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Supporting Information

High-efficiency Transfer of Fingerprints from Various Surfaces Using Nanofibrillated Cellulose

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12 **Experimental Procedures**

13 Materials

- 14 We purchased citric acid (CA), 1, 2-ethylenediamine (EDA), and sodium laurylsulfonate (SDS) from Aladdin (Shanghai, China). We obtained
- 15 cyanoacrylate ("502 glue") from Ailete Technology Co., Ltd. (Jiangsu, China). We obtained the commercial adhesive tape (FL-B01,
- 16 composition: gelatin) from United Vision Technology Co., Ltd. (Beijing, China).
- 17 We prepared NFC dispersion (2.3 wt%, pH 7.0) through the former method.¹ We synthesized super-paramagnetic iron oxide nanoparticles
- 18 $\,$ (SPIONs, size: 30-50 nm) according to a previously reported method.^2 $\,$
- 19 The substrates we used are glass slides, plastic culture dish, aluminum foil, office paper, common wall, cloth, and rubber gloves. We
- 20 purchased glass slides (brand: CAT. NO. 7101) from Sail Brand Co., Ltd. (Jiangsu, China). We obtained plastic culture dish (composition:
- 21 polystyrene, brand: 430167) from Corning Co. (USA). We obtained aluminum foil (brand: 0054) from Cleanweap Co., Ltd. (Korea). We
- 22 procured office paper (composition: cellulose, brand: No. 7362) from Deli Co., Ltd. (China). We acquired common wall (surface
- composition: acrylate) from laboratory. We obtained cloth (composition: polyurethane, brand: 23740263751) from Hengyuanxiang Co.
 (China). We obtained rubber gloves (composition: natural rubber, brand: KG3220) from Kirgen Bioscience Co., Ltd. (Shanghai, China).

25 The preparation of NFC/CDs paper

- 26 We mixed 1 mL CA (1 mol L⁻¹) solution and 1.75 mL EDA (1 mol L⁻¹) with magnetic stirring for 30 min to achieve a clarified solution A. We
- 27 added 2 mL NFC dispersion into the above solution A, and diluted to 20 mL by deionized water in a flask under ultrasonic for 2 h. We placed
- 28 the mixture into a microwave reaction system (MWO-1000S, Eyela, Japan) for 4 min at 700 W until the dispersion changed from colorless 29 to light vollow to obtain NEC/CDs dispersion
- 29 to light yellow to obtain NFC/CDs dispersion.
- 30 $\,$ We cast NFC/CDs dispersion and NFC dispersion to obtain NFC/CDs paper and NFC paper.^3 $\,$
- 31 In addition, we synthesized pure CDs dispersion without addition of NFC with the same procedure used to form NFC/CDs dispersion.⁴

32 $\,$ Characterization of NFC/CDs dispersion and NFC/CDs paper $\,$

- 33 We collected fourier transform infrared (FT-IR) spectra of samples in KBr from 4000 cm⁻¹ to 500 cm⁻¹ on FT-IR spectrometer (Spectrum
- 34 One, Perkin Elmer, USA).⁵ We measured size distribution and zeta potential by a laser size instrument (Zetasizer, Nano ZS, Malvern, UK).⁶
- 35 We determined the crystal structure of NFC and NFC/CDs paper by X-ray diffraction (XRD, D/MAX -TTRIII(CBO), Rigaku, Japan), and
- 36 recorded the patterns at an operating voltage of 40 kV and current of 20 mA.
- 37 We characterized the morphology of CDs and NFC/CDs dispersion by scanning electron microscope (SEM, Hitachi-SU8220, Hitachi, Japan)
- 38 operating at an accelerating voltage of 10 kV. We deposited a drop of CDs and NFC/CDs dispersion on a silicon wafer respectively and
- 39 allowed to dry at room temperature. To make samples conductive, we sputtered the surfaces of samples with a thin layer of gold using
- 40 ion sputtering equipment (Model E-1010, Hitachi, Japan) prior to SEM analysis. We observed the morphology of NFC by transmission
- 41 electron microscopy (TEM, Tecnai G2 20 S-TWIN, FEI, USA) at an accelerating voltage of 200 kV.⁷

