Electronic Supplementary Information

A coaxial triboelectric nanogenerator fiber for energy harvesting and sensing under deformation

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Experimental Section

Fabrication of a coaxial triboelectric nanogenerator fiber

The PDMS (Sylgard 184, Dow Corning) precursor was mixed with a curing agent at a weight ratio of 10/1, followed by injection into a heat-shrinkable tube with a diameter of 1.0 mm and then curing at 80 °C for 2 h. The PDMS fiber was obtained by taking off the outer tube. The aligned CNT sheets were drawn from a CNT array and uniformly wrapped onto the pre-stretched PDMS fiber (Figure S2).[S1] The aligned CNT sheets exhibited high electrical conductivity on the level of 10^2-10^3 S/cm.[S2] A copper wire was then connected with the CNT sheets as an electrode. Afterwards, PMMA microspheres were deposited onto the aligned CNT sheets by electrophoretic deposition. After that sucrose solution and particles were dip-coated on the fiber sequentially (Figure S3). Another layer of PDMS was then covered on the sucrose particles. The surface edge of PDMS layer was a bit lower than the sucrose in order to resolve the sucrose and release air bubbles easily. The fiber was inserted into the heat oven for curing again, followed by soaking in water for 24 h to remove the sacrificing sucrose. After the fiber was dried at room temperature, another layer of aligned CNT sheets was wrapped on the surface of the resulting composite fiber. Another copper wire was connected as the other electrode. Finally, the fiber device was encapsulated by PDMS and cured in the heat oven for 60 min.

Electrophoretic deposition

The aqueous dispersions (10% w/w) of PMMA microspheres with diameters of 0.2 μm, 0.5 μm and 1.0 μm were ordered from Zhenzhun Bio Technology Corp (Shanghai, China). They were diluted in ethanol (99.5 vol%) at a concentration of 2.5 mg/mL to form a uniform suspension. The aligned CNT sheet-wrapped PDMS fiber and a stainless steel (1.5×9 cm) were connected to the anode and cathode of the current source (Maynuo DC Source Meter, M8813), respectively. Both the fiber and stainless steel electrode were immersed into the PMMA microspheres suspension. PMMA microspheres were electrophoretically deposited onto the surface of the aligned CNT sheet-wrapped PDMS fiber at 30 V for 3 min.

Instruments and characterization

The photographs were taken from a digital camera (Nikon J1, Tokyo, Japan). Scanning electron microscopy images were recorded by Hitachi S-4800 operated at 1 kV. The PDMS layer was carefully peeled off for observing the inner surface. All of the samples were prepared by coating a thin layer of gold before observation. A pressure punch (MTS-200C-R, China) was used to provide programmed pressing forces to the CTNF. The open-circuit voltage was measured by a charge amplifier (YE5850, SINOCERA, China), and the short-circuit current of the CTNF was measured by a digital source meter (KEITHLEY 2400, USA). For the detection of the finger motion, four devices were fastened on four fingers and connected in parallel. For the detection of the car movement, one CTNF was suspended over the round lane for velocity monitoring. Then two CTNFs were connected in parallel and used for direction test of the car with the short one at Point A and the long one at Point B (Fig. S17a and S17b). The round lane demonstrated a perimeter of 699 mm and the distance between Point A and B was 198 mm. The speed of the moving car was set as 330 mm/s. The car moved in the clockwise direction in Fig. S17c and in the anticlockwise direction in Fig. S17d.

References

S1. X. Sun, J. Zhang, X. Lu, X. Fang, H. Peng, *Angew. Chem. Int. Ed.,* 2015, **54**, 3630-3634.

S2. H. Peng, X. Sun, F. Cai, X. Chen, Y. Zhu, G. Liao, D. Chen, Q. Li, Y. Lu, Y. Zhu, Q. Jia, *Nat. Nanotechnol.,* 2009, **4**, 738-741.

