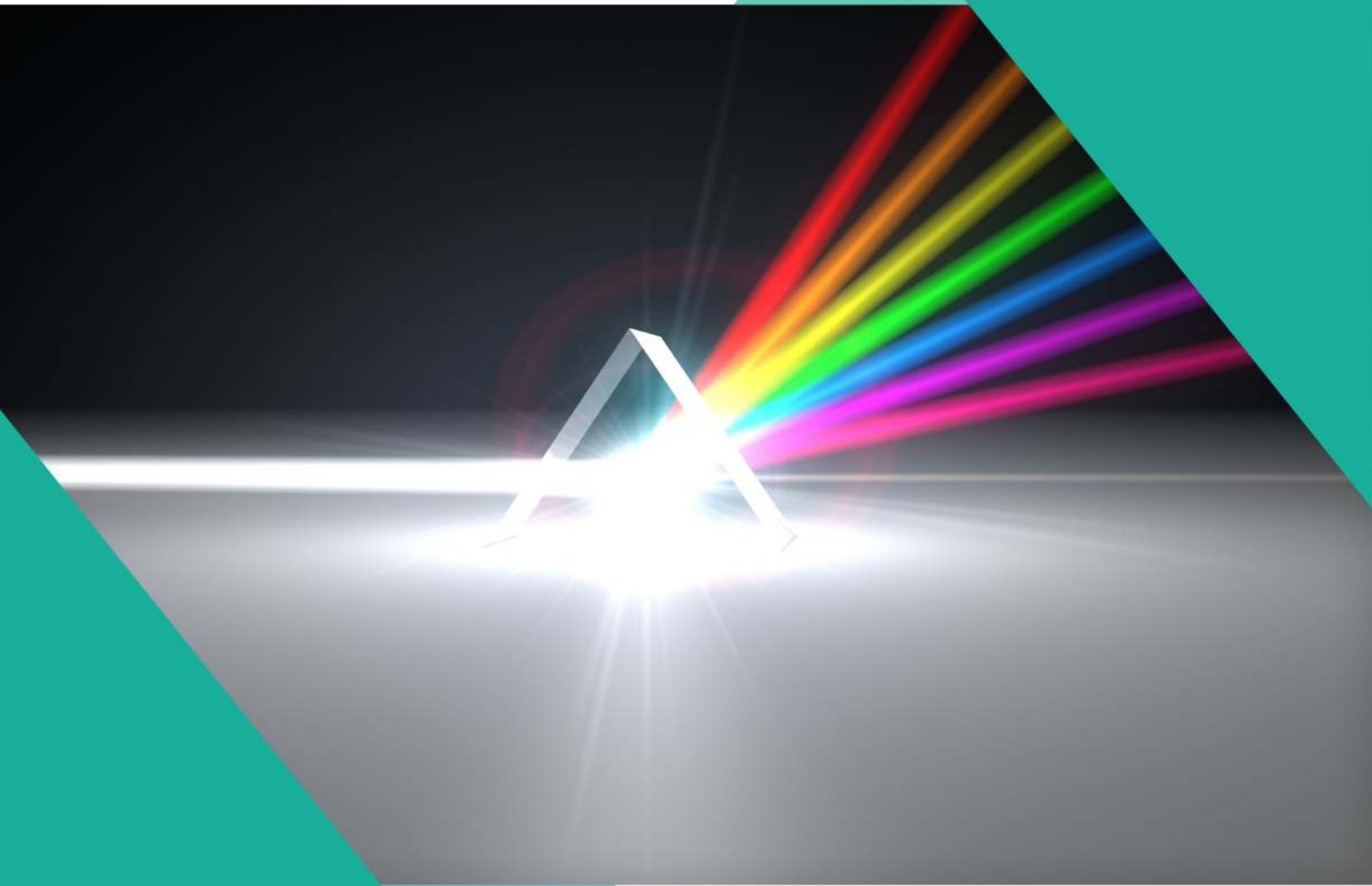
APPLICATION NOTE



Smile & Keystone

Smile and keystone are two types of optical aberrations which arise due to the relationship between gratings and optics that strongly impact the accuracy and the usability of push-broom hyperspectral cameras and are named as such due to the 'shape' of the distortions.

