Supporting Information

A weavable and wearable polymer ultrasonic transducer with large bandwidth

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Note S1. The design of the matching layer.

The transmittance of the ultrasonic wave relies on the acoustic impedance and thickness of the matching layer according to the formula

$$t_I = \frac{4R_1R_3}{(R_1+R_3)^2\cos(\frac{2\pi}{\lambda}D)^2 + (R_2+\frac{R_1R_3}{R_2})^2\sin(\frac{2\pi}{\lambda}D)^2}$$

where t_I is the transmittance, R_1, R_2 and R_3 are the acoustic impedance of the tissue, matching layer and PVDF, respectively; λ is the wave length of the sound in the matching layer; D is the thickness of the matching layer. When

$$D = \frac{\lambda}{4}$$

$$R_2 = \sqrt{R_1R_3}\ ,$$

the transmittance gets the maximum value 1. The material and thickness of the matching layer rely on this principle. When

$$D \ll \lambda$$

the transmittance is approximately

$$t_I = \frac{4R_1R_3}{(R_1+R_3)^2}$$

where the layer could be seen as nonexistent. Thus, the thickness of the adhesion layer should be much less than the wavelength of the ultrasonic wave.

Note S2. The removal of the noise.

It is important to remove the noise during the measuring and signal processing process because of the weak transmit signal of PVDF, which causes low SNR. During the measurement process, the electromagnetic wave will cause serious disturbance. The electromagnetic waves come from the electric appliance nearby, with 50 Hz frequency, as well as the port of the signal generator or wide-band amplifier. The shielding layer is necessary for PVDF devices, especially when the CW is transmitted. The bandpass filter will eliminate the electromagnetic wave with 50 Hz frequency. The lowpass filter can reduce the ripple of the IQ signals. To remove the influence of the noise caused by daily movement (typically less than 100 Hz) in wearable applications, a high-pass filter of 500 Hz was used during signal processing.

Note S3. The principle of the ultrasonic Doppler effect.

The ultrasonic echo has the frequency deviation compared with the original ultrasonic wave according to the formula:

$$f_d = f'' - f_0 = 2\frac{v}{c}f_0\cos\theta$$

where f_d is the frequency deviation; f_0 is the original frequency of the original ultrasonic wave; f'' is the frequency of the ultrasonic echo; v is the velocity of the blood flow; c is the speed of the sound and θ is the Doppler angle, which is the angle between the transmission direction of ultrasonic wave and the flow velocity[42,43]. The velocity distribution is in direct proportion to the frequency deviation, which can be achieved after the signal processing including demodulation, filtering and Fourier transform (see more in Methods).

Note S4. The principle of the vascular wall measurement.

The pulse wave was used in the measurements of vascular wall thickness. The interfaces of the vascular wall will reflect the ultrasonic wave. The thickness of the vascular wall can be calculated by measuring the time difference between the transmitting wave and the reflecting wave according to the relationship

$$2d = \mathrm{c}(t_r - t_t)$$

where d is the thickness of the vascular wall; c is the speed of the sound; t_r is the time of the received ultrasound echo; t_t is the time of the transmitted ultrasound wave.

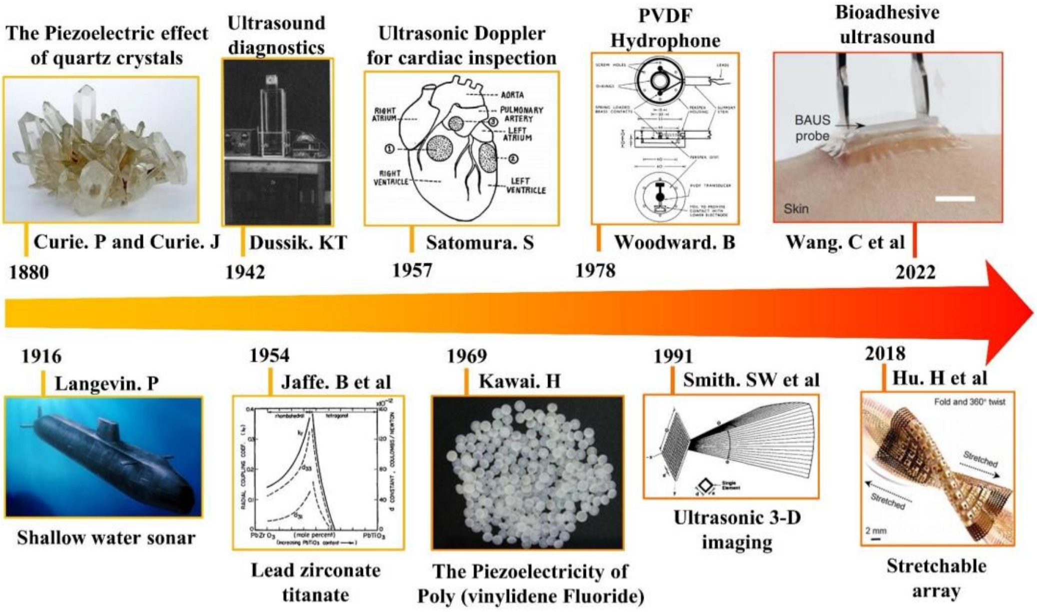

Figure S1. The development history of the ultrasonic technique [11, 18, 21-30].