Supplementary Figures

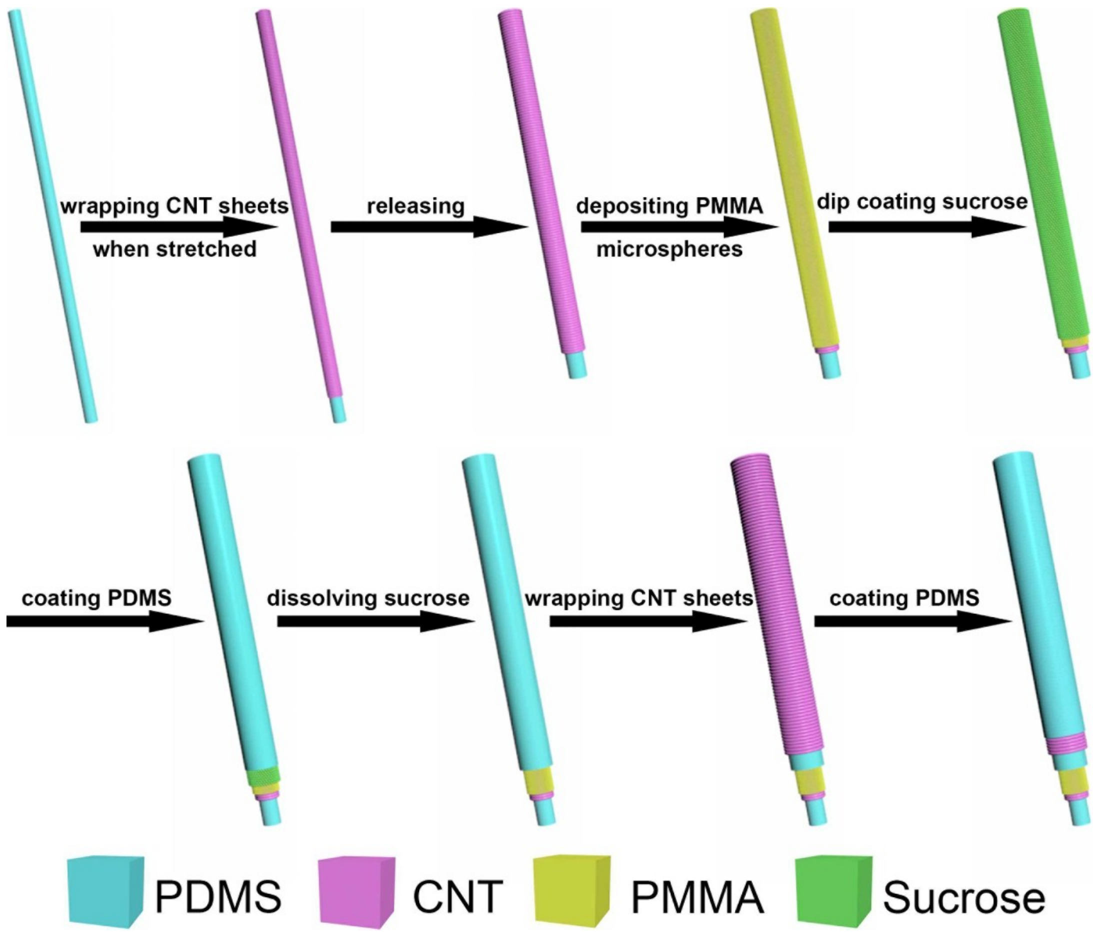

Figure S1. The fabrication process of the CTNF.

