

Supplementary Information

All-weather, natural silent speech recognition via machine-learning-assisted tattoo-like electronics

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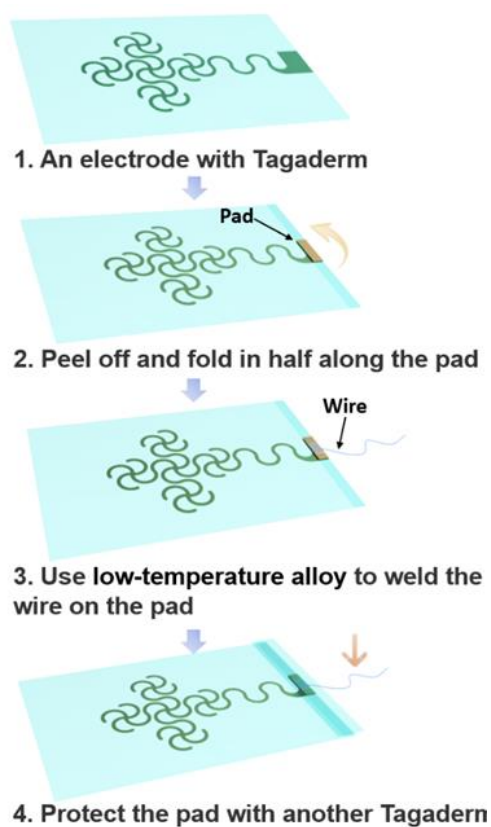
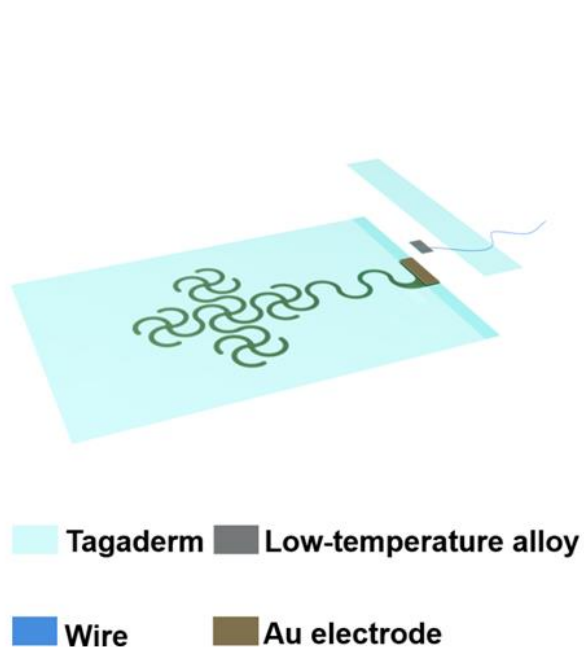
