Pan Sharpening

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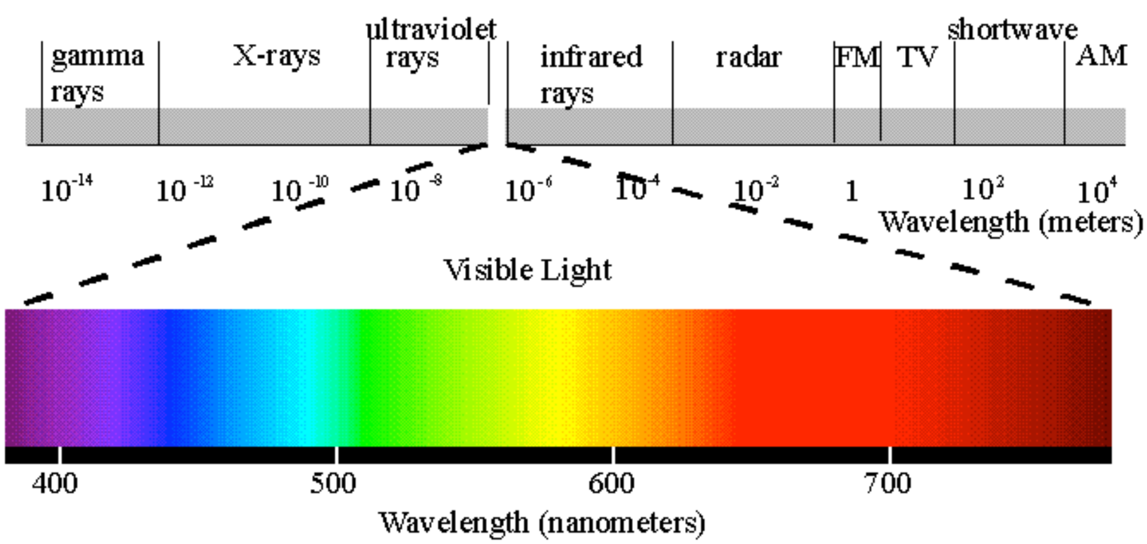
"Pan Sharpening" is shorthand for "Panchromatic sharpening". It means using a panchromatic (single band) image to "sharpen" a multispectral image. In this sense, to "sharpen" means to increase the spatial resolution of a multispectral image.

A multispectral image contains a higher degree of **spectral resolution** than a panchromatic image, while often a panchromatic image will have a higher **spatial resolution** than a multispectral image. A **pan sharpened image** represents a **sensor fusion** between the multispectral and panchromatic images which gives the best of both image types, high spectral resolution AND high spatial resolution. This is the simple *why* of pan sharpening. Most of this paper is concerned with the *how* of pan sharpening. First, a review of some fundamental concepts is in order.

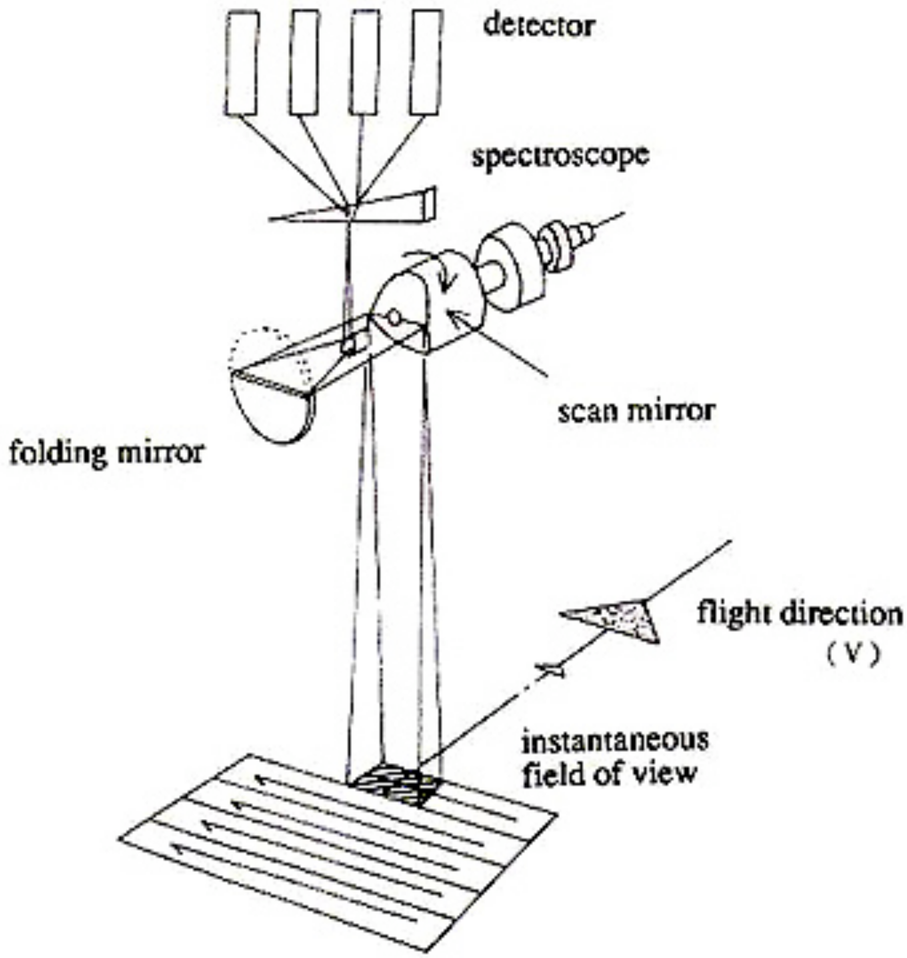
Multispectral Data

A **multispectral image** is an image that contains more than one spectral band. It is formed by a sensor which is capable of separating light reflected from the earth into discrete spectral bands. A **color image** is a very simple example of a multispectral image that contains three bands. In this case, the bands correspond to the blue, green and red wavelength bands of the **electromagnetic spectrum**. The electromagnetic spectrum is the wavelength (or frequency) mapping of electromagnetic energy, as shown below.



