Supporting Information

Triboelectric Nanogenerator enabled Mechanical Modulation for Infrared Wireless Communications

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Contents

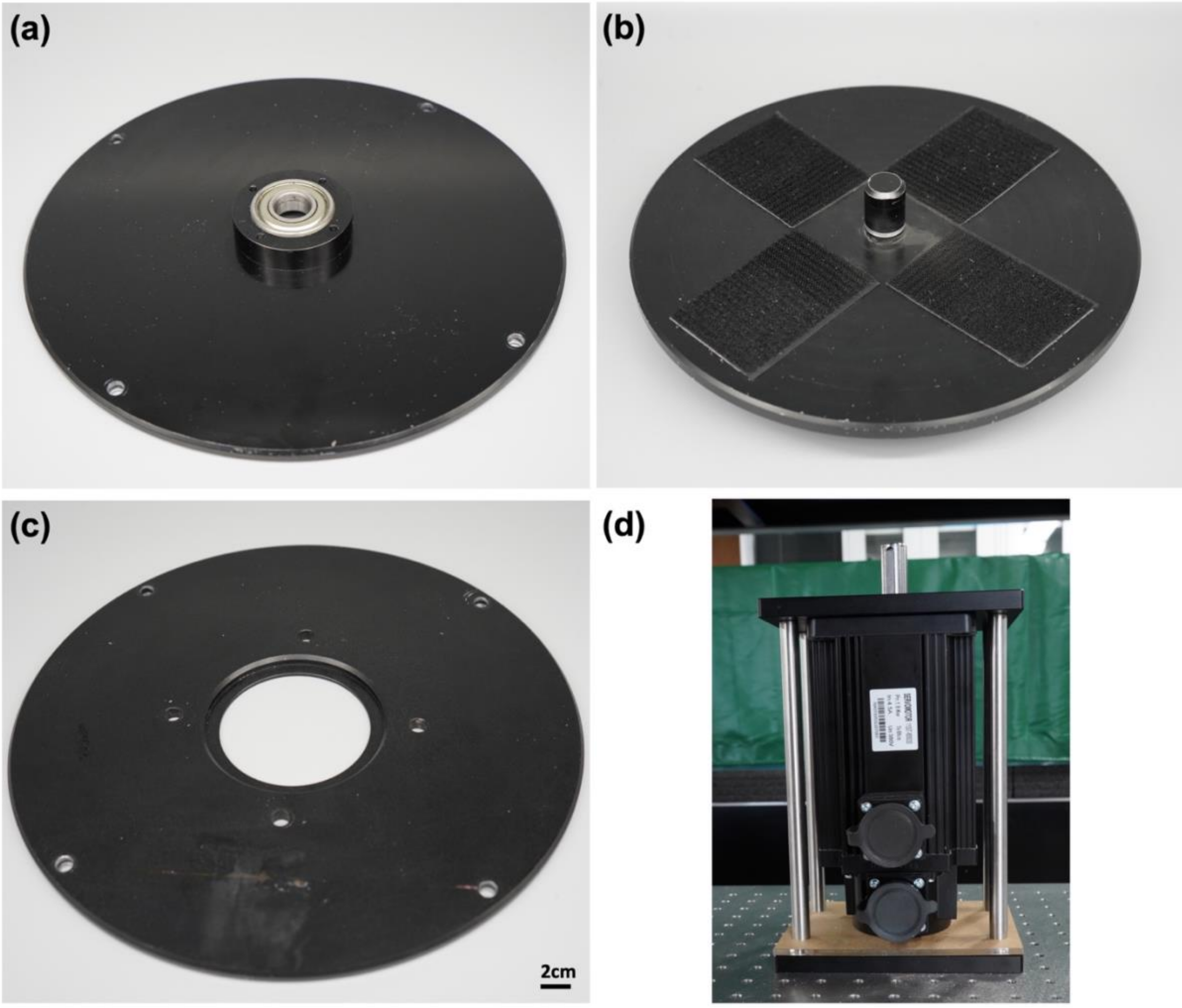

Figure S1. Photograph of mechanical parts of the RF-TENG. (a) Stationary Plate **(b)** Rotation Plate **(c)** Supporting Plate **(d)** Servo Motor

