An adaptive 3D machine vision system for electronic components inspection

Department of IE&M
Yuan-Ze University
Hsu-Nan Yen
Du-Ming Tsai
Contents

- Introduction
- Method
- System description
- Experimental results
- Conclusion
Introduction - Status in electronic industry

light, thin, small and multifunctional electronic products

minify electronic components
high-density packaging

3D measurement to ensure reliability
Introduction -
Some methods for 3D measurement

- Laser scanning techniques
- X-ray detection methods
- Microscope inspection with focus-based methods
- Projected fringes with phase shifting techniques
Introduction -
Some methods for 3D measurement

- **Laser scanning techniques**
  - slow with a point-by-point or line-by-line scan
  - measuring accuracy is affected by the beam spot reflection and stray light.

- **X-ray detection methods**

- **Microscope inspection with focus-based methods**

- **Projected fringes with phase shifting techniques**
Introduction -
Some methods for 3D measurement

- Laser scanning techniques

- X-ray detection methods
  - require expensive equipment
  - suffer from long measuring time

- Microscope inspection with focus-based methods

- Projected fringes with phase shifting techniques
Introduction - Some methods for 3D measurement

- Laser scanning techniques
- X-ray detection methods
- Microscope inspection with focus-based methods
  - inherently small effective area of detection
- Projected fringes with phase shifting techniques
Introduction - Some methods for 3D measurement

- Laser scanning techniques
- X-ray detection methods
- Microscope inspection with focus-based methods
- Projected fringes with phase shifting techniques
  - full-field 3D measurement ⇒ fast inspection
  - high accuracy
Method - Relationship between surface height and phase

The surface height \( h(x, y) \) is determined by the difference of the phase functions:\n
\[
h(x, y) = AC \frac{\tan \theta_d}{(1 + \tan \theta_d / \tan \theta_p)} \]

\[
= k \cdot [\phi_r(x, y) - \phi_o(x, y)]
\]

where \( k \) is a constant for a given system setup; \( \phi_r(x, y) \) is the phase function on the reference plane; \( \phi_o(x, y) \) is the phase function in the presence of object.

- The surface height \( h(x, y) \) is determined by the difference of \( \phi_r(x, y) \) and \( \phi_o(x, y) \).
Method -

Extracting phase from intensity images

\( \phi_r(x, y) \) and \( \phi_o(x, y) \) can be obtained by using phase shifting technique.

\[ \delta(t) = \pi \]

The fundamental formula of phase shifting technique is

\[ I_n(x, y) = I_b(x, y) + I_m(x, y) \cos[\phi(x, y) + \delta(t)] \]

where \( \delta(t) \) is the introduced phase shift.

Choose \( \pi /2 \) as phase shifting increment and adopt four-step phase shifting method.

\[ I_1(x, y) = I_b(x, y) + I_m(x, y) \cos[\phi(x, y) + 0] = I_b(x, y) + I_m(x, y) \cos \phi(x, y) \]

\[ I_2(x, y) = I_b(x, y) + I_m(x, y) \cos[\phi(x, y) + \frac{\pi}{2}] = I_b(x, y) - I_m(x, y) \sin \phi(x, y) \]

\[ I_3(x, y) = I_b(x, y) + I_m(x, y) \cos[\phi(x, y) + \pi] = I_b(x, y) - I_m(x, y) \cos \phi(x, y) \]

\[ I_4(x, y) = I_b(x, y) + I_m(x, y) \cos[\phi(x, y) + \frac{3\pi}{2}] = I_b(x, y) + I_m(x, y) \sin \phi(x, y) \]

\[ \Rightarrow \phi(x, y) = \tan^{-1}\left[\frac{I_4 - I_2}{I_1 - I_3}\right] \Rightarrow \phi_r(x, y) \text{ and } \phi_o(x, y) \]
System - Complete layout

- LCD Control Interface
- Precision Translation Stage
- Optical Bench
- Lens 2
- Lens 1
- LCD Panel
- Cool Light Source
- CCD
- PC
cool light source and lens 1
↓
supply the collimated white light
System - Complete layout

- LCD Control Interface
- LCD Panel
- Cool Light Source
- CCD
- Precision Translation Stage
- Optical Bench
- Lens 1
- Lens 2
- LCD panel

LCD panel

generate transparent sinusoidal grating
shift grating with accurate phase increment
System -
Complete layout

- LCD Control Interface
- Precision Translation Stage
- LCD Panel
- Cool Light Source
- CCD
- Optical Bench
- Lens 1
- Lens 2
- PC

lens 2

focus the image of sinusoidal grating
System - Complete layout

- Precision Translation Stage
- Optical Bench
- Lens 2
- LCD Panel
- Lens 1
- Cool Light Source
- CCD
- LCD Control Interface
- PC

precision translation stage

↓

place the object under inspection
System - Complete layout

- LCD Control Interface
- Precision Translation Stage
- Lens 1
- LCD Panel
- Cool Light Source
- Optical Bench
- Lens 2
- CCD camera
- CCD
- PC

CCD camera ↓
capture the projected fringe patterns
System -
Digital phase shifting

$I_1(x,y)$
System - Digital phase shifting

\[ I_2(x,y) \]

phase shifting is \( \pi/2 \)
System -
Digital phase shifting

Phase shifting is $\pi$
System -
Digital phase shifting

\[ I_4(x,y) \]

phase shifting is $3 \pi /2$
System - Adaptive projection

different fringe periods

easily changed fringe periods, phase-variation directions and grating patterns

accommodate the topography and reflectance of various electronic components on PCBs

avoid phase ambiguity
reduce overexposure area
increasing measuring speed
Experiment -
A 1mm gauge block

(a) The 1mm gauge block.
(b) The deformed sinusoidal fringes image of the 1mm gauge block.

(c) The 3D surface profile of the 1mm gauge block.

- mean step height is 1.03 mm
- standard deviation is 0.04 mm
Experiment -
A solder joint on the PCB

(a) A solder joint on the PCB.
(b) The deformed sinusoidal fringes image of the solder joint on the PCB.
(c) The 3D surface profile of the solder joint on the PCB.
Experiment -
A sample BGA-joint

(a) The sample BGA-joint.

(b) The deformed sinusoidal fringes image of sample BGA-joint.

(c) The 3D surface profile of the sample BGA-joint.
Conclusion

- **Full-field 3D measurement system with cost-effective equipment.**

- Efficient and effective in 3D inspection for small electronic components.

- System resolution can be considerably improved by adopting a higher resolution LCD panel, image grabber and CCD.