# Synthetic apertures for visible imaging using Fourier Ptychography: a review

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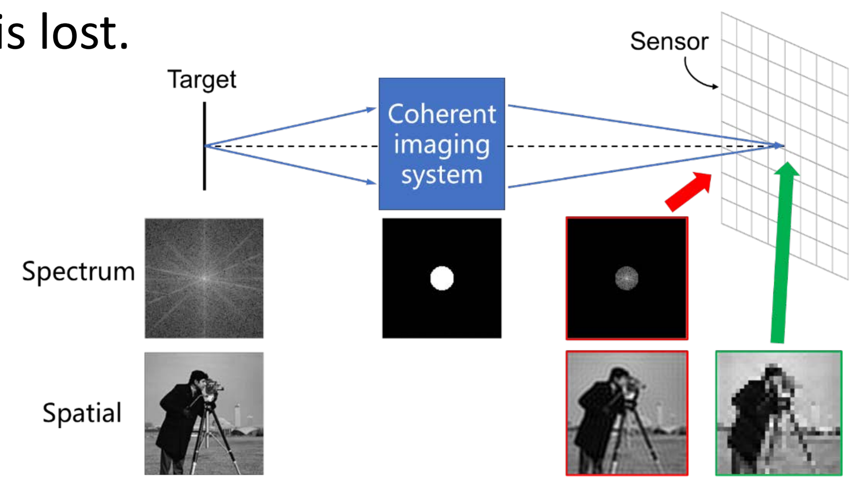
## Introduction

With the rapid development of photoelectric imaging and artificial intelligence, photoelectric imaging has been widely used in many fields such as sea, land, and air due to its advantages of full-time work, strong environmental adaptability, and long detection distance. However, for most conventional optical imaging systems, the aperture size is fixed, and the diffraction blur will result in the resolution loss, thus can't meet the resolution requirements for accurate detection in long distance imaging. In this work, the phase retrieval algorithm and synthetic aperture imaging in the computational optical imaging will be applied to the long-distance imaging and surpass the diffraction limit of the traditional optical imaging system. Several simulations and experiments are performed, the results demonstrate that the macroscopic Fourier ptychography can effectively improve the resolution of the traditional imaging system.

## Principle

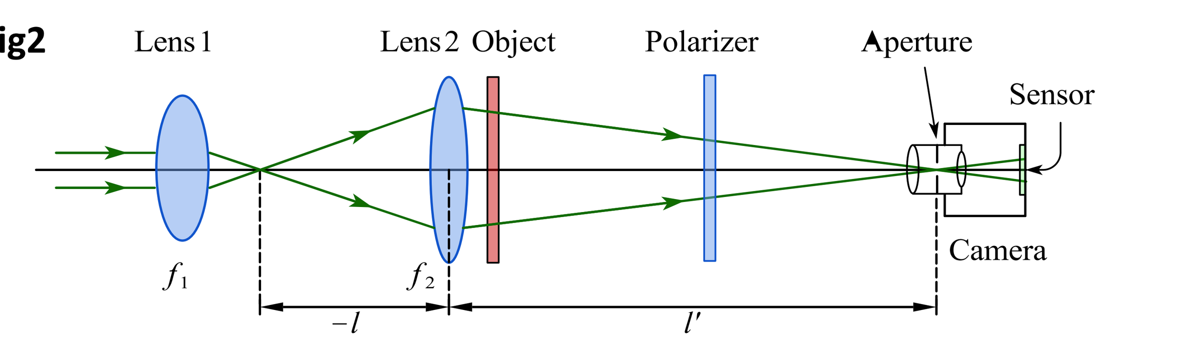
As shown in Fig.1, the coherent transfer function of the coherent optical imaging system is equivalent to a low-pass filter. Only the frequency components within the passband of the filter can pass through the imaging system, while the high frequency information outside the passband of the low-pass filter is lost.

Fig1




In Fourier ptychography microscopy, with the sample illuminated by plane waves at different angles, high frequency information is translated into the passband of aperture. Referring to this idea, we apply Fourier ptychography imaging to macro imaging. The schematic diagram of the macroscopic Fourier ptychography is shown in Fig.2.