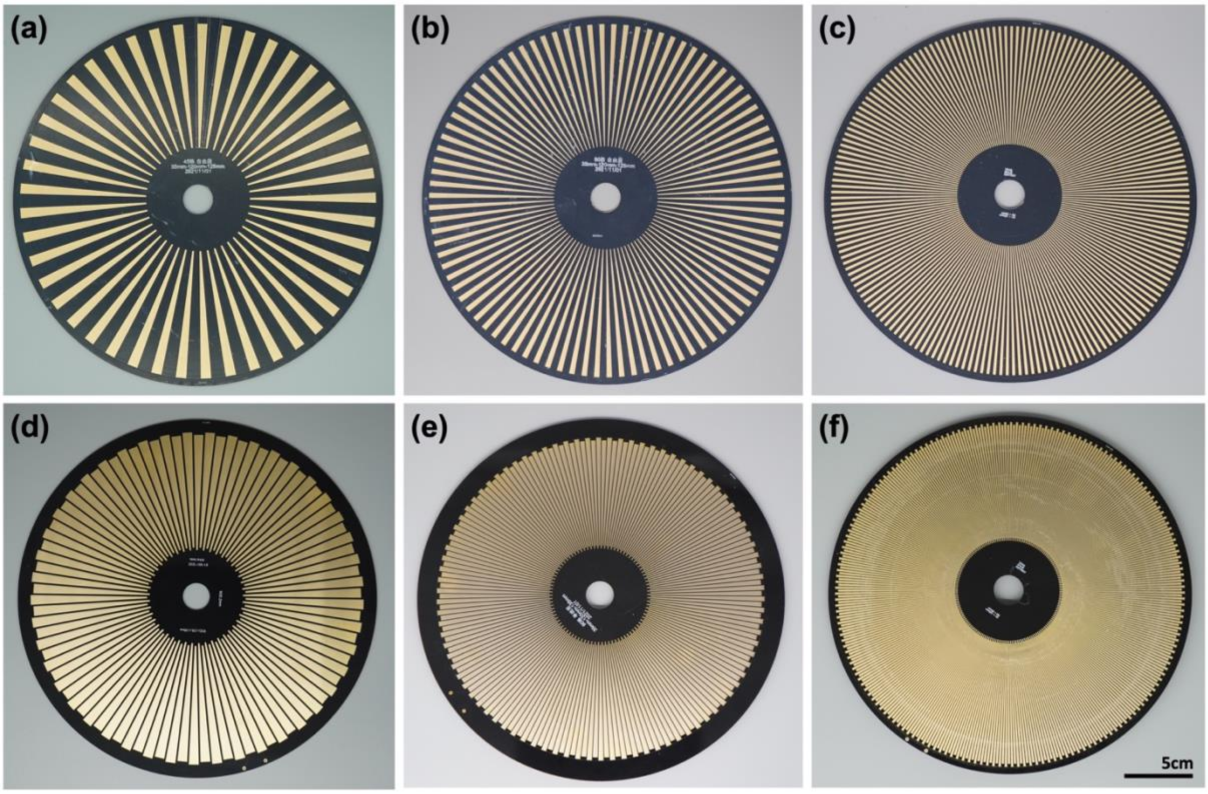

Figure S2. Photograph of rotator and stator PCB of the RF-TENG with different number of gratings. (a) 45 gratings rotator PCB **(b)** 90 gratings rotator PCB **(c)** 180 gratings rotator PCB **(d)** 45 gratings pairs stator PCB **(e)** 90 gratings pairs stator PCB **(f)** 180 gratings pairs stator PCB.