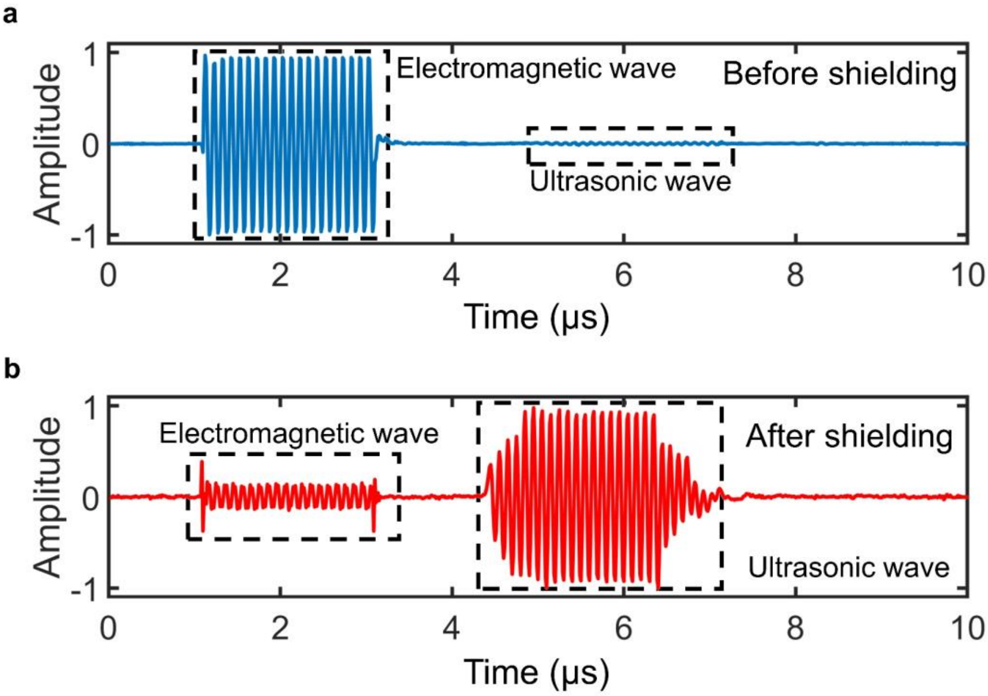

Figure S2. Comparisons between the sound (ultrasonic wave) and the noise (electromagnetic wave) with (b) and without (a) the shielding layer.

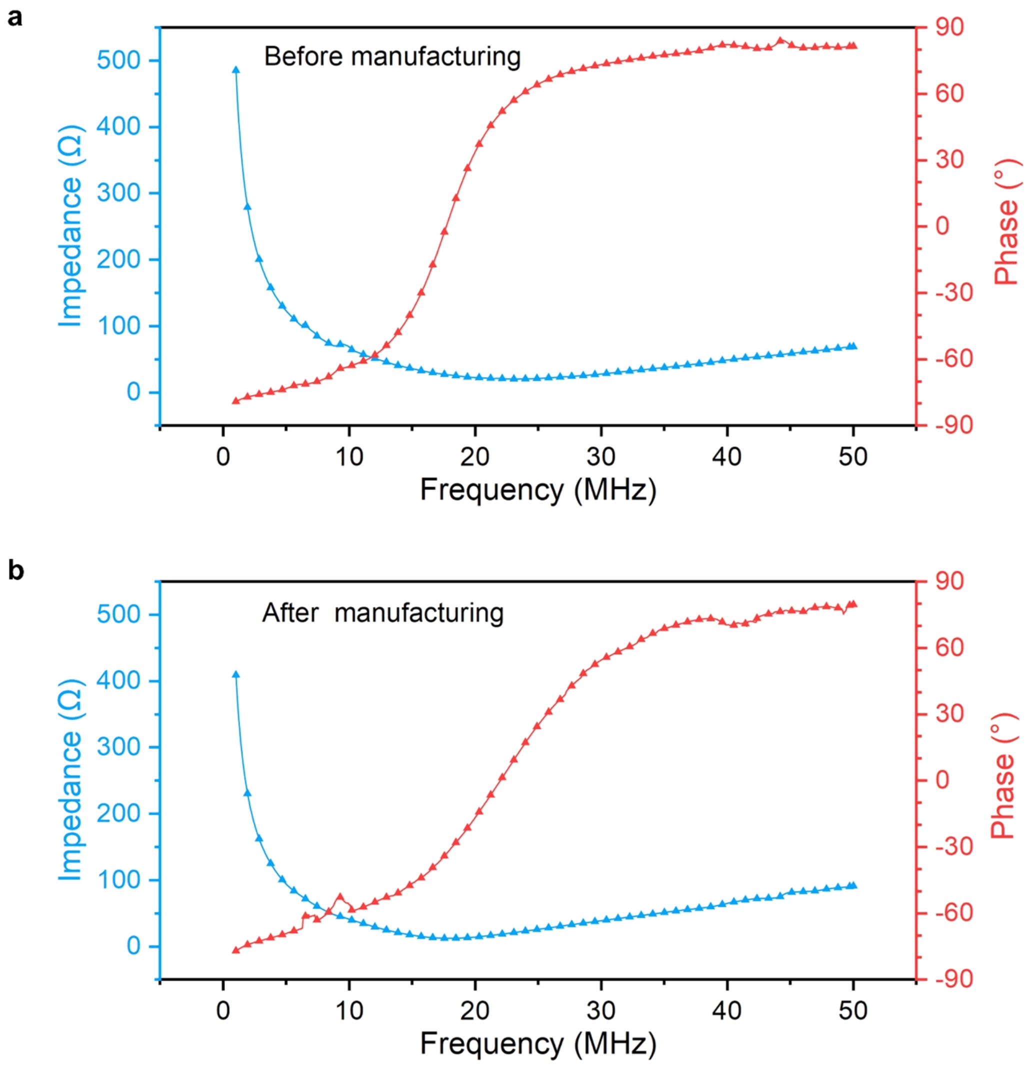

Figure S3. (a) The impedance (blue line) and phase angle (red line) spectrum of the PVDF. (b) The impedance (blue line) and phase angle (red line) spectrum of the PUT.

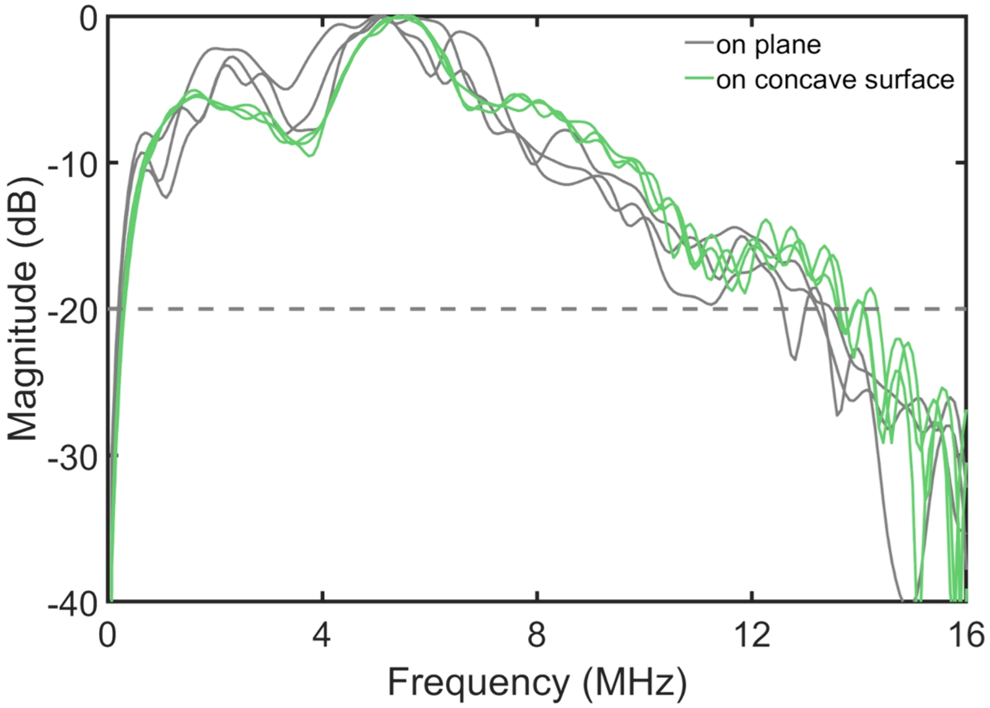

Figure S4. The bandwidth of the PUT attached to the concave surface.

