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# Grazing incidence polarized light imaging of footwear prints

**Key words:** Polarization; Image enhancement; Scattering; Particle

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# Motivation

- Criminal investigators can infer the personal characteristics of criminals by extracting and analyzing the footwear prints in the crime scene.
- For polarized photon scattering, the polarization states of the scattered light are sensitive to the microstructure of the samples.

# Main idea

- Using grazing incidence illumination and taking pictures right above the samples to collect scattered light at the vertical direction, one can effectively reduce the interference due to background reflection and enhance the contrast of the images.
- We place linear polarizers in front of both the illumination lamp and the camera, and examine in detail how contrasts of the footwear print images are affected by different polarizations.

# Experimental setup

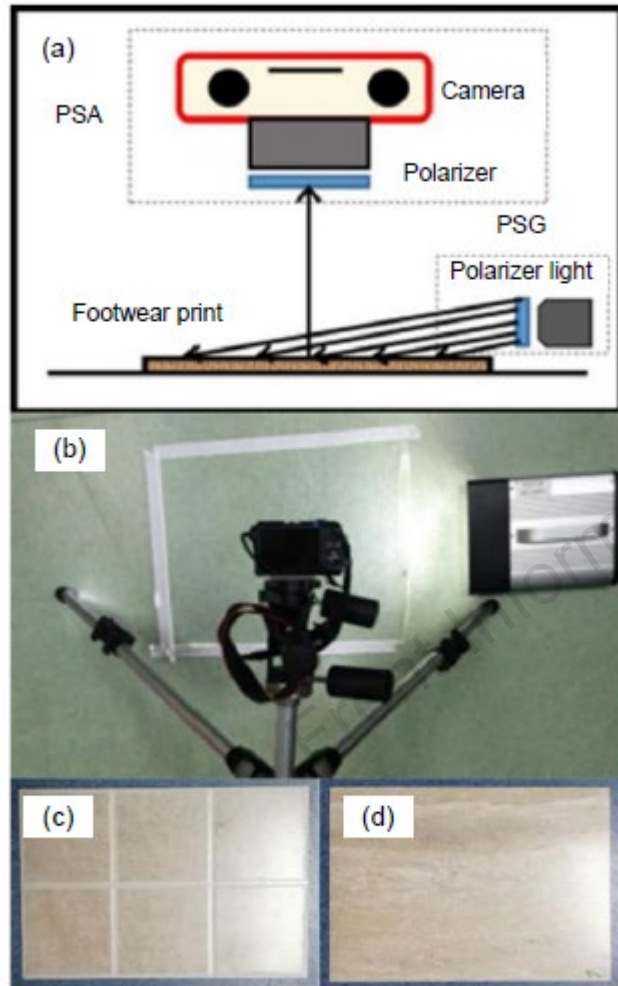


Fig. 1 Scene design of the experimental system: (a) schematic of the experimental setup; (b) real scene; (c) tile 1 bearing footprints; (d) tile 2 bearing footprints

