High-resolution 3D Line Confocal Imaging technology in real-time R2R measurement applications

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Abstract

This paper discusses FocalSpec's patented Line Confocal Imaging (LCI) technology and its use in in-line 2R2 web measurement applications. LCI enables high-speed 3D imaging of continuous web products, such as films, foils, laminates and coatings at sub-micron resolution. Operational principle of the LCI method and its strengths and weaknesses are presented. The method's use in three real-time R2R measurement applications are explored:

1. Coating and substrate surface roughness measurement.
2. Coating, ink and substrate thickness measurement.
3. Measurement of embossed and printed 3D features.

Keywords: Real-time; inline; web; inspection; surface; roughness; measurement; control; thickness; 3D features; printed electronics; embossing; process optimization; quality.

1. Introduction

FocalSpec is a designer, manufacturer and marketer of unique optical 3D imaging sensors and systems for metrology and inspection applications. The company was founded in 2009 as a spin-off from Technical Research Center of Finland (VTT) and is headquartered in Oulu, Finland. FocalSpec has wholly owned subsidiaries in Atlanta, GA and Ratigen, Germany; and an application center in Suzhou, China. The company also operates via sales representatives, distributors and system integrators in various other countries and geographical locations.

The company's core technology, Line Confocal Imaging, fills the gap between traditional 3D metrology technologies, namely laser triangulation, interferometry and confocal point sensing.

2. Line Confocal Imaging

Line Confocal Imaging (LCI) is an optical metrology method that enables high-speed imaging of various 3D characteristics at sub-micron resolution. LCI can be used in measurement of shapes, profiles, textures, surface roughness, thickness, dimensions, etc. The method is patented and products based on LCI are available only from FocalSpec.

2.1 LCI Principle

As the name suggests, Line Confocal Imaging is based on a measurement profile line. An LCI sensor is mounted on one side of the imaged product it contains both transmitter and receiver parts built in one single housing. The transmitter has a solid-state light source emitting white light containing all visible wavelengths. The optical system in the transmitter splits these wavelength into vertical spectrum where each dominating wavelength is focused at a different distance from the sensor. The measurement line is c continuous line of 2048 individual points with no gap in-between.

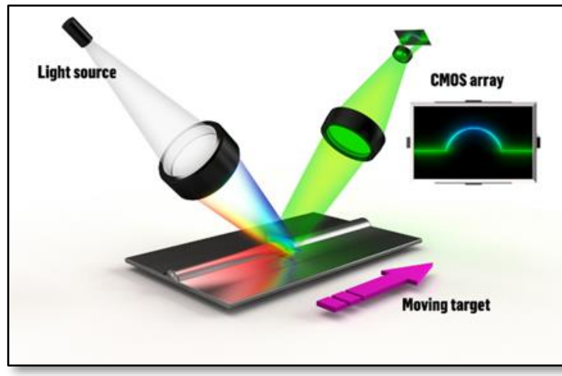

Figure 1. LCI Sensor Measurement Principle

The CMOS array in the sensor's receiver detects the wavelength i.e. color of each of the 2048 reflected points and converts this into z (height) data for each point. The sensor then outputs z and x coordinate information for the entire line for further processing.

The sensor's focal plane (measurement window) is thus a rectangle with wavelengths (colors) on z axis and the 2048 individual points on the x-axis.

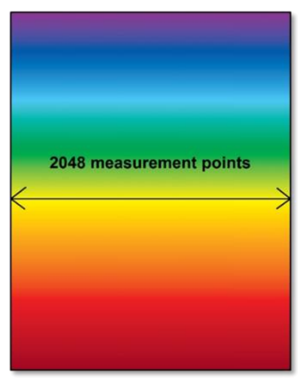

Figure 2. LCI Sensor's Focal Plane

When either the measured subject is moved under the LCI sensor or the sensor is moving above a stationary target, the captured lines for a 3D surface map or so-called point cloud that can be then analyzed for desired features and characteristics.

2.2 Line Confocal Sensors

FocalSpec offers a range of LCI sensors that offer different size of measurement windows, measurement resolutions, surface angle tolerance and speed.