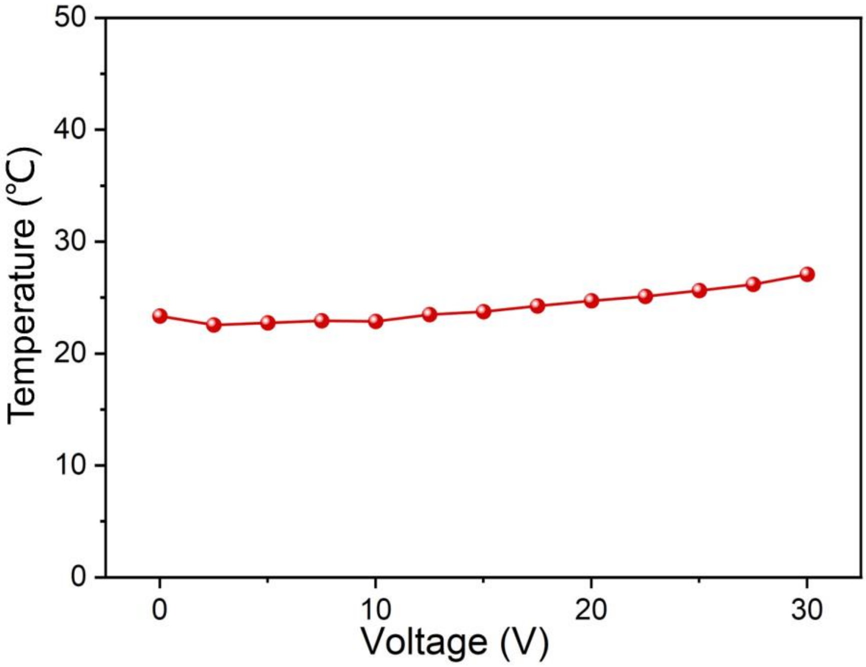

Figure S5. The relationship between the temperature of the PUT and the voltage applied on the PUT.

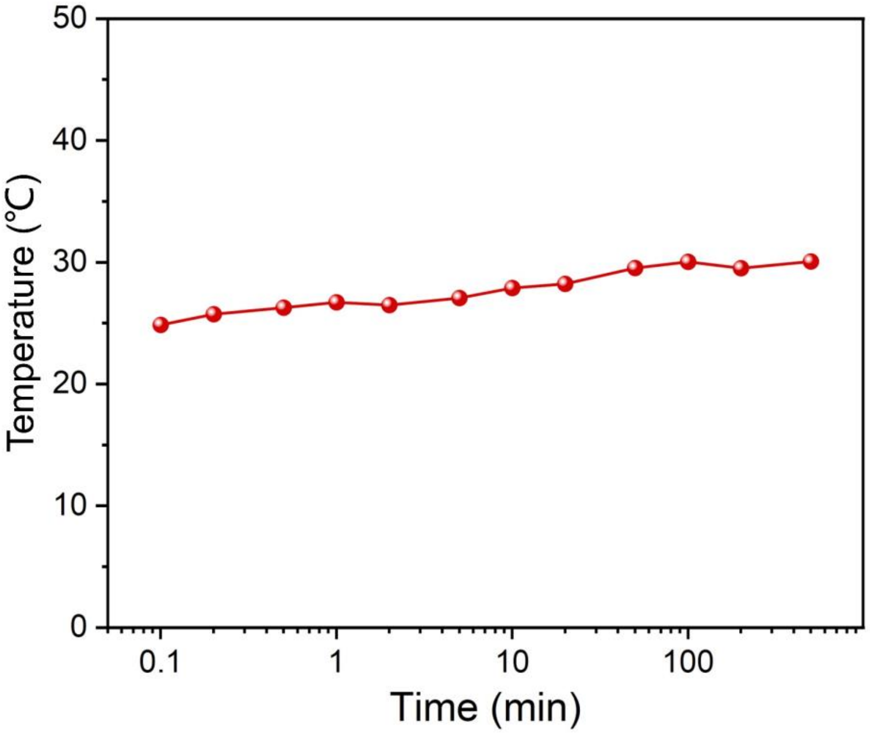

Figure S6. The relationship between the temperature of PUT and the continuous working time.

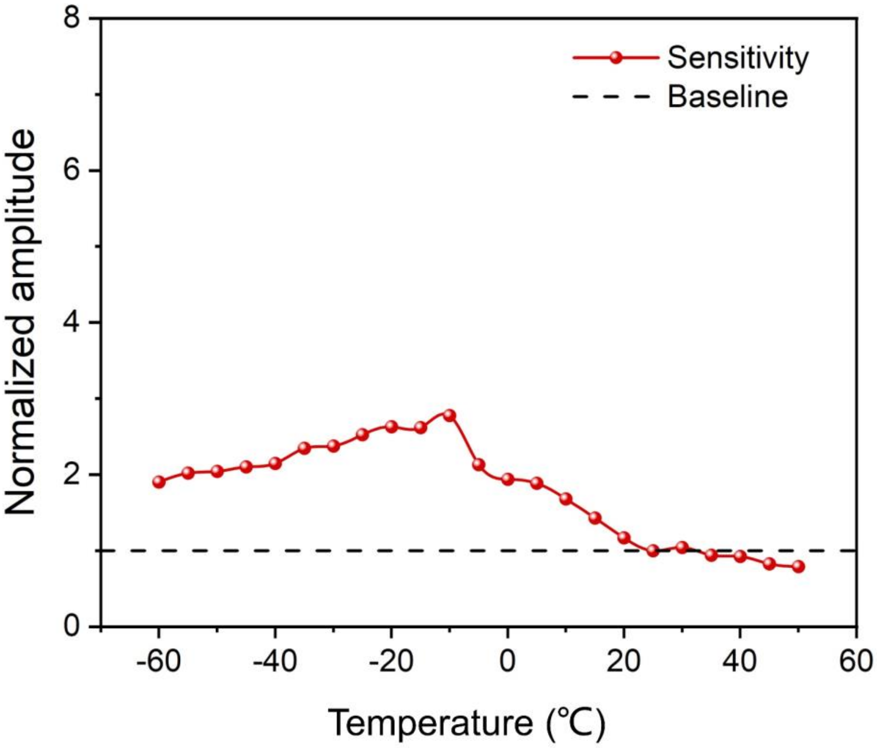

Figure S7. The relationship between the received echo amplitude and the circumstance temperature.