- 42 We determined the fluorescence lifetime and quantum yield of the synthesized CDs at room temperature on a PTI QM/TM/NIR system
- 43 (Photo Technology International, USA).
- 44 We measured energy-dispersive X-ray spectroscope (EDS) by SEM (Hitachi-SU8220, Hitachi, Japan) equipped with EDS microanalysis 45 software.
- 46 We measured UV-Vis absorption spectra and fluorescence (FL) emission spectra by UV-Vis spectrophotometer (UV-2450, Shimadzu, Japan)
- 47 and fluorescence spectrophotometer (RF-5301PC, Shimadzu, Japan).
- We captured fluorescence images of NFC/CDs paper and office paper by Canon D90 digital camera equipped with a Canon 10-55 zoomlens under UV light.
- 50 We evaluated the dimensional stability of NFC/CDs paper through executing uniaxial tensile mechanical test of NFC/CDs paper with a
- 51 universal testing machine (Instron 3365, Instron Co., USA) at room temperature. We cut the sample into strips of 6 mm × 35 mm, and
- 52 mounted them between the grips of machine. We set the initial grip separation of the machine at 15 mm. We loaded the strip at a
- 53 stretching rate of 10 mm/min until the strip broke down.

54 Transfer and detection of latent fingerprints

- 55 We collected latent fingerprints (LFPs) from five volunteer donors (three males and two females) ranging from 20 to 35 years old. We
- 56 asked the donors to use their thumbs to lightly touch three middle fingers to leave "uncharged" or natural fingerprints samples. They
- 57 rubbed their fingers around the forehead or nose area, which avoided possible contamination with cosmetics, to achieve the above 58 deposition process.
- 59 The thumbs deposited their fingerprint on different substrates, such as glass, plastic, metal, paper, wall, cloth, and rubber (planar and
- 60 curved) at approximately 3.5 N of force for 8 s. We placed the LFP samples at a natural environment for aging treatment for 18 h to 24 h.
- 61 We transferred the pretreated LFPs by using NFC/CDs paper wetted with 0.01 mol L⁻¹ SDS solution. We fixed the transferred fingerprints
- 62 with cyanoacrylate fume and stained with SPIONs by a magnetic to enhance contrast effect.
- 63 We also transferred the pretreated LFPs by commercial adhesive tape. As a control, we fixed and stained directly the LFPs deposited on 64 different substrates.
- 65 We took photos for the fingerprints by Canon D90 digital camera equipped with a Canon 10-55 zoom lens under bright light and UV light
- 66 source. We observed the sweat pore structure using Blackmagic WDM Capture with a 200 zoom lens.

67 Numerical simulation

- 68 Grayscale images. We converted the images of fingerprints to grayscale images through Microsoft office software.
- 69 Establishment of three-dimensional models and extraction of feature points. We transferred grayscale images of fingerprints to three-
- 70 dimensional (3D) models by 3D Max software (Figure 4 and S9). We extracted feature points from the 3D models according to the Galton-
- 71 Henry classification and compared with those of fingerprint model obtained from glass substrate after fixing and staining (Figure S9).⁸
- 72 The similarity analysis. In order to quantify the similarity between the fingerprint obtained from glass substrate after fixing and staining
- 73 and other fingerprints obtained through various methods, we chose cosine theorem for assaying the similarity of two fingerprints.^{9, 10} We
- transformed the grayscale images of fingerprints to "m×n" grayscale values, and constructed matrixes [Eq. (1)]. In our collected data, the $\frac{75}{100}$ membra of some and columns are seen in the last $\frac{7}{100}$ membra of some and columns are seen in the last $\frac{7}{100}$ membra of some and columns are seen in the last $\frac{7}{100}$ membra of some and columns are seen in the last $\frac{7}{100}$ membra of some and columns are seen in the last $\frac{7}{100}$ membra of some and columns are seen in the last $\frac{7}{1000}$ membra of some and columns are seen in the last $\frac{7}{1000}$ membra of some and columns are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{1000}$ membra of some are seen in the last $\frac{7}{10000}$ membra of some ar
- number of rows and columns are equal, which means "m=n" and the matrix is a square matrix possessing "n" rows and "n" columns. The theorem demonstrates that if there are two nonzero vectors and the included angle is θ , when the cosine of the angle is 1, the two nonzero
- 77 vectors possess similarities [Eq. (2)].

$$A = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}, B = \begin{bmatrix} y_{11} & \cdots & y_{1n} \\ \vdots & \ddots & \vdots \\ y_{m1} & \cdots & y_{mn} \end{bmatrix}$$

79 where, A is the matrix of the fingerprint obtained from glass substrate after fixing and staining; B is the matrix of the fingerprint obtained 80 through various methods.

$$\cos \theta = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij}y_{ij})}{\sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij})^{2}} \times \sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} (y_{ij})^{2}}}, (i = 1, 2, 3, \dots, m; j = 1, 2, 3, \dots, m)$$

81

(2)

(1)

82 Results and Discussion

83 Energy-dispersive X-ray analysis



85 Figure S1. The EDS analysis of NFC and NFC/CDs paper. (a) The EDS spectrum of NFC. Inset: The distribution of nitrogen element. (b) The element content analysis of NFC. (c) The

86 EDS spectrum of NFC/CDs paper. Inset: The distribution of nitrogen element. (d) The element content analysis of NFC/CDs paper.