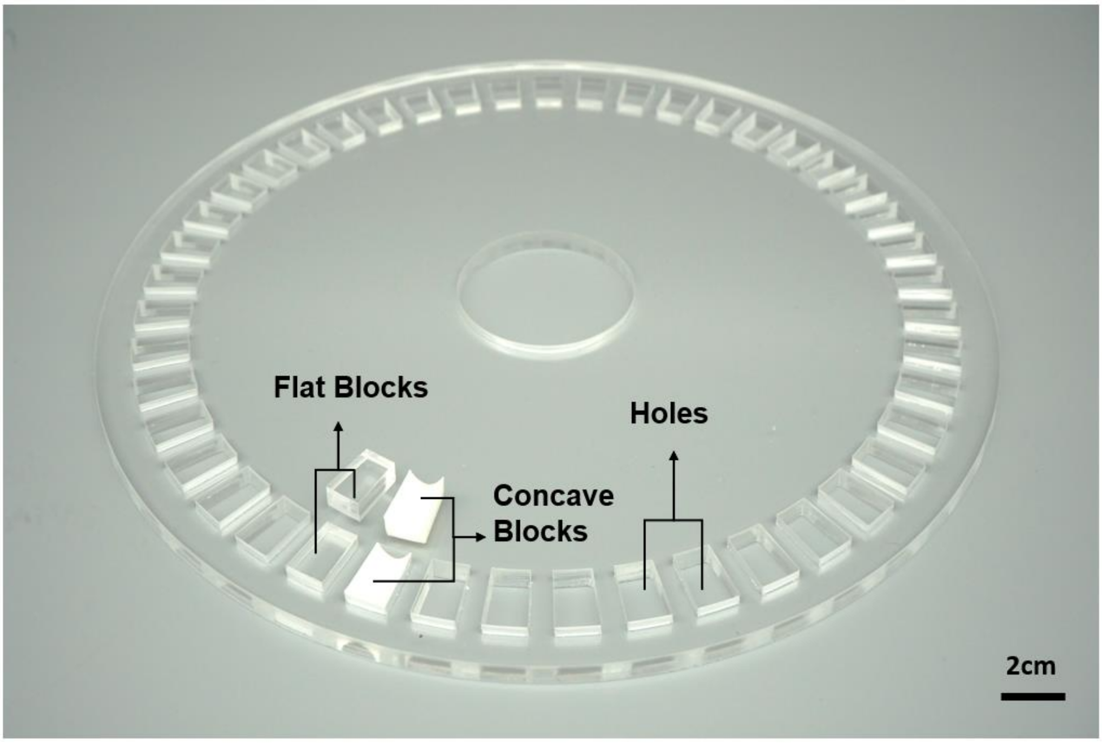

Figure S3. Photograph of the amplitude modulation plate with concave and flat blocks.