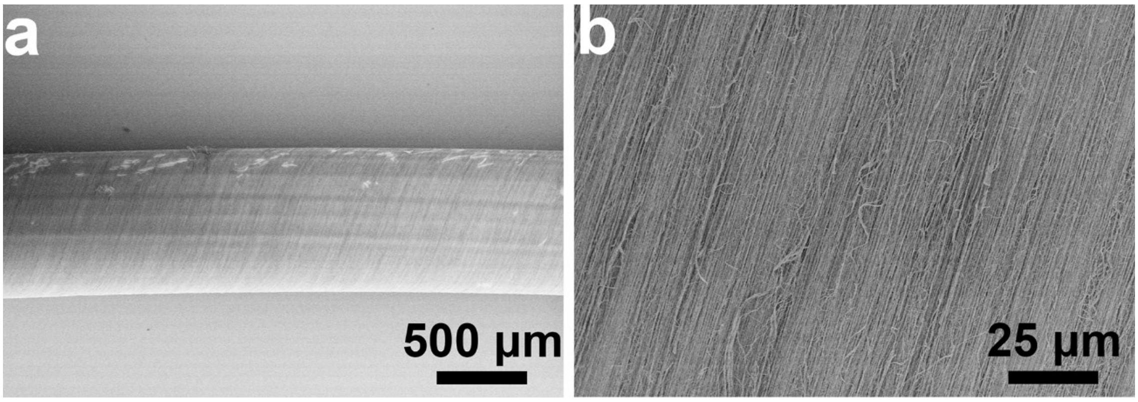

Figure S2. SEM images of aligned carbon nanotube sheets wrapped on a pre-stretched PDMS fiber at low (a) and high (b) magnifications.

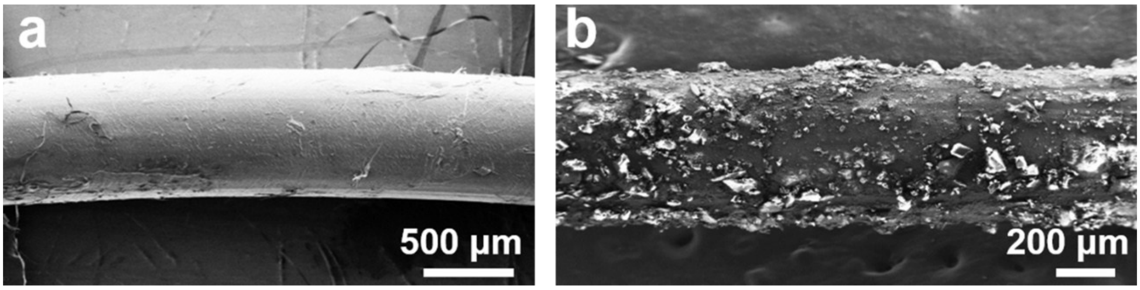

Figure S3. SEM images of the surfaces of aligned carbon nanotube sheets covered by sucrose solution (a) and sucrose particles (b).

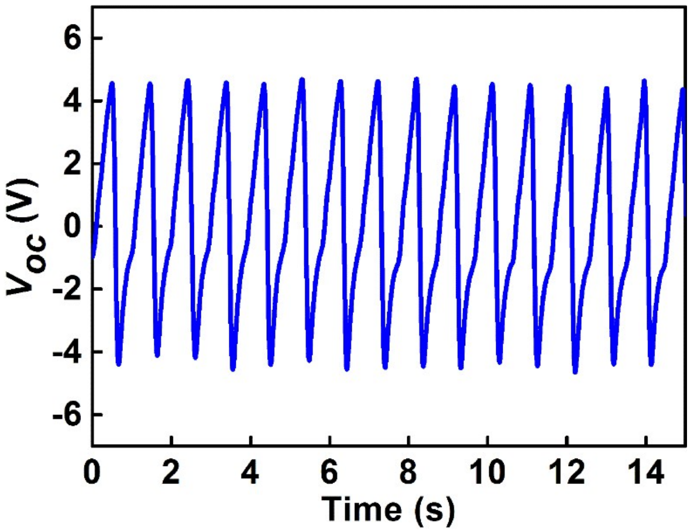

Figure S4. The open-circuit voltage (V_{oc}) generated by a CTNF with the length of 5 cm under a pressing force of 25 N.

