Supplementary Information

Parallel micro-Raman spectroscopy of multiple cells in a single acquisition using hierarchical sparsity

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The file includes:

(1) Algorithm of the hierarchical sparsity model.

(2) Algorithm of the L_1-norm regularization.

(3) Reconstructed Raman spectra of a 4-foci tweezers array occupied by four trapped cells from the same population.

(4) Reconstructed Raman spectra of a 4-foci tweezers array occupied by two trapped cells from one population while the other two foci being vacant.

Algorithm 1: hierarchical sparsity model

Goal: $\mathbf{x}^* = \min_{\mathbf{x}} \ \phi(\mathbf{x}) := \frac{1}{2}\| \mathbf{A}\mathbf{x} - \mathbf{y} \|_2^2 + \lambda_1 \sum_{g \in G} \| \mathbf{x}_g \|_2 + \lambda_2 \| \mathbf{x} \|_1$

Set t : = 0;

Choose η = 1.5, c = 0.01, $\alpha_{\min}$ =0.001, $\alpha_{\max}$ =5000;

Choose an initial $\mathbf{x}^0 = [1,1,...,1]$;

while $|\phi(\mathbf{x}^t) - \phi(\mathbf{x}^{t-1})| / \phi(\mathbf{x}^{t-1}) > 10^{-5}$ **do**

Choose α^t=$\alpha_{\min}$;

Set $\mathbf{u}^t \leftarrow \mathbf{x}^t - \frac{1}{\alpha^t} \nabla f(\mathbf{x}^t)$;

while $\phi(\mathbf{x}^{t+1}) > \max_{i=\max(t-3,0),...,t} \phi(\mathbf{x}^t) - \frac{1}{2}\| \mathbf{x}^{t+1} - \mathbf{x}^t \|_2^2 \cdot 10^{-3}$ **do**

for g= 1 to |G| **do**

Set r := 0;

Choose $\mathbf{p}^0 = [1,1,...,1]$, $\mathbf{b}^0 = [1/2,1/2,...,1/2]$, $\boldsymbol{\beta}^0 = [1/2,1/2,...,1/2]$

while $\| \mathbf{b}^{r+1} - \mathbf{b}^r \|_2 / \| \mathbf{b}^r \|_2 > 10^{-5}$ **do**

$$\mathbf{b}^{r+1} = \frac{1}{c+1} S(\mathbf{u}^t + c\boldsymbol{\beta}^r - \mathbf{p}^r, \lambda_1 / \alpha^t);$$

$$\boldsymbol{\beta}^{r+1} = \frac{1}{c} S_\upsilon(\mathbf{p}^r + c\mathbf{b}^{r+1}, \lambda_2 / \alpha^t);$$

$$\mathbf{p}^{r+1} = \mathbf{p}^r + c(\mathbf{b}^{r+1} - \boldsymbol{\beta}^{r+1});$$

Set $r \leftarrow r+1$

end

Set $\mathbf{x}_g^{t+1} := \mathbf{b}^{r+1}$;

end

Set $\alpha^t \leftarrow \eta\alpha^t$;

end

Set $t \leftarrow t+1$;

end

Notes:

1. $f(\mathbf{x}) := \frac{1}{2}\| \mathbf{A}\mathbf{x} - \mathbf{y} \|_2^2$

2. λ_1=1，λ_2=2

3. Soft-thresholding operator $S(a,c) = \text{sgn}(a) \cdot \max\{0, |a| - c\}$

4. Vector shrinkage operator $S_\upsilon(\mathbf{b}, \lambda) = \left[1 - \frac{\lambda}{\| \mathbf{b} \|_2}\right]_+ \mathbf{b}$

Algorithm 2: L_1-norm regularization

Goal: $\mathbf{x}^* = \min_{\mathbf{x}} \phi(\mathbf{x}) := \frac{1}{2} \| \mathbf{A}\mathbf{x} - \mathbf{y} \|_2^2 + \lambda_2 \| \mathbf{x} \|_1$

Set t : = 0;

Choose η = 1.5, $\alpha_{\min}$ =0.001, $\alpha_{\max}$ =5000;

Choose an initial $\mathbf{x}^0 = [1,1,...,1]$;

while $|\phi(\mathbf{x}^t) - \phi(\mathbf{x}^{t-1})| / \phi(\mathbf{x}^{t-1}) > 10^{-5}$ **do**

Choose α^t=$\alpha_{\min}$;

