Ultra-compact snapshot multispectral camera based on micro-optics and monolithically fabricated filter array

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Snapshot multispectral imaging is a growing non-invasive technology and approach to distinguish or identify objects based on their spectral characteristics. We report a versatile system approach for a compact and real-time capable snapshot camera in the short-wave infrared (SWIR) wavelength range based on a multi-aperture system and a monolithically fabricated Fabry-Perot filter array.

1 Introduction

Classical solutions for multi- and hyperspectral imaging are based on scanning approaches suffering from motion blur or a reduced signal-to-noise ratio in fast varying scenes. A trend is currently seen towards real-time capable and miniaturized systems especially adapted for UAV-supported applications for precision farming. Recently, we reported an approach [1] of a multispectral snapshot camera based on a multi-aperture imaging approach using a customized micro-lens array (MLA) and a linear variable filter. The system features a high spectral resolution and medium spatial resolution on a large image sensor for the visible and near-infrared range.

However, this approach cannot be easily adapted to the shortwave infrared (SWIR) range due to the available filter and image sensor technology (large pixel pitch, low resolution). In order to realize a multispectral system, we developed a tailored micro-lens array and a novel and customizable monolithically fabricated Fabry-Perot filter array to tailor the spectral channels individually and to achieve a higher spatial resolution.

2 System design

The object being far away is imaged via multiple miniaturized objective lenses on a common glass substrate (denoted as MLA) onto a commercial image sensor. The spectral filtering is realized through Fabry-Perot cavity filters in front of the lenslet array and close to the aperture.

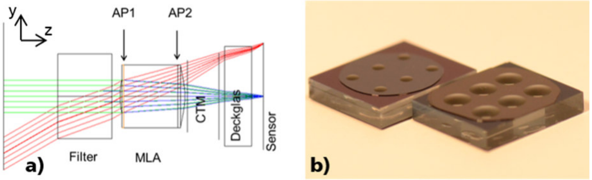

Fig. 1 *(a) Optical system design of one imaging channel. (b) Fabricated MLAs shown from both sides.*

Using this approach, a single shot acquisition of the spectral data cube has been achieved without an additional bulky objective lens.

As seen in Fig. 1 (a), the single channel consists of a double-sided MLA with a front aperture stop. In order to reach the low F/# of 3, both lens-lets are aspherical in shape and fabricated by a polymer-on-glass technology using ultra-precision tools (Fig. 1 (b)). The rms spot size is ~30 µm over the entire field of view of 70° (full-diagonal) which is ~2 pixels at 15 µm pixel pitch. In order to feature a high spatial resolution, the VGA InGaAs image sensor was divided in six channels, each with a resolution of 256x213 pixels.

The multispectral detection of our compact camera is accomplished by a novel monolithic filter tile array fabricated in wafer-scale. Each filter tile is based on a cavity Fabry-Perot interference filter with tailored cavity heights as shown schematically in Fig. 2 (a).

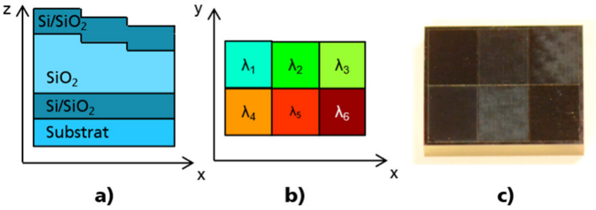

Fig. 2 *(a) Schematic Fabry-Perot cavity filter stack. (b) Lateral filter tile distribution in 2x3 array. (c) Fabricated filter tile array.*

The cavity height defines the central wavelength according to the spectral transmission band. Both mirrors are realized using a high/low (silicon/fused silica) refractive index material stack. The homogeneity and roughness of the cavity and the mirror surfaces are responsible for the spectral bandwidth which is designed to 10-15 nm FWHM. The lateral distribution of the filter tiles is shown in Fig. 2 (b) and the favored central wavelength for precision farming and industrial monitoring have been set to: 1020 nm, 1100 nm, 1210 nm, 1373 nm, 1450 nm and 1550 nm.

submitted: 28.10.2021 published: 18.11.2021

The manufacturing of the filter tile array is performed by a grayscale photolithography process [2] in resist and a subsequent proportional dry-etching process (RIE) into fused silica of the filter's cavity layer. The variation in resist height from grayscale lithography is transferred into a thickness modulation of the cavity layer, and consequently leads to an adjustment of pass band wavelengths across the filter arrangement. The coating has been realized by magnetron sputtering on Borofloat glass (Schott B33) wafers.