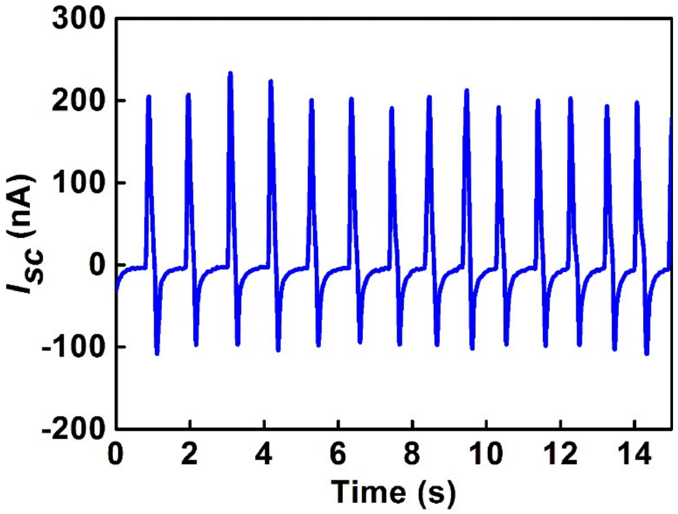

Figure S5. The short-circuit current (I_{sc}) generated by a CTNF with the length of 5 cm under a pressing force of 25 N.

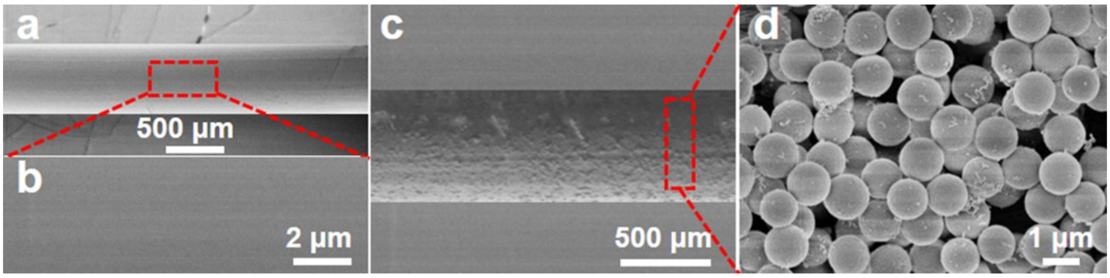

Figure S6. (a) and (b) SEM images of the triboelectric PMMA layer without the microspheres at low and high magnifications, respectively. (c) and (d) SEM images of the triboelectric PMMA layer assembled from the microspheres (diameter of 1 μm) at low and high magnifications, respectively.

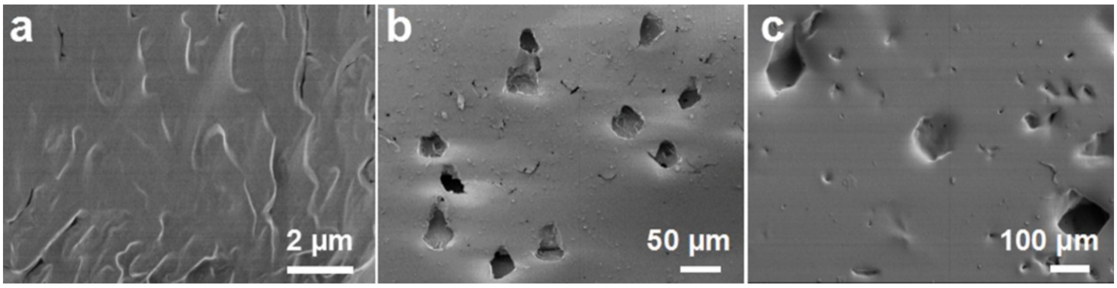

Figure S7. SEM images of the triboelectric PDMS layers without pores (a), with the pores of nearly 50 µm (b) and 100 µm (c).

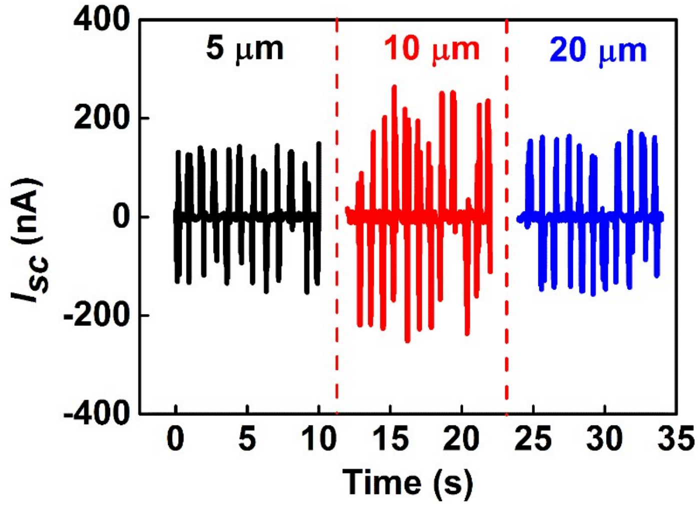

Figure S8. The I_{sc} generated by CTNFs with different spacing distances between two contact layers.