Set $\mathbf{u}^t \leftarrow \mathbf{x}^t - \frac{1}{\alpha^t} \nabla f(\mathbf{x}^t)$;

while $\phi(\mathbf{x}^{t+1}) > \max_{i=\max(t-3,0),...,t} \phi(\mathbf{x}^t) - \frac{1}{2} \| \mathbf{x}^{t+1} - \mathbf{x}^t \|_2^2 \cdot 10^{-3}$ **do**

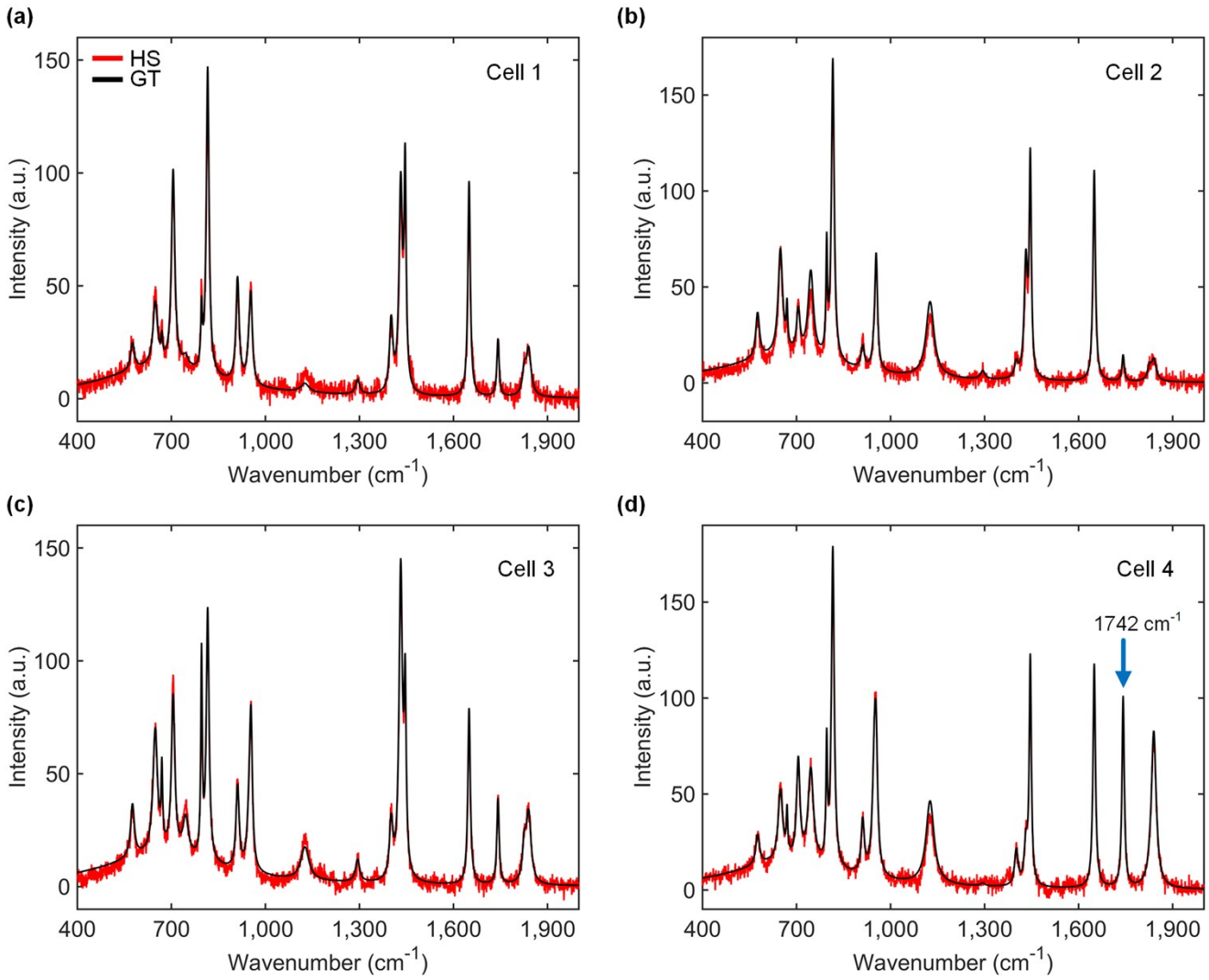
$\mathbf{x}_i^{t+1} = S(\mathbf{u}_i^t, \lambda_2 / \alpha^t)$;

Set $\alpha^t \leftarrow \eta \alpha^t$;