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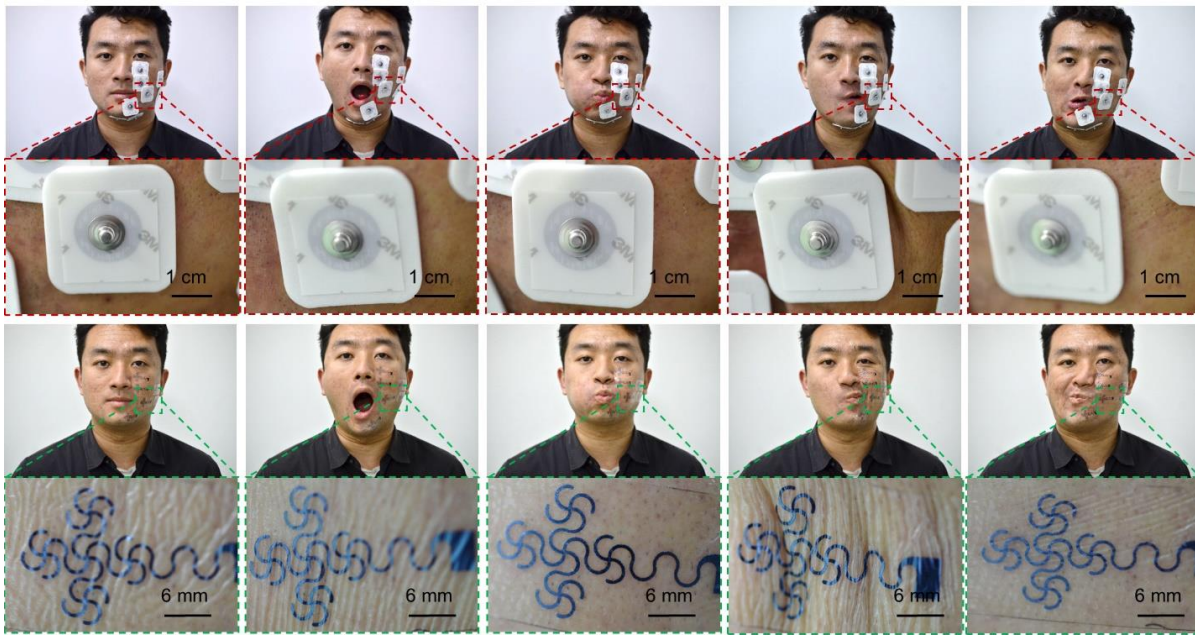
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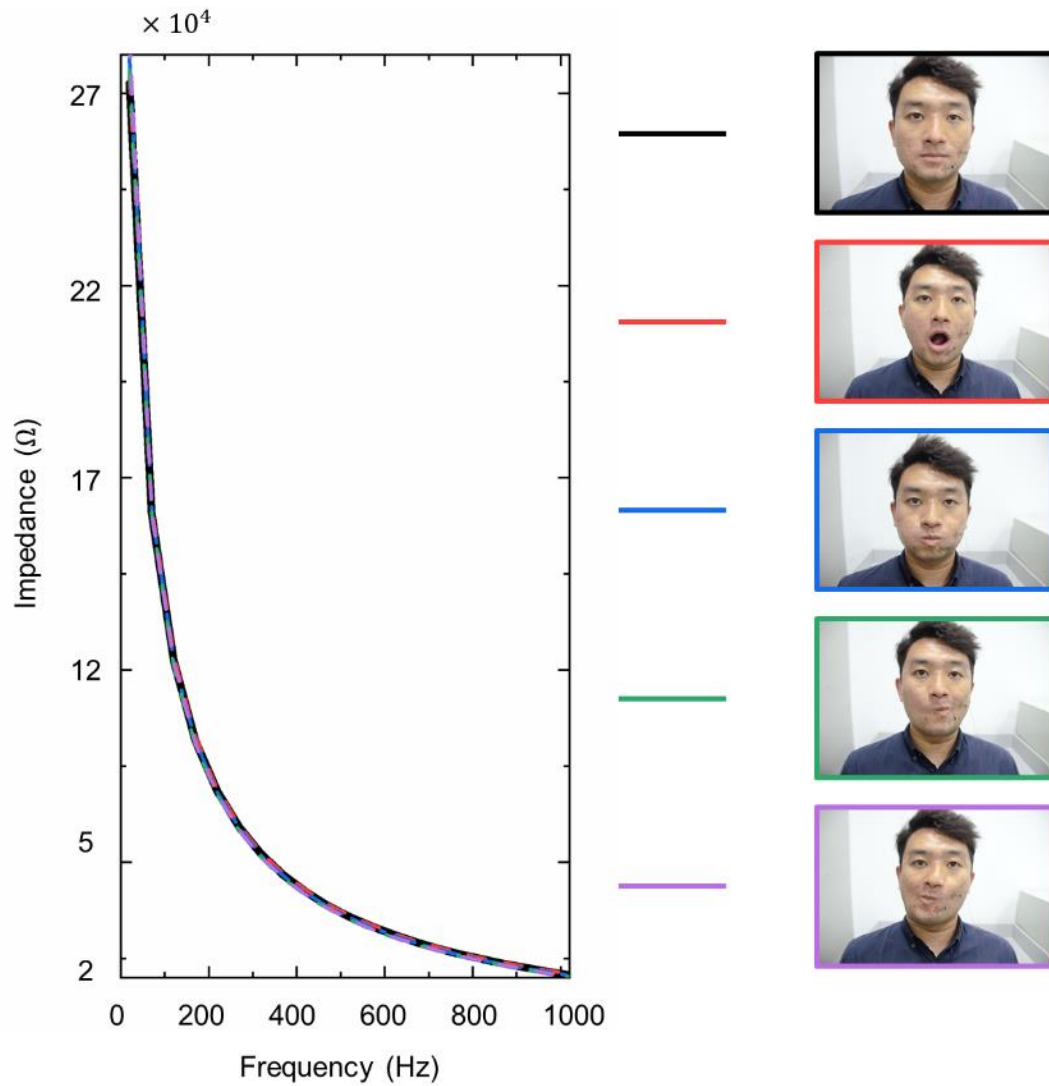
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Supplementary Figure 1. The process of low temperature welding.

