Spectral Imaging: A Comparison of Different Spectral Imaging Systems

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ABSTRACT: This paper describes briefly general methods and devices for capturing multi-spectral images. Different imaging devices use different approaches to capturing spectral information. Selecting a used system is depending totally on the target application. If spectral images are needed to take on the outside, the line scanning based camera is not so good an option for that, but when imaging is needed from the industrial line, line scanning cameras would be the best choice. This paper helps to select usable imaging system and the spectral camera for a wanted target by showing advantages and disadvantages of the different systems.

1. INTRODUCTION: Accurately defined colour is showing more and more important factor in many scientific and industrial targets. Normal digital cameras and displays use three colour component red, green and blue (RGB) representations for displaying colours. RGB information is useful for many cases but when colour is needed to capture accurately, a RGB cameras cannot be used. A metamerism is one good example where two different colours look the same under one illumination and totally different under another one. This cannot be detected by using normal RGB camera, therefore spectral approach is needed. This paper will describe differences between LCTF, AOTF, PGP and interferometric based spectral imaging systems.

2. SPECTRAL IMAGE: The spectral image (Fig. 1) can contain various wavelength channels for each pixel when a normal RGB image contains only three colour channels per pixel. For example a spectral image, which is captured from 380 nm to 780 nm wavelength areas by 5 nm steps, contains 81 different colour channels. This spectral image provides very high colour information for visible region than normal RGB camera. Spectral image can also be captured from the infrared or UV regions of the spectrum, where normal RGB cameras cannot be used. Use of the spectral imaging is expanded for many industrial fields, like in wood analysis [1], mineral detection [2], textile industry [3] and many other interesting targets.

3. SPECTRAL IMAGING DEVICES: There are various different spectral imaging and measuring devices for scientific and industrial use [4]. The main differences between the imaging systems are in the accuracy, speed and in the scanning methods. Some system use spectral domain scanning and other ones use spatial domain scanning for capturing spectral images. Figure 2 shows a general idea of the different scanning methods.
3.1 Line scanning devices (PGP): Line scanning based spectral camera systems are becoming more common in many research and industrial targets [4]. Finnish company Specim has developed line scanning prism-grating-prism (PGP) spectral camera system which is called ImSpector [4]. In line scanning based spectral imaging systems like PGP, the target object is needed to be scanned line by line until all wanted areas are measured.

![Scanning directions with PGP, AOTF / LCTF and Interferometric spectral imaging systems](image1)

The technical structure of ImSpector is illustrated in Figure 3. Measured light from the target line is controlled through a narrow slit where light is dispersed to CCD-sensor with prisms and grating. Spectral information is dispersed to y-axis and spatial information is dispersed to x-axis. After that, we can read full spectral information of the measured line from the CCD-sensor. The spectral and the spatial resolutions of the line scanning cameras are usually very high and one line spectral measurement can be done rapidly. Therefore the line scanning method is very usable for on-line industrial measurements where measurements are needed to be done at the real-time.

![Structure of ImSpector spectral camera](image2)

Figure 4 shows developed spectral imaging system where line scanning based spectral camera is used.

![Line scanning based spectral imaging system](image3)

A is the light source, B is the sample table and C is the spectral camera.
On Figure 4, (A) is the GretagMacbeth daylight simulator which can produce D65 illumination, (B) is the x-y sample table which is controlled through a computer and (C) is the InSpec tor V10E spectral camera which spectral response is from 400 nm to 1000 nm. The spectral image is scanned by moving the target which is connected to the sample table. The proposed imaging system can measure over square meter targets with very high spectral and spatial resolution by dividing the target into multiple slices. In general, the PGP system provides very good spectral and spatial resolution, but it is very slow to compare with another imaging systems. Figure 5 shows example spectra of colour checker board.

![Example Spectra](image1.png)

**Fig. 5.** An example of reflectance spectra from the colour checker board

3.2 Spectral cameras with a tunable filter (LCTF/AOTF): Liquid crystal tunable filter (LCTF) is controlled by electricity [5][8]. Idea of the LCTF imaging systems is that target object is imagined in spectral dimension by using the electrically controlled liquid crystal filter. When the controlling electricity of the filter is changed, liquid crystals turn to different positions and angles, therefore filtered wavelength band changes. In this way, the target can be measured with different wavelength bands by controlling the electricity of the liquid crystal tunable filter. Usually, the spectral resolutions of the LCTF systems are between 5-30 nm. One remarkable point in LCTF systems is that the spectral responses in the short wavelength areas (blue region) are commonly very low, therefore the imaging time can be rise to several minutes depending of the light source.

An acousto-optic tunable filter (AOTF) (Fig. 6) is controlled by using RF-signal acoustic waves. The filter is build from crystal element which is vibrated with different frequency acoustic waves. In this way, we can separate wanted wavelengths from the measured light. LCTF and AOTF systems are faster than interference filter systems. In interference filter systems, a filter wheel is controlled mechanically and therefore it is slower than LCTF and AOTF based imaging systems. There are also interferometric based spectral imaging systems which provide high spectral resolution measurements [5][7].

![Structure of AOTF](image2.png)

**Fig. 6.** Structure of AOTF [9].

Interferometric, interference filter, LCTF and AOTF -imagine systems scan the target in spectral domain and PGP-imagine system scan the target in spatial domain by capturing all spectral data from the one line at the same time. Thus, scanning methods and spectral resolution accuracy makes considerable difference between LCTF, ATOF and PGP-imagine systems. Main characteristics of the different spectral imaging systems are illustrated in Table I [10].
Table 1: Characteristics of spectral imaging systems. [10]

<table>
<thead>
<tr>
<th>Filter type</th>
<th>LCTF</th>
<th>PGP</th>
<th>AOTF</th>
<th>Interference filters</th>
<th>Interferometric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of channels</td>
<td>6-61</td>
<td>60-420</td>
<td>20-40</td>
<td>16-40</td>
<td>80</td>
</tr>
<tr>
<td>Scanning direction</td>
<td>Spectral</td>
<td>Spatial</td>
<td>Spectral</td>
<td>Spectral</td>
<td>Spectral</td>
</tr>
<tr>
<td>Acquisition time</td>
<td>Fast</td>
<td>Medium</td>
<td>Fast</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Scanning type</td>
<td>Electrical</td>
<td>Mechanical</td>
<td>Electrical</td>
<td>Mechanical</td>
<td>Electrical</td>
</tr>
<tr>
<td>Sensor</td>
<td>CCD</td>
<td>CCD</td>
<td>CCD</td>
<td>CCD</td>
<td>CCD</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>Channel dep.</td>
<td>Channel dep.</td>
<td>Channel dep.</td>
<td>AOTF-dep.</td>
<td>Channel dep.</td>
</tr>
</tbody>
</table>

4. CONCLUSION: This paper has described different spectral imaging systems and showed what the main differences of the systems are. Paper has described one developed PGP based spectral imaging system which has been used in many scientific purposes.

PGP imaging provides very good spectral and spatial information, but it is mainly used only in a laboratory or on the industrial line measurements. It is very hard to capture an image for example on outdoors by using the PGP camera because the measurement of one spectral image can take tens of minutes. Therefore faster systems like LCTF are used for natural targets and when the information is needed from the large objects.

REFERENCES:


