Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Supporting Information

Natural alginate fiber-based actuator driven by water or moisture for energy harvesting and smart controller

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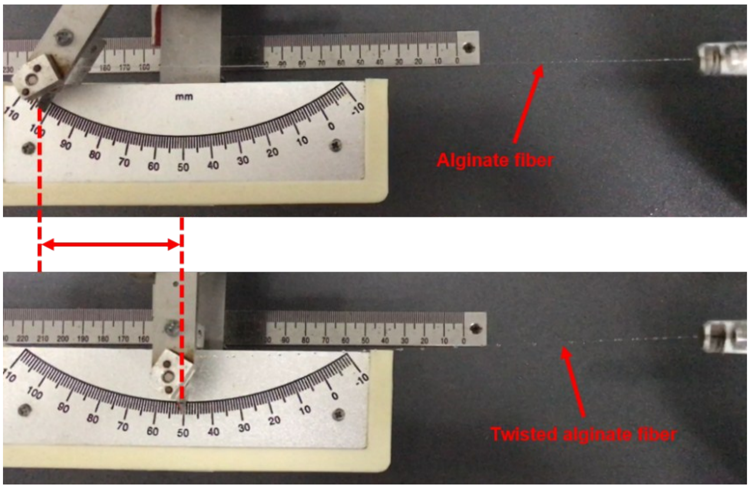

Fig.S1. Photos of alginate fiber before and after the twisting process. The red dotted line represents the change in fiber length.

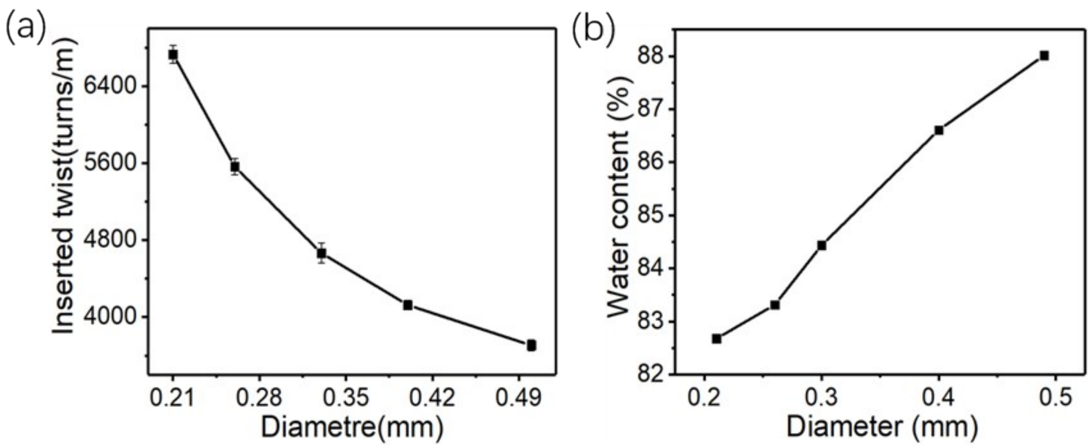

Fig.S2. (a) The maximum inserted twists of the raw alginate fiber with different diameters. (b) The water content of the raw alginate fiber obtained by wet spinning with different diameters.

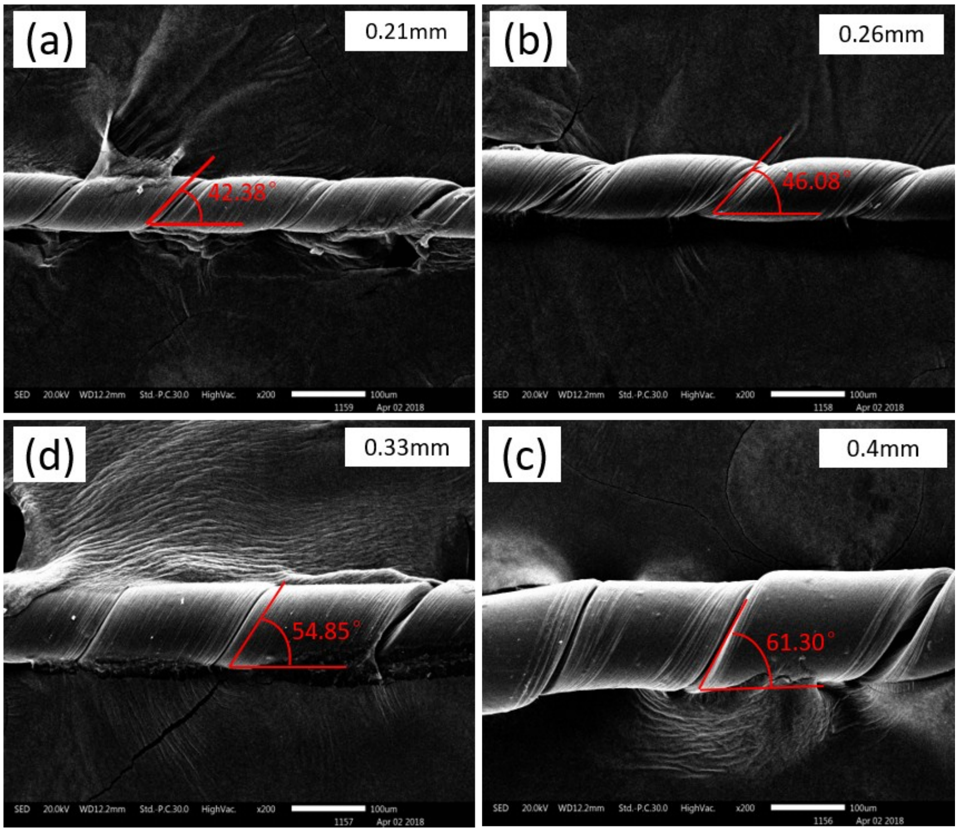

Fig.S3. SEM images of the TAFA fabricated by twisting the raw alginate fiber with different diameters of 0.21mm (a), 0.26mm (b), 0.4mm (c), 0.33mm (d). The initial applied twists were 4000 turns per meter.

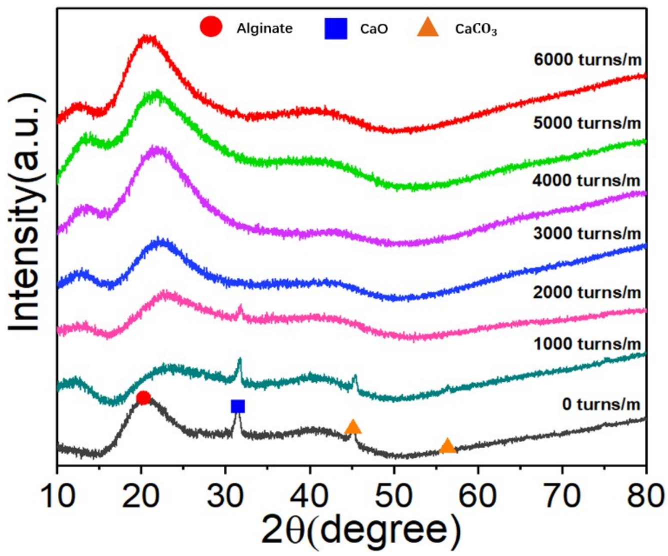

Fig.S4. The XRD spectrum of the TAFA with the fiber twists changed from 0 to 6000 turns/m.

As can be seen from the figure that with the increase of fiber twists, the crystalline peak of the alginate has not changed obviously, while the crystalline peak of calcium oxide (CaO) and calcium carbonate ($CaCO_3$) disappeared, which increased the hygroscopicity of the TAFA in a certain extent.

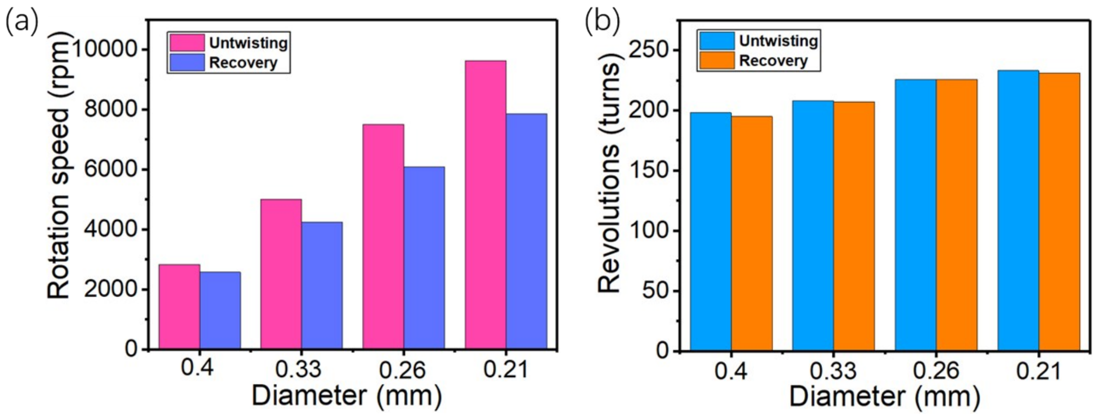

Fig.S5. Rotation speed (a) and full revolutions (b) of the TAFA fabricated by twisting the gel state alginate fiber with different diameters. The initial applied twists were 4000 turns per meter.

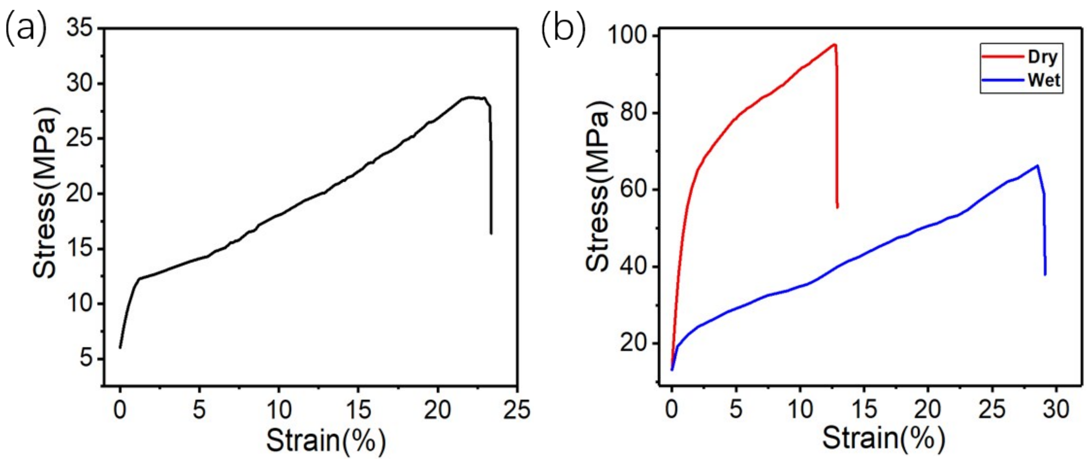

Fig.S6. Tensile strength of the untwisted alginate fiber (a), and 6000 turns per meter (b), where the red line and blue line respectively represented the twisted fiber that were in dry state and wetting state when stimulated by water.

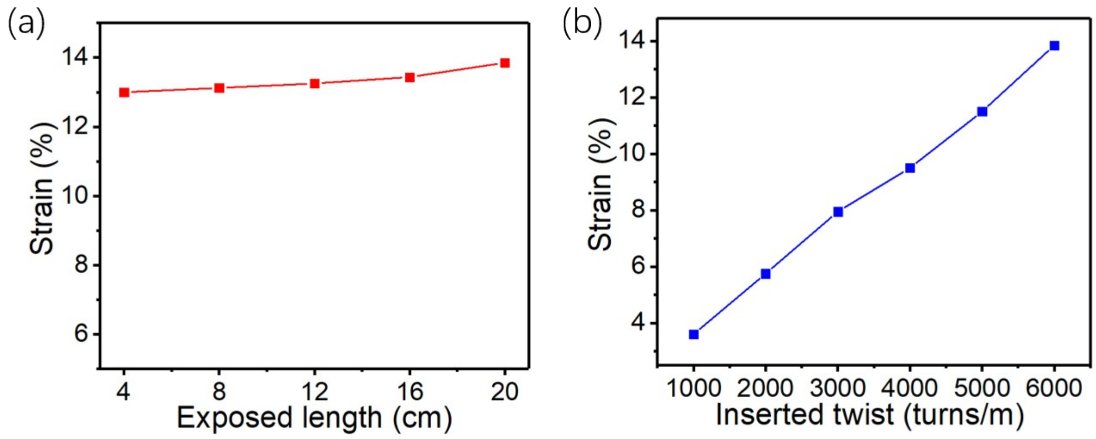

Fig.S7. Strain changes (elongation changes) of the TAFA with different exposed length (a) and fiber twists (b).

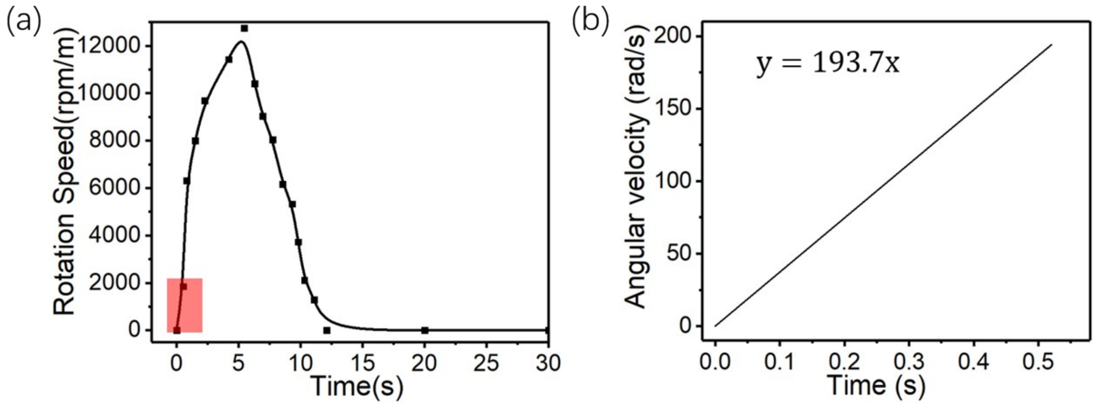

Fig.S8. (a) The rotation speed of the TAFA with 6000 turns/m as a function of time during untwisting process. (b) The angular velocity fitting curve at the beginning of the untwisting process (red shaded part in (a)).

The TAFA reached 194rad/s in 0.58s (Fig.S6(b)), the angular acceleration was calculated as follows:

$$\alpha = \frac{d_v}{d_t} = \frac{193.7}{0.58} \text{ rad/s}^2 = 372.5 \text{ rad/s}^2$$

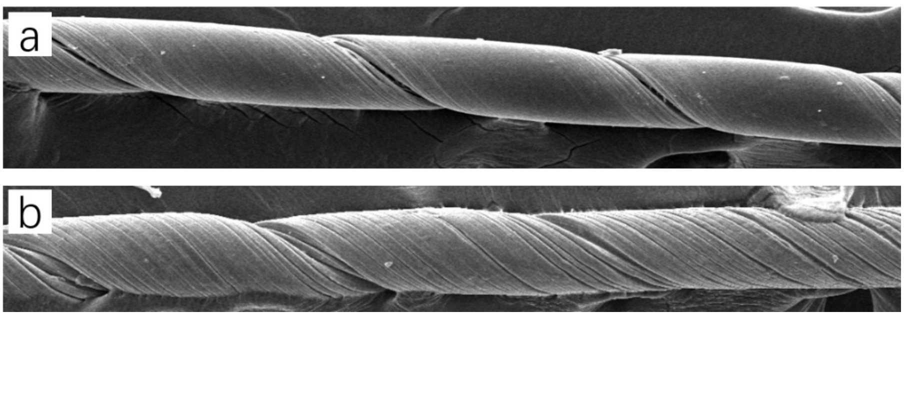

Fig.S9. SEM images of the TAFA before (a), and after 400 cycles of the twisted fiber when stimulated by water (b).

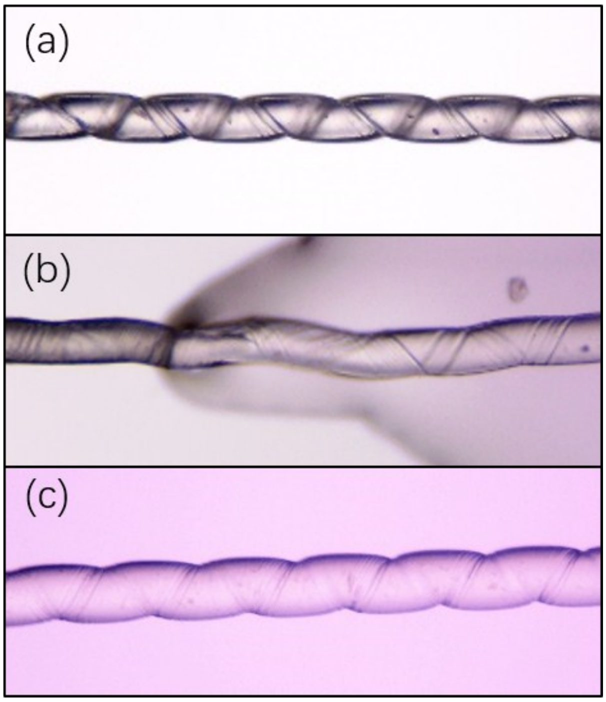

Fig.S10. Optical micrographs of theTAFA with 6000 turns per meter, (a) dry state when twisting from the raw alginate fiber (a), semi-wetting state in water (b), completely swollen in water (c).

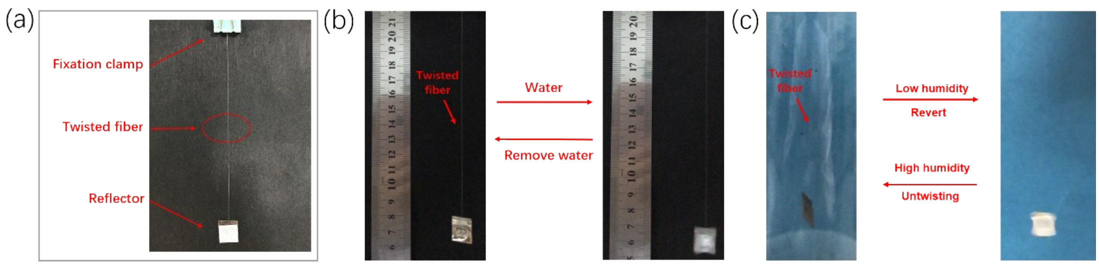

Fig.S11. (a) Compositions of the TAFA during the testing process, including the fixation clamp used for holding the fiber on the shelf, the twisted fiber which acted as the active region and the reflector (0.2g) which use for recording the rotation speed and revolutions. Reversible rotational behavior of the TAFA under water (b) and moisture stimulations from high humidity (left, RH=90%) to low humidity (right, RH=30%) (c).

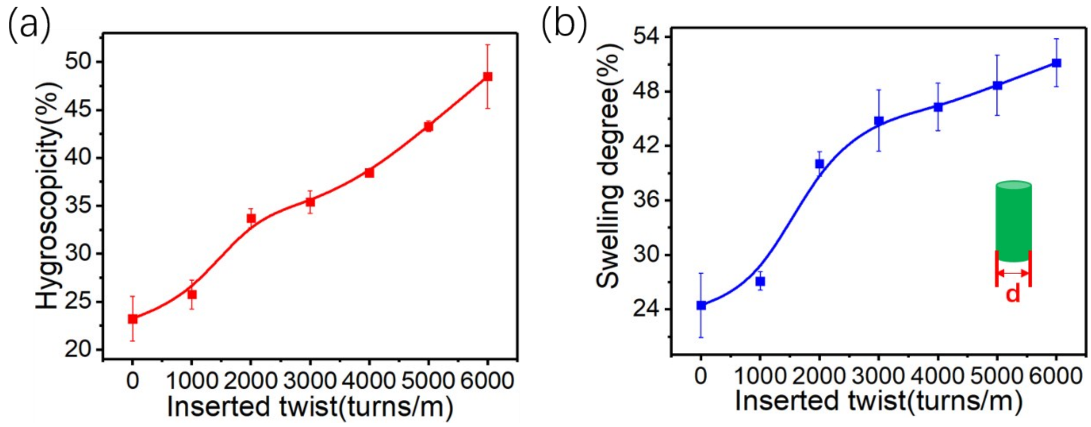

Fig.S12. The hygroscopicity, as well as the swelling degree in diametral direction versus theTAFA with inserted twist of 1000 to 6000 turns/m.

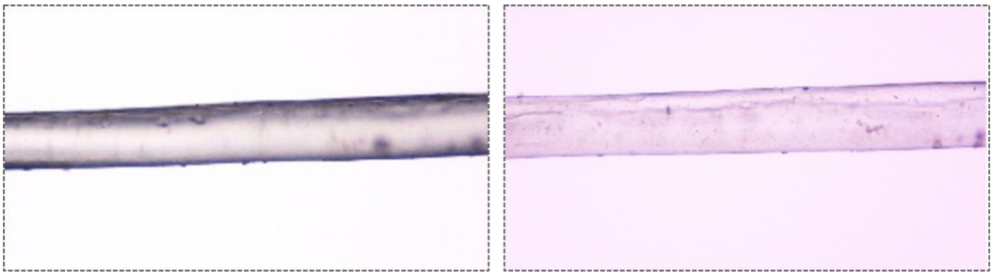

Fig.S13. Optical micrographs of the untwisted alginate fiber before (a) and after (b) swelling in water.

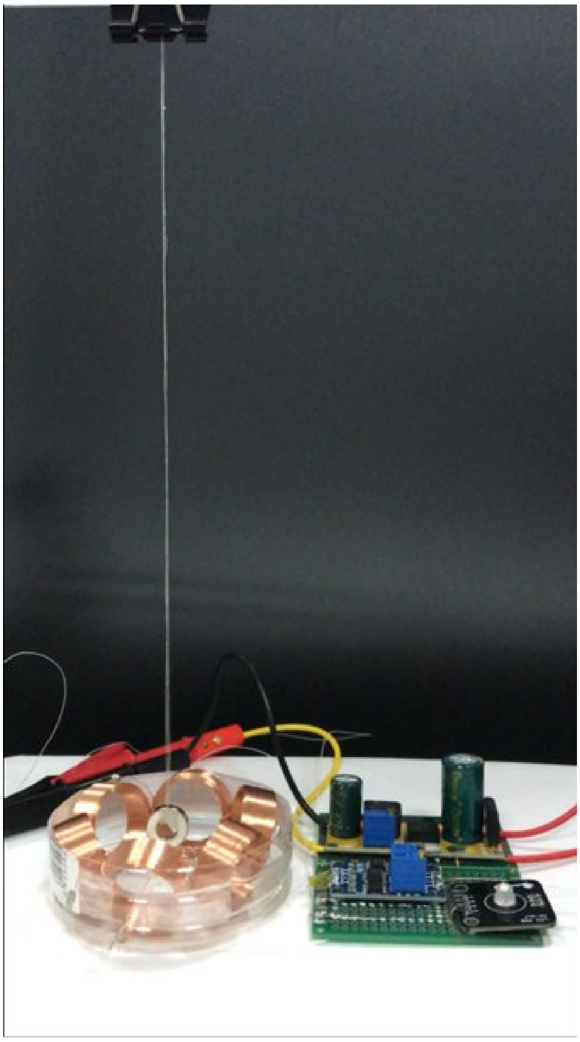

Fig.S14. Photography of the designed fiber-based water generator, as well as the corresponding amplification and AC-DC conversion circuit.

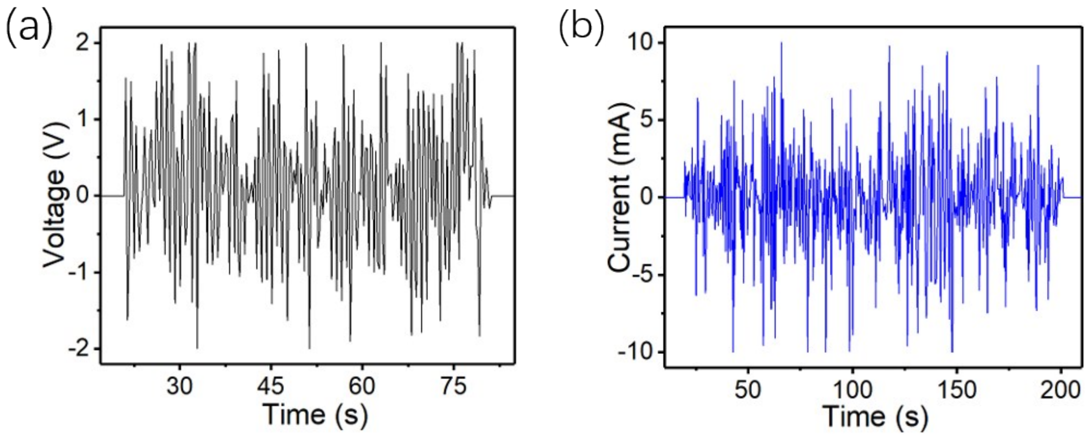

Fig.S15. The amplification of induction voltage (a) and current (b) of the fiber-based generator under water stimulation.

In this paper, different types of spinneriate were selected for wet spinning, and the

	This work	Torsional graphene-fiber motor[1]	A Mechanically actuating carbon-nanotube fiber[2]	Hybrid carbon nanotube yarn muscles[3]	MWCNTs helical fibre actuators[4]	Hybrid MWCNT yarn muscle[5]	Strong, Twist-Stable Carbon Nanotube Yarns and Muscles[6]
Materials	**Sodium alginate**	GO	MWCNT	Carbon nanotube yarns	MWCNT	MWCNT, Wax	Carbon nanotube yarns
Structural typing	**Single fiber**	Single fiber	Multiple fiber bundle	Single fiber made form CNT ribbon	Multiple fiber bundle	Multiple fiber bundle	Single fiber made from CNT yarns
Stimulus	**Water, Moisture**	Moisture	Water, Moisture	Water	Solvents (alcohol) and vapours	Thermal	Thermal
Preparation	**1**	2	4	3	3	4	3
Cost of production	**1**	3	4	3	4	4	4
Rotation speed (rpm)	**13000**	5190	700	31000	6361	12000	160
Revolution (turns/m)	**2100**	1635	160	3000	2050	—	—
Torque (N · m/kg)	**5.96**	0.082	0.4	0.52	0.63	8.42	4.12
Cyclic stability	**400 cycles**	500 cycles	—	50 cycles	50 cycles	Millions of cycles	—
Current output	**200 μA**	40μA	—	—	120μA	—	—

spinneriate types, as well as the corresponding diameters are shown in the table 1.

Table S1. The diameter of different spinneriate types.

Spinneriate type	27#	25#	23#	22#	21#
Diameter (mm)	0.21	0.26	0.33	0.4	0.5

Voltage output	**18 mV**	1 mV	—	—	—	—	—

Table S2. Comparisons between the TAFA and previously reported fiber-based actuator

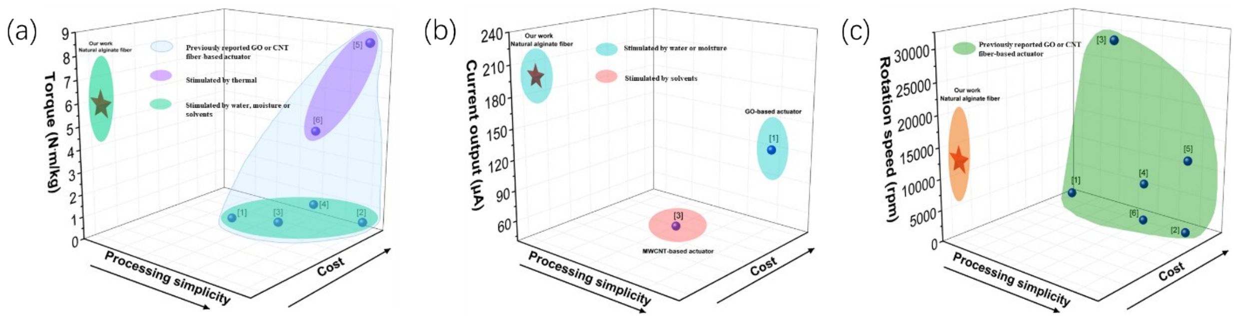

Fig.S16. Model diagram based on the data in Table S2

Table S3. The acoustic velocity of the TAFA with different fiber twists.

Fiber twists (turns/m)	0	1000	2000	3000	4000	5000	6000
(Ⅰ)Acoustic velocity (km/s)	1.35	1.67	2.19	2.40	2.53	2.61	2.63
(Ⅱ)Acoustic velocity (km/s)	-	1.85	2.25	2.44	2.59	2.65	2.66
(Ⅲ)Acoustic velocity (km/s)	-	1.82	2.24	2.45	2.58	2.64	2.65

The orientation was calculated by the following formula[7]:

$$f_s = \left(1 - \frac{C_0^2}{C^2}\right) \times 100\% \qquad (2)$$

Where f_s was the orientation degree, C_0 (km/s) was the propagation speed of acoustic waves in the unoriented samples, C (km/s) was the propagation speed of acoustic waves in the oriented samples. The detailed calculation process was shown in Table S3.

We defined the propagation speed of acoustic waves in untwisted fibers (0 turns per meter) as C_0, the fiber orientation Ⅰ of TAFA with different twists were calculated as follows:

$$F_{1000} = \left(1 - \frac{1.35^2}{1.67^2}\right) \times 100\% = 34.52\%$$

$$F_{2000} = (1-\frac{1.35^2}{2.19^2}) \times 100\% = 61.76\%$$

$$F_{3000} = (1-\frac{1.35^2}{2.40^2}) \times 100\% = 68.31\%$$

$$F_{4000} = (1-\frac{1.35^2}{2.53^2}) \times 100\% = 71.43\%$$

$$F_{5000} = (1-\frac{1.35^2}{2.61^2}) \times 100\% = 73.28\%$$

$$F_{6000} = (1-\frac{1.35^2}{2.63^2}) \times 100\% = 73.56\%$$

The fiber orientation Ⅱ of TAFA with different twists were calculated as follows:

$$F_{1000} = (1-\frac{1.35^2}{1.85^2}) \times 100\% = 46.28\%$$

$$F_{2000} = (1-\frac{1.35^2}{2.25^2}) \times 100\% = 63.74\%$$

$$F_{3000} = (1-\frac{1.35^2}{2.44^2}) \times 100\% = 69.22\%$$

$$F_{4000} = (1-\frac{1.35^2}{2.59^2}) \times 100\% = 72.62\%$$

$$F_{5000} = (1-\frac{1.35^2}{2.65^2}) \times 100\% = 74.02\%$$

$$F_{6000} = (1-\frac{1.35^2}{2.66^2}) \times 100\% = 74.24\%$$

The fiber orientation Ⅲ of TAFA with different twists were calculated as follows:

$$F_{1000} = (1-\frac{1.35^2}{1.82^2}) \times 100\% = 44.94\%$$

$$F_{2000} = (1-\frac{1.35^2}{2.24^2}) \times 100\% = 63.47\%$$

$$F_{3000} = (1 - \frac{1.35^2}{2.45^2}) \times 100\% = 69.47\%$$

$$F_{4000} = (1 - \frac{1.35^2}{2.58^2}) \times 100\% = 72.62\%$$

$$F_{5000} = (1 - \frac{1.35^2}{2.64^2}) \times 100\% = 73.85\%$$

$$F_{6000} = (1 - \frac{1.35^2}{2.65^2}) \times 100\% = 74.02\%$$

Movie 1. The twisting process of the TAFA on the twisting machine.
Movie 2. The reversible rotational motion of the TAFA under water stimulation.
Movie 3. The swelling process of the TAFA in water.
Movie 4. The TAFA was used for generating electricity and lighting LED lights.
Movie 5. The closing of the smart rainy curtain under water stimulation.
Movie 6. The automatic opening process of the smart rainy curtain as soon as the water molecules evaporated.
Movie 7. The lifting and descending process of the smart crane under alternating humidity stimulation.

References

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