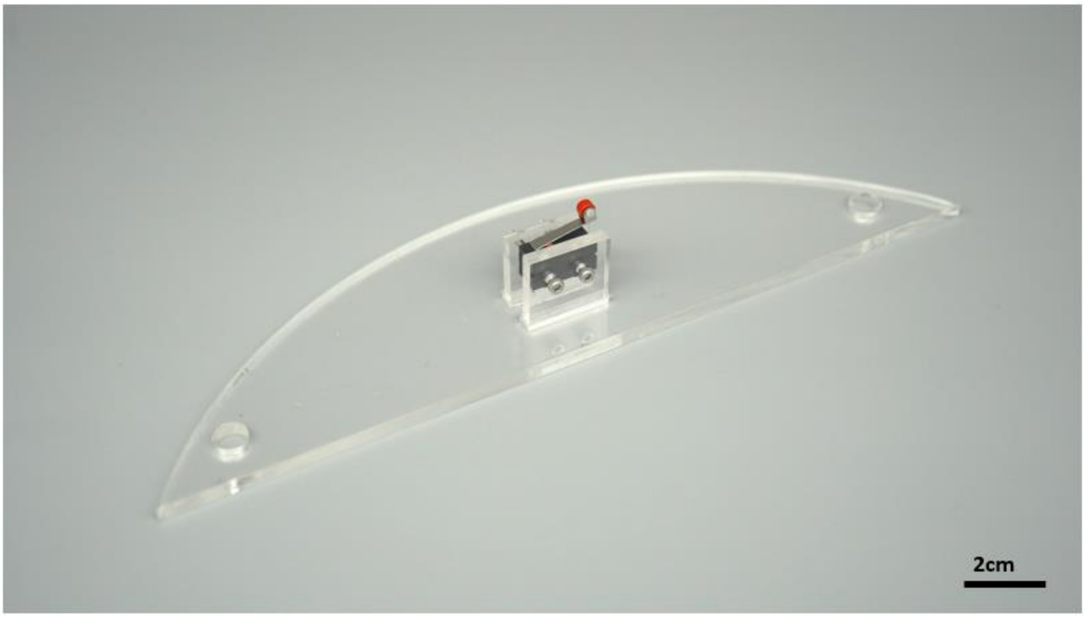

Figure S4. Photograph of the microswitches fixed on the stand.

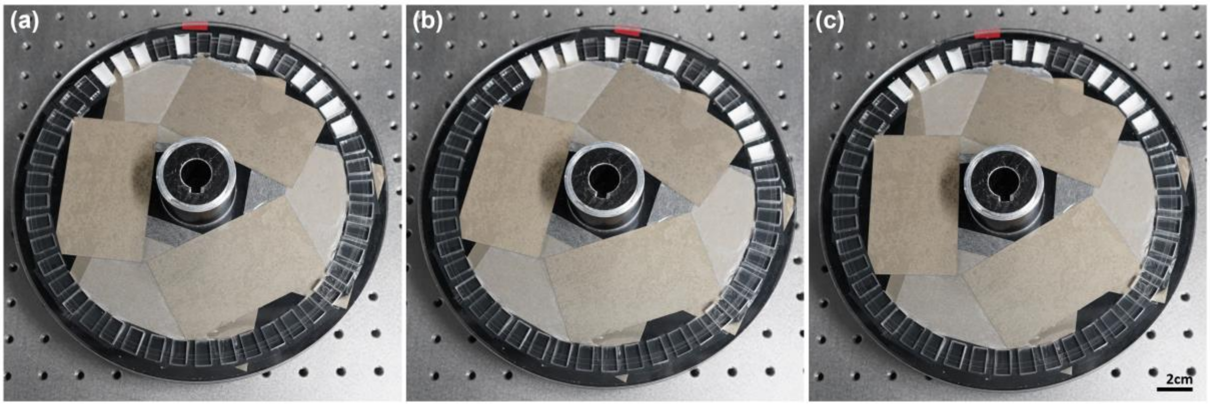

Figure S5. Photograph of the programmed amplitude modulation plate. The initial and last three concave blocks for the start/end symbol. (a) “01001101” for the extended Hamming code of 5. (b) “01011010” for the extended Hamming code of 5. (c) “10011001” for the extended Hamming code of 9.

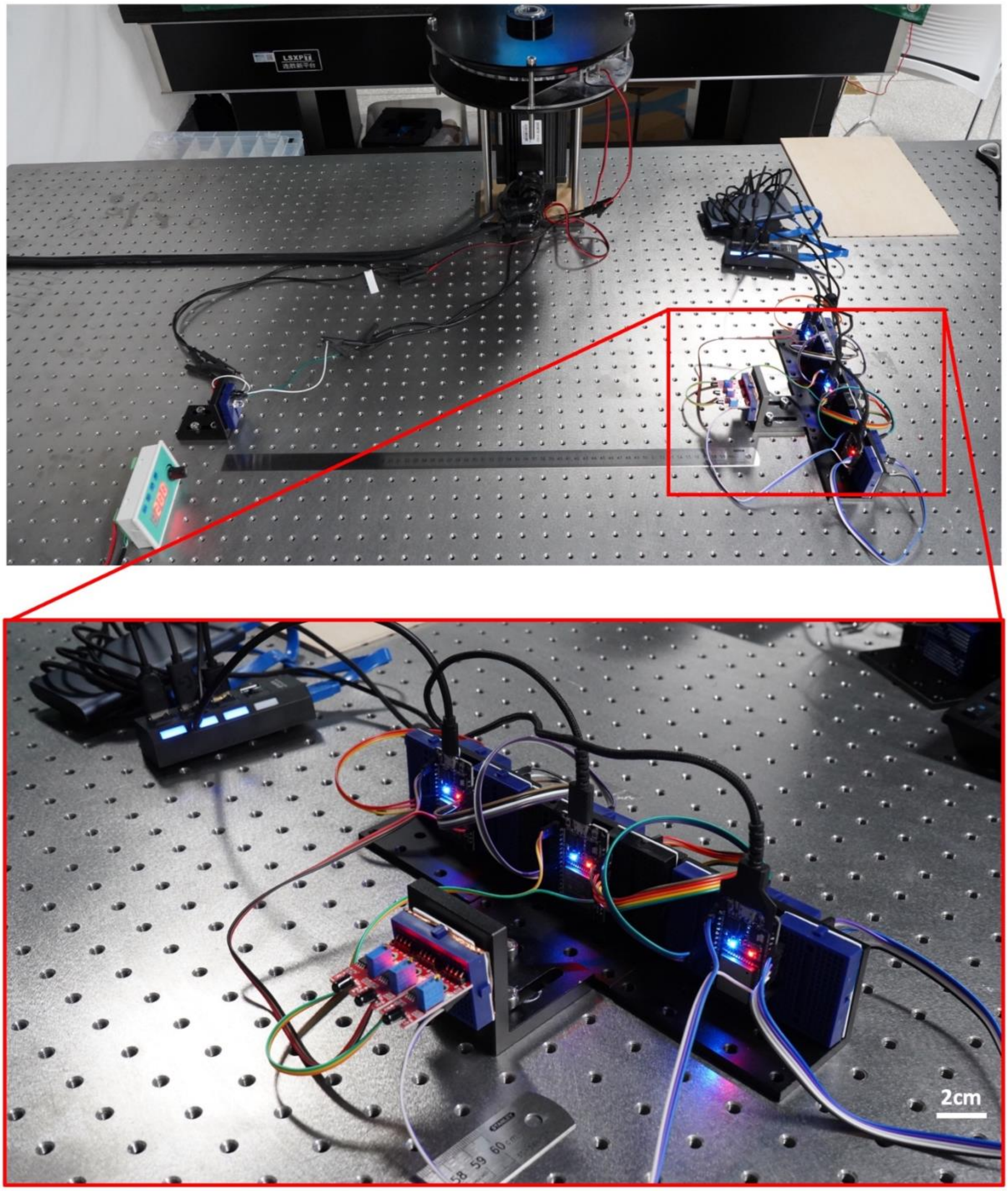

Figure S6. Experiment setup for the multichannel mechanical amplitude modulation demonstration.

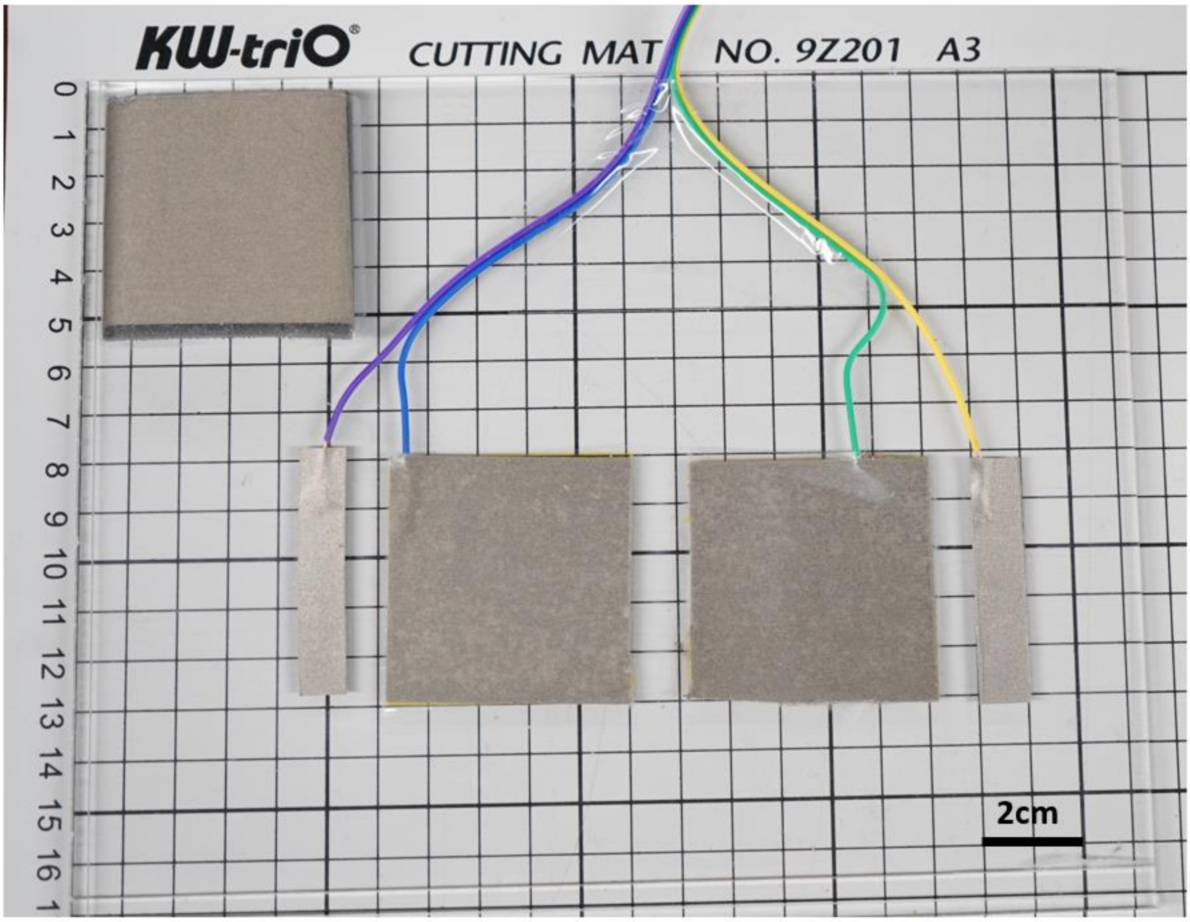

Figure S7. Photograph of the OCT-TENG

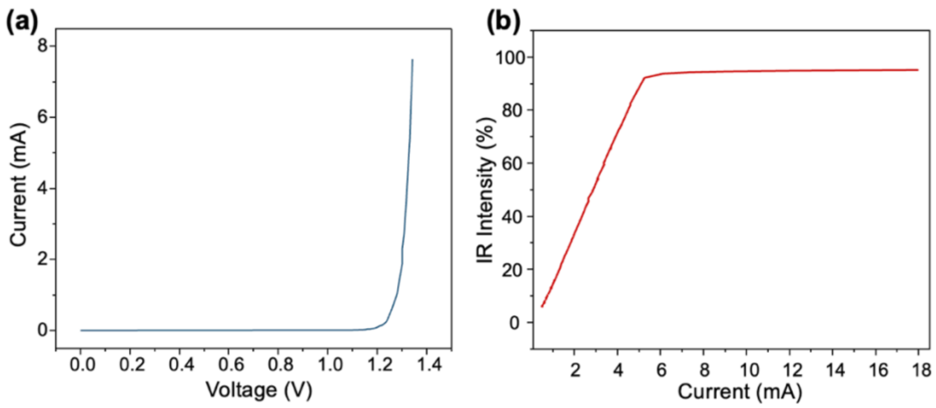

Figure S8. Characterization of adopted IR LED (a) The V-I curve of an adopted 940nm infrared LED. (b) The received IR intensity at 40cm distance under different forward currents pass through the infrared LED

Note S1. The calculation of signal to noise ratio

Signal-to-noise ratio (SNR) is a measurement of the intensity of the signal under noise. The definition of SNR is the ratio of signal power to noise power. In our work, SNR is used to compare the quality of IR signal in different mechanical modulation schemes. The SNR can be expressed as the square of the ratio of the signal amplitude to the amplitude of the noise. The mathematic expression of SNR is defined as:

$$\mathrm{SNR} = \frac{P_{Signal}}{P_{Noise}} = \left(\frac{A_{Signal}}{A_{Noise}}\right)^2, \quad \text{(S1)}$$

where P_{Signal} is the power of the signal, P_{Noise} is the power of noise, A_{Signal} is the signal's peak voltage amplitude, and A_{Noise} is the peak voltage amplitude of the noise. SNR is usually expressed in decibels, as the following expression:

$$\mathrm{SNR}_{dB} = 10\, log_{10}(\mathrm{SNR}). \quad \text{(S2)}$$

Note S2. Coding and decoding algorithm of extended Hamming code

Hamming codes are a category of linear error-correcting codes, which divide the message into *k*-bit data segments and append *r*-bit parity segments to form a codeword. The parity segments and information segments can be associated with a linear equation, so-called the linear relationship. The most classic Hamming code is [7,4] Hamming code, which encodes four data bits into seven bits by adding three parity bits. The generator matrix $\boldsymbol{G}$ and the parity-check matrix $\boldsymbol{H}$ of [7,4] Hamming code are:

$$\boldsymbol{G} = \begin{pmatrix} 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 \end{pmatrix}, \boldsymbol{H} = \begin{pmatrix} 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 1 \end{pmatrix}. \tag{S3}$$

By adding an extra even parity check bit, the [7,4] Hamming code can be extended to [8,4] Hamming code with the ability to correct the one-bit error and detect the two-bit error. The generator matrix $\boldsymbol{G}$ and the parity-check matrix $\boldsymbol{H}$ of [8,4] Hamming code are:

$$\boldsymbol{G} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 \end{pmatrix}, \boldsymbol{H} = \begin{pmatrix} 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}. \tag{S4}$$

For encoding the bits $\boldsymbol{a}$, the codeword $\boldsymbol{x}$ can be obtained by the modulo-2 matrix product. For example, let the data bits $\boldsymbol{a} = (1 \quad 0 \quad 0 \quad 1)$, then

$$\boldsymbol{x} = \boldsymbol{aG} = (1 \quad 0 \quad 0 \quad 1)\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 \end{pmatrix} = (1 \quad 0 \quad 0 \quad 1 \quad 1 \quad 0 \quad 0 \quad 1). \tag{S5}$$

As equation S6 shows, the receiver multiplies $\boldsymbol{H}$ and the transverse of $\boldsymbol{x}$ by modulo-2 matrix product to check whether the result is zero vector, which means there is no transmission error.

$$\boldsymbol{z^T} = \boldsymbol{Hx^T} = \begin{pmatrix} 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 1 \end{pmatrix} = (0 \quad 0 \quad 0 \quad 0) \tag{S6}$$

If one bit error happens on bit 3. For example, the $\boldsymbol{x_{err}} = (1 \quad 0 \quad 1 \quad 1 \quad 1 \quad 0 \quad 0 \quad 1)$, the product will not be a zero vector:

$$\boldsymbol{z^T} = \boldsymbol{H}\boldsymbol{x_{err}^T} = \begin{pmatrix} 0 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 1 \\ 1 \\ 1 \\ 0 \\ 0 \\ 1 \end{pmatrix} = (1 \quad 1 \quad 0 \quad 1). \tag{S7}$$

By observing the parity check result $\boldsymbol{z}$, the incorrect bit 3 can be detected and corrected.

