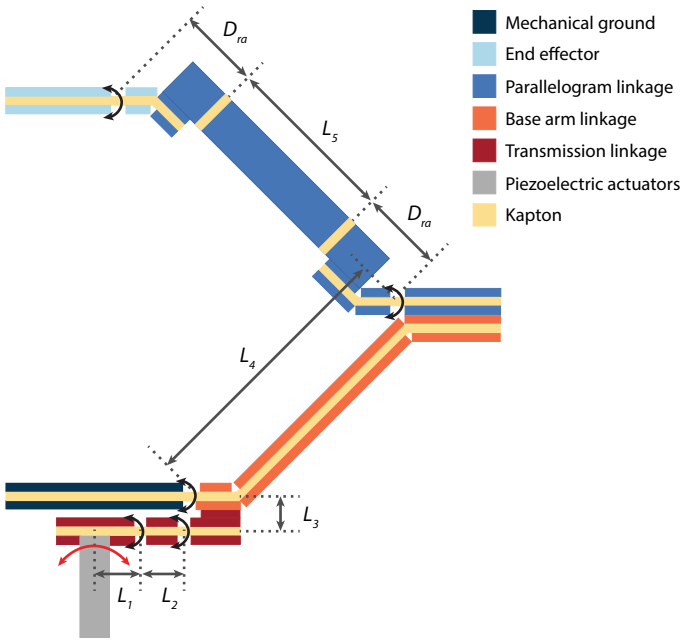

Figure S1: Relevant linkage parameters (with corresponding values in Table S1) for one arm of the milliDelta. The input motion of the piezoelectric bending actuator is represented with a curved red arrow and the resulting flexure motions are represented with curved black arrows. The composite laminate structure is shown with the flexible polyimide and rigid layers as described in the legend. The parameter D_{ra} represents the axis bias between the two perpendicular revolute joints used to approximate a universal joint. Linkage length L_3 determines the transmission ratio of the milliDelta.