The blackened baffle array (CTM) serves as a field aperture suppressing crosstalk between neighboring channels and out-of-FOV false light.

The essential parts have been integrated in a mechanical frame and the stack is axial aligned in front of the VGA image sensor. An additional long pass filter is used to suppress higher orders of the Fabry-Perot filter at wavelength smaller than 1000 nm as can be seen in Fig. 3.

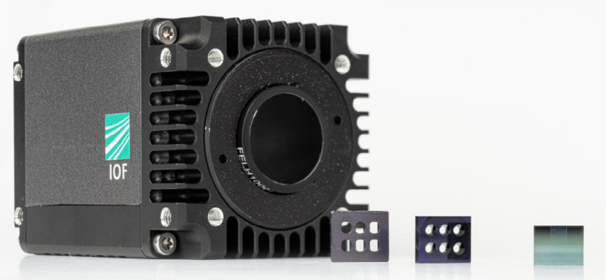

Fig. 3 *Small form factor snapshot multispectral camera demonstrator based on Goldeye G-030 TEC1 camera.*

3 Characterization and Results

The spectral characterization of this multispectral snapshot camera is performed using a method described in [1]. The spectral pixel response over the whole image sensor is shown in Fig. 4.

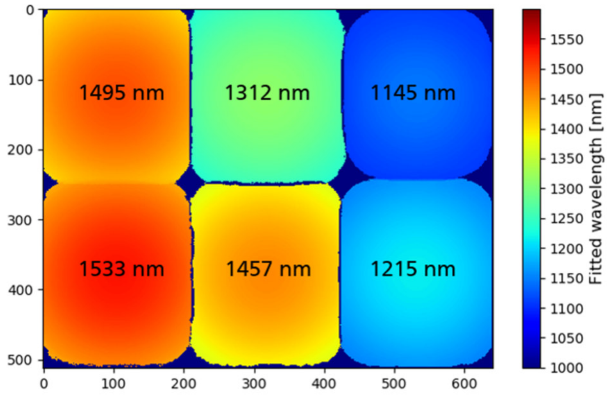

Fig. 4 *Spectral pixel response over whole image sensor.*

The central wavelength is different compared to the favored ones mainly due to a thickness variation during the grayscale lithography and a different selectivity during the dry-etching process. In addition, a spectral shift to shorter wavelength of up to 6% of the central wavelength is observed for off-axis fields. Furthermore, the spectral bandwidth is approximately 18-22 nm for the five longest wavelength channels and ca. 18-33 nm for the shortest wavelength channel 1145 nm. This is mainly due to roughness emerging from writing artefacts of grayscale lithography and could likely be observed in Fig. 2 (c).

A first proof-of-concept measurement is shown in Fig. 5 using the developed snapshot multispectral camera for SWIR wavelength range. The standard RGB image depicts two apples without attracting attention, but the raw image of the SWIR camera shows a dark patch on the right apple resulting from the water absorption behind the apple peel due to a pressure mark.

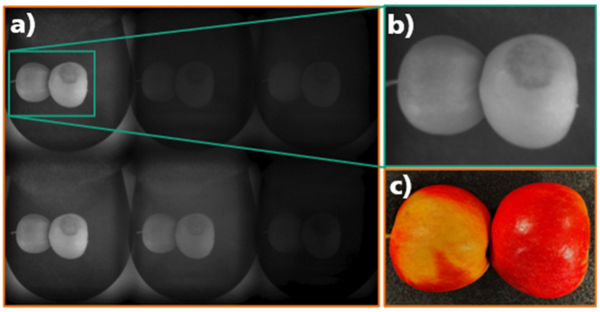

Fig. 5 *(a) Raw image of the scene with two different apples. (b) Enlarged image with recognizable pressure mark. (c) Standard RGB image of the scene.*

4 Conclusion

The versatile approach shows a high potential for capturing spectrally resolved, extended object field in a single shot for a wide range of applications, that benefits from the compact setup. It is customizable regarding wavelength range and filter channels and adaptable to different image sensor architectures. A bigger challenge is the accurate manufacturing of the filter tile array.

Funding

Supported by the Free State of Thuringia and the European Social Fund (FKZ: 2019 FGR 0077).

Acknowledgements

The authors would thank Daniela Stumpf** for performing the dry etching process of the filter elements and Elisabeth Montag* for optical characterization measurements of the finalized demonstrator.

References

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submitted: 28.10.2021 published: 18.11.2021