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Optical difference engine for defect inspection in highly-parallel manufacturing processes

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Abstract: Traditional defect inspection for highly-parallel manufacturing processes requires the processing of large measurement datasets, which is often not fast enough for in-situ inspection of large areas with high resolution. This study develops an all-optical difference engine for fast defect detection in highly-parallel manufacturing processes, where the detection of defects (differences from nominal) is performed optically and in real-time. Identification of defects is achieved through an optical Fourier transform and spatial filtering, detecting differences between two real objects by nulling information that is repeated in each object. The developed prototype device is demonstrated using geometric patterns of similar scale to components in printed electronic circuits.

Introduction

Highly-parallel manufacturing (e.g. printed electronics, coatings in solar cells, micro devices for medical applications) deploys defect inspection for quality control:

- 2D optical imaging + data processing
- Laser scanning methods
- 3D scanning optical surface measurement techniques

Current techniques are limited by the computational speed when imaging large areas with high resolution. An optical difference engine (ODE) utilises coherent optical processing technique to enable defect inspection at high speed.

Working principle

A perfect reference object and a test object with defects are positioned side by side, illuminated with coherent light and imaged with a 4f-system (Fig 2).

- An optical grating is used to perform spatial filtering in the Fourier plane.
- All the information repeated in both images is nulled, resulting in a single image containing only the difference between two objects.
- A detector can be placed at the *U* plane to record the difference.

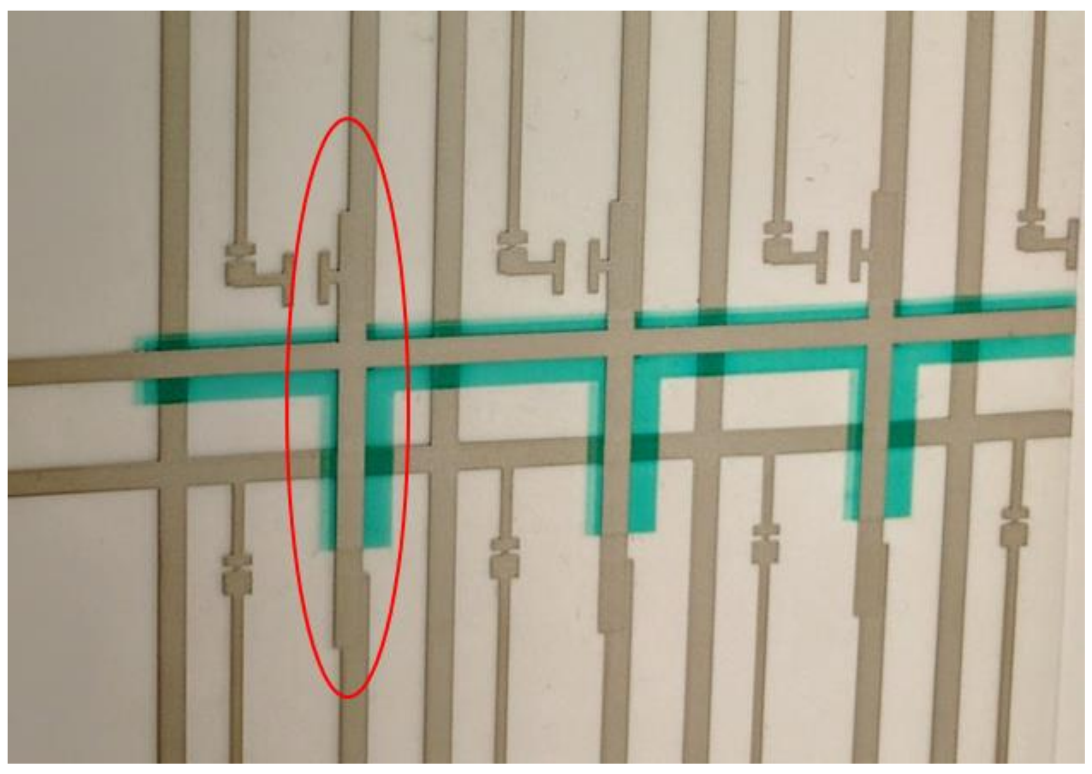

Fig 1. A sample of printed electronic circuits with defects (provided by VTT).