Figure 3. FocalSpec Sensors

3D points per line	2048
Z (height) resolution	0.10 – 0.98 µm 0.004 – 0.039 mil
Lateral resolution	2.2 – 36 µm 0.087 – 1.417 mil
Z range	1.0 – 5.5 mm 0.04 – 0.22”
Profile line length	4.50 – 16.40 mm 0.18 – 0.65”
Measurement rate	300 – 4000 lines/second
Data acquisition rate	0.6 – 8.2 million 3D points/sec

Table 1. LCI Sensor Key Specifications

2.3 Strengths of Line Confocal Imaging

- High speed, enables real-time in-production scanning
- Sub-micron resolution
- Works well on
  - Matte, glossy and mirror-like surfaces
  - Opaque and transparent surfaces
  - High-contrast (matte/glossy, dark/light) surfaces
  - Soft, fragile, porous surfaces
  - All materials
  - All colors
- Enables measurement of
  - Thickness of transparent layers and air gaps
  - Topography under transparent layers (tomography)
- Single-sided operation → simple scanners
- Acquires 2048 surface points simultaneously → reduced error caused by target vibration
- Native 3-dimensional method
- Produces high-quality raw data
- No speckle effect
- Safe

2.4 Weaknesses of Line Confocal Imaging

- Sensors are relatively
  - Large
  - Heavy
  - Costly to produce

2.5 LCI scan examples

All non-filtered, unprocessed raw data shown below.

Figure 4. Detail of a U.S. Dime Coin

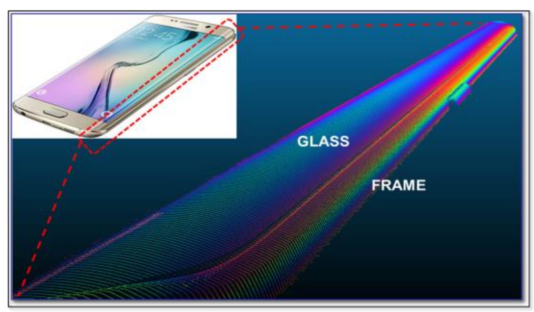

Figure 5. Glossy Curved Glass Surface

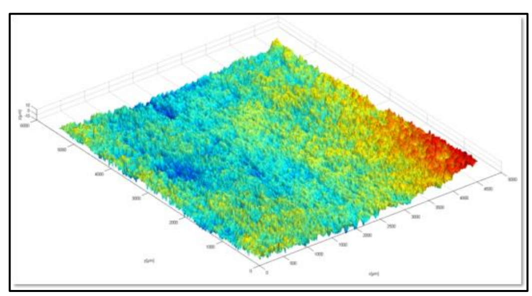

Figure 6. Paper Surface Microtopography

3. Off-line 3D Measurement

FocalSpec's new Line Confocal Scanner is a general purpose 3D metrology tool that can be used in various Research & Development, Quality Control and Failure Analysis applications.

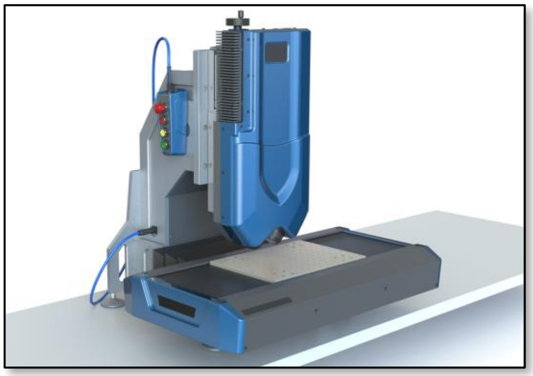

Figure 7. FocalSpec's Off-line Line Confocal Scanner

4. Surface Roughness Measurement

FocalSpec's range of surface roughness metrology systems has evolved during the past two years:

4.1 Off-line Measurement

- MicroProfiler MP 300
- General purpose laboratory & at-line unit
- Introduced in 2015
- LCI 400 sensor
- Will be replaced by Line Confocal Scanner

Figure 8. FocalSpec MicroProfiler MP 300

4.2 On-line Narrow Product Measurement

- MicroProfiler MP 900
- For cables, tubing, tapes, profiles, etc. applications
- Introduced in 2016
- LCI 1200 sensor

