Snapshot Multispectral Imaging

Customized multispectral analysis tool for advanced object classification

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Snapshot multispectral camera demonstrator (Source all images: the authors)

A multispectral imaging concept based on a multi-aperture system approach using a customized microlens array combined with a slanted continuously variable bandpass filter and a silicon-based image sensor helps to overcome the restrictions of scanning techniques or wafer-level coated detectors.

Hyperspectral and multispectral imaging have been used for a couple of decades in applications such as satellite imaging, air reconnaissance, and other not overly price sensitive markets. The advent of alternative approaches makes spectral imaging attractive for volume and consumer markets, for example cancer detection, precision farming with unmanned aerial vehicles (UAV) or directly at the plant, or food testing in supermarkets. Alternative approaches comprise wafer-level coated sensors with fixed wavelength bandpass filters. Thin film coatings on glass substrates that can be patterned during deposition (in situ), or by using a photolithographic process over the coating to block the addition or subtraction of materials deposited on the substrate surface are also common. These micro-patterning techniques allow filters in a 2D mosaic structure (suited for the snapshot technique, i.e. acquisition of the hyperspectral data cube with only one camera exposure).

A smart combination

A novel snapshot multispectral camera with high spectral performance and high spatial resolution was achieved by combining a micro lens array imaging system by German Fraunhofer IOF and a continuously variable bandpass filter by Danish Delta Optical Thin Film. The continuously variable bandpass filters (CVBPF) developed and manufactured by Delta Optical Thin Film offer high transmission and are fully blocked in the light-sensitive wavelength range of silicon-based detectors. The combination of CVBPFs with silicon detectors (Fig. 2) allows the design of compact, robust, and affordable spectral imaging detectors that offer several advantages and benefits over conventional approaches:

- huge aperture compared with grating and prism,
- higher transmission than grating and prism,
- short measurement time,
- high suppression of stray light,
- excellent signal to background ratio,
- 3D and snapshot capability.

Fig. 1 shows the transmission characteristics of a CVBPF that covers a center wavelength range in VIS/NIR with a bandwidth of approximately 2 % of its center wavelength. In a wide wavelength range, the transmission is higher than 90 %. But even more important than the peak transmission all undesired radiation from 200 to 1150 nm is suppressed better than OD4.

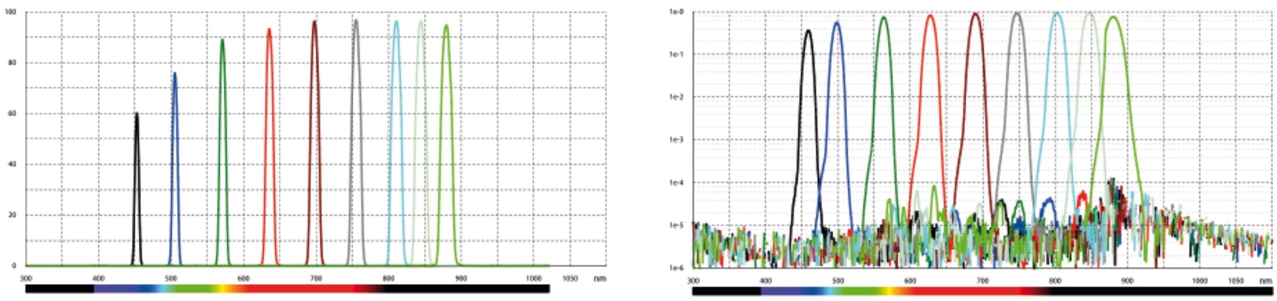

Fig. 1 Transmission and blocking characteristics of the continuously variable bandpass filter

Comparison with grating and prism-based systems

Due to the diffractive nature of gratings or prims, a slit is needed to obtain high spectral resolution. The spectral information along a narrow line of the object is imaged through the slit and spread out into one dimension of the imaging sensor. The other dimension is spatial. The second spatial dimension is built by push broom scanning. This inherently makes such systems incapable of snapshot acquisition.

Comparison with wafer-level coated detectors

Wafer-level coated detectors can be produced with arbitrary filter patterns. This makes snapshot acquisition possible. In this case, the sensor is coated with a 2D pattern of bandpass filters with different but constant center wavelengths. The snapshot capability of course comes at the cost of reduced spatial resolution. Another typical trade-off of coating at wafer level is the limited spectral complexity of the filters.

