Ultra-compact multispectral camera based on micro-optics

Whether from a satellite or a drone, multispectral imaging becomes increasingly important. There, every gram counts. Thanks to a specific microoptical concept, a new multispectral camera system weighs just 200 g and can be produced cost-efficiently.

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40 years ago Sigmund Jähn was the first German to fly into space. His most important scientific experiment was remote sensing of the Earth with a multispectral camera. The MKF6 multispectral camera from East-German VEB Carl Zeiss Jena was celebrated as a top technological achievement at that time. The interest in multispectral imaging has grown ever since. Today, for example, the type and maturity of plants or the water content of soil can be measured during overflight. In geographic information systems (GIS), the data is recorded and analysed with a precision down to one meter. The weight played a major role in the development of the MKF6, as it does today: the developers had to trim the mass to 175 kg at that time. In later years, the introduction of electronic sensors has resulted in considerable weight savings. Today, special micro-optics can reduce the mass of the optics further more.

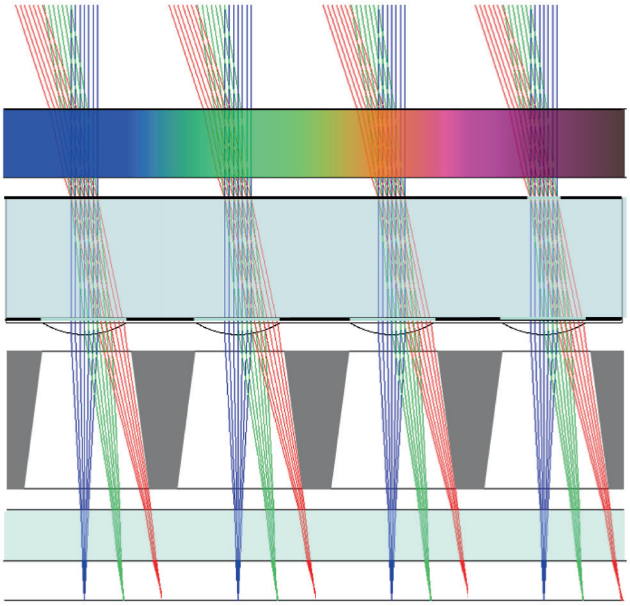


Figure 1: The optical system of the ultra-compact multispectral camera is only 7.2 mm thick

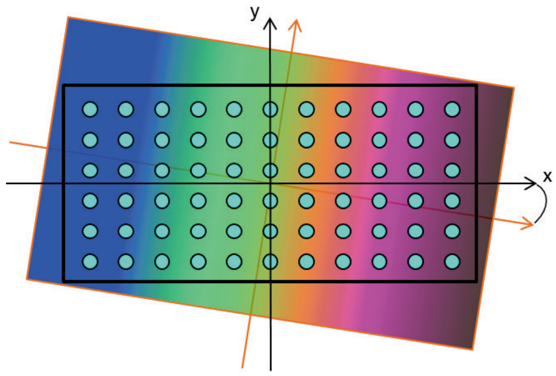
Multispectral acquisition through micro-optics

The task of multispectral systems is the simultaneous recording of a scene through different wavelength filters. This was the case with the MKF6 and its six spectral channels and the new system presented here works quite similarly. Where originally bulky optics with separate lenses

Figure 2: The complete camera system including heat sink and FireWire connection

Summary

The multispectral camera based on micro-optics and opto-mechanical standard components fits on the palm of a hand and is therefore interesting for many applications. While for space flight individual components still have to be qualified, a drone mission can be started very quickly. The system can also be used in areas such as quality assurance or waste management. Further applications are being considered in biomedical analytics.



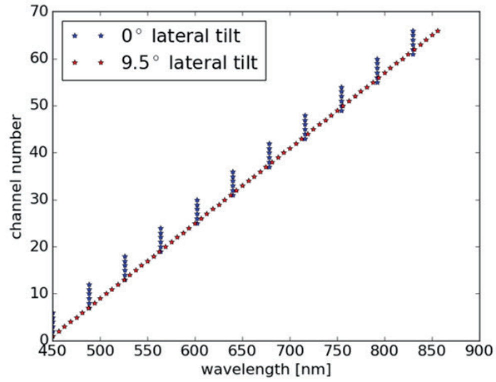


Figure 3: By tilting the spectral filter against the microlens array by 9.5°, a simultaneous acquisition of 66 spectrally equidistant channels is possible

and separate spectral filters dominated, today a linear variable spectral filter is combined with a microlens array (**figure 1**) and thus creates 66 parallel optical channels [1]. The individual channels are separated from each other by a tailored baffle array to prevent crosstalk.

Both, the new and the old system record data as whole images in different spectral bands. This method is called ‘staring system’. In contrast to this, the ‘pushbroom’ detection method acquires the image line by line or strip by strip. The ‘whiskbroom’ method even scans such a line point by point. Since the camera usually flies at high speed over ground, offset or smearing effects can occur. The problem can be reduced with the sequence of area shots in the staring system, whereby the MKF6 already had automatic compensation on-board to account for the movement.

The real advantage of multispectral detection with micro-optics can be seen in the dimensions: From the filter to the CCD sensor, the entire system is 7.2 mm thick (**figure 1**). The complete structure (**figure 2**) fits on the palm of a hand and is therefore also ideally suited for mobile use on drones. The width of the optical system is essentially based on the size of the linear variable filter. Each microlens underneath the filter images the complete field of view. A commercial CCD sensor with a size of 24 x 36 mm² matches well with the filter size. Optimising the parameters of the microlenses to achieve a focus size close to the pixel size (7.4 µm) resulted in a minimum aperture of f/7 for a field of view of 68°.