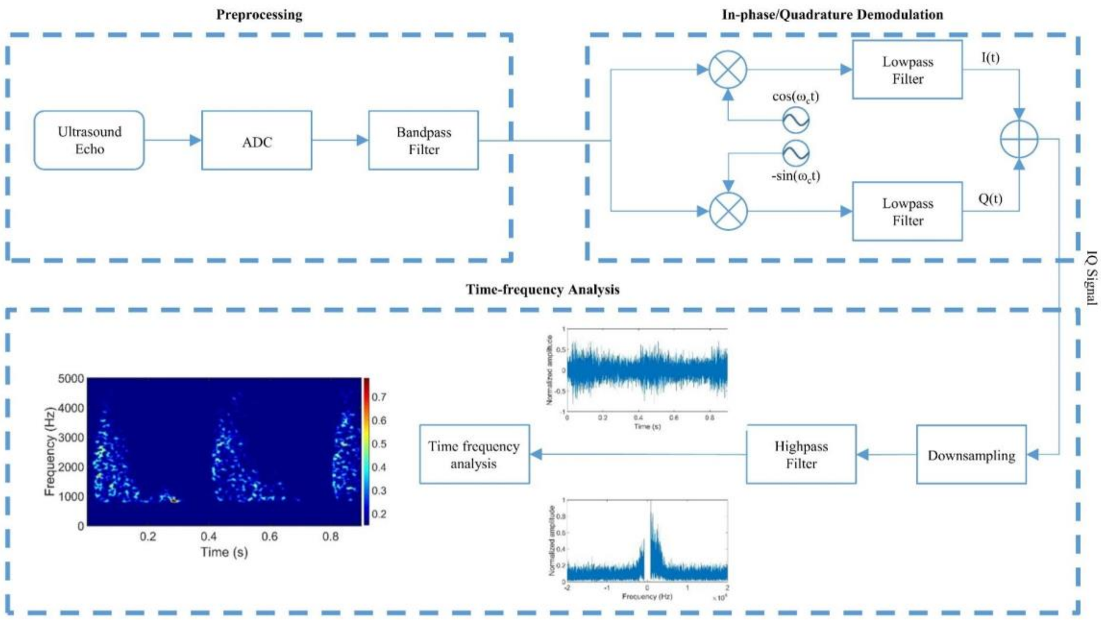

Figure S8. The procedure of signal processing. ω_c is the angular frequency of the transmitted wave.

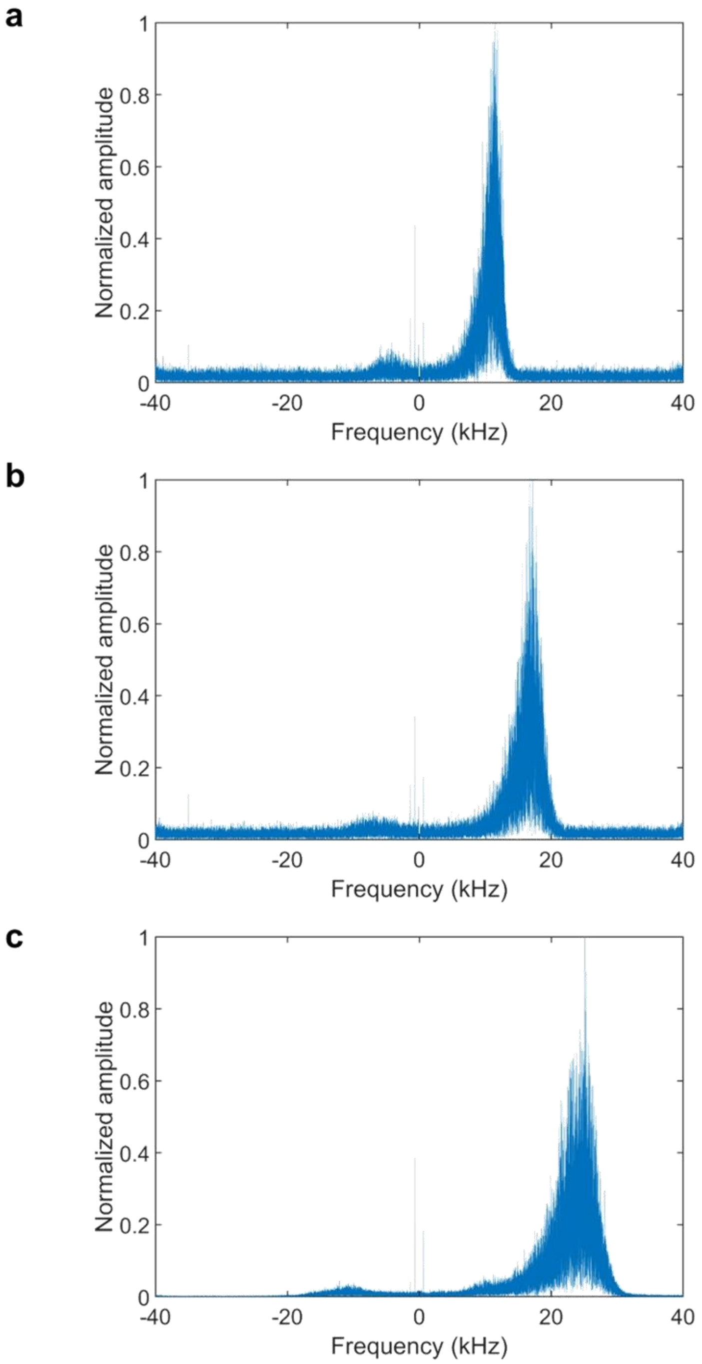

Figure S9. The frequency spectrum of the frequency deviation when the flow velocity is (a) 300, (b) 450 and (c) 600 L/h in the phantom.

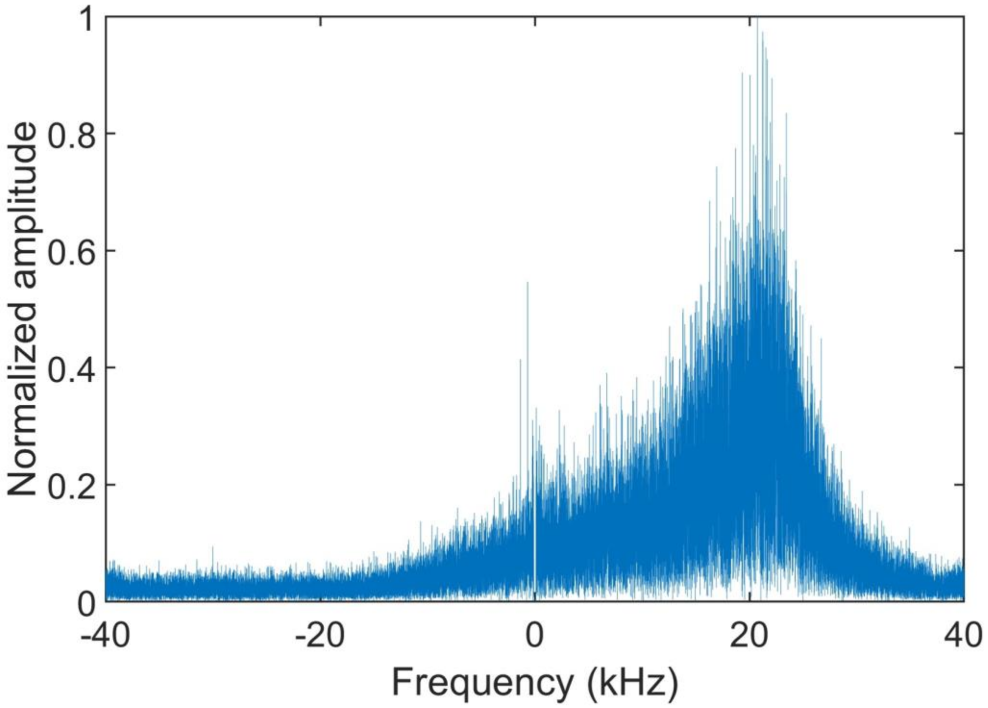

Figure S10. The frequency spectrum of the frequency deviation when the channel is narrowing at a flow velocity of 600 L/h in the phantom.

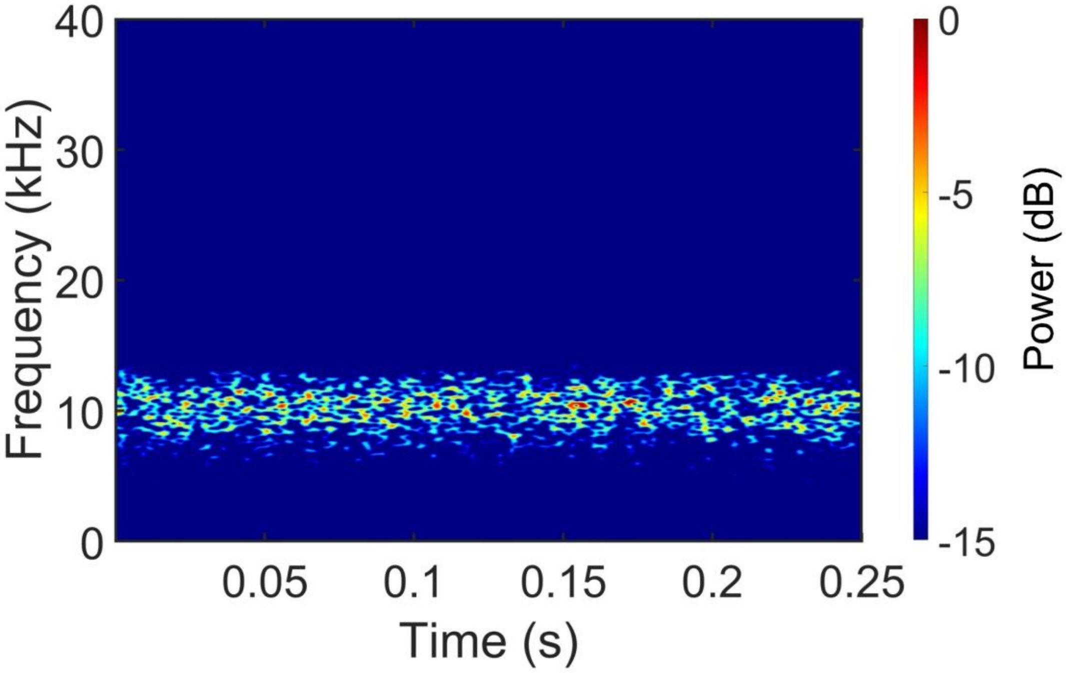

Figure S11. Time frequency analysis of the frequency deviation when the surface of the phantom is concave.

