# Supporting Information

## Airbrushed PVDF-TrFE Fibrous Sensors for E-Textiles

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**Table S1. Applied Forces and Output Voltages for Tapping APTDs.** Table showcases the various frequencies, forces, pressures, and voltages measured from the tapping APTD experiments.

| Tapping Condition Label | Tapping Frequency (Hz) | Tapping Force (N) | Tapping Pressure (kPa) | Peak-to-Peak Voltage (mV) |
|---|---|---|---|---|
| 0.5 Hz - F1 | 0.5 | 1.4 ± 0.21 | 4.46 ± 0.67 | 113.3 ± 20.6 |
| 1 Hz - F2 | 1 | 1.7 ± 0.22 | 5.41 ± 0.70 | 189.0 ± 31.5 |
| 5 Hz - F3 | 5 | 19.5 ± 14.9 | 62.07 ± 47.43 | 504.8 ± 143.5 |
| 5 Hz - F4 | 5 | 161.3 ± 128.3 | 513.43 ± 408.39 | 667.1 ± 162.1 |

**Table S2. Output Voltages for Bending APTDs.** Test conducted at a bending frequency of 0.5 Hz.

| Bending Radius (mm) | Peak-to-Peak Voltage (mV) |
|---|---|
| 4.5 | 45.1 ± 5.7 |
| 5.75 | 105.2 ± 11.9 |
| 7.25 | 132.1 ± 21.8 |
| 8.25 | 147.4 ± 27.6 |
| 9.25 | 191.0 ± 15.0 |
| 9.75 | 245.5 ± 53.2 |
| 10.5 | 276.9 ± 59.0 |

**Table S3. Power Density and Integration Comparisons.** Direct comparison of proposed APTD's to other electrospun devices reported in literature. Note APTD's show both wearable and textile integration.

| Active Material(s) | Processing | Device Structure | Max Areal Power Density | Wearable Integration | Textile Integration | Citation |
|---|---|---|---|---|---|---|
| PVDF | Electrospun | Aluminum Foil – Fibers – Aluminum Foil | 0.60 µW/cm$^2$ | No | No | (1) |
| PVDF & Boron Nitride Nano Flakes | Electrospun | Cu Foil – Fibers – Cu Foil (Wrapped in Kapton) | 53.2 µW/cm$^2$ | No | No | (2) |
| PVDF & PANI & g-C3N4 | Electrospun | Cu Foil Pasted PVC Film – Fibers – Cu Foil Pasted PVC Film | 14.7 µW/cm$^2$ | No | No | (3) |
| PVDF & PCZ | Electrospun | Cu Tape – Fibers – Cu Tape (Laminated with Teflon) | 0.64 µW/cm$^2$ | Yes | No | (4) |
| PVDF-TrFE & BT NPs | Electrospun | ITO-coated PET – Fibers & PDMS – ITO-coated PET Film | 2.28 µW/cm$^2$ | Yes | No | (5) |
| PVDF | Airbrush | PVA/PEDOT:PSS – Fibers – Aluminum Foil | 0.0011 µW/cm$^2$ (1) | Yes | No | (6) |
| PVDF-TrFE | Airbrush | Inkjet Printed Nonwoven – Fibers – Inkjet Printed Nonwoven | 0.04 µW/cm$^2$ | Yes | Yes | This Work |

(1) Estimated calculated value. Authors did not report value.

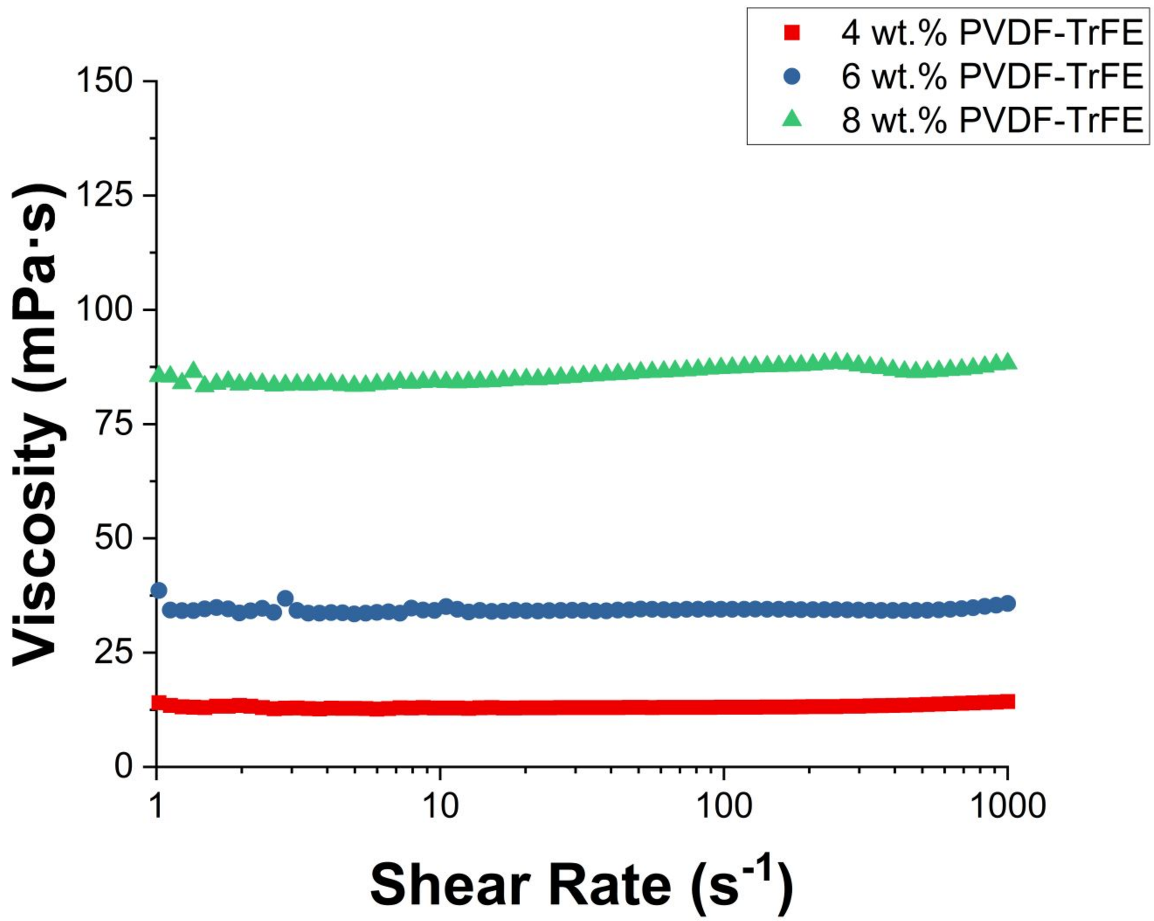


**Figure S1. Viscosities of the various Wt.% PVDF-TrFE solutions in Ethyl Acetate.** Viscosity of polymer solutions increase with increasing wt.%. Solutions also show Newtonian like behavior.

