Micron-scale depth sensing: applications

inspektion

fabrication

defects on wing

1 mm

SWI depth

3D-printed coin

1 mm

SWI depth
Fiber-based SWI

- Fiber-based SWI diagram
- Fiber splitter
- Beam steering
- Single frequency lasers $\lambda_1$ and $\lambda_2$
- Detector / spectrometer
- Reference mirror
- Scene
Fiber-based SWI

single frequency lasers

fiber splitter

isolator

collimator

d

x

scene

reference mirror

detector / spectrometer

\( \lambda_1 \)

\( \lambda_2 \)
Fiber-based SWI

single frequency lasers

isolator

fiber splitter

collimator

scene

$I$

$\lambda_1$

$\lambda_2$

d

$x$

detector / spectrometer

reference mirror

$I$

$\lambda_1$

$0$

$d - x$
Fiber-based SWI

- Single frequency lasers
- Fiber splitter
- Isolator
- Collimator
- Scene
- Detector / spectrometer
- Reference mirror

\[ \lambda_1 \quad \lambda_2 \]
\[ d - x \]
Fiber-based SWI

- Single frequency lasers
- Fiber splitter
- Isolator
- Collimator
- Scene
- Detector/spectrometer
- Reference mirror

\[ \lambda_1 \]
\[ \lambda_2 \]
\[ I \]
\[ \lambda_s \]
Fiber-based SWI

- Single frequency lasers
- Fiber splitter
- Isolator
- Collimator
- Scene
- Detector / spectrometer
- Reference mirror

\( \lambda_1 \)
\( \lambda_2 \)

Beam steering

Mathematical expressions:

\[ I \]
\[ \lambda_s \]
\[ d \]
\[ d - x \]
Full-field SWI

$\lambda_1$

single frequency lasers

$\lambda_2$

reference mirror

scene

lens

splitter

camera
Full-field SWI errors: indirect light

- Single frequency lasers
- Splitter
- Lens
- Reference mirror
- Scene
- Camera

\( \lambda_1 \) and \( \lambda_2 \)
Full-field SWI errors: aberrations

\[ \lambda_1, \lambda_2 \]

single frequency lasers

\[ \text{splitter} \]

\[ \text{reference mirror} \]

\[ \text{scene} \]

\[ \text{lens} \]

\[ \text{camera} \]
Swept-angle SWI

Single frequency lasers

$\theta$

Scene

Reference mirror
Constructing swept-angle source

- Single frequency lasers
- Splitter
- Lens
- Reference mirror
- Camera
- Scene
Error mitigation with swept-angle scanning

indirect light

free-space optics aberrations

reference mirror only

target

without swept-angle

with swept-angle
Signal processing pipeline

- raw frames
- interference-free
- interference-only
- denoised envelope
- envelope
- depth
### Comparison with other interferometric methods

| Method          | Axial Resolution | Lateral Resolution | Acquisition Time | Indirect Light Robustness |
|-----------------|------------------|--------------------|------------------|---------------------------|
| FD-OCT scanning | high             | low                | slow             | yes                       |
| TD-OCT full-field | high               | high               | slow             | no                        |
| SWI scanning    | high             | low                | slow             | yes                       |
| SWI full-field  | high             | high               | fast             | no                        |
| SWI swept-angle | high             | high               | fast             | yes                       |
Results: $20 bill eagle

dollar bill  scene  recovered depth surface  recovered depth map
Results: 1 mm depth range

| Scene       | Input Image | Swept-angle SWI, ours | No swept-angle scanning |
|-------------|-------------|-----------------------|-------------------------|
| quarter     |             |                       |                         |
| euro        |             |                       |                         |
| soap        |             |                       |                         |
| music box   |             |                       |                         |
Results: microscopic scenes

- chocolate
- PlusPlus®
- business card

- scene
- input image
- swept-angle SWI, ours
- no swept-angle scanning

1 mm
0.90 mm
0.27 mm
0.10 mm
Results: macroscopic scenes

corner

pawn

toy cup

scene input image swept-angle SWI, ours no swept-angle scanning

1 mm
Acquisition time v/s quality

source  

100 ms  

25 ms  

10 ms  

{3, 4}-shift = 12  

{4, 4}-shift = 16  

{5, 4}-shift = 20  

{5, 5}-shift = 25
Acquisition time v/s quality

- **100 ms**
- **25 ms**
- **10 ms**

Source: {3, 4}-shift = 12, {4, 4}-shift = 16, {5, 4}-shift = 20, {5, 5}-shift = 25
Robustness to environmental conditions

scene  ours, no ambient light  ours, 10% laser to ambient light ratio
Passive interferometry

swept-angle SWI passive interferometry

artificial light sources

dark room

vibration isolation

natural light

no active isolation

bright outdoors

passive interferometry
Swept-Angle Synthetic Wavelength Interferometry

more details: https://imaging.cs.cmu.edu/swept_angle_swi

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