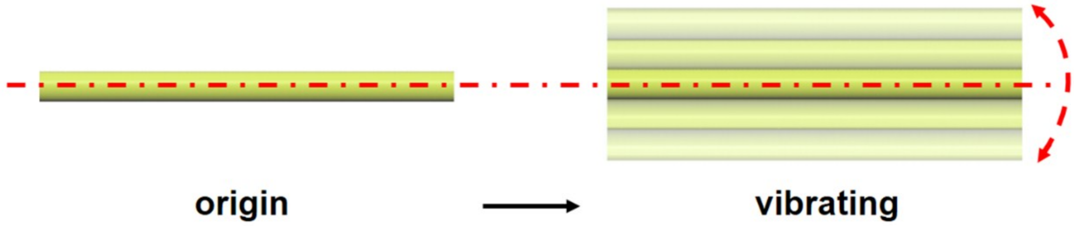

Figure S9. Schematic illustration to the vibration state of a CTNF.

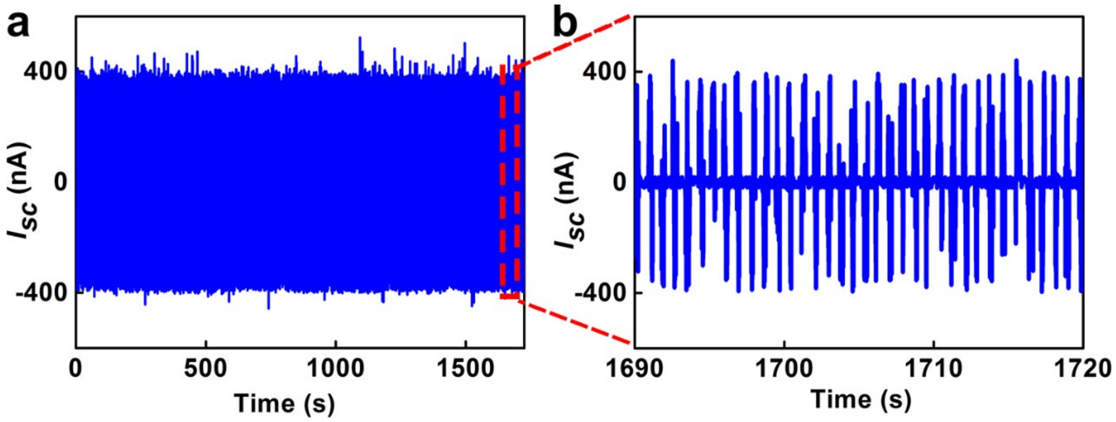

Figure S10. The evolution of I_{sc} over 2000 cycles of a CTNF under a pressing force of 50 N at a frequency of 1.2 Hz.

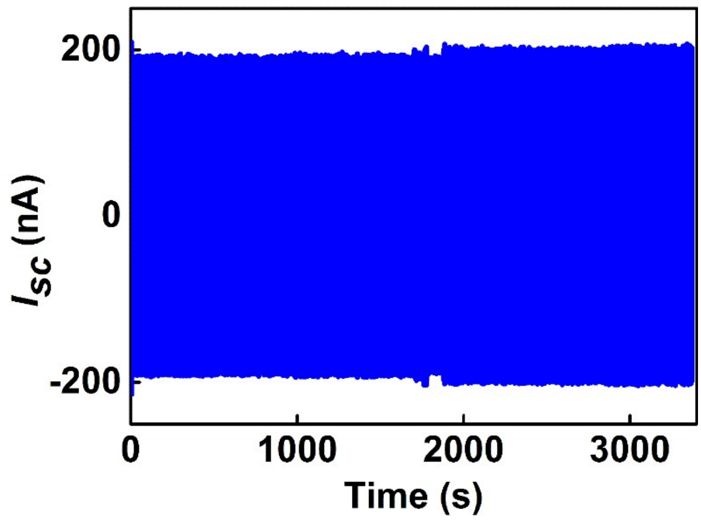

Figure S11. The evolution of I_{sc} over 8000 cycles of a CTNF under bending.