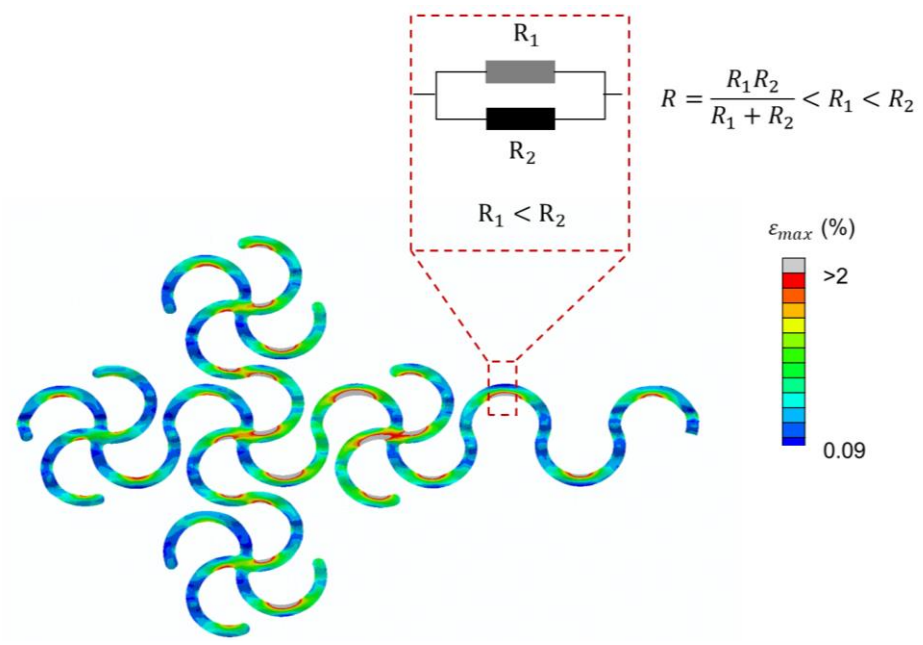


Supplementary Figure 2. The zoom-in wearability of tattoo-like electrodes and gel electrodes when attached on subject's face. The identifiable photographs are fully consented by the written consents.



Supplementary Figure 3. The identical impedance of the tattoo-like electrodes under various large deformation. Two tattoo-like electrodes were attached on the levator anguli oris (LAO) and the depressor anguli oris (DAO). The identifiable photographs are fully consented by the written consents.