Fig2




Assume that the field emerging from the object is $\psi(x, y)$ , then the filed propagates a large distance $l'$ to the aperture plane of the camera. The filed between the object plane and the aperture plane can be described as a Fourier transform:

$$\Psi(u,v) = \frac{\exp(jkz)\cdot\exp\left(jk\frac{u^2+v^2}{2z}\right)}{j\lambda z}\mathcal{F}_{1/\lambda z}[\psi(x,y)]$$

Since the camera sensor only detects optical intensity, the image measured by the camera is

$$I(x,y,u_c,v_c) \propto |\Phi(x',y')|^2 = |\mathcal{F}[\Psi(u,v)\cdot P(u-u_c, v-v_c)]|^2$$

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## Numerical Simulation

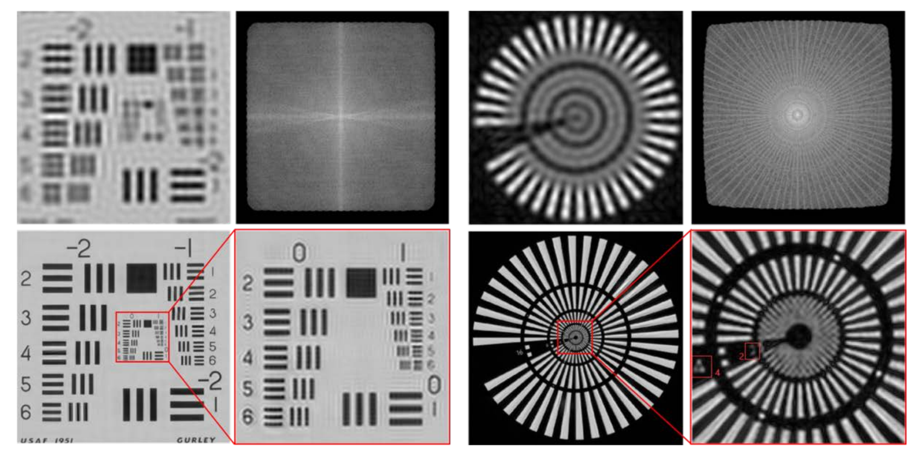
We explore the key parameters of the system and the reconstruction algorithm via simulation. The parameters of the system are shown in the below chart and the data redundancy requirement, the sub-aperture positional misalignment effects are explored.

A HR image of the USAF1951 target is supposed as the HR object, the captured LR image, reconstructed HR spectrum and the reconstructed HR amplitude image are shown in **Fig.3**. it shows that the resolution ability of the system has a improvement, which is approximate with the theoretical SAR.

**Table 1.** Parameters in MFP simulation experiment

| Index | Parameter | Index | Parameter |
|---|---|---|---|
| Image distance | 1700$mm$ | Image number | $25\times25$ |
| Pixel size | 3.75$\mu m$ | Camera offset | 0.7$mm$ |
| Focal length | 75$mm$ | Overlap ratio | $\approx 70\%$ |
| F# | 32 | Synthetic aperture ratio | $\approx 8$ |

Fig3

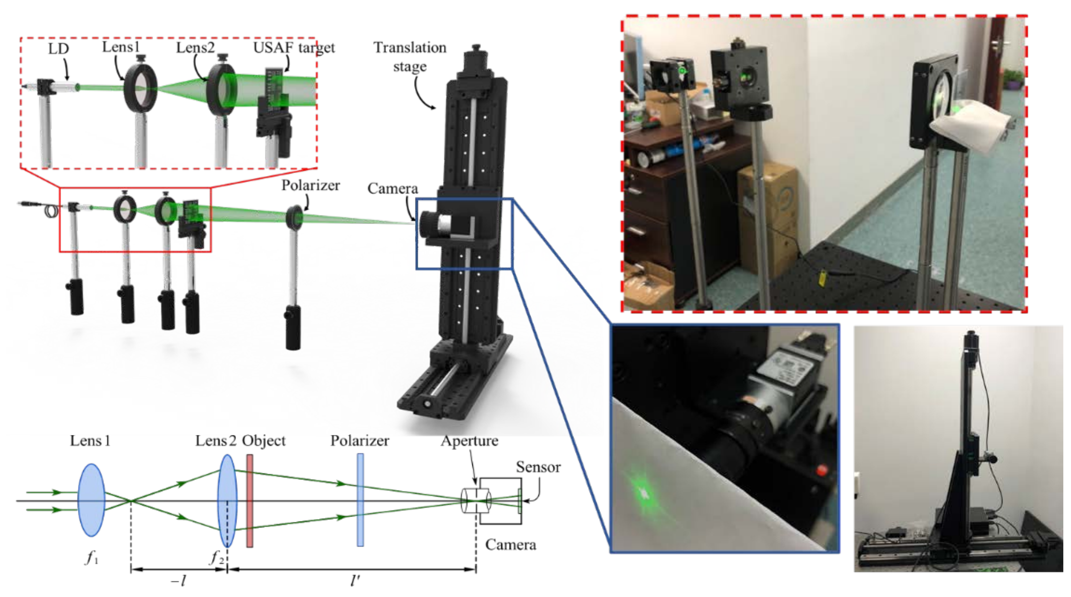


## Experiment setup and Results

To verify the simulations of the macroscopic Fourier ptychography system, a transmission mode MFP experimental system including the imaging system hardware and a set of C ++-based automatic image acquisition software has been introduced.