87 Fluorescence emission spectra



88 Wavelength (nm)
 89 Figure S2. FL emission spectra of NFC/CDs dispersion at different excitation wavelengths from 410 to 480 nm.

- 90 With the gradual increase of excitation wavelength from 410 to 480 nm, the emission peak generates red-shifting from 460 to 525 nm,
- 91 which leads NFC/CDs dispersion to emit multiple colors. The overall complex behavior of the PL emission spectra is associated with a
- 92 variety of emission centers presented in the NFC/CDs dispersion.¹¹ The proposed fluorescence mechanism is possibly owing to the radiative
- 93 $\,$ recombination of the energy-trapping sites in the NFC/CDs dispersion.^{12}



94 95

- 5 Figure S3. Fluorescence images of NFC/CDs paper and office paper under the excitation of 360 nm UV light.
- 96 Dimensional stability



 $99\$ Transfer of latent fingerprints and analysis of details



- 101 Figure S5. The fingerprint images and sweat pores obtained from glass, paper, wall, cloth, planar rubber, and curved rubber substrates through three different methods: directly
- 102 fixed with cyanoacrylate fume and stained with SPIONs, NFC/CDs paper transferred method, and tape-lift method. The first column is LFPs images. The second and third columns
- 103 are fingerprint images obtained directly after fixing with cyanoacrylate fume and staining with SPIONs. The fourth to sixth columns are fingerprint images transferred by NFC/CDs
- 104 paper. The seventh and eighth columns are fingerprint images transferred by tape-lift method (commercial adhesive tape). The scale bars in column 1, 2, 4, 6, and 7 are 10 mm.
- 105 The scale bars in column 3, 5, and 8 are 1 mm.



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Figure S6. The optical images, fluorescence images, and sweat pores of fingerprints transferred by NFC/CDs paper from plastic and metal substrates after pretreatment. The scale

108 bars in column 1, 2, and 4 are 10 mm. The scale bars in column 3 are 1 mm.

109 Table S1. The zeta potential of samples.

Component	LFPs residues	SPIONs	Polycyanoacrylate	NFC/CDs paper + SPIONs + LFPs residues
Zeta Potential (mV)	-1.20	4.36	-1.99	-13.90



 $\begin{array}{c} 110\\ 111 \end{array}$ Figure S7. The sweat pores of the LFP on glass substrate.



$\,$ Figure S8. The analysis of ridgelines and sweat pores about real finger.



Figure S9. The analysis of feature points of fingerprints obtained from glass, paper, wall, cloth, planar rubber, and curved rubber substrates through three different methods: directly fixed with cyanoacrylate fume and stained with SPIONs, NFC/CDs paper transferred method, and tape-lift method. Feature points 1, 1', 7, and 7' are the eye structures of

117 fingerprints. Feature points 2 and 2' are the endpoints of fingerprints. Feature points 3, 3', 4, 4', 5, 5', 6, 6', 8, 8', 9, and 9' are the bifurcations of fingerprints.



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Figure S10. The images of fingerprints aged for various time and from different donors from paper substrate. (a) The optical images and fluorescence images of fingerprints 120 transferred by NFC/CDs paper after different aging time: 1 day, 7 day, and 21 day. (b) The optical images and fluorescence images of fingerprints transferred by NFC/CDs paper 121

from 4 donors, including 2males and 2 females. Donor 2 and 3 are male, and donor 4 and 5 are female.

122 The imaging effect of fingerprints depends on the content of LFPs residues (principally sweat and natural oils). The biologically active 123 components of sweat and natural oils in the LFPs would denature and degrade during the aging process, leading to less adhesion of powder 124 on ridgelines of fingerprints.^{13, 14} Even so, our transfer method can transfer and detect successfully LFPs with a few residuals after 21 days 125 aging time, and is of high sensitivity and high reliability in a practical application.

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