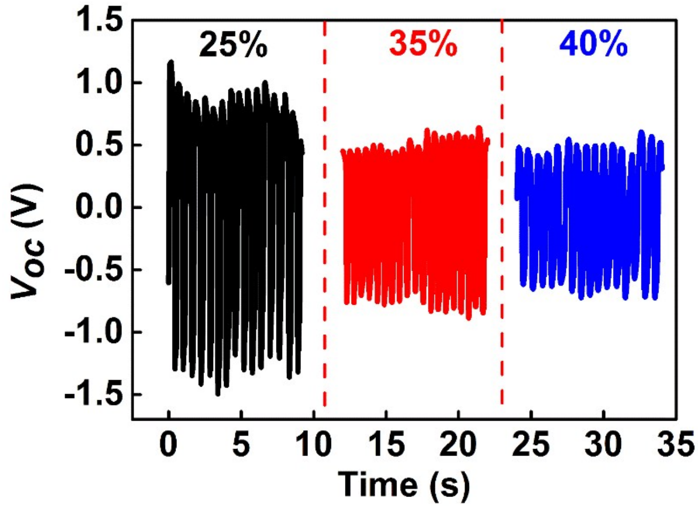

Figure S12. The V_{oc} of a CTNF by varying the humidity in environment.

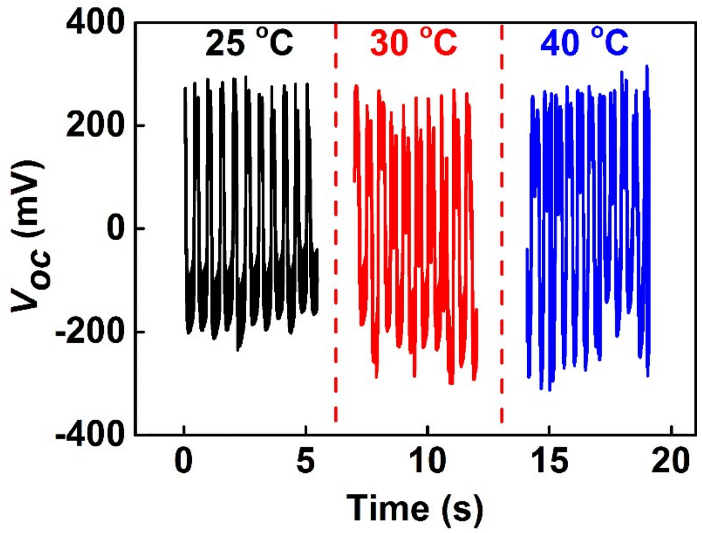

Figure S13. The V_{oc} of a CTNF under different temperatures.

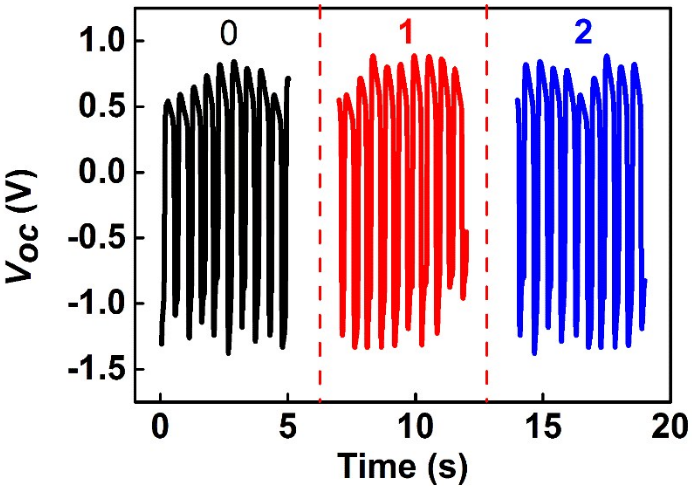

Figure S14. The V_{oc} of a CTNF before and after being washed for one and two times.