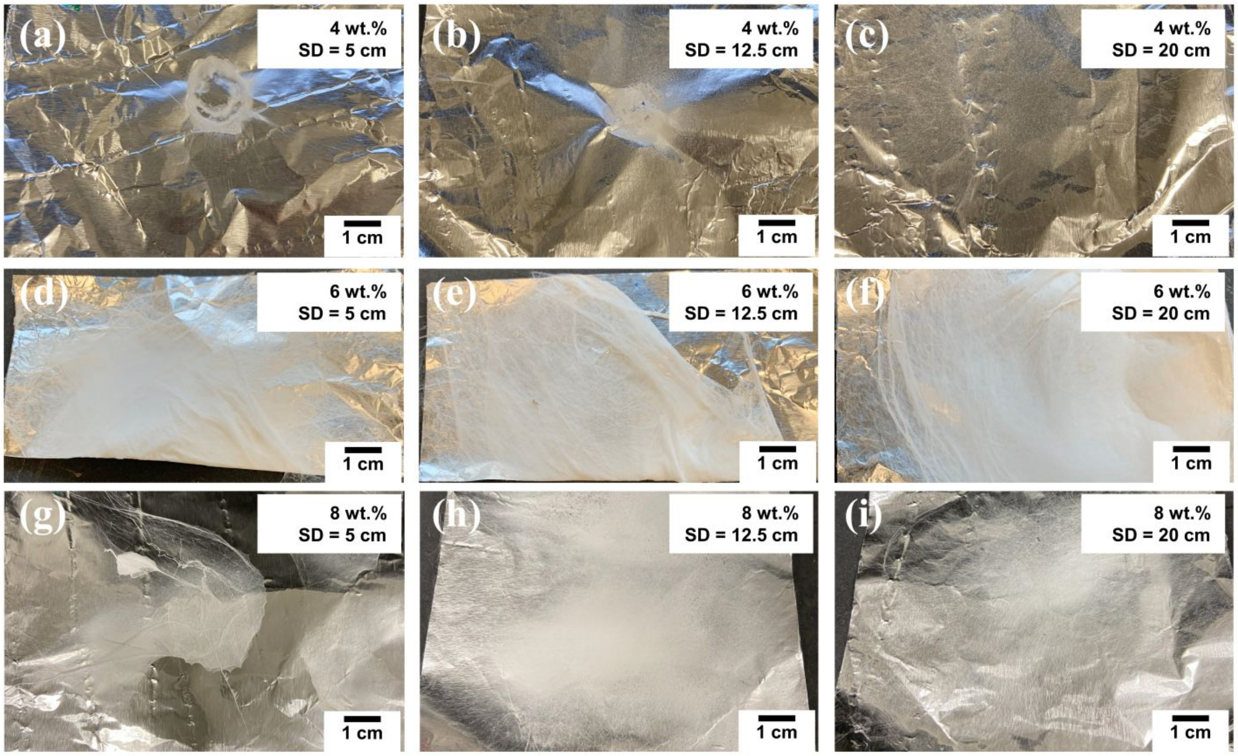


**Figure S2. Optical Images of Airbrushed PVDF-TrFE Fibrous Scaffolds.** (a-c) Scaffolds prepared using 4 wt.% PVDF-TrFE and spray distances of (a) 5 cm, (b) 12.5 cm, and (c) 20 cm. (d-f) Scaffolds prepared using 6 wt.% PVDF-TrFE and spray distances of (d) 5 cm, (e) 12.5 cm, and (f) 20 cm. (g-i) Scaffolds prepared using 8 wt.% PVDF-TrFE and spray distances of (g) 5 cm, (h) 12.5 cm, and (i) 20 cm. Nozzle clogging effects can be seen for the 8 wt.% PVDF-TrFE scaffolds. A spray pressure of 60 psi sprayed all the imaged scaffolds. SD represents the spray distance used for the scaffolds.

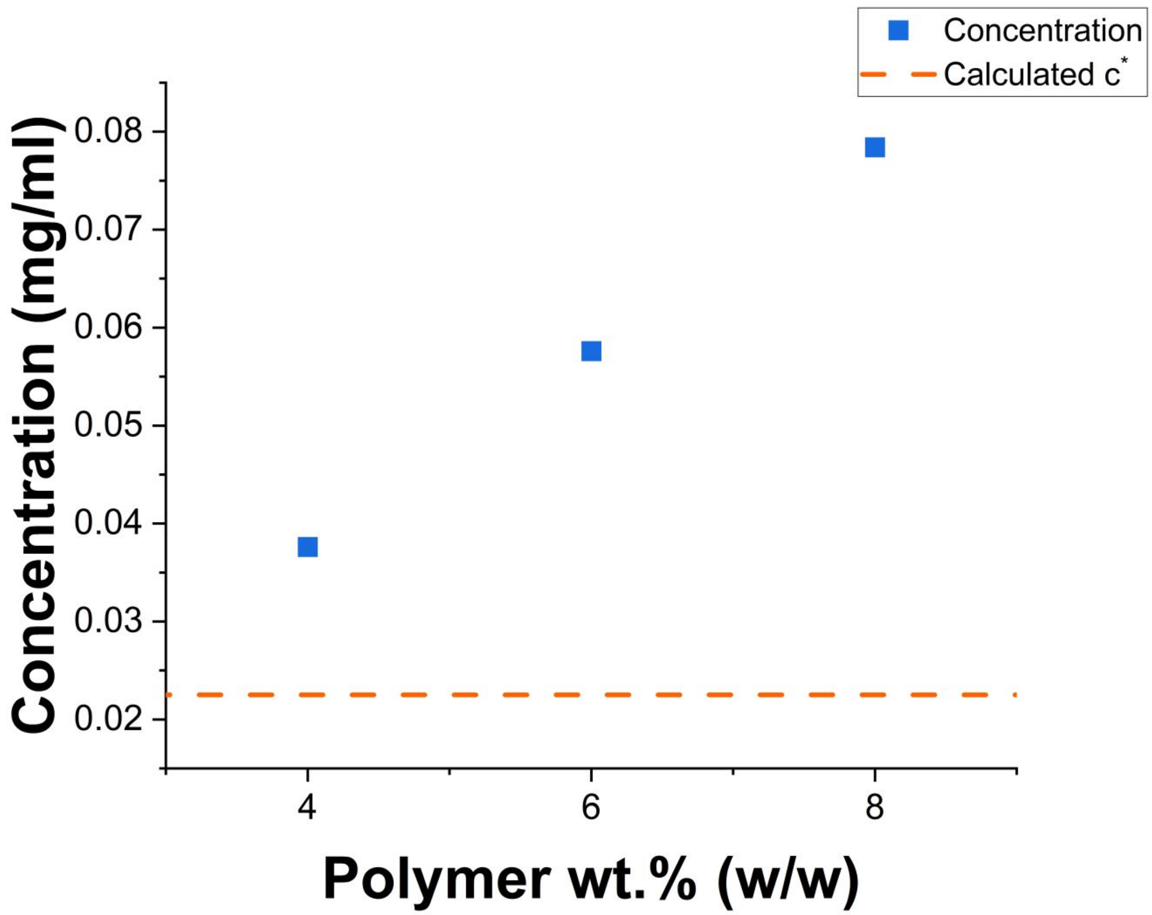


**Figure S3. Critical Overlap Concentration ($c^*$) Calculation for Airbrushed PVDF-TrFE Fiber Formation.** The orange dashed line indicates the estimated critical overlap concentration and the blue squares represent the concentrations of the various PVDF-TrFE solutions (4, 6, and 8 wt. %)