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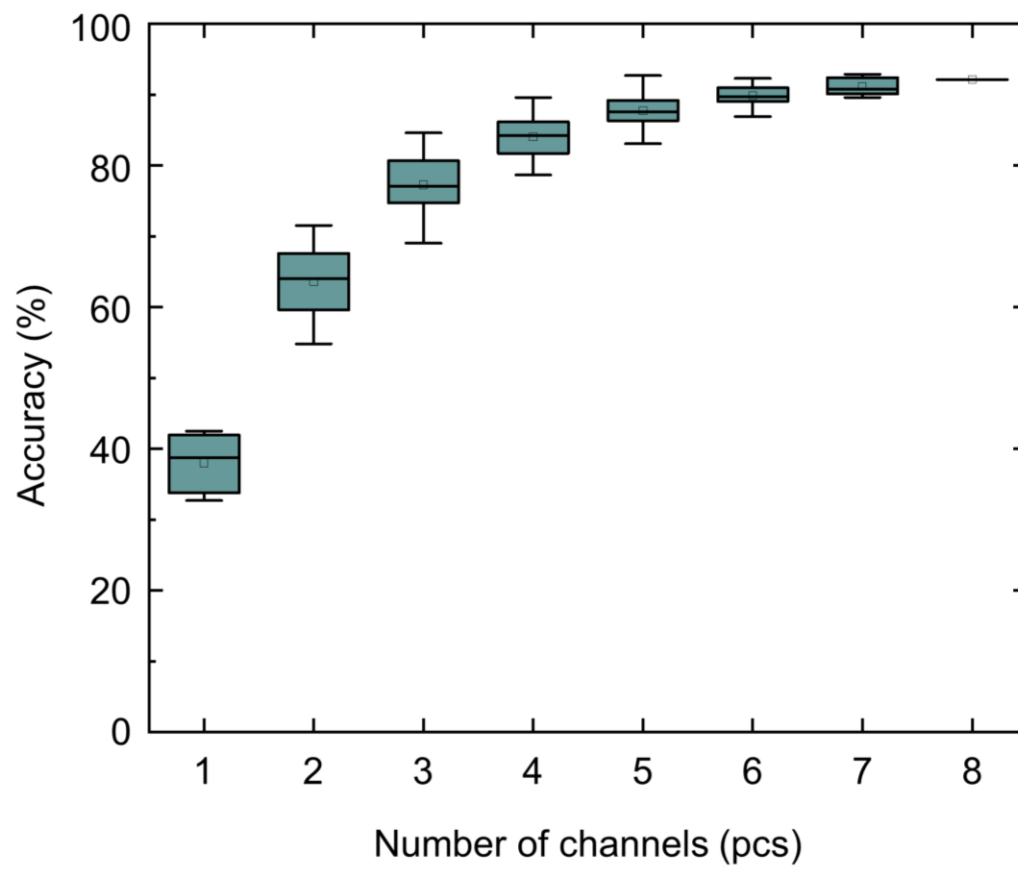
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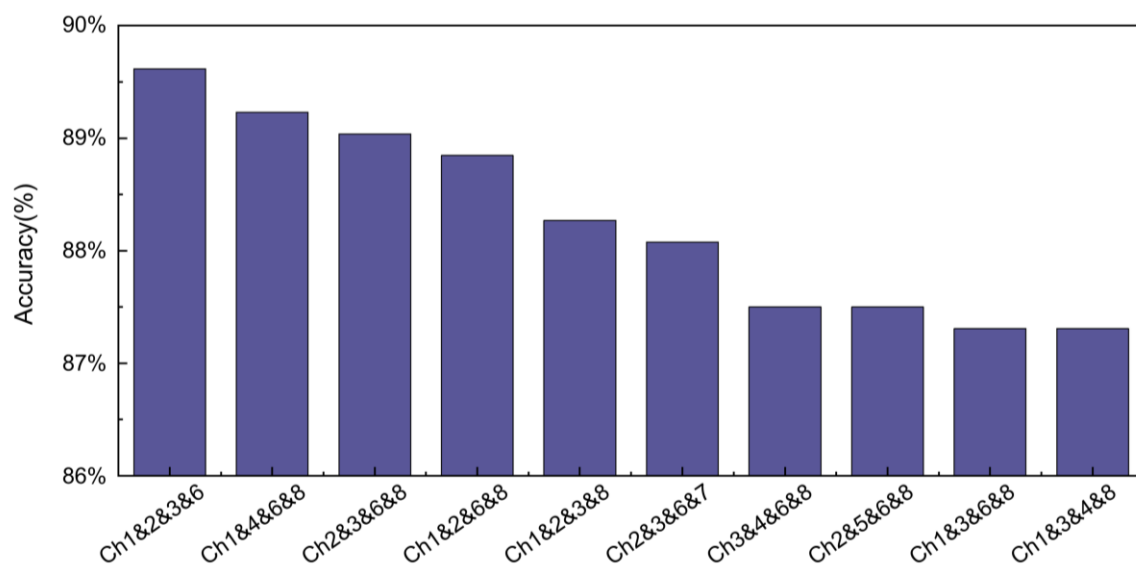
Supplementary Figure 4. The strain distributions of tattoo-like electrodes under vertical tensing with 45%.



Supplementary Figure 5. Electrode locations for detecting EMG signals of facial and neck muscles. Location 1-7 are buccinators, levator anguli oris, depressor anguli oris, zygomaticus, masseter, anterior belly of digastric, the right side of the larynx, the lower 1/3 point of the sternocleidomastoid, respectively. The identifiable photographs are fully consented by the written consents.



Supplementary Figure 6. Box graph of the accuracy of different channel combinations from one muscle to eight muscles.



