GUIDE TO SELECTING

HYPERSPECTRAL INSTRUMENTS

SPECIM

SPECTRAL IMAGING

Safe
Non-contact
Non-destructive
Applicable to many biological, chemical and physical problems

Hyperspectral imaging (HSI) is finally gaining the momentum that it deserves as a new vision technology for industrial on-line quality control, inspection and process monitoring. Applications cover wide range of fields from food sorting to printing, recycling and vegetation to name a few. Compared to more familiar black and white or RGB -imaging it provides more detailed chemical, physical and biological information for automation and decision making.

Technological power comes from measuring the information above visible wavelength range of light to extract relevant information. Ambitious machine vision companies that want to stay at the technological forefront should not bypass current opportunity to adopt HSI as an important competition asset.

Recently, many different HSI technologies have appeared as potential alternatives and it may turn out to be difficult to make reasonable comparison. This short article gives you a basic understanding on a few selection criterias and shows the major differences between the different technologies.

Hyperspectral imaging has already shown to be viable solution in many cases, however the selection of right technology for solving any industrial measurement tasks is always a key step to success.

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01 - General considerations

When selecting instrument for hyperspectral application there are many functional and non-functional quality attributes to consider. Typically, spectral range, resolution, speed and cost (return of investment) set by application are the first ones to think of. However, one should also consider how selected technology affects the need for illumination, light collection efficiency, purity of spectral data, accuracy and simplicity of data processing.

Main technological differences are related to how areal and spectral measurement is carried out in practice. It is not possible to measure two dimensional spatial image and spectrum from each position simultaneously. This dilemma divides current instruments as follows.

Push-broom based instruments

Push-broom instrument is based on matrix camera and spectrograph to form a line imaging device where one axis of the detector registers spatial position from a line and the other axis spectral information in each spatial position. This assures that resulting spectrum is perfectly co-registered so that all spectral bands are measured simultaneously and from the exactly same sample position. Illumination is needed only for this narrow line and result can be processed immediately after each line measurement.

Other HSI technologies

Current main competing technologies are tunable filter and variable filter instruments. In tunable filter only one wavelength band is measured from two-dimensional area at each time.
In linear variable filter all wavelength bands are measured

simultaneously but each band from different position on the target area. Both suffer from difficulty in getting co-registered spectrum and wasting most of the illumination energy due to operation principle. Co-registration problems lead to difficulties in data processing, unreliable spectral signatures and delayed processing results. Furthermore these technologies require homogenous and stable illumination for much wider two-dimensional area.

	Push-broom	Tunable filter	Linear variable filter
Data co-registration	Good	Poor	Poor
Illumination efficiency	Good	Poor	Poor
Spectral resolution	Good	Medium	Poor
Spectral purity	Good	Poor	Poor
Spatial resolution / image quality	Good	Good	Medium
Transmission throughput	Good	Medium / Poor	Medium

Table: Basic quality attributes of different HSI technologies while used in industrial on-line applications.

Push-broom for industrial on-line applications

It is reasonable to conclude that only line imaging push-broom HSI is suitable to all industrial on-line applications where moving and changing targets are measured and spectral co-registration is required. This property is necessary to assure spectral purity and for getting reliable classification results. Similar exact co-registration is practically impossible to achieve with any other methods. Push-broom gives instant measurement result because one does not need to wait for spectral scanning or sample movement to receive all spectral components.

02 - Illumination requirements

Hyperspectral imaging needs more light than ordinary machine vision systems. This is fundamental and independent on used technology as light is always divided to narrow wavelength bands and each band is measured separately. Therefore, each pixel receives less light during fixed integration time than compared, for example, to RGB color imaging. However, requirements for illumination are also intrinsically very different within available HSI technologies.

Lighting for line imaging

Push-broom instrument is line imaging and all wavelengths are collected simultaneously from this line. Therefore, while using push-broom HSI instrument one only needs to illuminate a narrow line in a conveyer belt or sample.

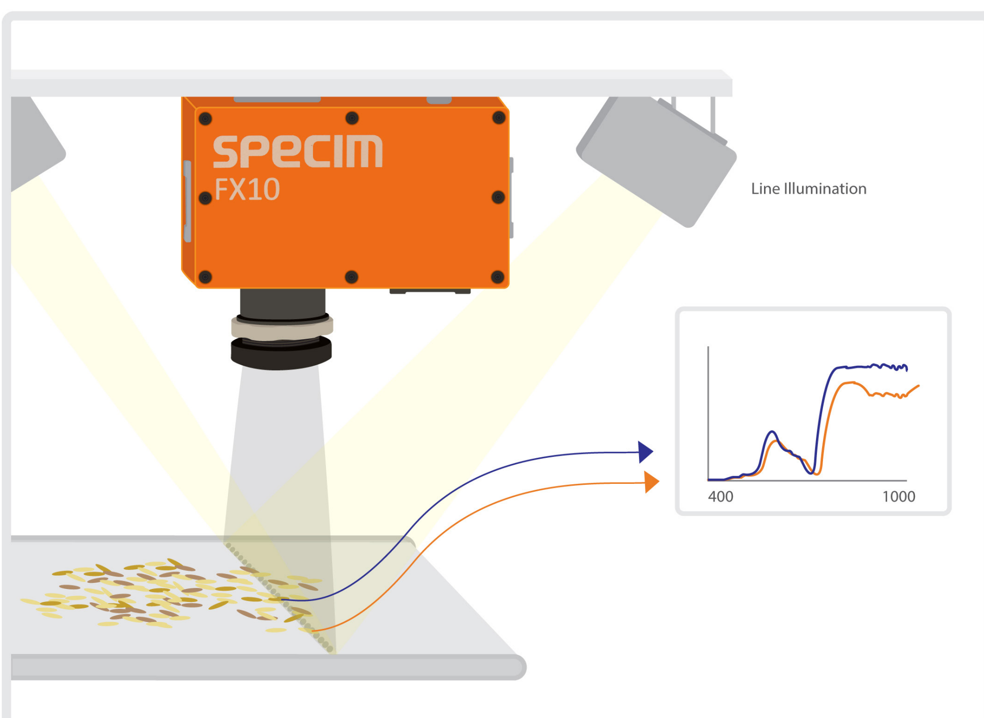

Illustration: Example of two line light setup.