Figure 9. FocalSpec MicroProfiler MP 900

4.3 On-line Web Roughness Measurement

- MicroProfiler MP 9000
- European launch at K 2016
- North American introduction at ICE USA 2017
- LCI 1200 sensor

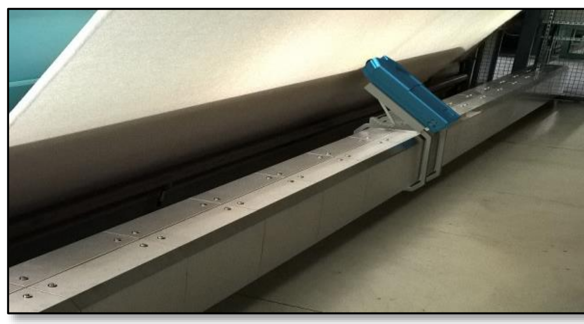

Figure 10. FocalSpec MicroProfiler MP 9000

Applications for the MP 9000 include:

- Films (e.g. PVB)
- Sheets
- Coatings
- Paper
- Foils
- Laminates
- Glass
- Composites
- Metals

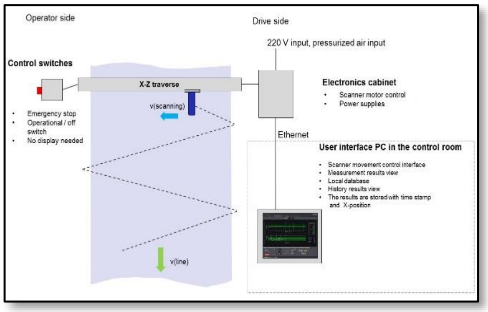

Figure 11. MP 9000 System Components

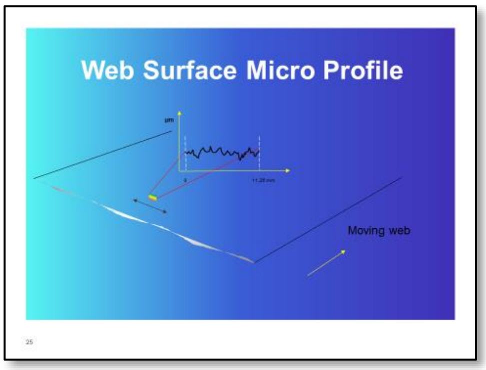

Figure 12. Web Surface Micro Profile

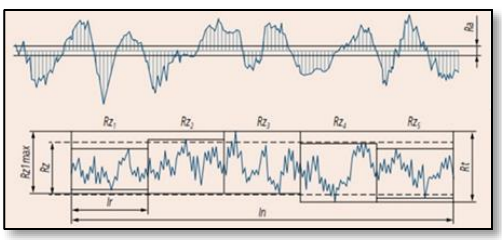

Figure 13. Ra and Rz Calculation Methods

Figure 14. Reporting: Real-time Single Profile Display

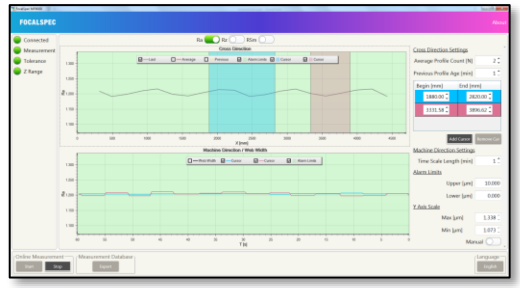

Figure 15. Reporting: Real-time Cross Direction & Machine Direction Roughness Charts

Other MP 900 features include:

- Top and/or bottom side measurement
- Automatic visual and audible operator alarms
- Integrated results database
- Reporting and data export functions
- Connectivity to factory network

Material	Any
Color	Any
Parameters	Ra, Rz, Rsm
Ra range	0.5 to 20 µm
Ra precision	Better than 0.03 µm
Line speed	150 m/min (max)
Web width	No practical limits

Table 2. MP 9000 Key Specifications

5. Inline Thickness Measurement

Depending on the transparency of the material, either of the two thickness measurement methods can be used for the task.