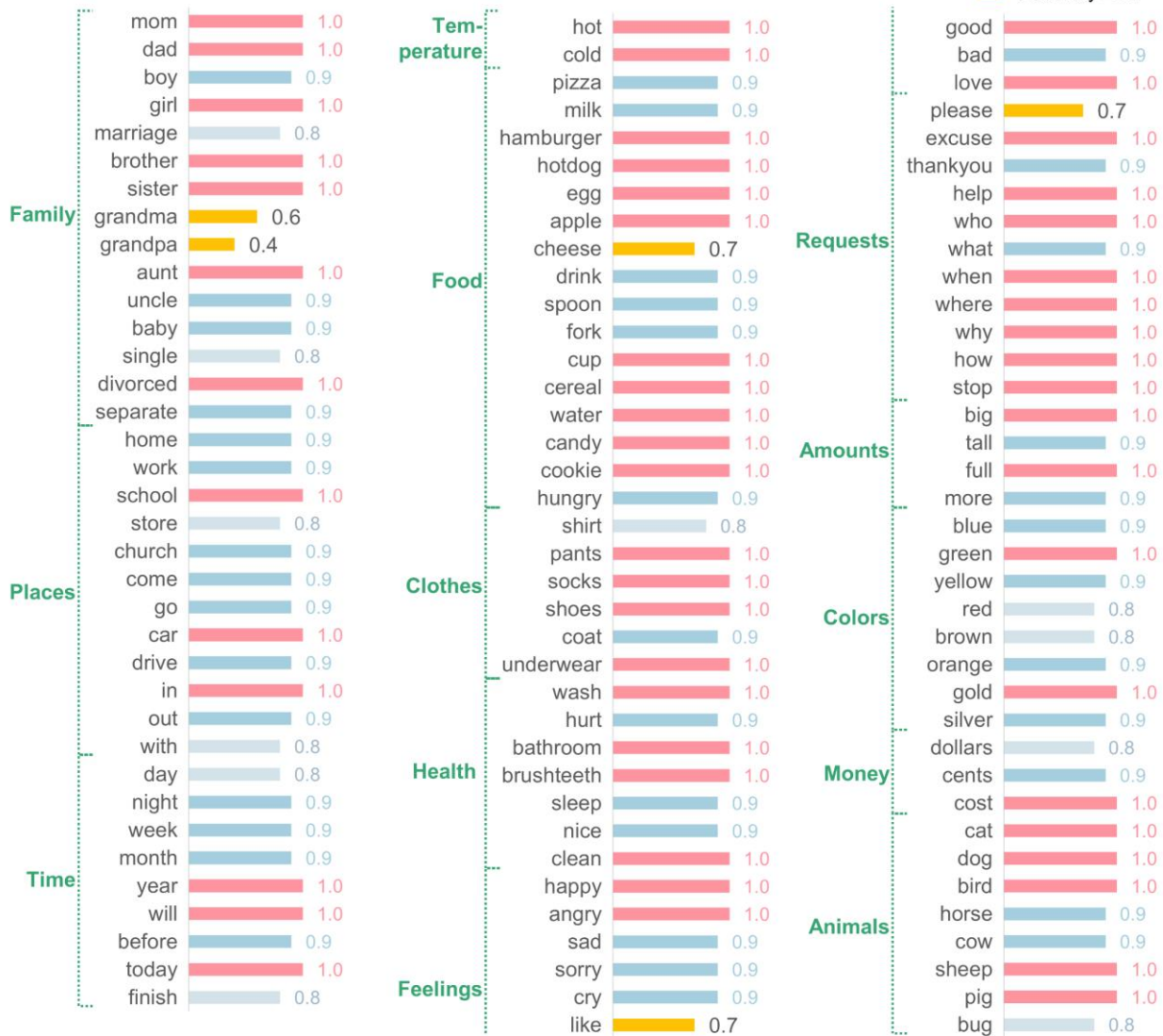
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