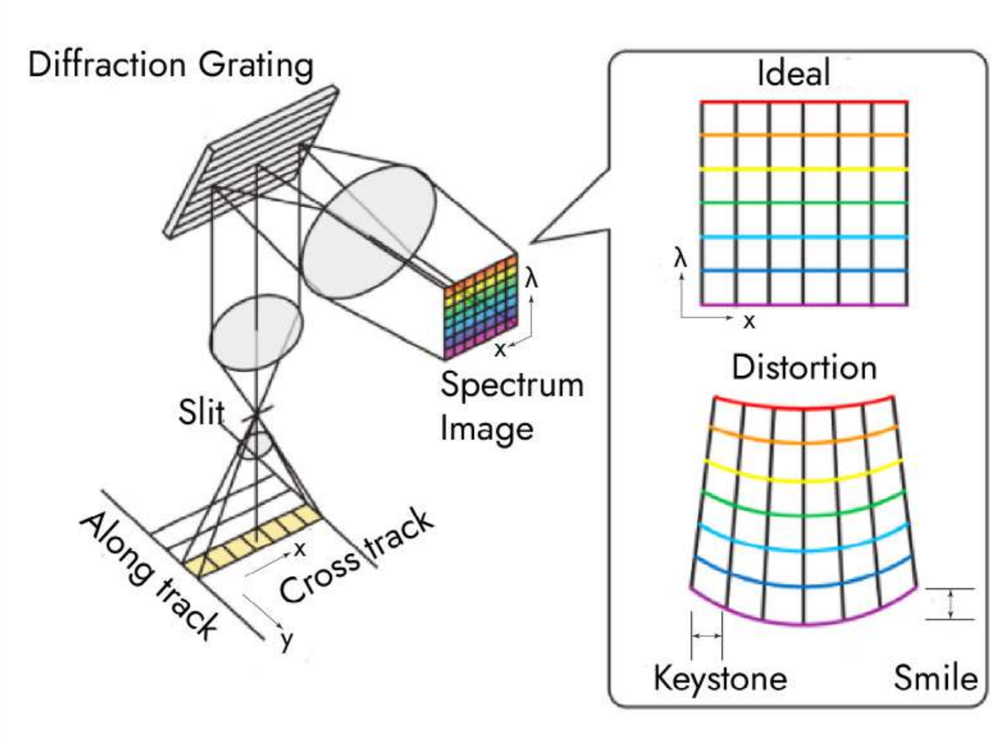
Smile is a spectral distortion. It is primarily a property of the spectrograph and measured by calculating the maximum displacement a wavelength makes as it moves across the entire height of the region of interest.

Keystone is a spatial distortion. It is mainly a property of the front objective and measured by calculating the maximum displacement a field slit makes as it moves across the entire spectrum.

There are consequences of optical systems with dispersion gratings and are the result of optical design limitations for the static case not a dynamic (motion) case.

They can be effectively corrected during post-capture if design tolerances are reproducible and consistent. Otherwise they may need to be done for each instrument.

Smile and Keystone on a Push-broom Hyperspectral Sensor [N. Yokoya, et al]



SMILE, DEFINED

SMILE is defined as *a mapping of the same wavelength to different columns of the focal plane array for different spatial channels.*

Per the figure above, smile can be seen as a spectral shift of the sensor over its entire field of view (FOV).

If the user images a homogeneous target over its full FOV, the spectra measured at the middle and on the side of the FOV will have an offset.

KEYSTONE, DEFINED

KEYSTONE is defined as the measure of how much a signal *does not* map to the correct spatial channel across the focal plane array. Keystone causes the signal to be "mixed" between spatial channels.

Band-Sequential-Based Hyperspectral Imagers

Motion is required when using push-broom systems. More precisely, capturing a full scene, subject, or target is accomplished **one line at a time** through the cross-track dimension (y).

This means that any non-uniformity of motion encountered by a push-broom imager (in terms of velocity) will induce image artifacts.

Image co-registration and image stitching based on concurrent geo-data (for example, INS/GPS) can be used to correct some of these artifacts...but not all of them (aircraft platform turns where data must sometimes be discarded is one example). Basically, a single line of spatial data does not provide sufficient information for purely image-based co-registration.