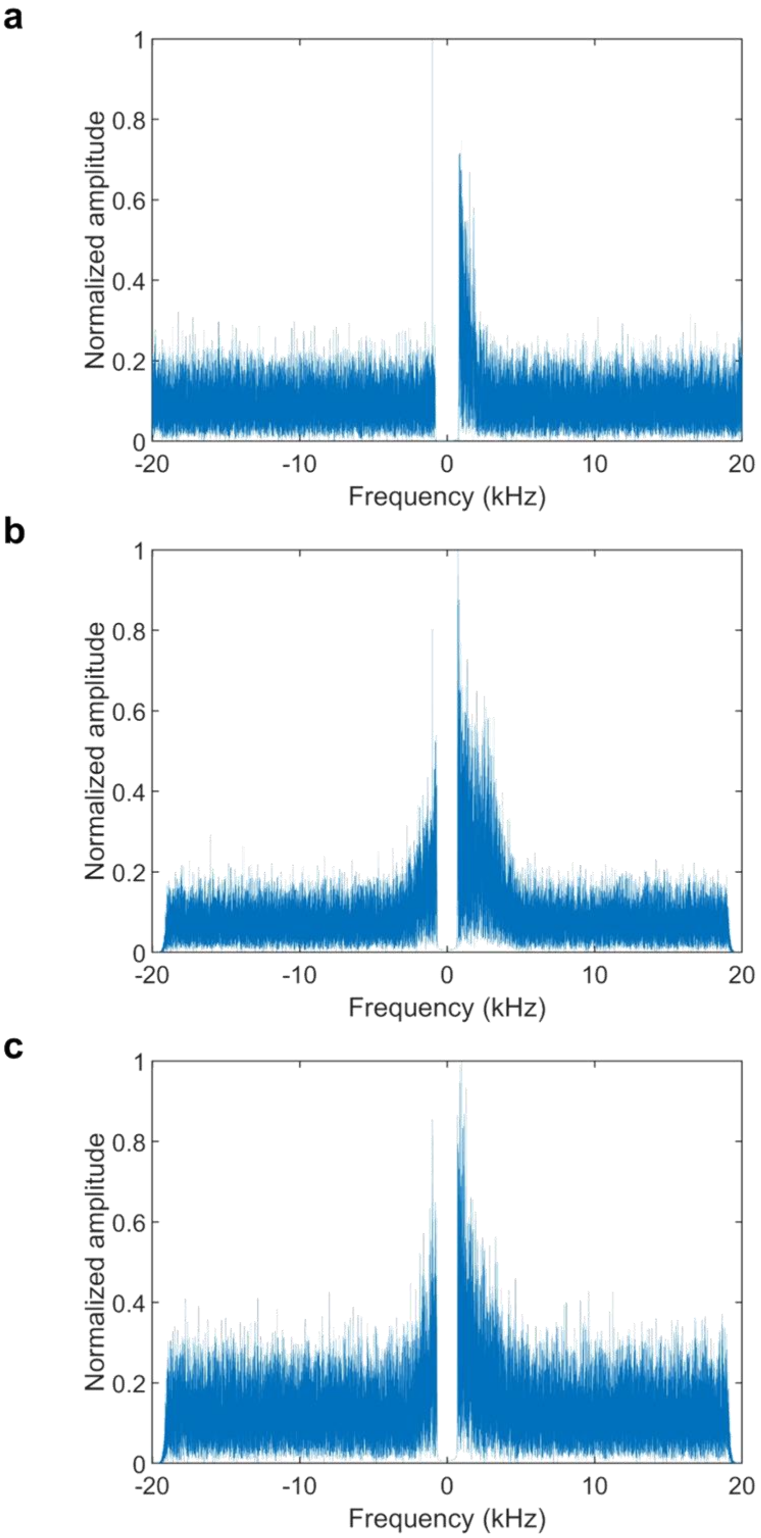

Figure S12. The frequency spectrum of the frequency deviation measured on the carotid artery before running (**a**), right after running (**b**) and after resting for 5 minutes (**c**).

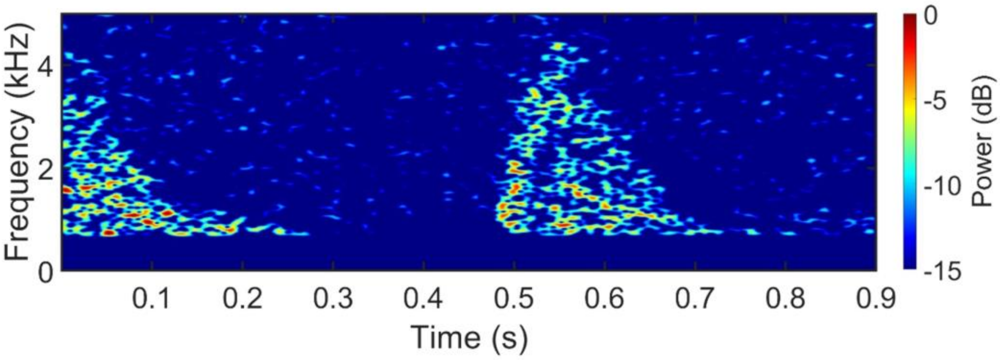

Figure S13. The time frequency analysis of the frequency deviation measured on the carotid artery after resting for 5 minutes.