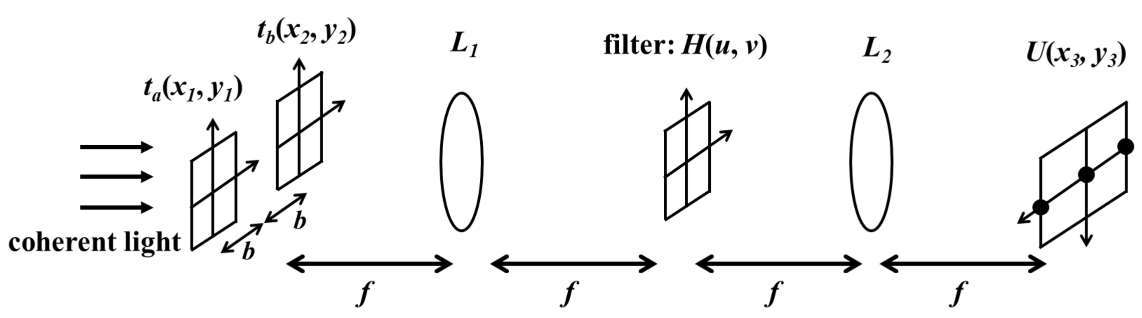

Fig 2. Illustration of an optical difference engine.

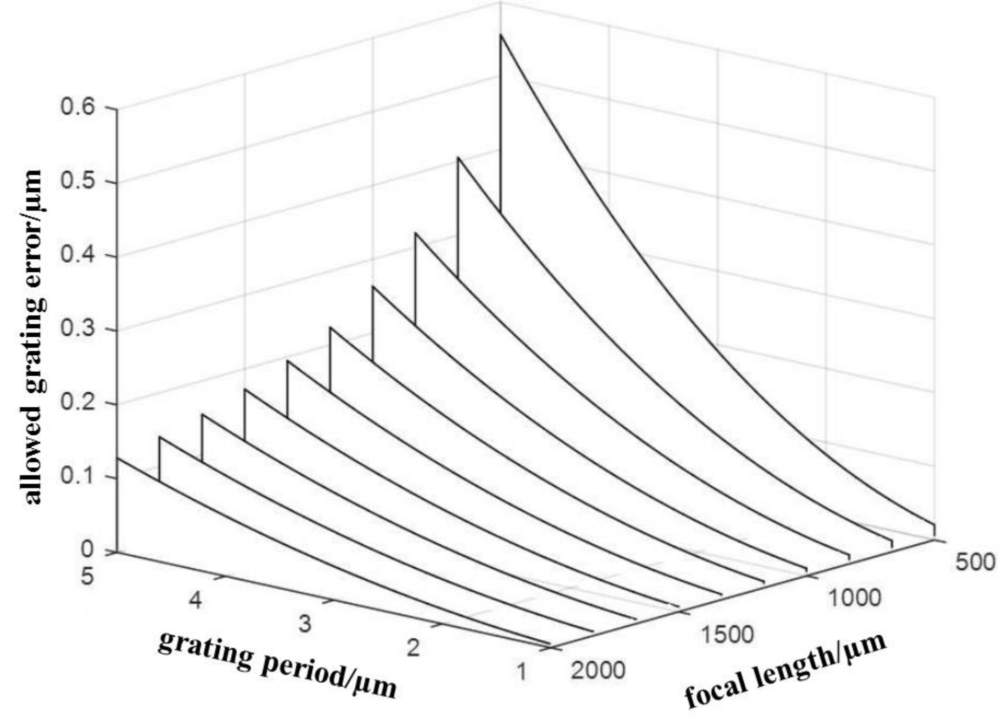

Fig 3. Allowed error in the grating period for the maximum central shift of 5 µm, assuming wavelength λ = 0.5 µm.

Sensitivity analysis

The main challenge of implementing the ODE is the need for high precision positioning of the optics, as the alignment errors and grating period error (Fig 3) causes shifting of the images of the two objects, resulting in poor registration and false detection. However, such shift can be minimised through adjustment of the offset distance between the two objects.

Prototype ODE

The prototype device (Fig 5) was implemented:

- using off-the-shelf products (Table 1);
- with additional components introduced to overcome a few practical challenges.

Conclusion

An ODE system has been:

- developed and implemented using off-the-shelf components;
- demonstrated with geometric patterns (Fig 4) cut from a thin sheet, from which defects as small as 30 µm can be detected.

Data post-processing is minimised by conducting optical processing.