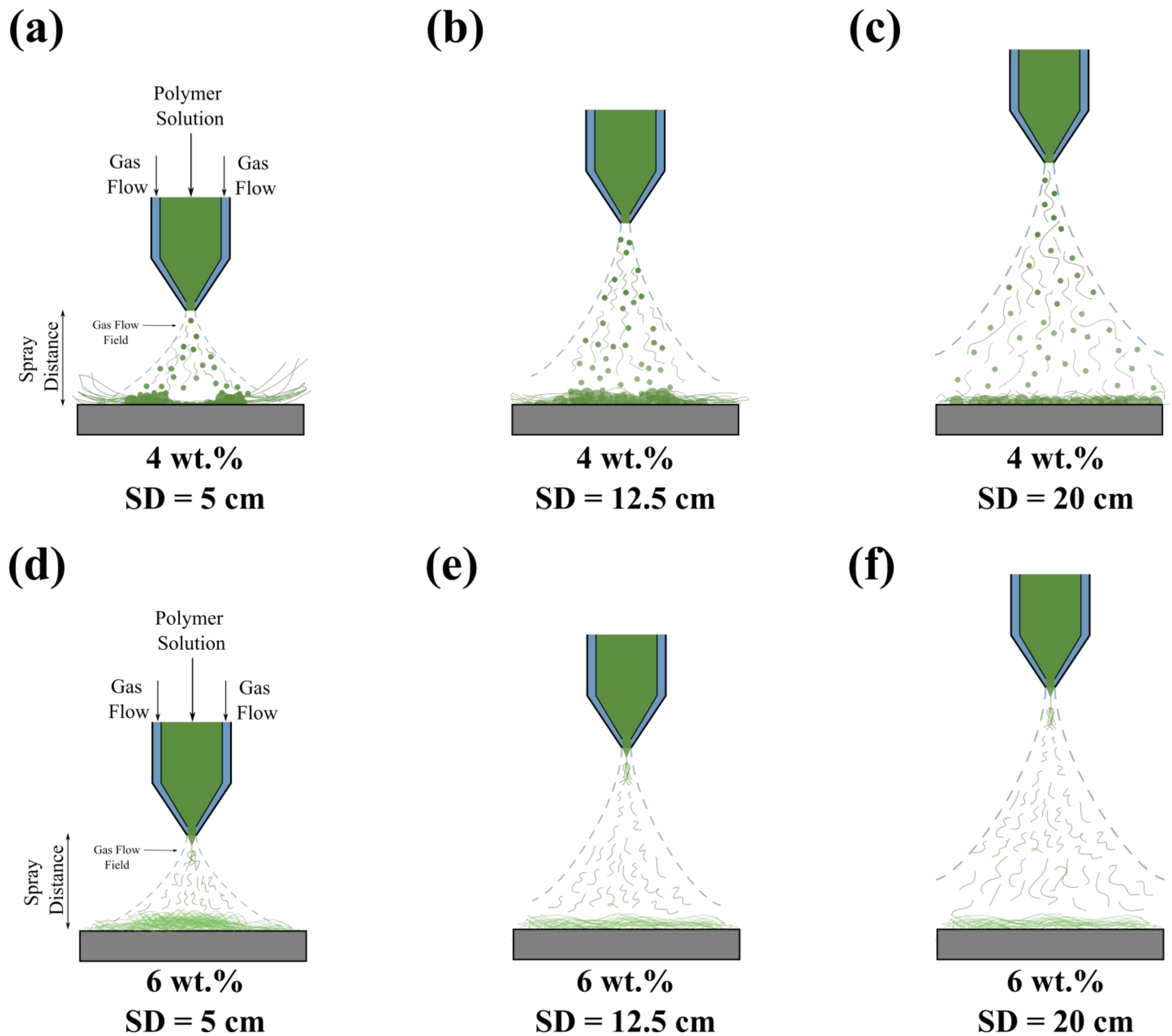


**Figure S4. Schematic of PVDF-TrFE Fiber Formation vs. Spray Distance.** Fiber formation of a 4 wt. % polymer solution when airbrushing with a spray distance of (a) 5 cm, (b) 12.5 cm, and (c) 20 cm. Fiber formation of a 6 wt. % polymer solution when airbrushing with a spray distance of (d) 5 cm, (e) 12.5 cm, and (f) 20 cm. SD represents the spray distance used for the scaffolds.