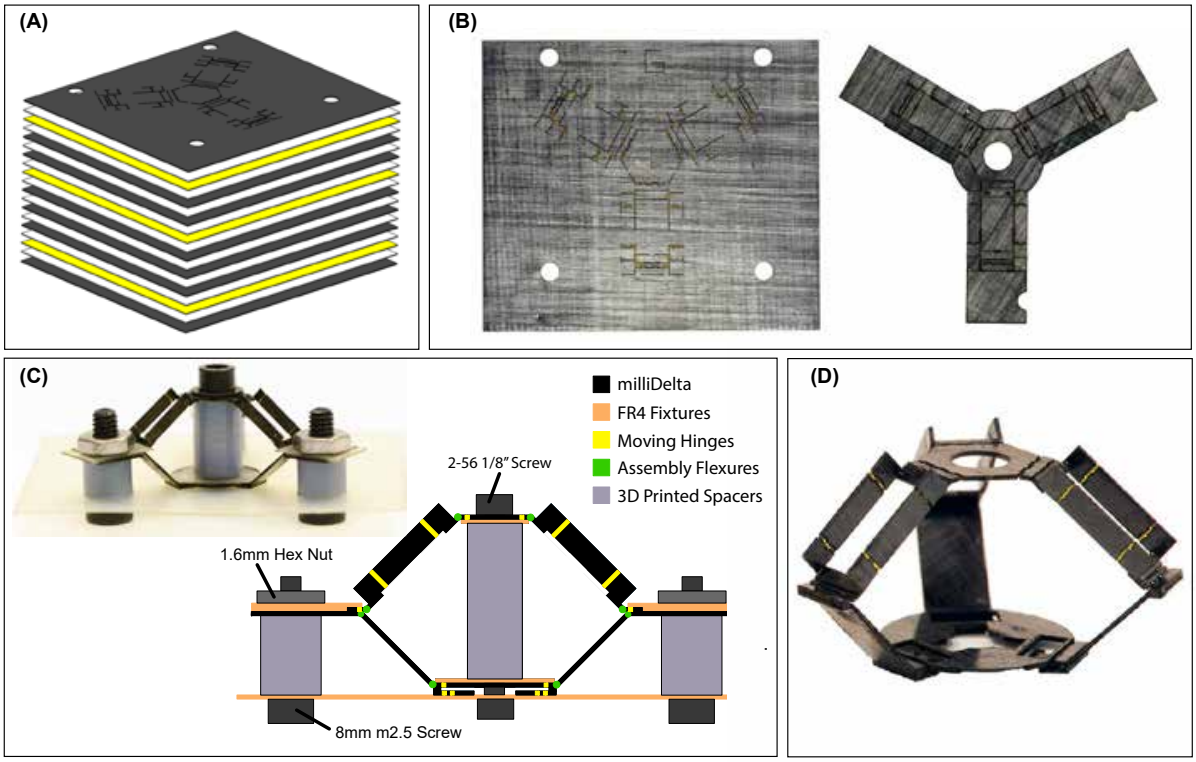

Figure S2: Manufacturing process for the milliDelta. (A) Cut files for the 19 constituent layers designed in popupCAD. Each layer is laser machined, and the layers are aligned using dowel pins and laminated using a heat and pressure (B, left). The laminated structure is laser machined to release the mechanism from the surrounding bulk material (B, right). A schematic and image of the jig used to fixture the milliDelta during manufacturing for improved alignment is shown in (C). Fiberglass sheets are used to clamp moving flexures in a neutral state and align linkages, and the assembly flexures are glued in place. The finished device in its neutral position before attaching to piezoelectric bending actuators is shown in (D).

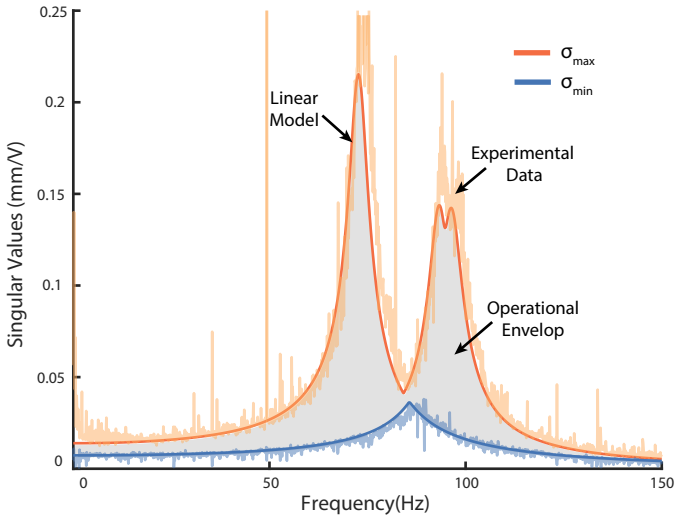

Figure S3: Maximum (orange) and minimum (blue) singular values of the transfer function matrix, $H(j\omega)$, as a function of frequency. The linear model and experimental data are labeled. The region between the singular values (shaded in gray) is the operational envelope of the milliDelta, and can be considered as the bounding region for the nine magnitude responses plotted in Fig. 5 (*51*).

Table S1: Link length parameters of the milliDelta, piezoelectric bending actuator dimensions, and flexure stiffnesses (all flexures have the same dimensions). Length L_3 determines the transmission ratio of the milliDelta.

Parameter	Value
L_1 (mm)	0.65
L_2 (mm)	0.65
L_3 (mm)	0.45
L_4 (mm)	5.66
L_5 (mm)	3.90
D_{ra} (mm)	0.80
PZT Thickness (μm)	135
CF Thickness (μm)	50
PZT Length (mm)	9.69
Nominal Width (mm)	5.26
Extension Length (mm)	.92
Width Ratio	1.5
Flexure Stiffness (μN-m/rad)	11.6