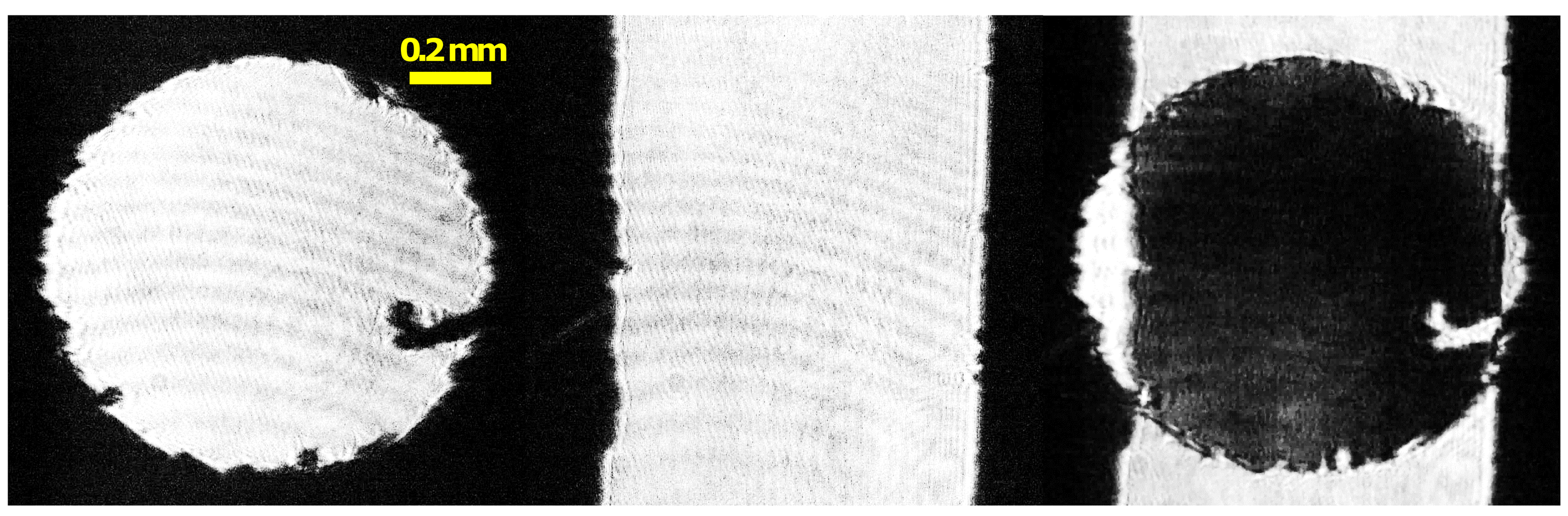

Fig 4. Inspection comparing a hole of Φ1 mm (left) and a rectangular bar of 0.8 mm width (middle), resulting in the optical difference of two objects (right).

Table 1. Specifications of the optical components in the prototype ODE.

Laser wavelength/nm	532	Laser beam diameter/mm	3.5
Grating type	blazed	Grating period/µm	3.33
Imaging lens focal length/mm	30	Image sensor type	CMOS
Image sensor colour	monochrome	Image sensor pixel size	1280 × 1024

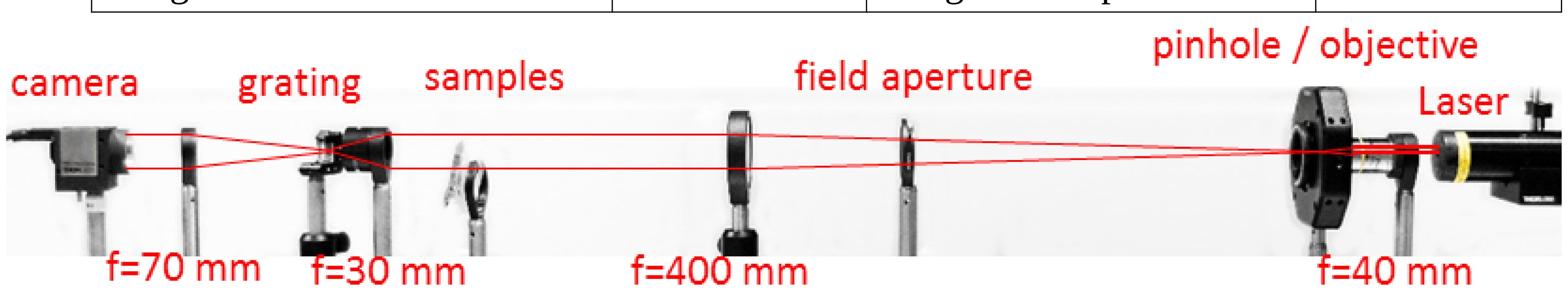

Fig 5. Setup of the prototype ODE system with off-the-shelf components.