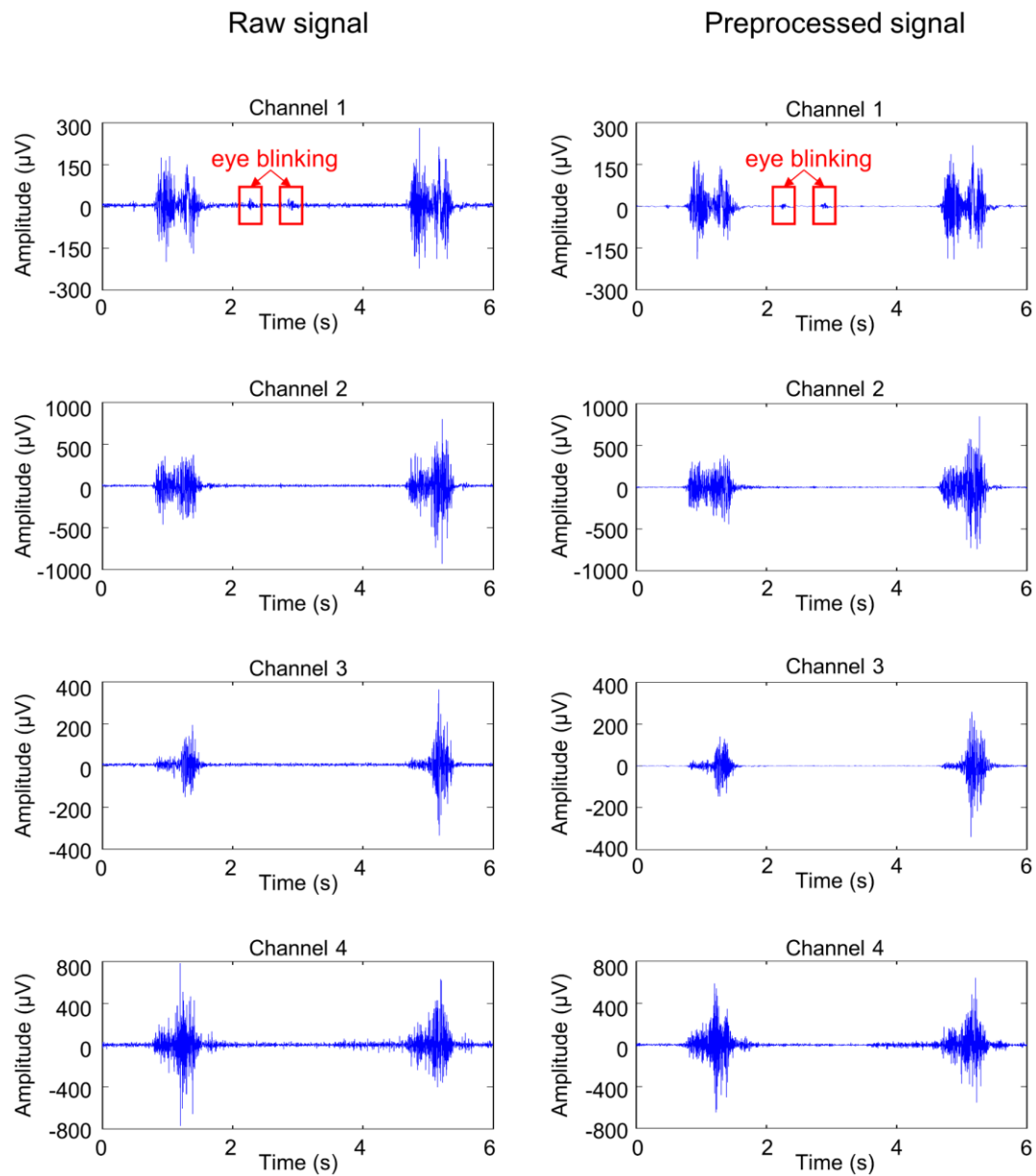
Supplementary Figure 7. The combination with the highest accuracy among the four channels.