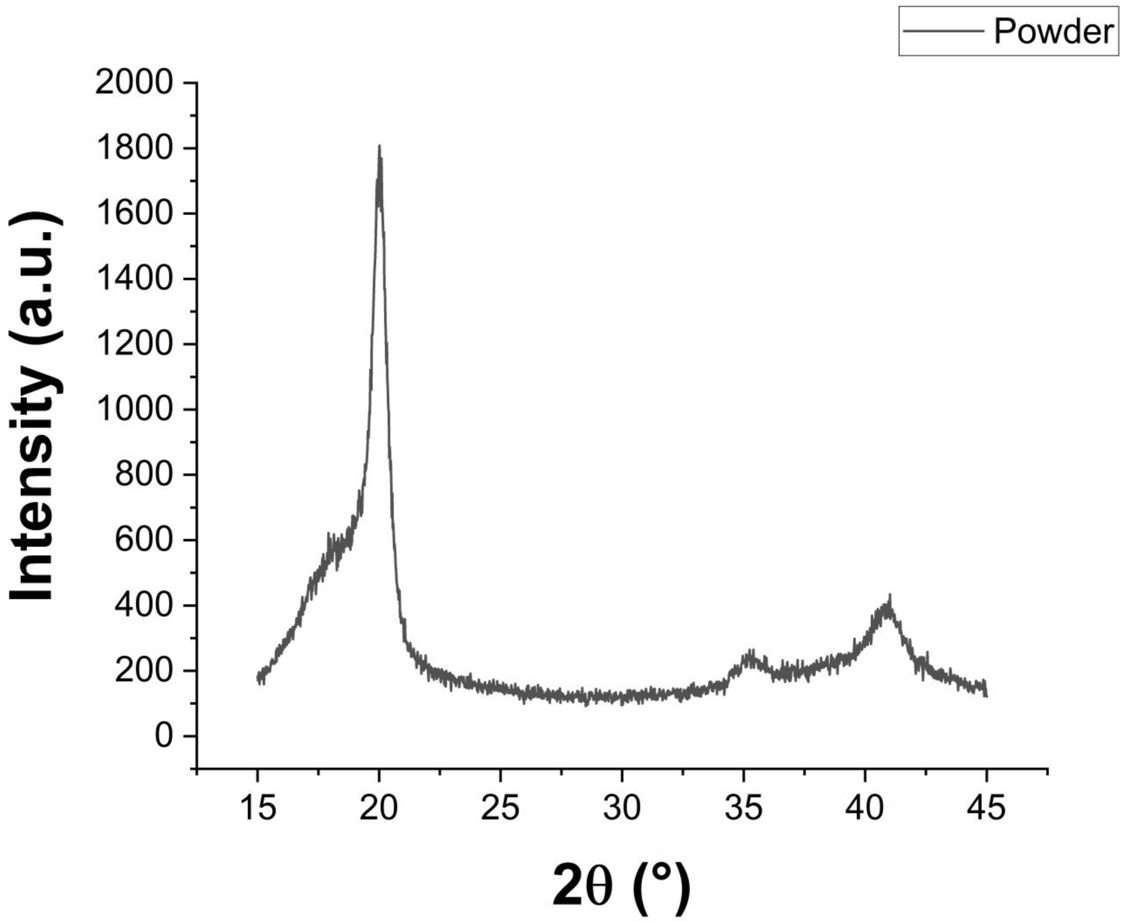


**Figure S5. XRD Diffraction Pattern for the raw PVDF-TrFE powder.** The raw polymer powder shows a peak at $2\theta = 19.99°$ and two additional peaks at $2\theta = 35.38°$ and $2\theta = 40.73°$ which are all peaks associated with the $\beta$-phase .

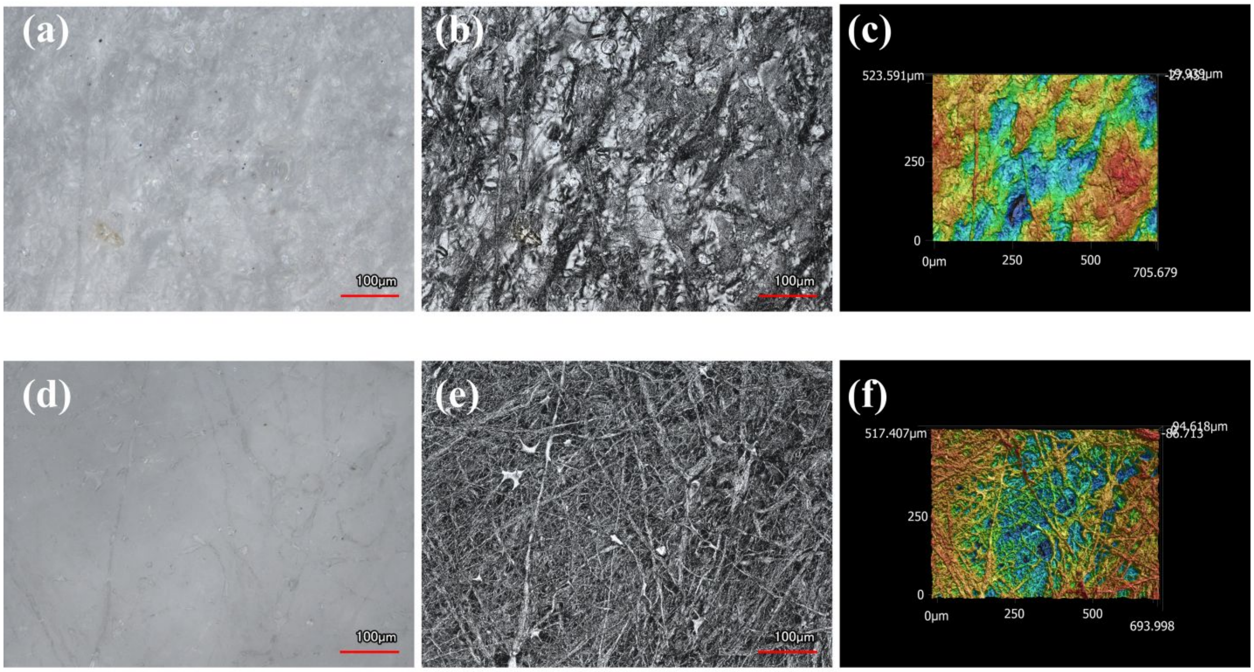


**Figure S6. Images of the 6 wt.% scaffolds airbrushed at 5 cm and 12.5 cm spray distances.** (a) Optical, (b) Combined Laser & Optical, and (c) 3D Optical Image of the 5 cm spray distance 6 wt.% scaffold. (d) Optical, (e) Combined Laser & Optical, and (f) 3D Optical Image of the 12.5 cm spray distance 6 wt.% scaffold. A combined optical and laser profilometer microscope provided these images. All images were taken near the airbrush center.

