ASSOCIATED CONTENT

Supporting Information:

Rapid-response, Widely Stretchable Sensor of Aligned MWCNT/Elastomer Composites for Human Motion Detection

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Scheme 1. Data Collection

Cyclic strain tests were conducted using a one-dimensionally moving stage operated by a crank-lever mechanism. A data logger (NR250, KEYENCE Osaka Japan) was used for data collection, and the sampling rate was 1 msec (1 kHz). The strain was measured using a linear scale (BIL EMD0-T060A-01-S75, B&PLUS KK, Saitama Japan) with an accuracy of 1 μm.

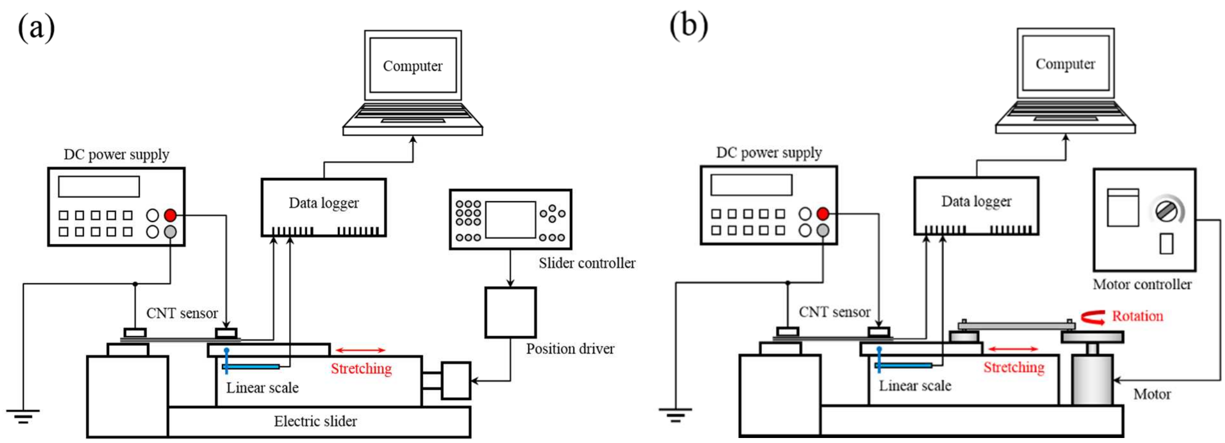

Figure S1. CNT strain sensor performance evaluation block diagrams. (a) Static performance evaluation block diagram. (b) Dynamic performance evaluation block diagram.

Scheme 2. Stretchable Wire

Although metallic wires are desirable for both their low resistance and ease of connection to a device, such wires are normally not sufficiently stretchable or flexible for this application. Consequently, the authors developed a stretchable wire from silvered, conductive fibers made of general synthetic fibers (e.g., polyester and nylon). The silvered, conductive fibers used for making the stretchable wire were purchased from Mitsufuji Corporation, Japan. To ensure good conductivity of the silvered fibers, short fibers were silvered before they were used to form long fibers. Then, these silvered fibers were covered with polyester fibers and knit using normal textile manufacturing processes to provide stretchability.

Figure S2(a) shows an enlarged view of the stretchable wiring. As shown in the figure, this stretchable wiring consists of non-conductive synthetic fibers and the aforementioned silvered fibers, which are interwoven parallel with each other. As indicated in Figure S2(b) and S2(c), a light-emitting diode (LED) was connected to one end of each of the two stretchable wires with parallel stretchable conductive parts using conductive adhesive; a several-milliampere current was applied to the other end. The LEDs were constantly lit, even when the textile at 100% elongation or inflected (folded), indicating that good conductivity was maintained without breakage.

Figure S3(a) shows the relationship between the strain applied to the stretchable wiring and the applied force, and Figure S3(b) shows the relationship between strain and resistance. The stretchable wire had a width of 2.5 mm and a thickness of 1.5 mm. The approximately 0.5-MPa elastic modulus at 100% elongation, shown in Figure S3(a), is evidence of the flexibility of the wire. Additionally, the constant resistance of 15 Ω shown in Figure S3(b) is indicative of low resistance variation during elongation. The constant resistance during elongation/contraction and the shorter times required for resistance value stabilization resulted in steady conductivity. Given these results, the wire can be employed as signal wiring for broad sensing applications. In a 0-100% repetitive-stretching strain test (100% = 200% of the initial length), the elongation/contraction durability was demonstrated to persist after one million cycles.