5.1 Direct Thickness Measurement

- Can be used to measure thickness of transparent and translucent layers
- Can be used to measure thickness of single or multi-layer structures
- Applications include
  - Polymer films
  - Glass sheets
  - Coatings and inks on non-transparent substrates
  - Air gaps, etc.

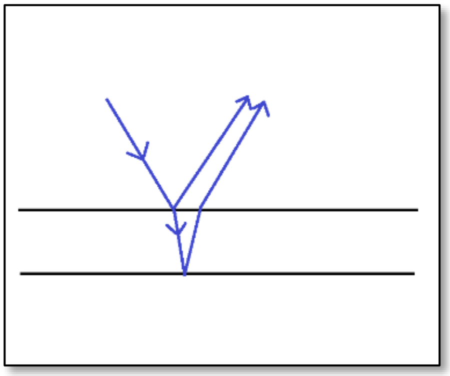

Figure 16. Single-sided thickness measurement of transparent layer

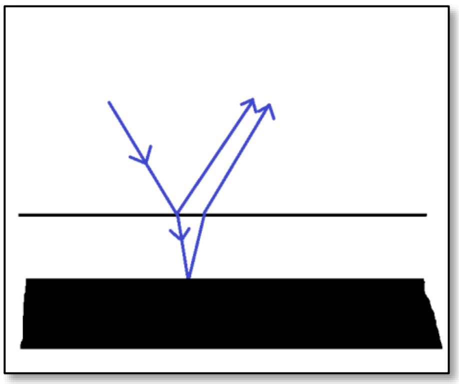

Figure 17. Single-sided thickness measurement of transparent layer on non-transparent substrate

- Thickness range 30 – 5500 µm
- Resolution up to 50 nm
- Line Confocal Imaging sensor
  - For thickness & 3D characteristics measurement
  - For transparent layers only
- Monochromatic Point sensor MCP 100
  - IR reflection-based dual point sensor
  - For thickness measurement only
  - For transparent and translucent layers

Figure 18. Monochromatic Dual-Point Thickness Sensor MCP 100

5.2 Step Height Measurement

- For non-transparent and transparent layers
- Single and multi-layer structures
- Applications
  - Coatings
  - Inks, etc.
- For Line Confocal Sensors only
- Thickness range ~0.5 – 5500 µm
- Resolution up to 100 nm

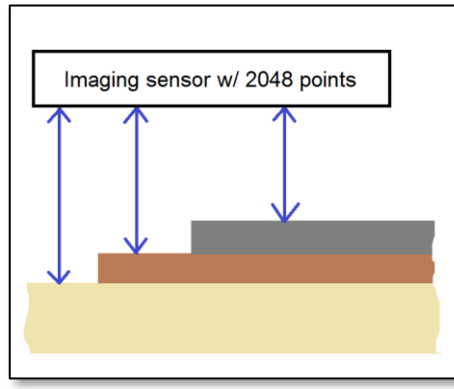

Figure 19. Thickness measurement of two individual layers with Step Height method

6. Inline 3D Feature Measurement

Line confocal imaging sensors can be used for real-time imaging of 3D features from moving narrow and wide webs. Applications include:

- Embossed 3D features
- Printed 3D features
- Tomography i.e. 3D features under transparent layers, such as embedded micro-fluidic channels, etc.
- Line Confocal Sensor with stationary or traverse mounting
- Up to 0.1 µm height resolution
- Up to 2.2 µm lateral resolution