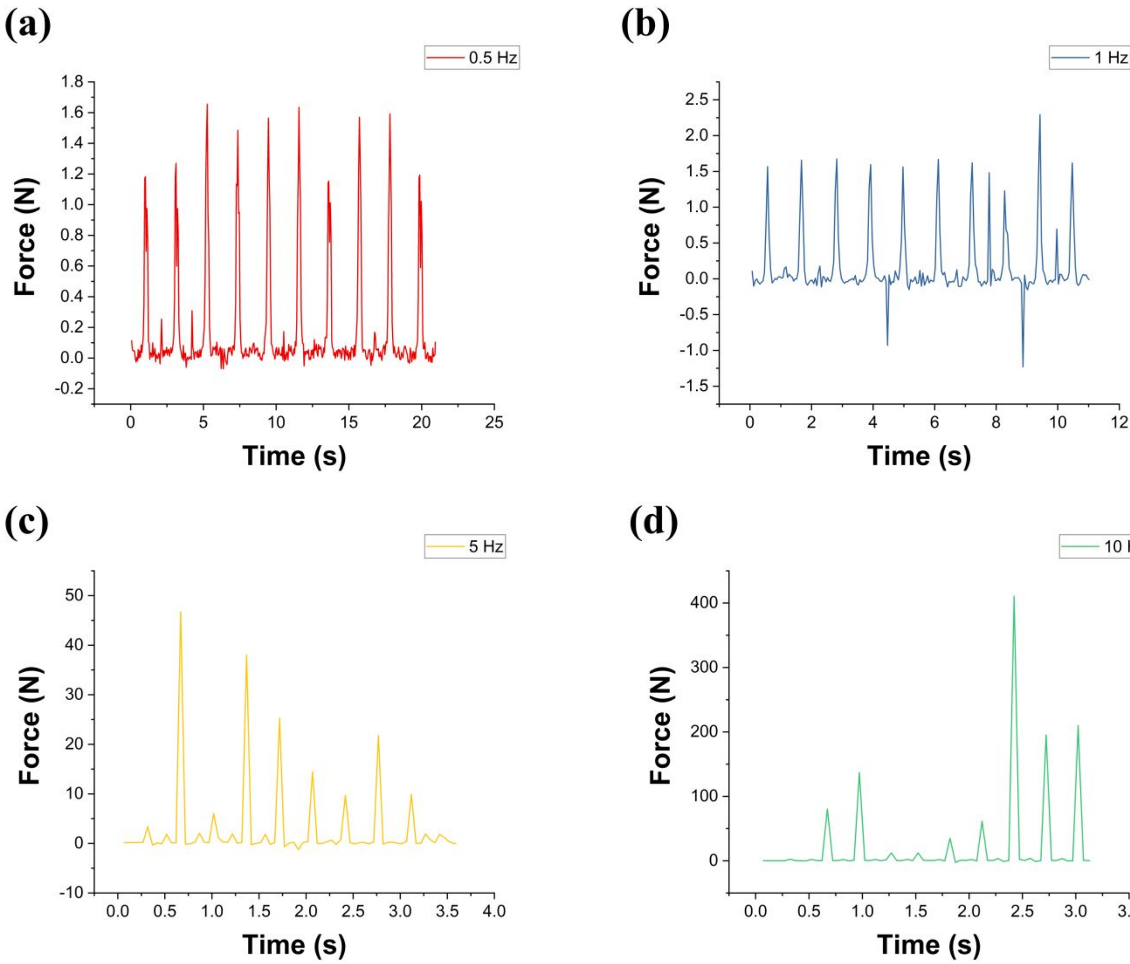


**Figure S7. APTD Tapping Forces.** (a) 0.5 Hz tapping APTD. (b) 1 Hz tapping APTD. (c) 5 Hz tapping APTD lower applied force. (d) 5 Hz tapping APTD higher applied force.