Band-sequential systems (Fabry-Perot, Lyot Filter/LCTF, AOTF, LCI, filter wheel, and others) capture spectral bands per exposure frame for the entire scene, assuming a fixed-position for the imager.

In band-sequential systems, there are no gratings or slit optical alignment components, which means they do not have smile and keystone artifacts.

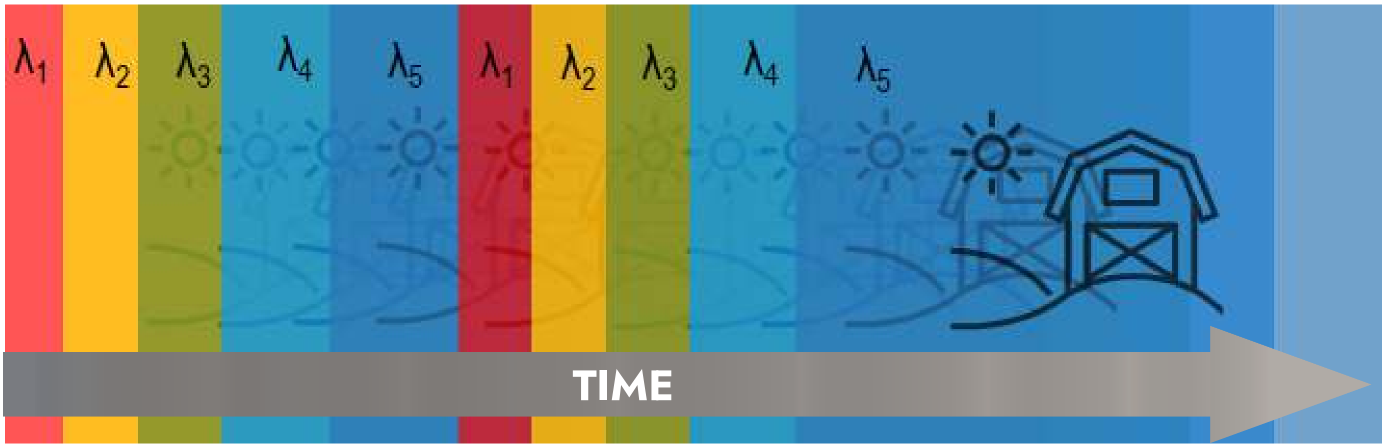
Co-registration errors can be introduced due to motion, but they are more easily corrected due to the availability of full spatial features for scene, target or *subjects*.

Impact of Motion-Band Sequential Based Hyperspectral Imagers For Static Subject/Target Capture — Vibration

While it is possible to have "spatial co-registration differences between bands" during collection if the sensor moves, as the full spatial information is captured per band in a band sequential system, such features permit relatively easy realignment.

For the oscillatory or vibration case, the full field of view of the data-cube may not be compromised due to the redundant spatial and spectral data available.

Impact of Motion Band Sequential Based Hyperspectral Imagers – Translation



For the case where motion is in one vector, the full cube for the full field of view is relatively easy to reconstruct through use of object features or fiducials.

While the initial and final frames may not be reconstituted into complete data-cubes, subsequent frames can be.

Summary

By definition, band-sequential, tunable-filter or frame camera systems such as Fabry-Perot based hyperspectral imagers ***do not have keystone or smile artifacts regardless of whether motion occurs during image acquisition.***

In cases where motion occurs, induced artifacts can be easily corrected since the full spatial information is captured per band in a band sequential system. Such features permit relatively easy realignment through use of machine vision/machine learning image processing.

To create an equivalent case for a push-broom imager, consider a scanning platform that is **also** subject to vibration. Another set of complications can be encountered in data translation, which is sometimes the case for airborne systems. Here, cross winds or other factors will invariably impact uniform velocity and thus lead to unusable data.

Through reduction of bands, such systems can operate in real-time (or near real-time) with classification so that motion artifacts are negligible and immaterial to the application.

SMART HYPERSPECTRAL IMAGING ACROSS FOUR KEY MARKETS

Band-sequential imagers from HinaLea Imaging are much less susceptible to smile and keystone artifacts than imagers that use diffraction gratings.

4200c VNIR

4250 VNIR

4400 SWIR

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