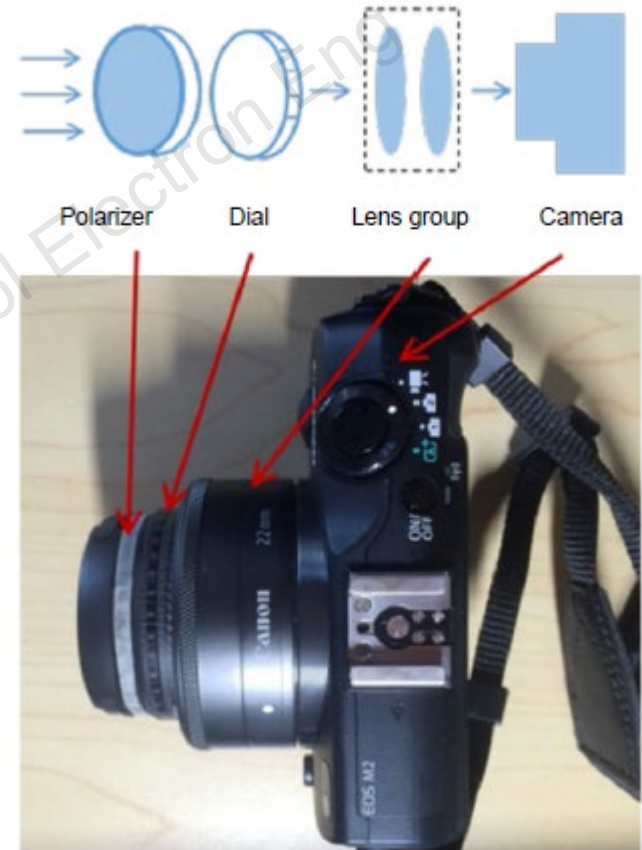
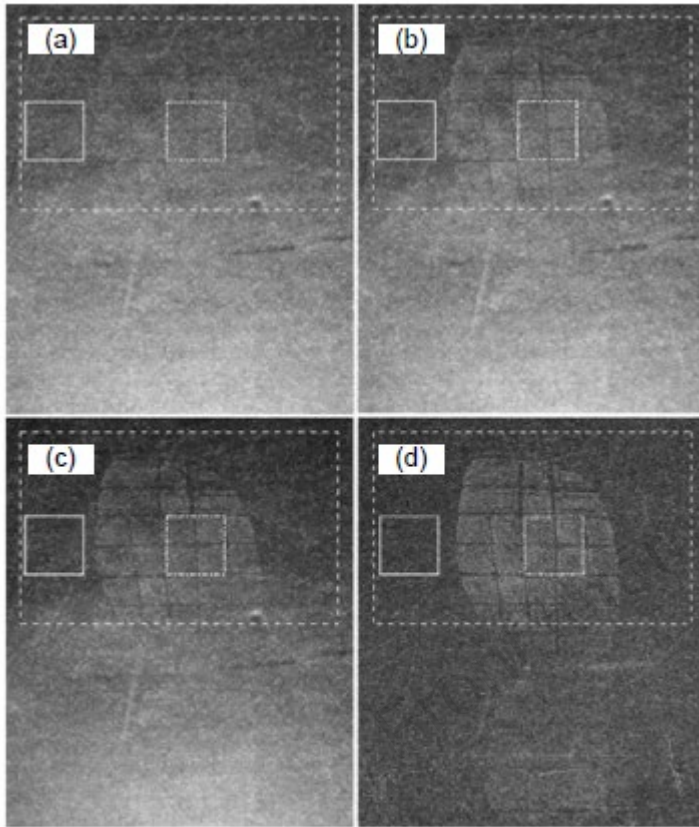


Fig. 2 Photograph and configuration of the polarized camera device

# Experimental results



**Fig. 3** Footwear print images in different experimental conditions: (a) image with unpolarized illumination and unpolarized imaging; (b) image with polarized illumination and unpolarized imaging; (c) image with polarized illumination and polarized imaging; (d) DoLP image

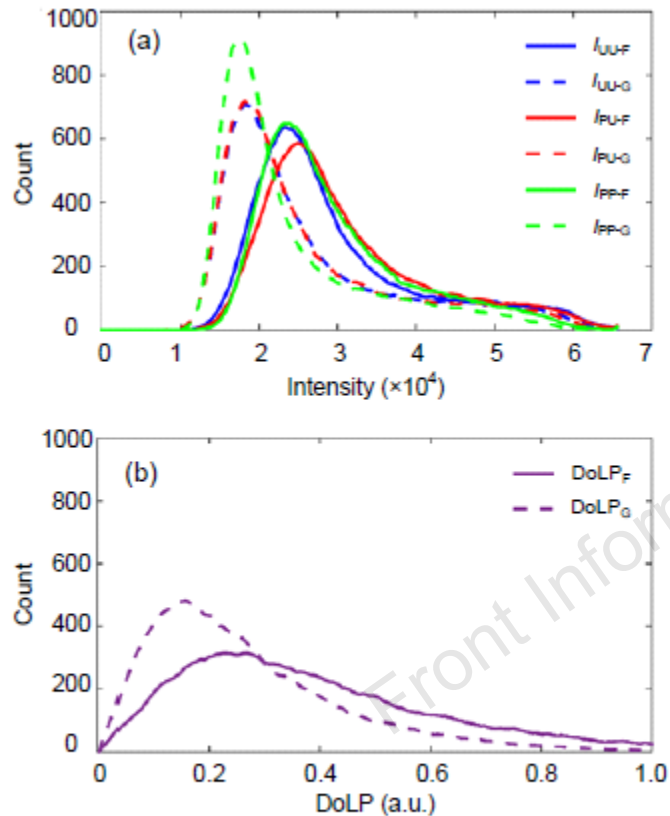
Fig. 3a shows that grazing incidence illumination helps obtain footwear prints on the PVC floor cover, but the image contrast is not high.

Fig. 3b shows the footwear print intensity image under linearly polarized illumination with the polarization direction parallel to the ground. The comparison between Figs. 3a and 3b shows that polarized grazing incidence illumination improves the footwear print contrast.