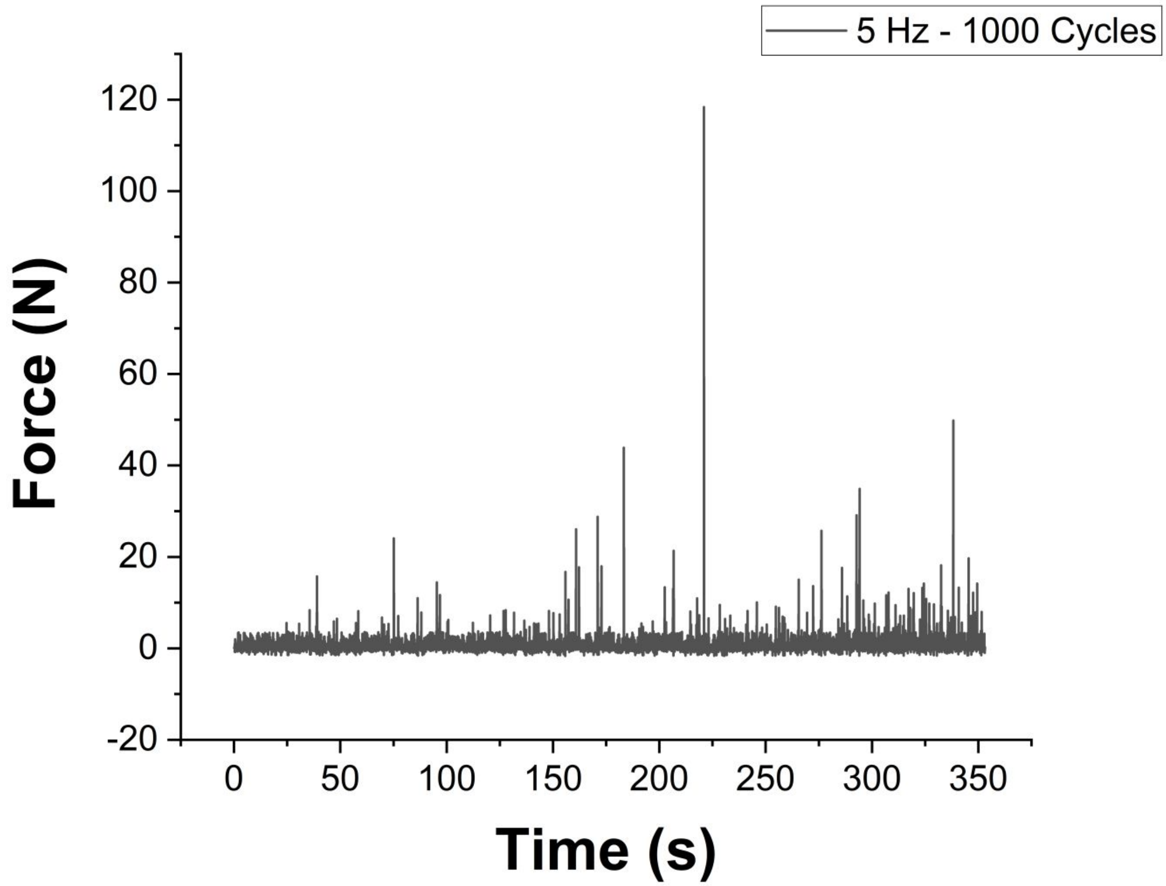


**Figure S8. APTD Tapping Force for 1000 Cycles of 5 Hz Tapping.** Tapping forces equivalent to 640.1 ± 429.3 N.

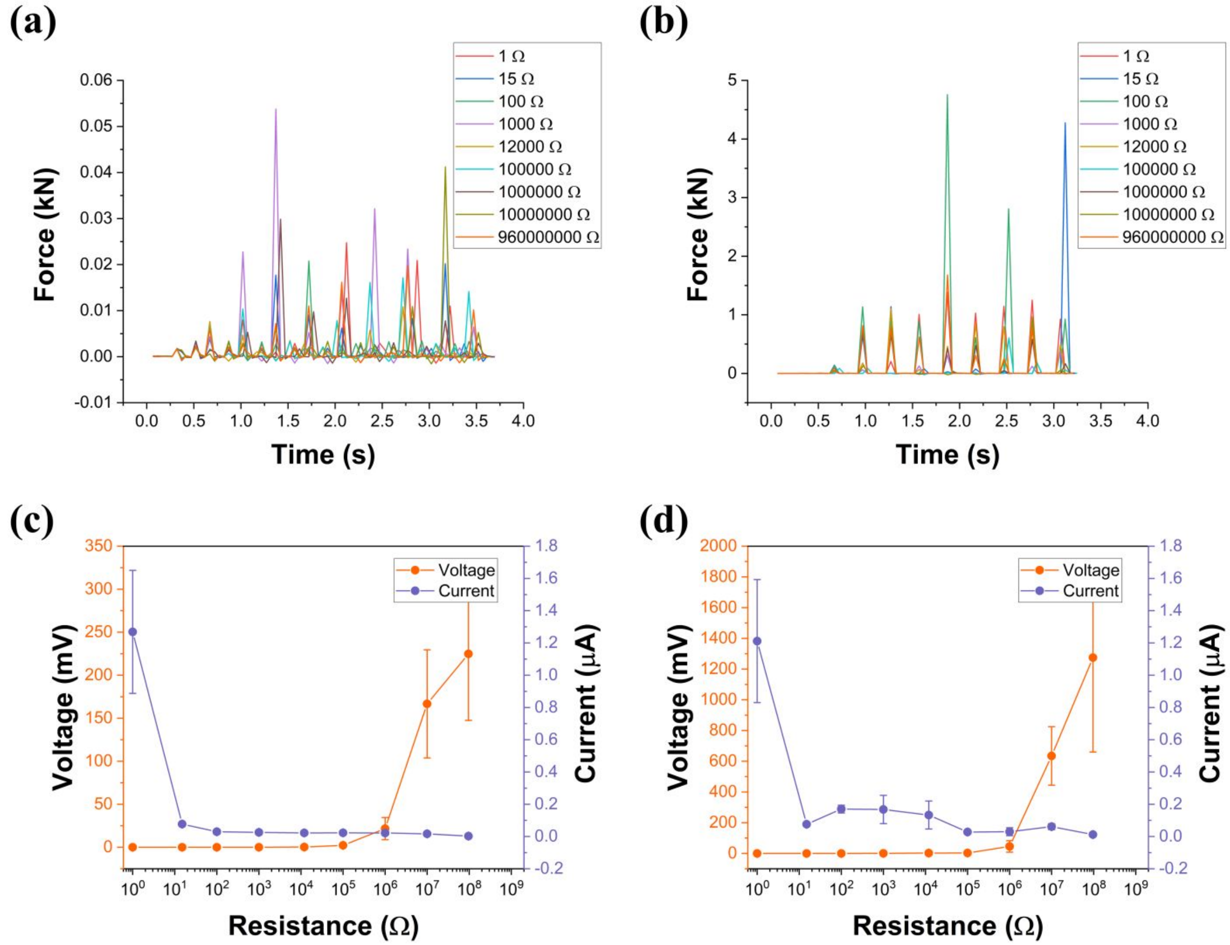


**Figure S9 APTD Energy Harvesting Characterization Forces and Electrical Currents.** Tapping forces at a 5 Hz tapping frequency for the different load resistances with average forces of (a) 9.7 ± 3.9 N and (b) 640.1 ± 429.3 N. Current outputs for the (c) 9.7 ± 3.9 N and (d) 640.1 ± 429.3 N energy harvesting characterization.

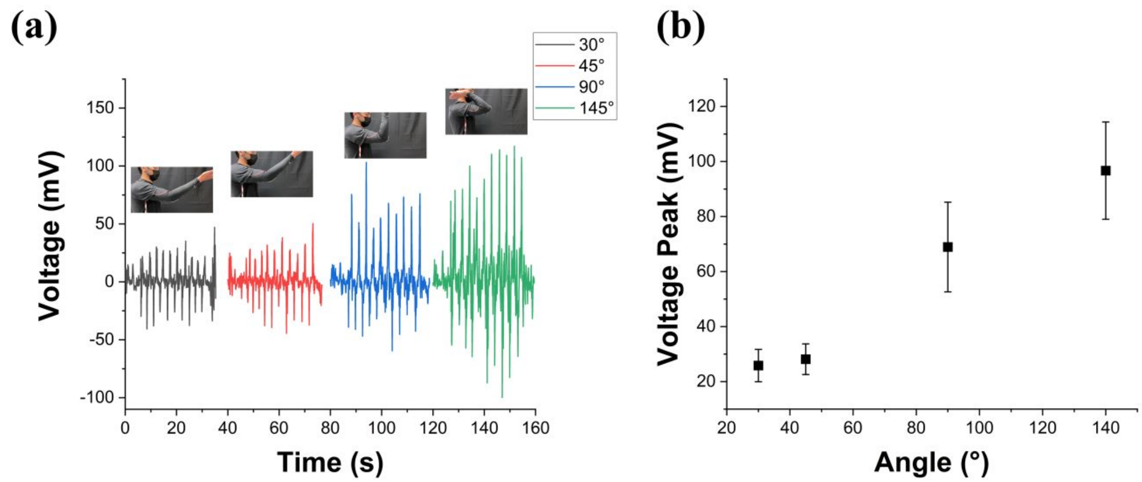


**Figure S10. Benchmark Voltage Outputs of the APTD-Integrated Basketball Sleeve.** (a) Voltage outputs of the basketball sleeve under different flexing angles followed by extension of the arm to a fully straightened position. (b) Calculated positive voltage peaks for the respective flexing angles. The voltage shows a big jump from a 45° to 90° elbow flexion. However, the 90° to 145° elbow flexion voltage peaks show similar values with overlapping standard deviations. The elbow flexion during phase (ii) of free throw shooting (see Section 3.4.4. of main text) was found to be 93.1 ± 3.5° and 96.6 ± 3.8° for make and misses, respectively. Not only is this angle difference not significant between makes and misses, the low difference of ~3-5° makes it difficult for the basketball sleeve to detect. In other words, the armband sensitivity is not high enough to detect such subtle differences in elbow flexion such as ~3-5°. Al measurements were done at a ~0.5-1 Hz movement frequency and used the amplifier circuit with a 80 MΩ resistance as described in Section 3.4.4. of the main text.