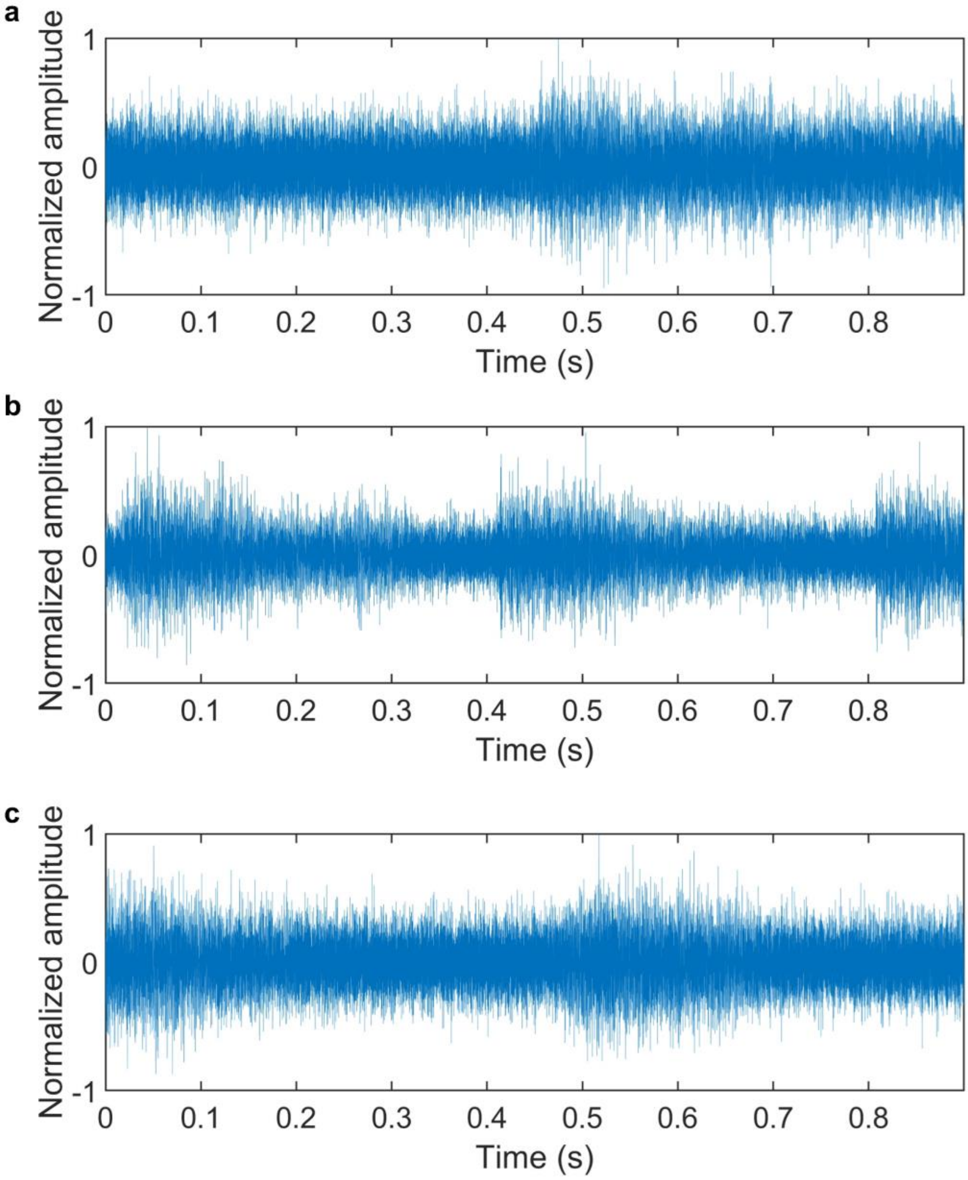

Figure S14. The time domain signal of the frequency deviation measured on the carotid artery before running (a), right after running (b) and after resting for 5 minutes (c).

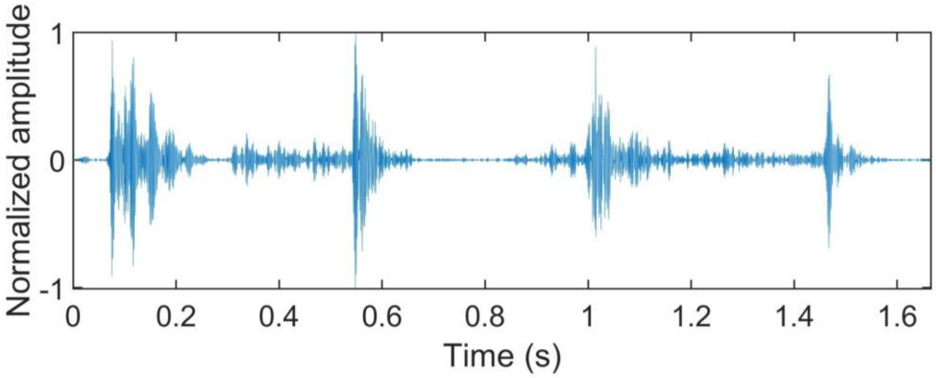

Figure S15. The time domain signal of the frequency deviation measured on the cardiac vessel.

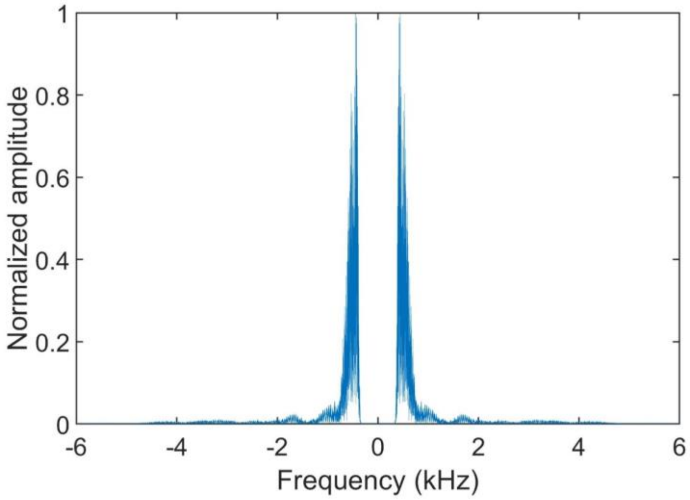

Figure S16. The frequency spectrum of the frequency deviation measured on the cardiac vessel.

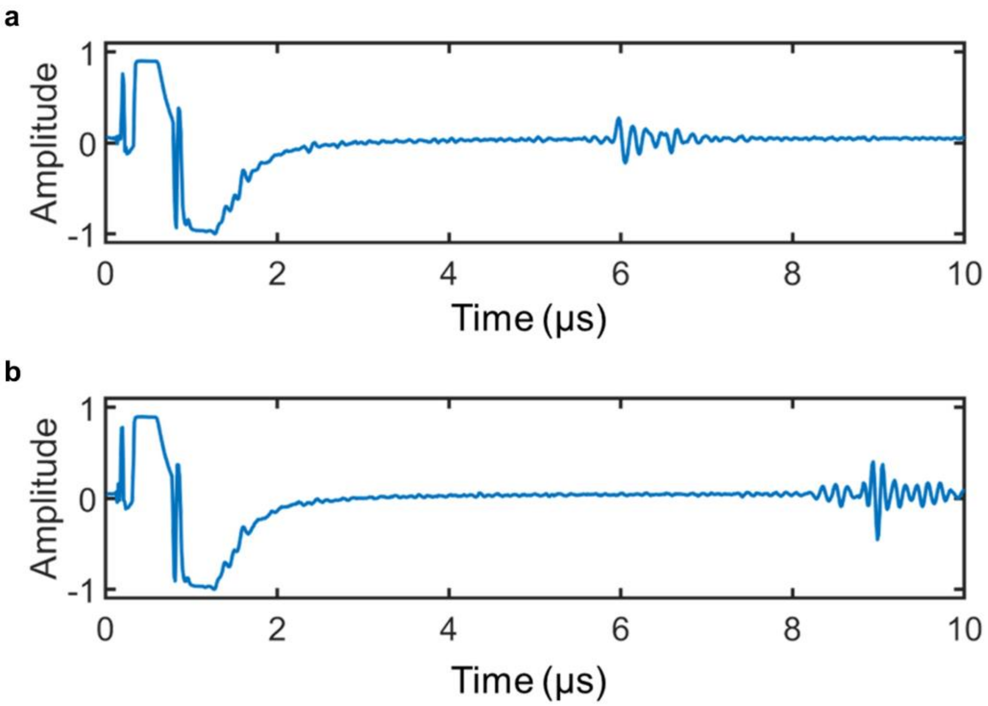

Figure S17. The received echo of the PUT attached to the vascular wall of the bovine vessel of the thickness of (a) 3.4 mm and (b) 5.9 mm.