In most cases this is accomplished by having two line light sources in 45° angles providing reasonably good and homogenous illumination also with samples having height and surface structure variance.

Lighting for area imaging

On the other hand tunable filter and linear variable filter devices are area imaging and require illumination within much larger surface area and with homogenous brightness. Generating uniform and stable illumination over an area is much more challenging than over a line. This is especially true as most light sources are point sources and having homogenous illumination means long distance from sample area – leading to additional losses.

Exposure time and heat load

Focusing the light energy along a line will easily provide 30 times higher intensity with the same total source power than illuminating a square area.

In other words this means that push-broom HSI can have at least 30 times shorter exposure time and 30 times higher image rate that filter systems.

On the other hand, if the speed is not the primary requirement, a push-broom system can work at 30 times lower light power and heat load on the sample. This may become a very essential benefit with biological, medical and food samples.

03 - Light collection efficiency

Not all hyperspectral instrument technologies are equal when it comes to how well it utilizes available illumination. Light collection efficiency in a HSI instrument depends on following parameters:

- Light throughput of optics
- Polarization characteristics
- Optical transmission (which includes reflection and absorption losses in optical elements and spectral efficiency of the element which separates the spectral bands)

Throughput

The throughput is determined by the maximum solid angle by which the optics can collect light from the object (usually related to F –number of optics) and transfer it to the detector multiplied by the area of the detector element.

As an example here, we are taking a look at a NIR hyperspectral imager with spectral resolution of 10 nm and having 640 x 256 pixels of 24x24 microns each referring to current InGaAs or a MCT detector arrays. Note that the same reasoning applies also to silicon based devices in VNIR range.

F-number

The maximum light collection angle in imaging optics is determined by its F-number. High quality objective lenses and imaging spectrographs are working with an F-number of F/1.7, resulting in the total collection angle of 34° and corresponding solid angle of 0.28 sr. In an imaging system, the light detection

element is one pixel. Multiplying the solid angle by the pixel area, we get the light throughput value of 16 x10-6 cm2sr for a high performance push-broom hyperspectral imager.
In all tuneable filter technologies, the maximum incident angle has to be kept much lower (corresponding to higher F-number).

> High quality objective lenses and imaging spectrographs are working with an F-number of F/1.7

Throughput with other technologies

For the 10 nm resolution in a Liquid Crystal Tuneable Filter (LCTF), the total incident angle has to be limited to ca. 7° corresponding to F/8. LCTF's are currently available in the size of 20 mm in diameter. It is larger than the detector, and thus the optics from the filter to the detector can have a demagnification. This increases the total incident angle on the detector to 10.5° corresponding to a solid angle of 0.025 sr. Multiplying this by the pixel area, we have the light throughput of 2.4 x10-7 cm2sr. This means that LCTF's have nearly two orders of magnitude lower transmission compared to push-broom imagers.

Acousto-optical tuneable filters (AOTF) have the same or even tighter limitation to the incident angle as LCTF's, and their active areas are not larger than 10 mm in diameter in current technology. This results in even lower light throughput. Fabry-Perot type tuneable filters with large areas are available, but we leave them out from this consideration because of their relatively narrow tuneable spectral range. However, they have same limitation as other tuneable filters due to limited F-number.

Linear variable filters have better efficiency compared to tuneable filters mainly due to higher transmission properties and large area. Due to operation principle (deposited Fabry-Perot filter) the input solid angle is limited thus reducing throughput to same values as LCTF.

Polarization and spectral transmission

The technologies differ also in terms of polarization and spectral transmission, the biggest difference being in light polarization behavior. When push-broom HSI is based on a transmissive spectrograph it is practically independent of polarization and efficiency is only limited by diffraction properties.

Tuneable filters light loss

All the tuneable filters require linearly polarized incident light in order to work properly, and must have a linear polarizer in the input. It automatically results to 50% light loss with randomly polarized incoming light. Linear variable filter is better in this respect because light does not need to be polarized.

Other factors affecting the optical transmission and total efficiency are fairly similar in all the technologies and do not have major contribution to total energy budget.

Summary of collection efficiency

Summarizing the analyses done above, we can conclude that compared to push-broom other technologies require from 20, up to 50 times more light or by the same order of magnitude longer exposure times per image to have same signal to noise ratio.

This analysis shows considerable difference in the light collection efficiency of HSI technologies.

Combining the results from both the light collection efficiency and illumination efficiency, we come to the very significant conclusion that push-broom type HSI is capable of working at 450 to 900 times shorter exposure time and equally higher image rates.

04 - Summary

1. Push-broom technology is the only suitable technology for all on-line application where you have to measure moving and changing targets with spectral co-registration.

2. Hyperspectral imaging needs light, if you want to have easy and cost effective lighting setup and your objects suffer from high heat load then make sure that you select push-broom based instrument.

3. High quality objective lenses and imaging spectrometers are working with an F-number of F/1.7.

4. Aim for high light throughput.

About the Author

Esko Herrala is a co-founder of Specim and has been working in the field of hyperspectral imaging since 1992.

At the moment he is taking part on sales and marketing activities as a senior expert in the field of machine vision and industrial applications.

Follow me on Twitter: @EskoHerrala

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