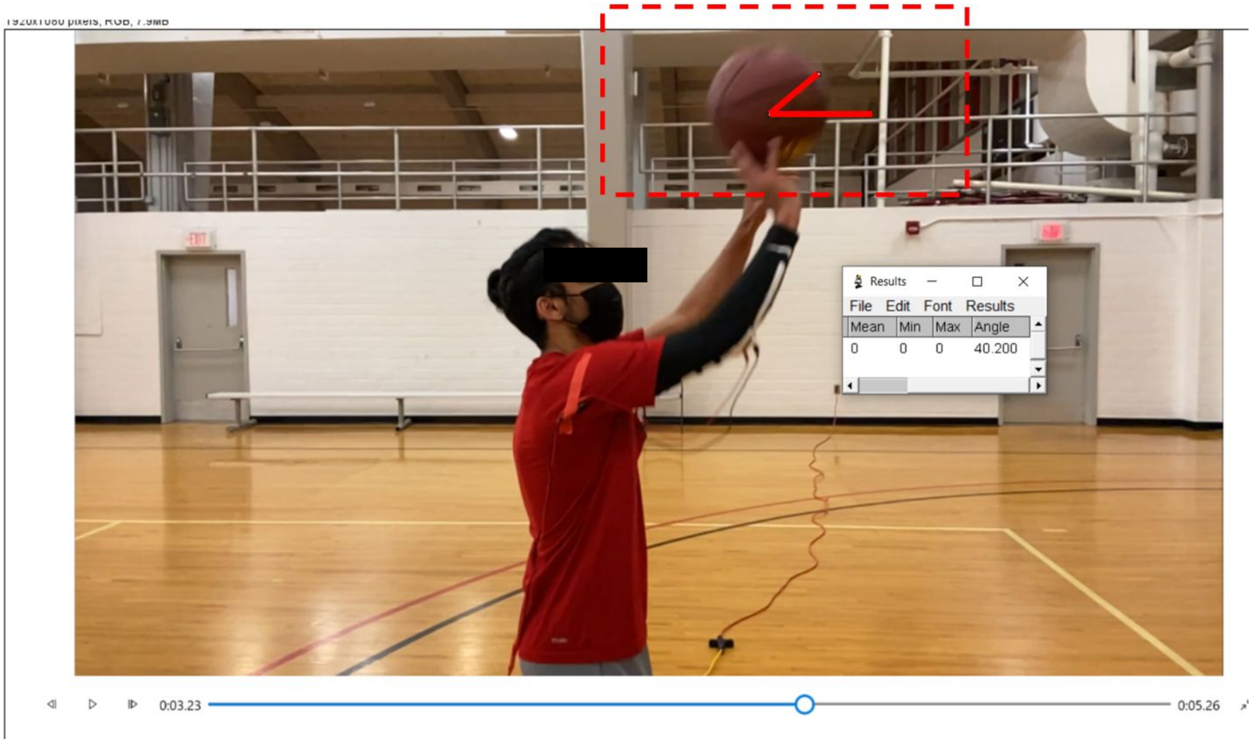


**Figure S11. Shooting Release Angle Calculation.** A screenshot taken from Movie S1. Dotted red box indicates the area used to measure shooting release angle. The angle is the shooting trajectory of the basketball as it leaves the volunteers hand.

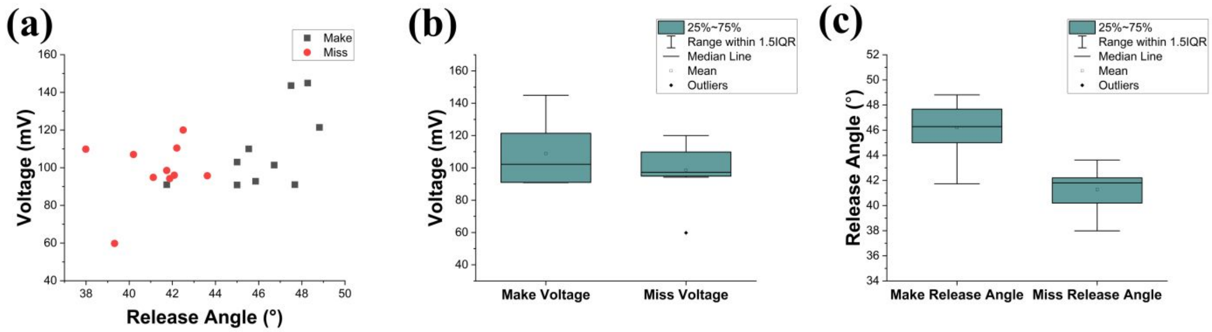


**Figure S12. Shooting Release Angle and Extension Voltage Statistical Analysis.** (a) Correlation plot of the extension voltage vs. shooting release angle with nor clear observable trend. (b) Box chart of make and miss voltage values showing no significant difference (p-value > 0.05). (c) Box chart of make and miss shooting release angles showing a significant difference (p-value < 0.05).

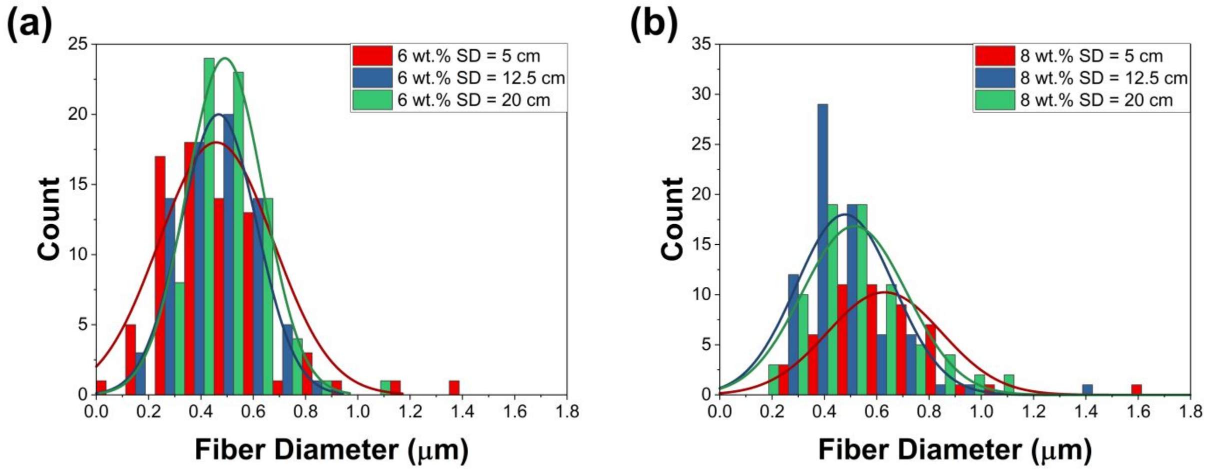


**Figure S13. Fiber Distributions of Airbrushed PVDF-TrFE Scaffolds.** Fiber distributions for (a) 6 wt. % scaffolds and (b) 8 wt.% scaffolds. Distributions for 4 wt.% scaffolds were not calculated due to mostly globular morphology. See main text for further discussion and explanation.