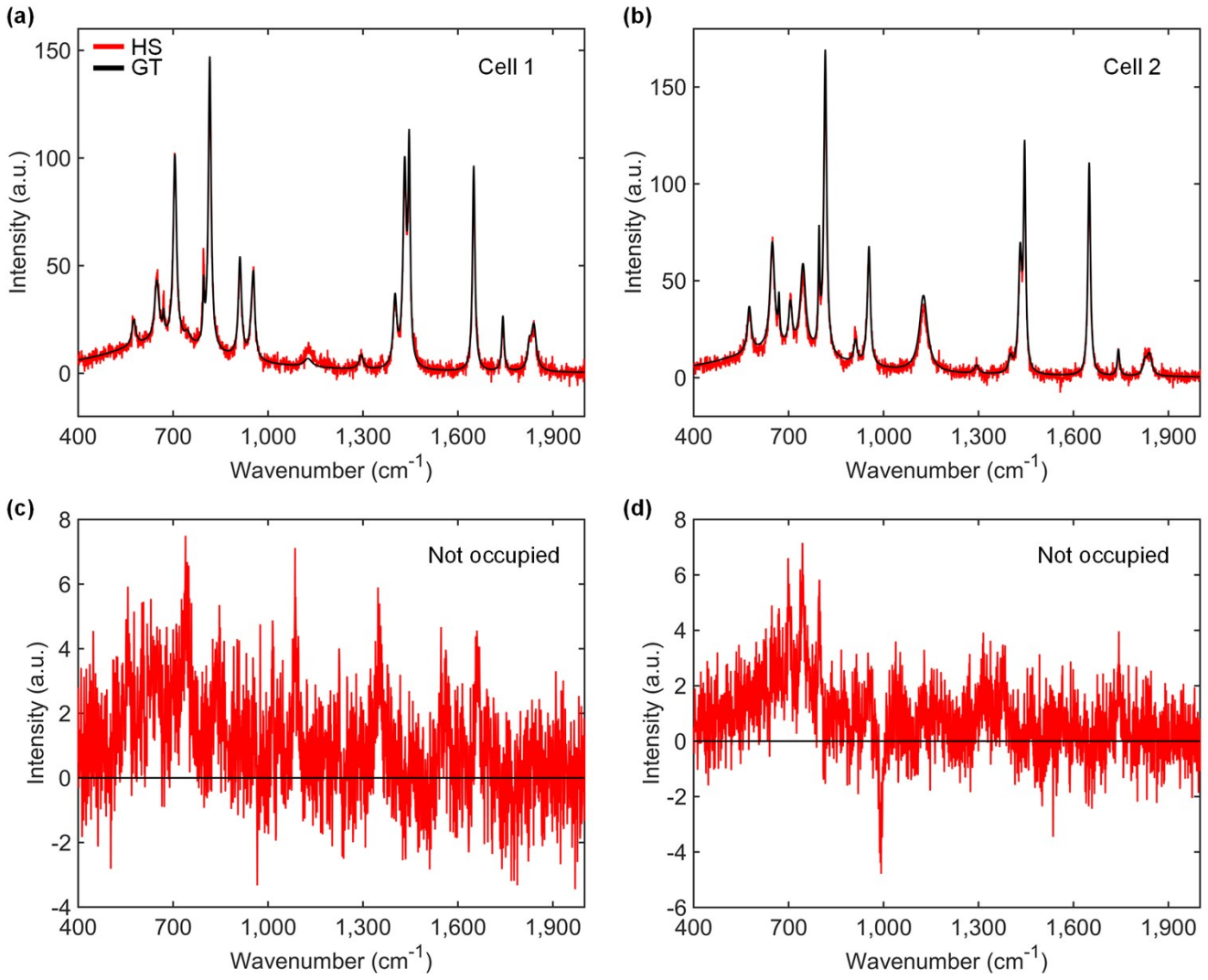
end

Set $t \leftarrow t + 1$;

end



Supplementary Figure S1 | Demultiplexing of the superimposed Raman spectrum acquired by a 4-foci tweezer array that traps four cells from the population 1. (a-d) Reconstructed spectra of the individual cells using the hierarchical sparsity model (red) as well as their ground truths (black). A 10-fold variation in the componential contributions (e.g. the peak at 1742 cm^{-1}) was simulated, and noises were also added to the superimposed spectra, which results in a SNR of 40.



Supplementary Figure S2 | Demultiplexing of the superimposed Raman spectrum acquired by a 4-foci tweezers array loaded with only two cells. Two cells from the population 1 are trapped while the other two traps being not occupied. (a-d) Reconstructed spectra using the hierarchical sparsity model (red) as well as their ground truths (black). Noises were also added to the superimposed spectra, which results in a SNR of 40.