Snapshot multispectral camera

In order to overcome the restrictions of using scanning techniques or wafer-level coated detectors, Fraunhofer IOF Jena proposes a multispectral imaging concept based on a multi-aperture system approach using a customized microlens array (MLA) combined with a slanted CVBPF and a silicon-based image sensor (Fig. 3). In addition, a tailored baffle array is utilized for preventing optical crosstalk between adjacent optical channels. A customized multispectral analysis tool features the capabilities for advanced object classification.

Design and fabrication

The main advantage of choosing a microoptical imaging system in combination with a CVBPF is the simultaneous capturing of spectral and spatial information in a single shot due to distinct spectral coded channels. The multi-aperture principle allows a degree of freedom between the spectral and spatial sampling according to the constraints of the CVBPF and the size of the image sensor. The number of spectral channels is therefore equal to the number of microlenses. As a proof of concept, the optical design of the MLA employs a single microlens surface. The optimization yields the system parameters that can be seen in table 1.

The CVBPF is slightly rotated around the optical axis with respect to the MLA in order to achieve a linear spectral sampling over the extended spectral range.

The ultra-compact microoptical system comprises microlenses in an array within diameters and sag heights in the range of hundreds of micrometers. Hence, the fabrication of the MLA was performed by state-of-the-art wafer-level-optics technologies. A spherical microlens master is fabricated by UV lithography and reflow of photoresist. A replication tool is created and used for molding the final lens elements. The CVBPF, the MLA and the baffle array were mounted in a mechanical holder, actively aligned to the image sensor, and fixed to the housing. The snapshot multispectral camera demonstrator has an overall size of only $60 \times 60 \times 28$ mm³.

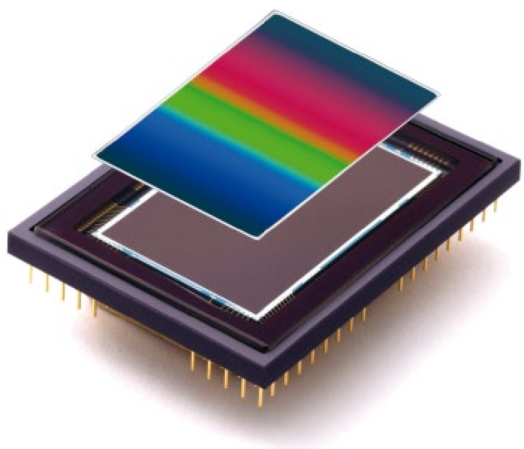

Fig. 2 Hyperspectral imaging detector based on a continuously variable bandpass filter

system parameter	value
channels	11 × 6 (on Cartesian grid)
optical system length	7.2 mm
f-number (*F*/#)	7
field of view (FOV)	68° (diagonal)
image resolution	400 × 400 pixels (per channel)
spectral range	450 – 850 nm
spectral sampling	~6 nm (linear)