Note S3. Pseudocode of decoding on MCU

Algorithm 1 Decoding in mechanical frequency modulation

Initialize MCU GPIOs, ADC Sampling Timer and BLE
while receive data buffer $\boldsymbol{D}_i$ length > 10000 **do**
  $f_{IR} = \text{argmax}(fft(\boldsymbol{D}_i))$
  if new frame **do**
    $byte_i = \frac{f_{IR}-1000}{100}$
    if i is even **do**
      $str = byte_{i-1} \times 16 + byte_i$
      Send *str* to smartphone
    end if
  end if
end while

Algorithm 2 Decoding in mechanical amplitude modulation

Initialize MCU GPIOs, ADC Sampling Timer
while receive data buffer $\boldsymbol{D}_i$ length > 10000 **do**
  Average data value $a = \text{avg}(\boldsymbol{D}_i)$
  for d in D_i **do**
    if $d - a >$ threshold **do**
      Binary code $\boldsymbol{x}.\text{append}(1)$
    else
      $\boldsymbol{x}.\text{append}(0)$
    end if
  end for
  $\mathbf{z}^{\boldsymbol{T}} = \boldsymbol{H}\boldsymbol{x}^{\boldsymbol{T}}$
  if z is zero vector **do**
    $\boldsymbol{a} = \text{remove\_parity\_bits}(\boldsymbol{x})$
    Display $\boldsymbol{a}$ on LED display
  end if
end while

Here, $\mathbf{z}, \boldsymbol{x}, \boldsymbol{H}, \boldsymbol{a}$ are consistent with the notation defined in Note S2.

Algorithm 3 Decoding in multi-channel mechanical amplitude modulation

Initialize MCU GPIOs, ADC Sampling Timer
while receive data buffer $\boldsymbol{D}_i$ length > 10000 **do**
  $f_{IR} = \text{argmax}(fft(\boldsymbol{D}_i))$
  if $f_{IR} = f_{\text{ch1}}$ **do**
    Average data value $a = \text{avg}(\boldsymbol{D}_i)$
    for d in D_i **do**
      if $d - a >$ threshold **do**
        Binary code $\boldsymbol{x}.\text{append}(1)$
      else
        $\boldsymbol{x}.\text{append}(0)$
      end if
    end for
    $\mathbf{z}^{\boldsymbol{T}} = \boldsymbol{H}\boldsymbol{x}^{\boldsymbol{T}}$
    if z is zero vector **do**

$\boldsymbol{a}$ = remove_parity_bits($\boldsymbol{x}$)
Display $\boldsymbol{a}$ on LED display connected to channel 1
end if
end if
end while

As an example, f_{ch1} denotes the identification frequency of channel 1.

Table S1. Performance of self-powered optical wireless communication systems

Ref.	Author	Light source	Transmission distance	Simple remote control	Transmit text	Multichannel transmission
1	A. Yu *et al.*	550nm green LED	N/A	Yes	No	No
2	W. Ding *et al.*	550nm green LED	~ 20cm	Yes	No	No
3	H. Guo *et al.*	524nm OLED	~5cm	Yes	No	No
4	J. Huang *et al.*	550nm green and 650nm red LED	~ 20cm	Yes	No	Yes
5	Z. Tian *et al.*	510nm ZnS:Cu phosphors	~ 30cm (in darkroom)	Yes	No	No
	Ours	940nm IR LED	Up to 150cm	Yes	Yes	Yes

Reference

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2. W. Ding, C. Wu, Y. Zi, H. Zou, J. Wang, J. Cheng, A. C. Wang and Z. L. Wang, *Nano Energy*, 2018, **47**, 566-572.
3. H. Guo, J. Zhao, Q. Dong, L. Wang, X. Ren, S. Liu, C. Zhang and G. Dong, *Nano Energy*, 2019, **56**, 391-399.
4. J. Huang, X. Yang, J. Yu, J. Han, C. Jia, M. Ding, J. Sun, X. Cao, Q. Sun and Z. L. Wang, *Nano Energy*, 2020, **69**, 104419.
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