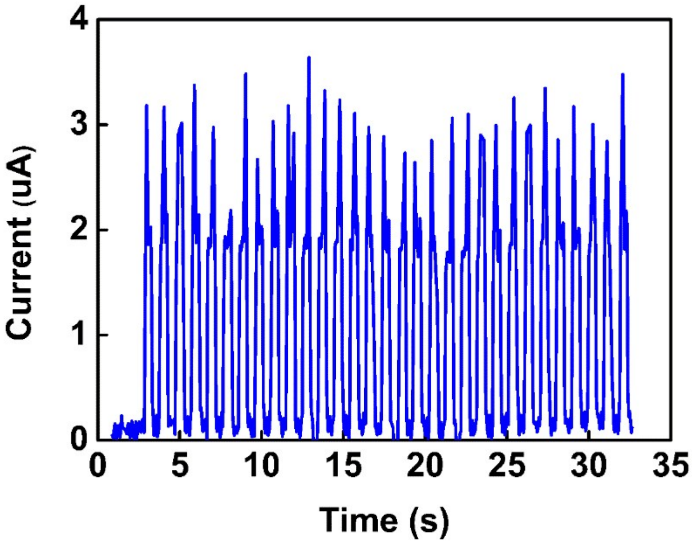

Figure S15. Rectified currents of four CTNFs connected in parallel.

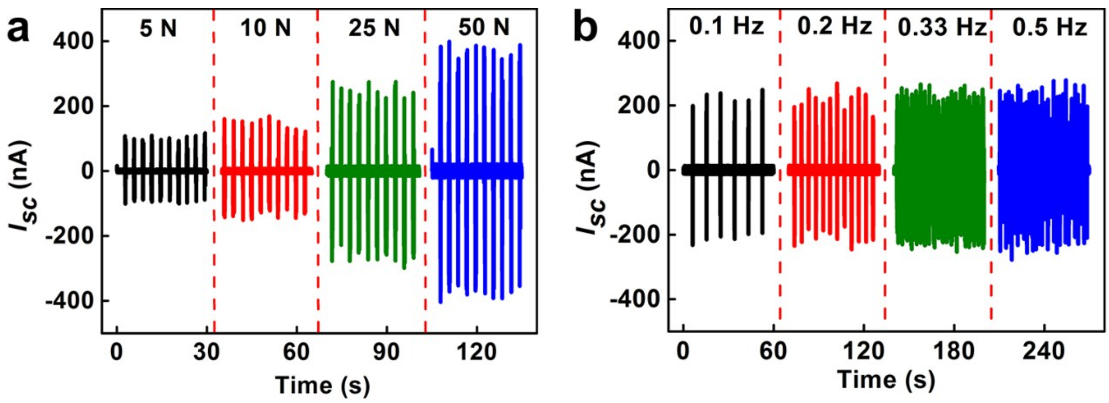

Figure S16. Influences of pressing force and frequency on the I_{sc} of the CTNF. (a) The I_{sc} of CTNF under increasing pressing forces at the frequency of 0.33 Hz. (b) The I_{sc} of CTNF under increasing frequencies at the pressing force of 25 N.