Accuracy of each word
(110 words in total)

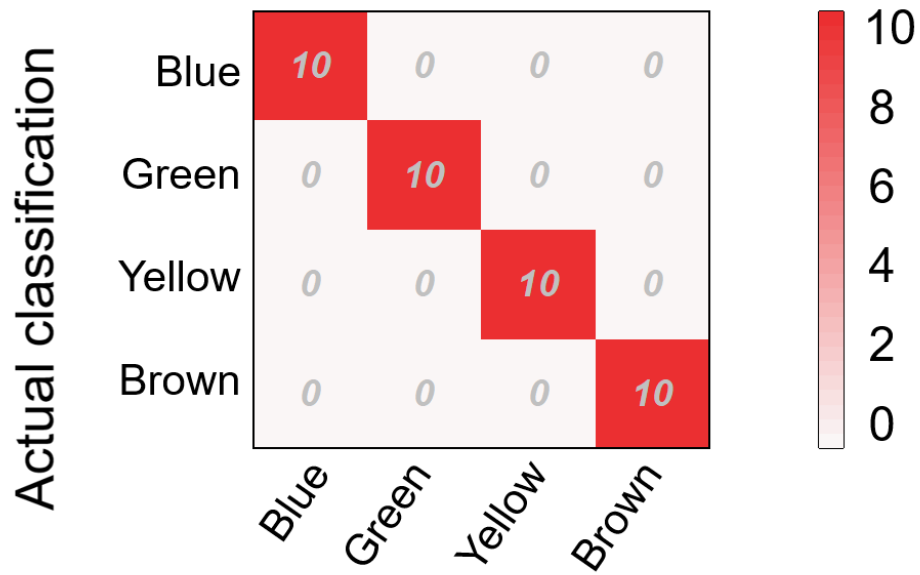
Accuracy = 1
Accuracy = 0.9
Accuracy = 0.8
Accuracy ≤ 0.7



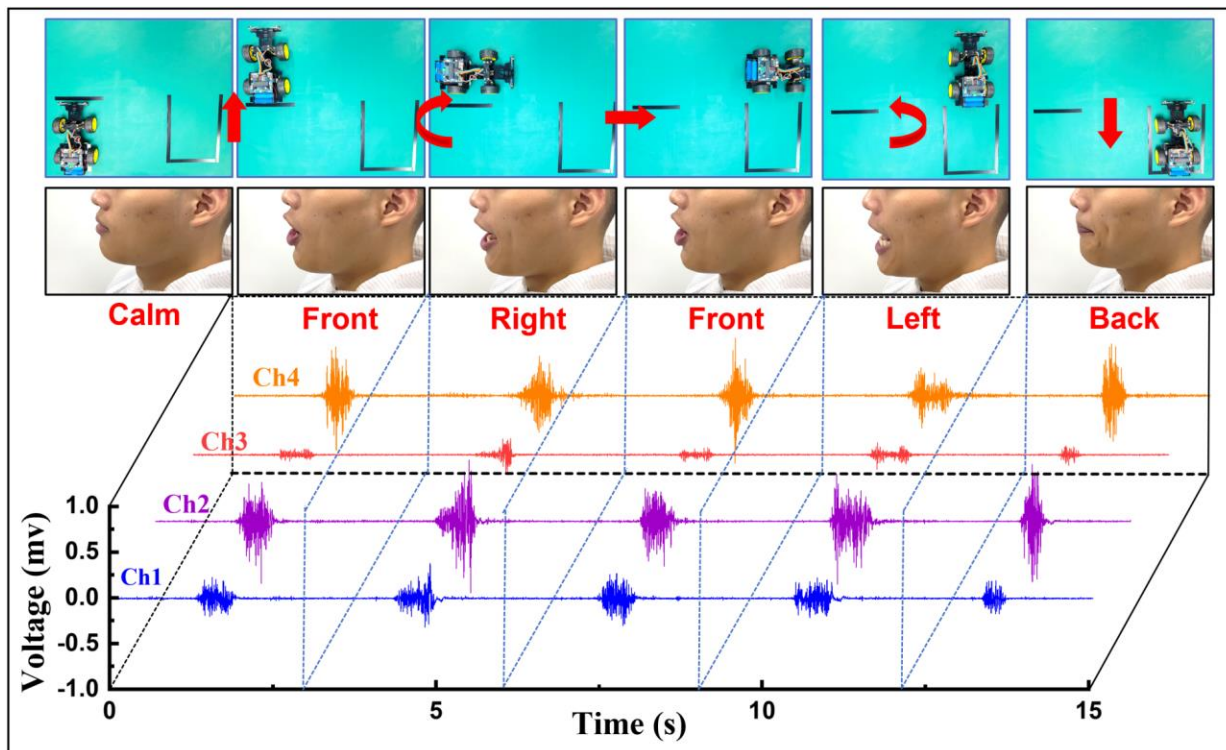
Supplementary Figure 8. Accuracy of each word in 110 classification.



Supplementary Figure 9. EOG before and after preprocessing.



Supplementary Figure 10. The confusion matrix of Four words in noisy environment.