Because the wire is in the form of a knitted textile, it can be easily stitched onto or integrated into textile products. Moreover, it has sufficiently high flexibility and affinity to conform to human skin and is sufficiently durable against the large strains that may be applied while donning or removing sensor apparel. These properties all support the wiring of wearable devices. Additionally, as indicated in Figure S4, it is possible to create narrow- or wide-pitched, multipole wiring by interweaving the conductive and non-conductive fibers at the desired intervals. In addition, as the sensor is stretchable in the direction orthogonal to the wiring, the degree of freedom in pitch adjustment is high, and a conductive connection with a flexible base can be easily established using anisotropic conductive film (ACF), as shown for the device described in the “Human Motion Sensing Apparel” section.

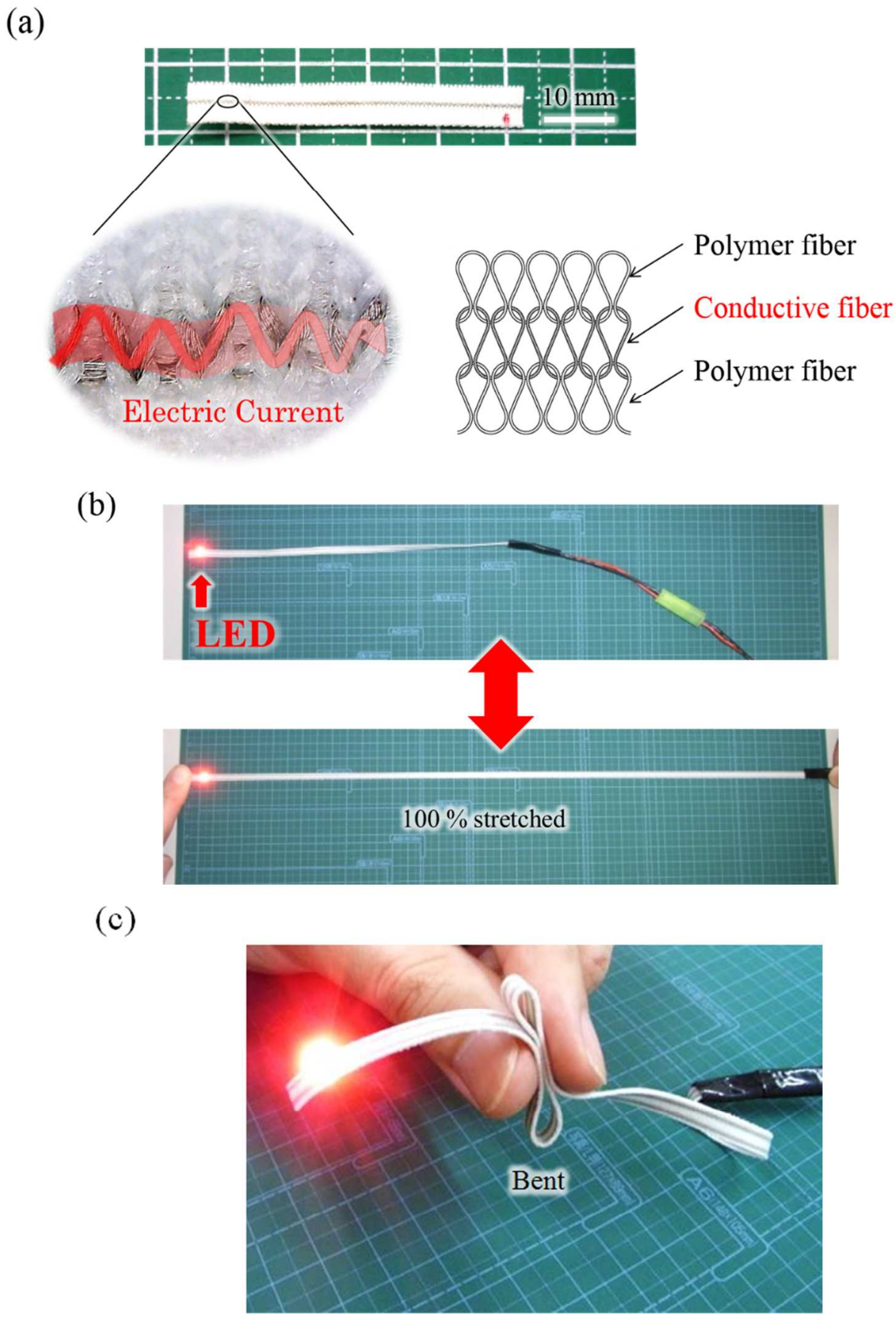

Figure S2. Enlarged view and appearance of conductive stretchable wire. (a) Enlarged. (b) No breakage at 200% elongation. (c) No breakage under bending.

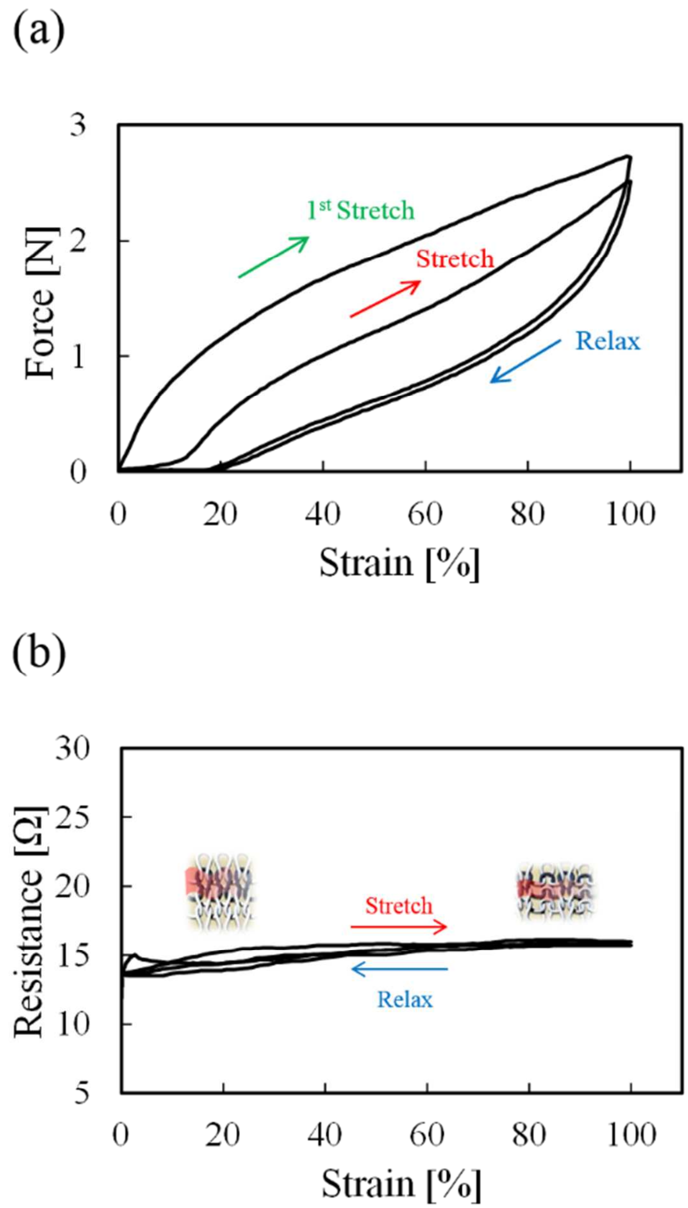

Figure S3. Conductive, stretchable wire performance. (a) Strain-force relation. (b) Strain-resistance relation.