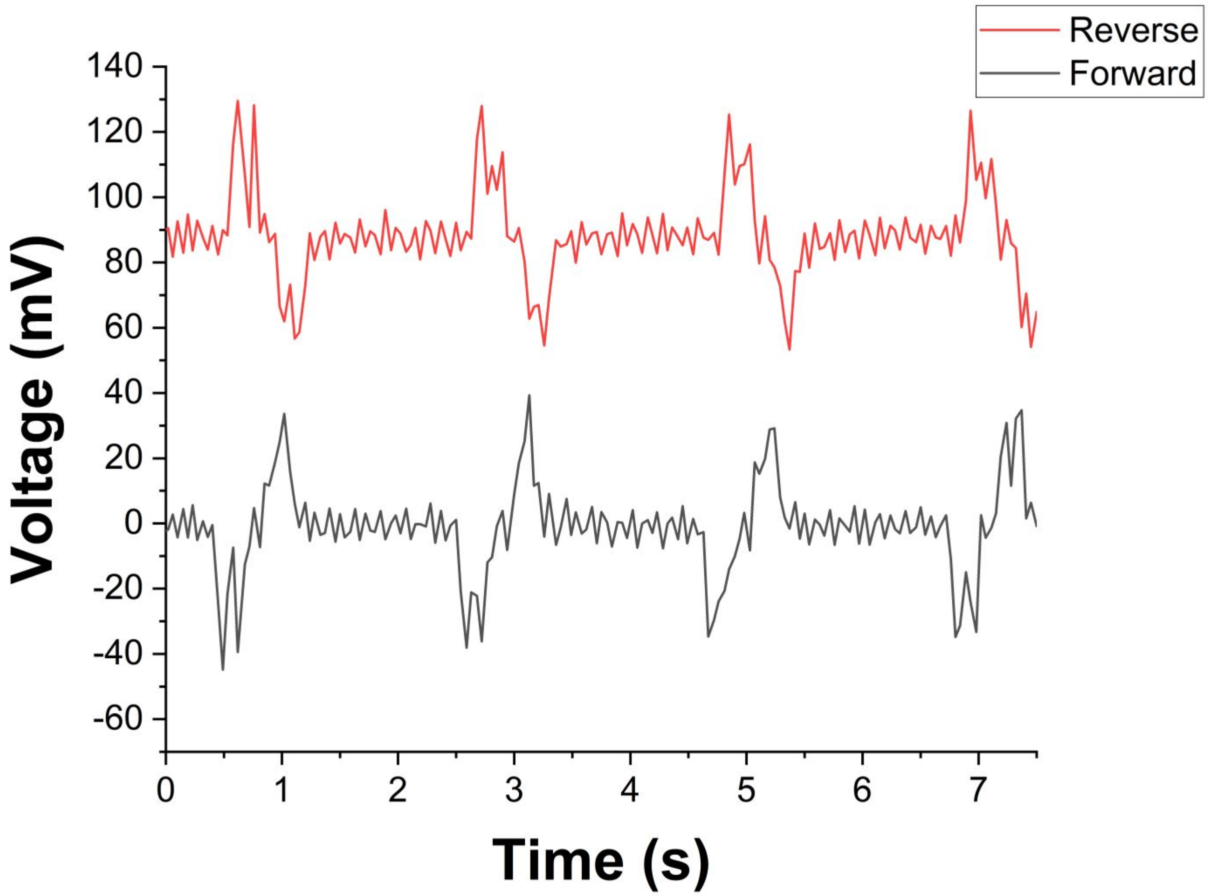


**Figure S14. Forward – Reverse Connection of APTD.** Voltage outputs of APTD under 0.5 Hz of tapping. Connections to be APTD were reversed and changes in voltage polarity were observed ruling out the electrostatic effect.

**Supplementary Note. Power Generation in a Typical National Basketball Association (NBA) Game**

By using the 80 MΩ resistance from the amplifier circuit and the average elbow extension voltage from each shot, we calculated the average power per shot to be 0.14 ± 0.05 nW/shot. Although the average power per shot is low, let's consider real scenario power generation values by analyzing stats from players in the national basketball association (NBA). Players in the NBA are not limited to flexing and extending of their elbow during free throw shots. Players exhibit a wide range of flexing and extending motions of their upper limbs through activities such as dribbling, field goal shots, and three-point shots. Thus, the following power generation calculation will assume movements such as dribbling, field goal shot attempts, three-point shot attempts, and free throw shot attempts exhibit approximately the same power output value of 0.14 nW/per movement. The 0.14 nW/per movement number is assuming the aforementioned movements exhibit about the same range of motions for a free throw shot. For this calculation the authors agreed to use the first author's favorite basketball player as a model example, Jeremy Lin. During the 2013-2014 season Jeremy Lin had a total of 58.1 touches per game with an average dribble per touch of 3.62. This gives a total dribble per game value of 210.322 and multiplying this number by the 0.14 nW/per movement assumption gives a total power generation of 29.45 nW per game. Lin also had a total of 9.3 field goal attempts, 3.2 three-point attempts, and 3.7 free throw shot attempts per game. Multiplying each shot attempt per game by the 0.14 nW/per movement assumption and adding each calculated power generation value gives a total power generation of 2.27 nW per game for the aforementioned shot attempts. The final power generation considering all the movements calculates to ~31.8 nW per game. The calculation can be extended to other players as seen in Table S4. Based on the analysis using statistics from the 2021 season, shooting guards generate the most power because they dribble and shoot the ball the most. In addition, high profile players such as Stephen Curry and Luka Donic generate more power compared to average players such as Nikola Jokic. Although this calculation results in a low power output, the calculation serves as a basis for future modeling and calculations for researchers interested in wearable energy harvesting with specific use-cases focusing on basketball.

| Player | Stephen Curry | Nikola Jokic | Damian Lillard | James Harden | Luka Donic | Lebron James | Kevin Durant | Trae Young | Russel Westbrook | Kyrie Irving |
|---|---|---|---|---|---|---|---|---|---|---|
| **Touches per game** | 80.6 | 101.8 | 81 | 93.2 | 90.5 | 87.5 | 67.9 | 86.4 | 94.8 | 79.4 |
| **Dribble per touch** | 4.07 | 1.35 | 5.64 | 5 | 5.54 | 3.4 | 2.2 | 5.74 | 4.74 | 3.87 |
| **Dribble per game** | 328.0 | 137.4 | 456.8 | 466.0 | 501.4 | 297.5 | 149.4 | 495.9 | 449.4 | 307.3 |
| **FGA per game** | 21.4 | 20 | 20 | 17.2 | 20.6 | 18.1 | 17.8 | 17.7 | 18.9 | 20.6 |
| **FTA per game** | 6.2 | 2.3 | 7.3 | 7.5 | 7.3 | 5.8 | 7.1 | 8.8 | 6.2 | 4.2 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **3PA per game** | 12.6 | 6.3 | 10 | 7.8 | 8.3 | 6.4 | 5.6 | 6.3 | 4 | 7.1 |
| **Total movements** | 368.2 | 166.0 | 494.1 | 498.5 | 537.6 | 327.8 | 179.9 | 528.7 | 478.5 | 339.2 |
| **Power Generated per game** | 51.6 | 23.2 | 69.2 | 69.8 | 75.3 | 45.9 | 25.2 | 74.0 | 67.0 | 47.5 |

**Tables S4. NBA Player Power Output.** Calculations done using statistics from the 2020-2021 season.