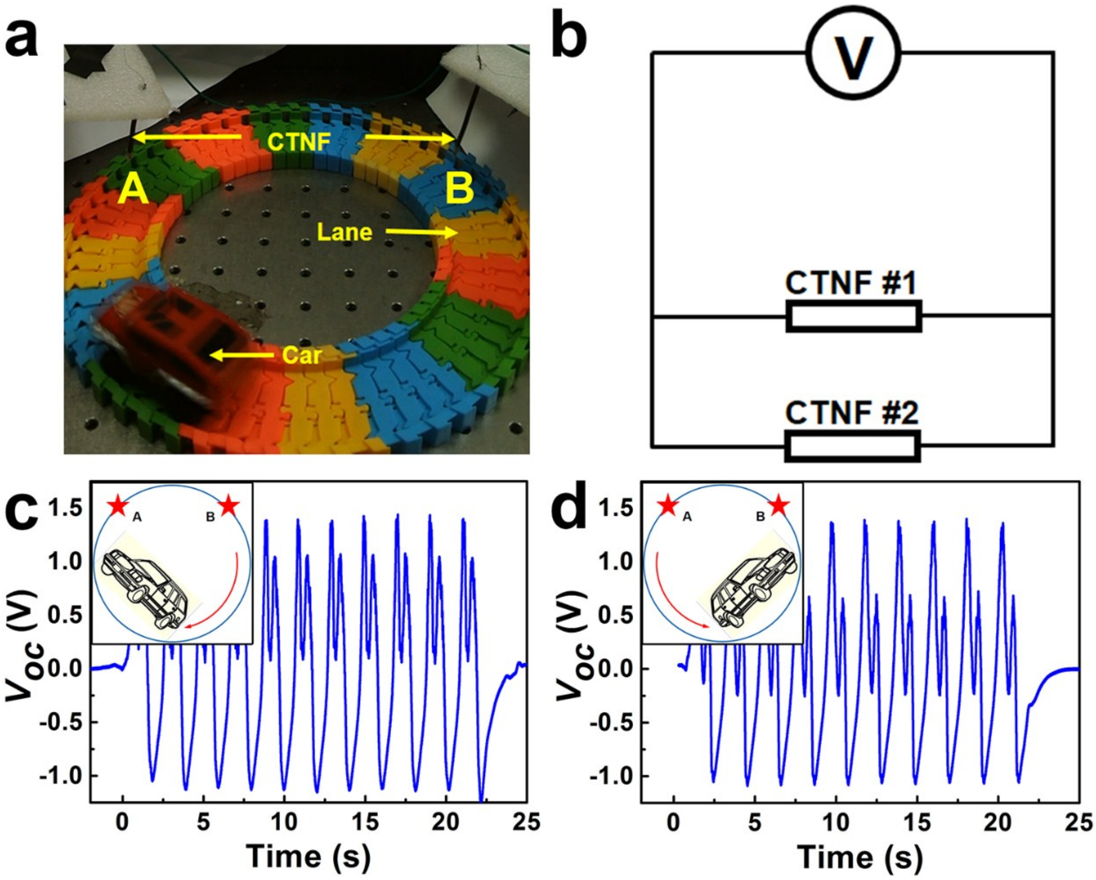

Figure S17. (a) The photograph of the experimental set-up for the detection of car direction. (b) The electric circuit of the test for two CTNFs. The V_{oc} of a car driving in (c) clockwise and (d) anticlockwise directions. The insets indicate the driving directions of the car at (c) and (d).

***Text S1*. Calculation of speed and relative deviation of car movement.**

(1) The speed of the car (V) was calculated from the following equation:

$$V = \frac{\Delta d}{\Delta t}$$

Where Δd is the length of round lane, and Δt is time interval.

(2) The relative deviation was defined as E_s, which can be calculated by using the following equation:

$$E_s = \left| \frac{V - V_0}{V_0} \right|$$

Where V is the experimental velocity, and V_0 is the actual velocity of the moving car.

Table S1. The calculation results on detecting the car velocity.

t (s)	**Δt (s)**	**V (mm/s)**	**E_s (%)**
t_1=14.273	Δt_1=2.134	V_1=327.55	0.74
t_2=16.407	Δt_2=2.009	V_2=347.93	5.43
t_3=18.416	Δt_3=2.157	V_3=324.06	1.80
t_4=20.573	Δt_4=2.104	V_4=332.22	0.67
t_5=22.677	Δt_5=2.113	V_5=330.81	0.25
t_6=24.790	Δt_6=2.147	V_6=325.57	1.34
t_7=26.937			

Where Δt is defined as the difference of initial and terminate time: $\Delta t_n = t_{n+1} - t_n$