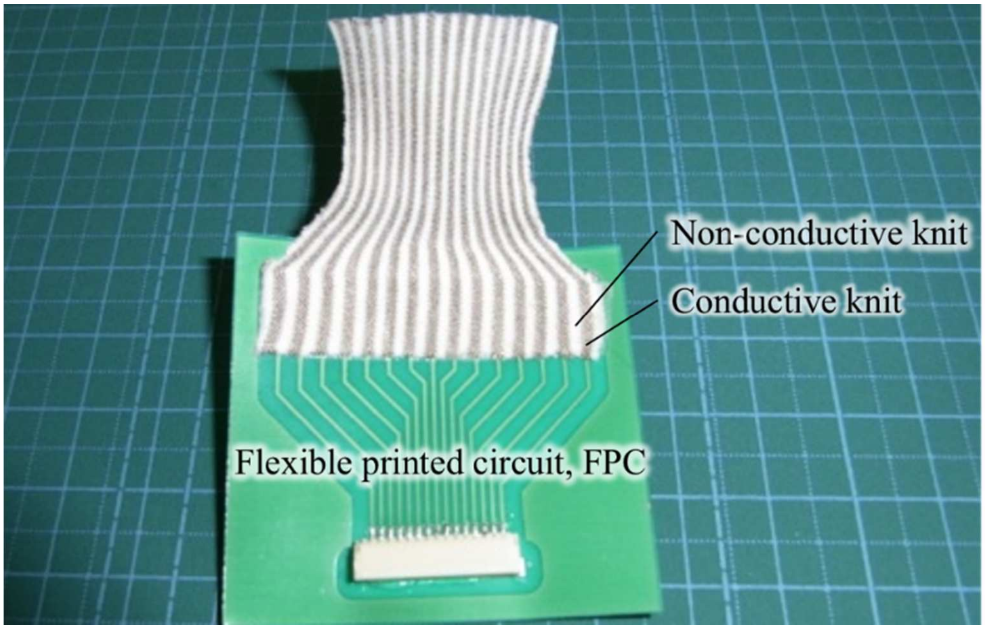

Figure S4. Multipole wiring of the stretchable wire onto a flexible printed circuit.

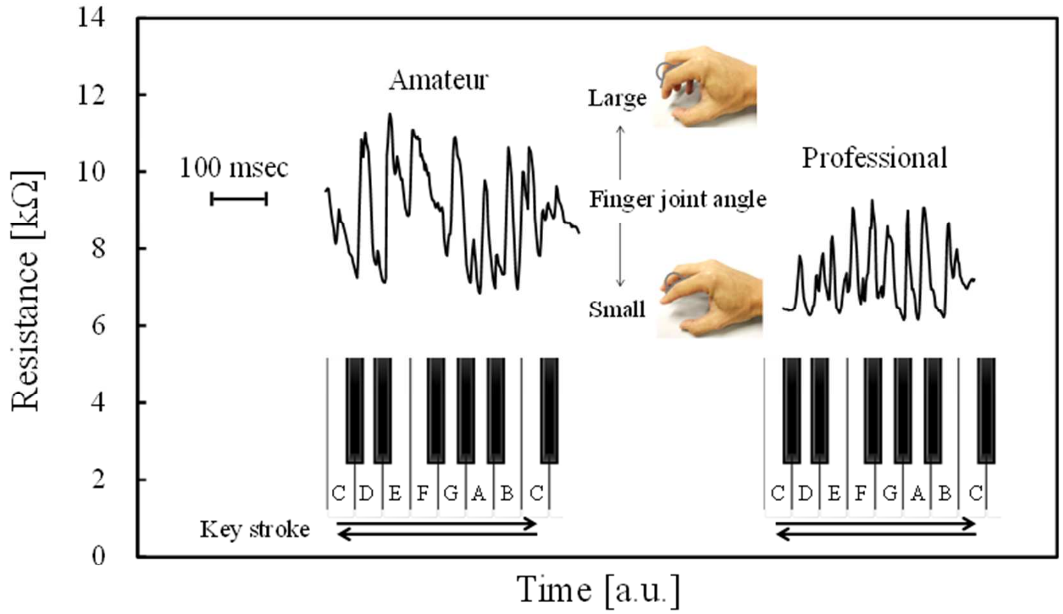

Figure S5. The time-varying waveforms of the angles at the proximal-interphalangeal (PIP) joints of the index finger of a pianist. Comparison of finger-bending data measured during piano performances by amateur and professional players.