Figure 20. MicroProfiler MP 400 Inline Feature Scanner

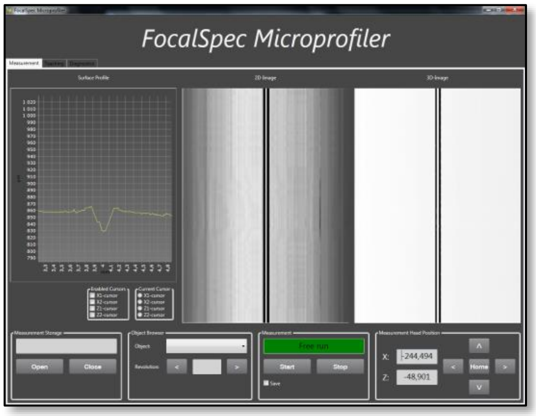

Figure 21. Real-time Groove Width and Depth Measurement

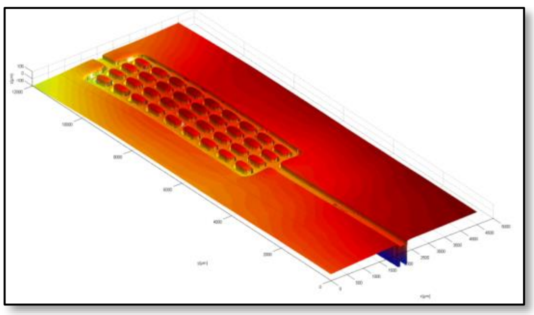

Figure 22. 3D Point Cloud of Hot-embossed Microfluidic Device

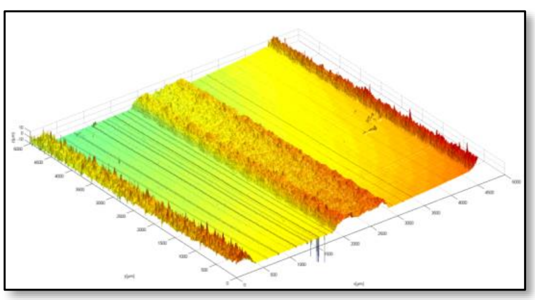

Figure 23. Printed Conductors on PET Film

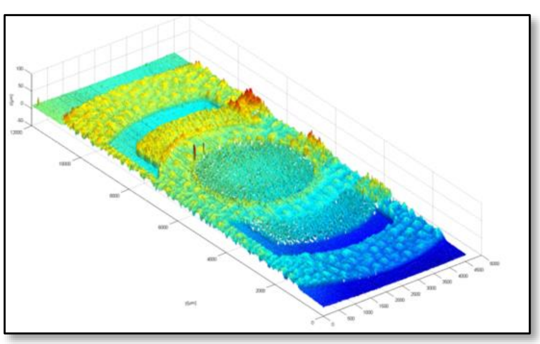

Figure 24. Printed Bio Sensor

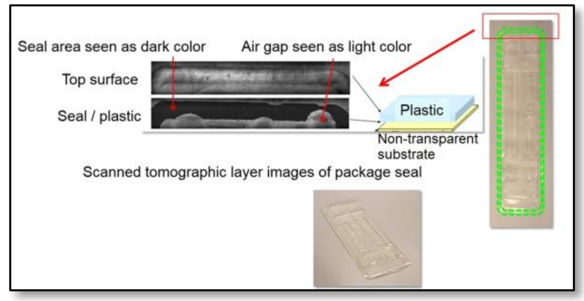

Figure 25. Heat Seal Tomography in Medical Packaging

7. Other 3D Web Imaging Ideas

- 3D edge height/burr height measurement
- 3D fold/wrinkle detection/measurement

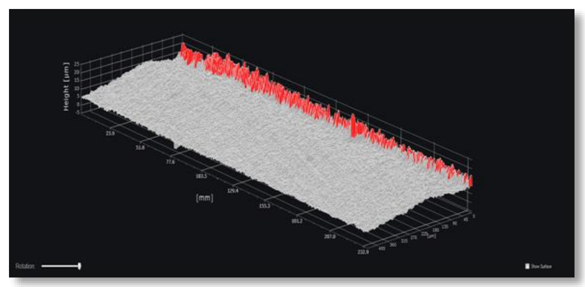

Figure 26. High Edge/Burr in Metal Foil

8. About the Author

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Juha Saily is a technical sales and marketing professional with FocalSpec, Inc., located in Metro Atlanta, Georgia, USA. He is a graduate of the Raahe Institute of Computer Engineering in Raahe, Finland, with a Bachelor Degree in Computer Engineering. Prior to joining FocalSpec, Juha held various technical, sales, marketing and management positions with Nokia Cellular Phones in Finland, TopWave Ltd in Finland and Mexico City, and Computone Corporation, Inx-Systems, Inc. and Techno Product, Inc. in Georgia. Juha's special interests include manufacturing processes, Statistical Process Control and optical sensors.