Tab. 1 Overview of system parameters of the snapshot multispectral camera

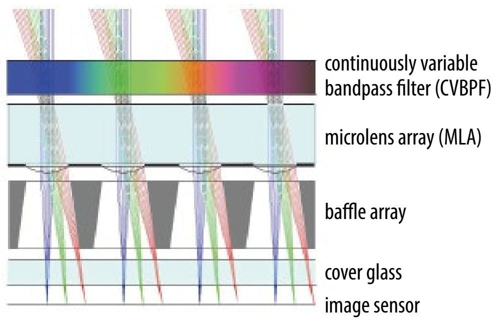

Fig. 3 Microoptical system concept for snapshot multispectral imaging

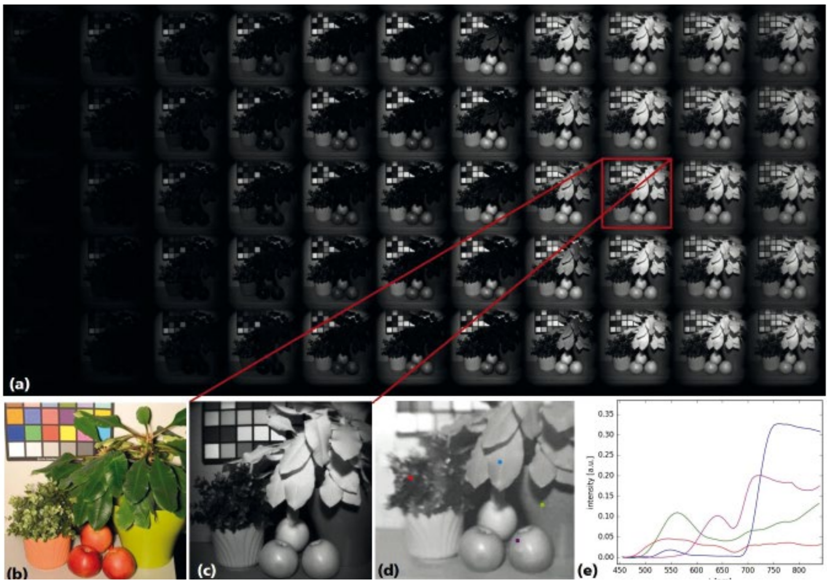

Fig. 4 Captured raw image of a scene seen in (b) of two plants (left artificial, right natural), apples and a color checker board in the background (a). Photograph of the scene with a standard RGB camera (b), sub image of one spectral channel (c), averaged image over all 66 channels (d), and smoothed spectra of four selected spatial positions (e).

Calibration and experimental results

The spectral response of each individual pixel depends on the bandwidth of the CVBPF and the angle of incidence on the filter. A spectral calibration corrects these effects using a tunable light source. The multispectral camera enables the snapshot acquisition of sixty-six spectral channels with a linear spectral sampling of approximately 6 nm over a wavelength range of 450 to 850 nm with a spectral resolution between 10 and 16 nm. In addition, an object distance depended spatial calibration of the channels provides an accurate overlay of the individual sub images in the data cube.

Fig. 4a illustrates the raw image of an extended scene in the lab and in comparison, an image captured with a standard RGB camera (Fig. 4b). Due to the short focal length of the microlenses, the imaging module comprises a large depth of field and therefore every object in the sub image is in focus (Fig. 4c). Our custom-developed software tool allows for a comprehensive analysis of spectra of objects in the scene as seen in Fig. 4d/e. For example, four processed and corrected spectra provide detailed object information, which constitutes the basis for an advanced object classification.

Summary

The camera demonstrator combines state of the art micro-optical manufacturing methods and a multi-aperture imaging principle with a commercial CVBPF. It enables the realization of highly compact and cost-efficient devices, capable of capturing spectrally resolved, extended object fields in a single shot with high resolution. Moreover, the proposed system concept provides a high flexibility with respect to spatial and spectral resolution by tailoring the number of spatial and spectral channels. The prospective fields of application of the developed system include environmental and agriculture monitoring, industrial surveillance and sorting, as well as biomedical imaging.

DOI: 10.1002/phvs.201900019

Company

Delta Optical Thin Film

Delta Optical Thin Film A/S is the leading supplier of advanced, high performance linear variable filters commonly used in a variety of biomedical imaging applications including fluorescence microscopy, flow cytometry, monochromators, and micro-plate readers among others.
The company from Denmark also provides, fluorescence filter sets, bandpass filters, short wave pass filters, long wave pass filters, dichroic and polarisation beamsplitters, AOI tolerant dichroic beamsplitters, beamsplitter cubes, and SMART coatings in the UVA/VIS/NIR range, along with other custom coated optical components, and offers a wide range of high efficiency durable ultra-hard coated filters that have set the standard for high performance and precise operation.

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Authors

Oliver Pust, director sales and marketing, has a background as mechanical engineer and earned his doctoral degree within the field of laser optical measurement techniques. He has a long-term experience in working together with international partners and sales of high-tech equipment to research and industry customers and joined Delta Optical Thin Film A/S in 2011.

Martin Hubold received his master's degree in photonics from the Friedrich-Schiller-University (FSU) Jena in 2017. Since then, he has been working as optical engineer in the department of Microoptical Systems at the Fraunhofer IOF in Jena. His research includes miniaturized multi-spectral imaging systems as well as multi-aperture camera systems for automotive.

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