The linear variable spectral filter [2] developed and manufactured by Delta Optical Thin Film A/S has a bandpass filter on one side and a dielectric interference filter wedge on the other. The filter transmits a spectral range from 450 to 880 nm with a bandwidth (FWHM) of about 2 % of the centre wavelength and completely blocks the other light sensitive wavelength range of silicon based detectors. With micro-optical arrays consisting of 6 x 11 lenses, 11 different spectral bands can be used. With a slight tilting of the filter, each optical channel can image its own band; with a tilting of 9.5°, the bands connect exactly to each other and 66 different spectral filter channels are obtained (**figure 3**). The optical parameters of the components are summarised in **table 1**.

Design and test of the sensor

The microlens array was manufactured using modern UV lithography and reflow of photoresist on a 4“ wafer. For >

the baffle array, thin holes were milled into an aluminium block with a rectangular cross-section on the back. The black anodised aluminium part was then bonded to the micro-optic. The complete assembly with linear variable spectral filter, microlens array and baffle array in a holder was finally adjusted relative to the CCD sensor, which is located in a housing with a cooling fin structure. The distance was set with spacers.

To determine the image quality, the modulation transfer function (MTF) was measured with a setup according to ISO 12233. The resolution of the multispectral camera is about 65 line pairs per mm (at MTF = 0.1), which corresponds to a resolution of 4.2 LP/° in the object space. The spectral resolution was measured with a tunable monochromatic light source. The system is designed for 66 spectral bands with a linear sampling of about 6 nm in the range of 450 – 850 nm. The test source was used to perform both spectral and spatial calibration of the individual images. A point light source was used to precisely determine the position of the individual images as a function of the object distance.

The system's ability was demonstrated in a final test in order to classify objects spectrally. For this purpose, a test scene was set up at a distance of about 50 cm. It consisted of artificial and natural plants, red apples and a colour scheme (**figure 4b**). A halogen lamp with a colour temperature of 2900 K was used for illumination. **Figure 4a** shows the unprocessed raw data of the image. Each of the 66 single images has a spatial resolution of about 400 x 400 pixels. Thanks to the small focal length of the micro lenses, the depth of field is very large and the image is sharp for all details (**figure 4c**). Using proprietary software, the spectra of the various objects were derived from the image data (**figure 5**). The objects can be clearly distinguished by the spectral signatures. In particular a high reflectivity in the NIR (which is typical for chlorophyll) is clearly recognisable in the data of the natural green leaf.

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Component	Parameter	Value
Linear variable spectral filter	Average transmission rate	60 – 90 %
	Total transmission spectrum	450 – 880 nm
	Dimensions (L x W x H)	50 x 25 x 1 mm³
	Tilt angle relativ relative to the microlens array	9.5°
Microlens array	Lens diameter	1.4 mm
	Distance of lens centres	3 mm
	Aperture diameter (front side)	510 µm
	Curvature radius (back side)	1940 µm
	Aperture diameter (back side)	1600 µm

Table 1: Summary of optical system parameters

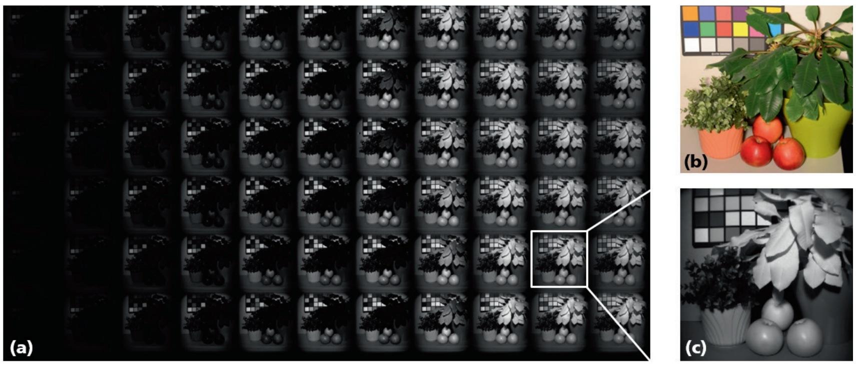

Figure 4: a) Raw image of a test scene at a distance of 50 cm; b) Photograph of the test scene with a standard RGB camera; c) Enlarged image from the range 780 – 790 nm

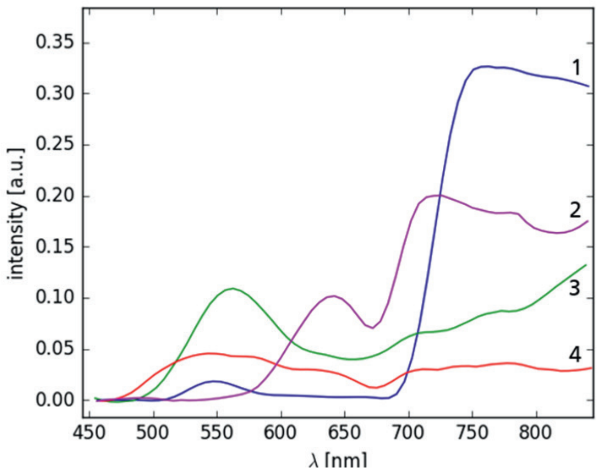

Figure 5: Measured spectral signatures of the various objects in the test scene: 1) green leaf, 2) red apple, 3) green flower pot (plastic), and 4) green leaf (plastic)

[1] M. Hubold, R. Berlich, C. Gassner, R. Brüning and Robert Brunner, Ultra-compact micro-optical system for multispectral imaging, Proc. SPIE 10545, MOEMS and Miniaturized Systems XVII, 105450V, 2018

[2] www.deltaopticalthinfilm.com

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