Fig. 3c shows the polarization component images with  $0^\circ$  analyzer. It shows that images of the parallel linear polarization component result in further improvement in the contrast of footwear print images.

Using the three linear polarization component images and Eqs. (1)–(3), we can further calculate the degree of linear polarization (DoLP) image (Fig. 3d). It is apparent that the DoLP image can effectively reduce the background and significantly improve the contrast of the footprint image.

# Experimental results



**Fig. 4** Histogram curves corresponding to the intensity (a) and the DoLP (b) of footwear prints

We calculate the histograms of the selected image areas (large dashed box) with and without the footwear print in Fig. 3 and display the histogram curves in Fig. 4.

$I_{UU-F}$  and  $I_{UU-G}$  represent the intensity values of the footwear prints and the ground in the unpolarized illumination and unpolarized imaging condition, respectively;  $I_{PU-F}$  and  $I_{PU-G}$  represent the intensity values of the footwear prints and the ground in the polarized illumination and unpolarized imaging condition, respectively;  $I_{PP-F}$  and  $I_{PP-G}$  represent the intensity values of the footwear prints and the ground in the polarized illumination and polarized imaging condition, respectively;  $DoLP_F$  and  $DoLP_G$  represent the DoLP values of the footwear prints and the ground in the polarized illumination and polarized imaging condition, respectively.

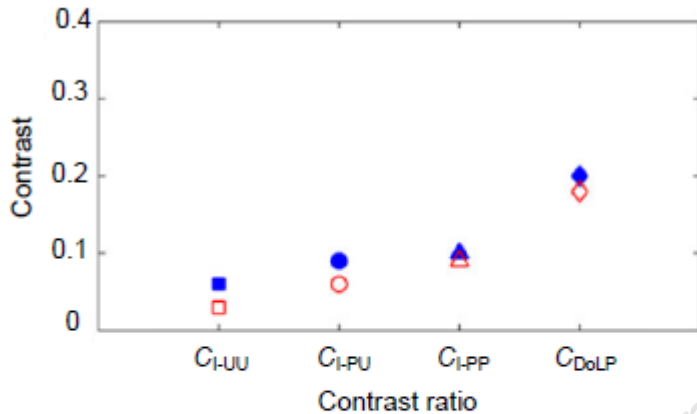
# Experimental results

**Table 1** Contrast ratios of different background materials

Background	Color channel	$C_{I-UU}$	$C_{I-PU}$	$C_{I-PP}$	$C_{DoLP}$
PVC floor	Red	0.06	0.09	0.11	0.17
	Green	0.06	0.08	0.10	0.18
	Blue	0.06	0.09	0.10	0.20
Tile 1	Red	0.04	0.10	0.11	0.19
	Green	0.04	0.10	0.11	0.19
	Blue	0.07	0.15	0.17	0.19
Tile 2	Red	0.02	0.06	0.07	0.20
	Green	0.02	0.06	0.07	0.21
	Blue	0.02	0.07	0.08	0.23

We carry out similar experiments on footwear prints left on two types of household tiles (Figs. 1c and 1d). Table 1 shows that the experimental data for the footwear prints on these tiles is quite similar to that on the PVC floor. Contrast ratios increase from  $C_{I-UU}$  to  $C_{DoLP}$ , and the blue channel achieves the highest contrast ratio.

# Experimental results



**Fig. 5** Experimental and simulated contrast ratios under different imaging conditions at 467-nm wavelength incident light

Solid dots represent experimental values on the PVC floor cover, and hollow dots represent simulation values

For better understanding the physical mechanisms for contrast enhancement of footwear prints by polarized grazing incidence and polarized scattering detection, we use a very crude scattering model and a Monte Carlo simulation program to demonstrate how the intensity and polarization states of the scattered light vary for different samples and experimental configurations.

Fig. 5 shows the simulated contrasts. The simulation results follow the trend of the experimental results on the PVC floor cover, both of which indicate that polarization incidence and detection enhance the contrast. The relatively small size or the probable sharp edges of the extraneous particles on the footwear prints may play a vital role in the contrast enhancement of the polarization images.

# Conclusions

- Results showed that illumination by linearly polarized light with the polarization direction parallel to the ground will improve the image contrast for even unpolarized detection.
- Further enhancement of the contrast has been achieved by detection of the linearly polarized component parallel to the incident beam polarization.
- Significant improvement is achieved for degree of linear polarization (DoLP) imaging, but not for angle of polarization (AoP) imaging.
- For the blue, green, and red color channels, DoLP contrast increases for smaller wavelengths.