The system includes an acA1300-30gm Basler ace GigE camera with a pixel pitch of 3.75um, coupled with a 75mm Fujinon lens (HF75SA), a two-axis automatic translation stage and optical cage systems. The distance between the object and the camera is 1.7 meters and the object is illuminated with a laser diode which emits a beam with a wavelength of 633 nm. In order to simulate building a cheap lens with a small aperture, we stopped the lens down to F#16.

Fig4




We test our setup with two scenes. Firstly, a USAF1951 target is illuminated with a LD and LR image sequence are capture by the camera. By acquiring a 21×21 grid of images, with the 0.7mm moving interval between neighboring images, corresponding ~70% overlap. Theoretical synthetic aperture ratio is 4. The results of the reconstruction are shown as the **Fig.5**, where the spatial resolution has increased from 2.24lp/mm (Group1 Element2) to 8.98lp/mm (Group3 Element2), with a 4× improvement in resolution.

Fig5

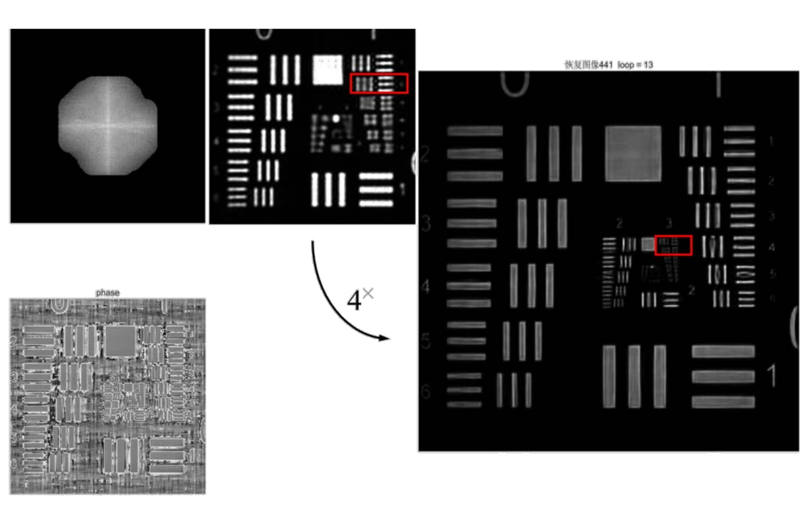
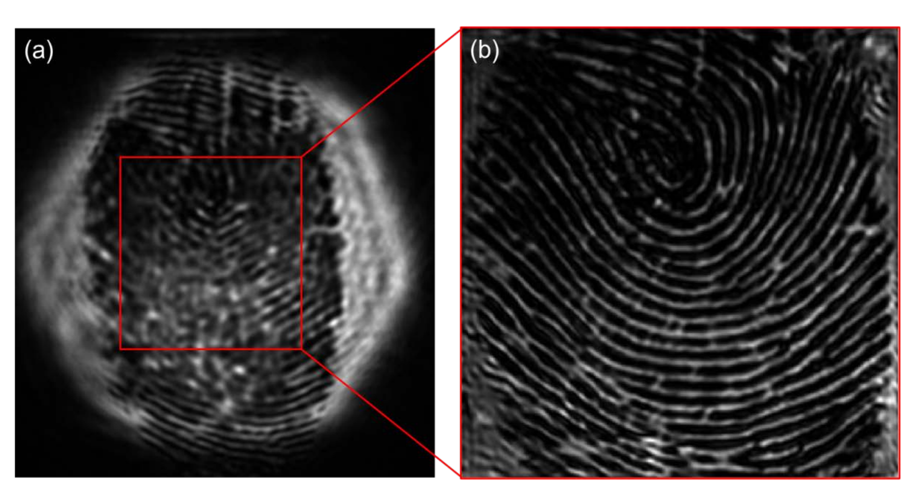


Fig6




We next use the same setup to capture a fingerprint, shown in **Fig.6**. With a 3*3 grid of images and the 0.7mm moving interval between neighboring images. In the LR fingerprint pattern shown in Fig.6(a), most high spatial frequency information can not be distinguished. After running phase retrieval, we recover a HR magnitude image and the phase of the fingerprint. The HR magnitude image of the fingerprint is shown in Fig.6(b).

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