Supplementary Figure 11. Intelligent car controlled by the sEMG signals of the action instructions from Four channels. The identifiable photographs are fully consented by the written consents.

110 categories(Wired DAQ equipment)	
Sampling frequency(Hz)	Recognition rate(%)
1000	91.82
500	91.27
250	81.09

Supplementary Table 1. The recognition rate of 110 words at the sampling frequency of 1000Hz, 500Hz, and 250Hz, respectively.

American Sign Language (ASL) - First 100 Signs:

Class	Words								
Family	Mom	Dad	Boy	Girl	Marriage	Brother	Sister	Grandma	Grandpa
	Aunt	Uncle	Baby	Single	Divorced	Separate			
Places	Home	Work	School	Store	Church	Come	Go	Car	Drive
	In	Out	With						
Time	Day	Night	Week	Month	Year	Will	Before	Today	Finish
Temperature	Hot	Cold							
Food	Pizza	Milk	Hamburger	Hot dog	Egg	Apple	Cheese	Drink	Spoon
	Fork	Cup	Cereal	Water	Candy	Cookie	Hungry		
Clothes	Shirt	Pants	Socks	Shoes	Coat	Underwear			
Health	Wash	Hurt	Bathroom	Brush teeth	Sleep	Nice	Clean		
Feelings	Happy	Angry	Sad	Sorry	Cry	Like	Good	Bad	Love
Requests	Please	Excuse	Thank you	Help	Who	What	When	Where	Why
	How	Stop							
Amounts	Big	Tall	Full	More					
Colors	Blue	Green	Yellow	Red	Brown	Orange	Gold	Silver	
Money	Dollars	Cents	Cost						
Animals	Cat	Dog	Bird	Horse	Cow	Sheep	Pig	Bug	

Supplementary Table 2. ASL first 100 signs word list.

Features	Formula
Variance(Var)	$\text{Var} = \frac{1}{N} \sum_{i=1}^N (X_i - \bar{X})^2$
Standard Deviation(SD)	$\text{SD} = \sqrt{\frac{1}{N} \sum_{i=1}^N (X_i - \bar{X})^2}$
Skewness(Skew)	$\text{Skew} = \frac{\frac{1}{N} \sum_{i=1}^N (X_i - \bar{X})^3}{\left(\frac{1}{N} \sum_{i=1}^N (X_i - \bar{X})^2\right)^{\frac{3}{2}}}$
Enhanced Mean absolute value(EMAV)	$\text{EMAV} = \frac{1}{N} \sum_{i=1}^N (X_i)^p , \quad p = \begin{cases} 0.75, & \text{if } i \geq 0.2L \& i \leq 0.8L \\ 0.50, & \text{otherwise} \end{cases}$
Zeros Crossing(ZC)	$\text{ZC} = \sum_{i=1}^{N-1} \text{sng}(X_i X_{i+1}) \cap X_i - X_{i+1} \geq \alpha, \quad \text{sng}(x) = \begin{cases} 1, & \text{if } x \geq \alpha \\ 0, & \text{otherwise} \end{cases}$
Slope Sign Change(SSC)	$\text{SSC} = \sum_{i=2}^{N-1} (X_i - X_{i-1})(X_i - X_{i+1}) $
Root Mean Square(RMS)	$\text{RMS} = \sqrt{\frac{1}{N} \sum_{i=1}^N X_i^2}$
Log Detector(LOG)	$\text{LOG} = e^{\frac{1}{N} \sum_{i=1}^N \log(X_i)}$
Modified Mean Absolute Value(MMAV)	$\text{MMAV} = \sum_{i=1}^N W_i X_i , \quad W_i = \begin{cases} 1, & \text{if } 0.25N \leq i \leq 0.75N \\ 0.5, & \text{otherwise} \end{cases}$
Willison Amplitude(WAMP)	$\text{WAMP} = \sum_{i=1}^{N-1} f(X_i - X_{i+1}), \quad f(x) = \begin{cases} 1, & \text{if } x \geq \text{threshold} \\ 0, & \text{otherwise} \end{cases}$
Relative Wavelet Energy (RWE)	$P(X_{i,j}) = \frac{\sum_{k=1}^N d_{i,j}(k) ^2}{\sum_{j=1}^{16} (\sum_{k=1}^N d_{i,j}(k) ^2)}$

Supplementary Table 3. The time domain and frequency domain characteristic formulas are used.

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