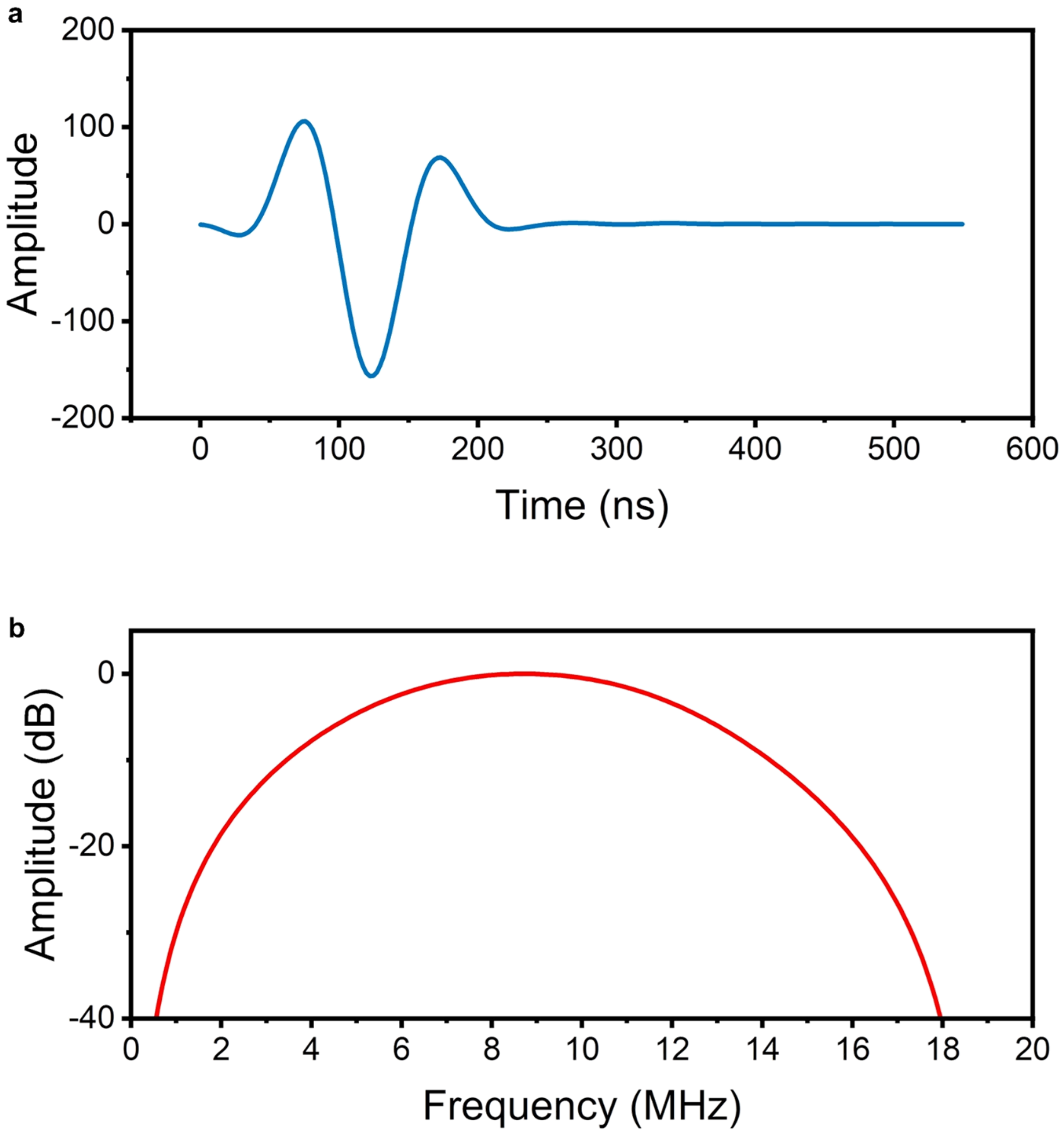

Figure S18. (a) The simulated time domain curve of the pulse-echo signals. (b) The simulated frequency response curve.

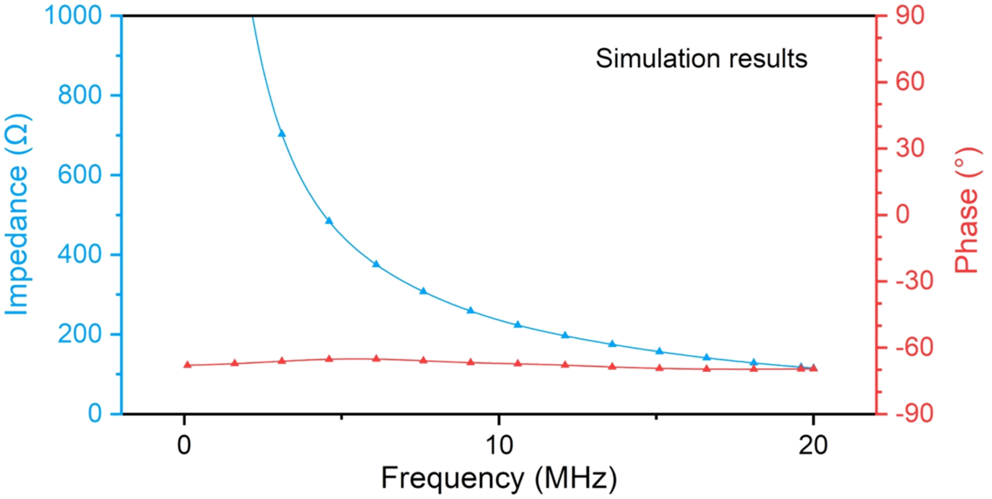

Figure S19. The simulated impedance (blue line) and phase angle (red line) spectrum of the PUT.

Table S1. Acoustic impedance of the common polymer materials.

Material	**Acoustic Impedance (MRayl)**
PU	2.38
PE	1.83
PET	3.12
PI	3.38
PVC	3.30

Table S2. Parameters of the PZT and its composites used in the bandwidth measurements.

Material	**PZT**	**1-3 composite PZT**
Central Frequency	6.25 MHz	5.70 MHz
Electromechanical Coupling Coefficient K_t	0.47	0.55
Dielectric Constant K^T3	3400	3800
Loss Tangent	2%	2%
Piezoelectric Constant d_{33}	650 pC/N	650 pC/N
Piezo Charge Constant g_{33}	23.9 m^2/C	-9.5 m^2/C
Quality Factor Q_m	70	30
Acoustic Impedance	22.42 MRayl	16.97 MRayl
Poisson Ratio	0.36	0.31

Captions for Supporting Videos and Audios

Supporting Audio 1. The audio file of the frequency deviation in the measurement of carotid artery.