The electromagnetic spectrum

The full electromagnetic spectrum covers all forms of radiation, from extremely short-wavelength gamma rays through long wavelength radio wave. In Remote Sensing imagery, we are limited to radiation that is either reflected or emitted from the earth, that can also pass through the atmosphere to the sensor. Electro-optical sensors sense solar radiation that originates at the sun and is reflected from the earth in the visible to near-infrared (just to the right of red in the figure above) region. Thermal sensors sense solar radiation that is absorbed by the earth and emitted as longer wavelength thermal radiation in the mid to far infrared regions. Radar sensors provide their own source of energy in the form of microwaves that are bounced off of the earth back to the sensor. A conceptual diagram of a multispectral sensor is shown below.



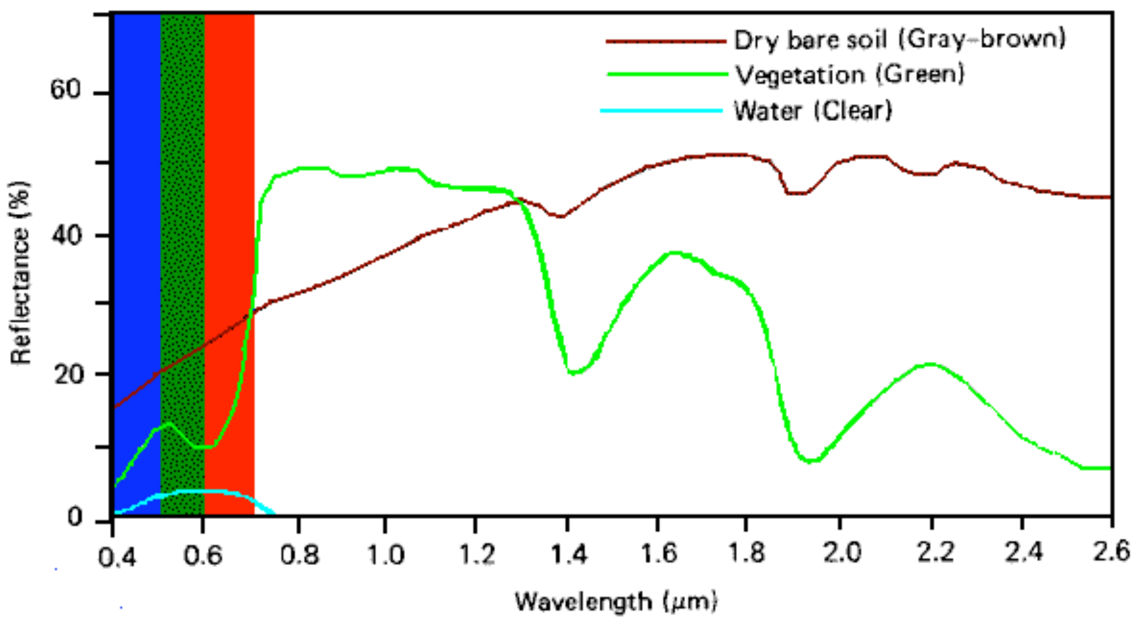
A Simplified diagram of a multispectral scanner

In this diagram, the incoming radiation is separated into spectral bands using a prism. We have all seen how a prism is able to do this and we have seen the earth's atmosphere act like a prism when we see rainbows.

In practice, prisms are rarely used in modern sensors. Instead, a **diffraction grating** which is a piece of material with many thin grooves carved into it is used. The grooves cause the light to be reflected and transmitted in different directions depending on wavelength. You can see a rough example of a diffraction grating when you look at a CD and notice the multi-color effect of light reflecting off of it as you tilt it at different angles.

After separating the light into different "bins" based on wavelength ranges, the multispectral sensor forms an image from each of the bins and then combines them into a single image for exploitation.

Multispectral images are designed to take advantage of the different **spectral properties** of materials on the earths surface. The most common example is for detection of healthy vegetation. Since healthy vegetation reflects much more near-infrared light than visible light, a sensor which combines visible and near-infrared bands can be used to detect health and less healthy vegetation. Typically this is done with one or more **vegetation indices** such as the Normalized Difference Vegetation Index (NDVI) defined as the ratio of the difference of the red and near-infrared reflectance divided by the sum of these two values. Some typical **spectral signatures** of vegetation, soil and water are shown below.



Reflectance spectra of some common materials. Red, Green and Blue regions of the spectrum are shown. Near-IR is just to the right of the Red band. Ultraviolet is to the left of the Blue band.

These are only representative spectra. Each type of vegetation, water, soil and other surface type has a different reflectance spectra, and outside of a laboratory, these also depend on the sun's position in the sky and the satellite's position as well.

When there are more bands covering more parts of the electromagnetic spectrum, more materials can be identified using more advanced algorithms such as supervised and unsupervised classification, in addition to the simple but effective band ratio and normalization methods such as the NDVI.

RemoteView has several tools which take advantage of multispectral data including the Image Calculator for performing NDVI and other indices and a robust Multispectral Classification capability which includes both supervised (using training sets) and unsupervised classification. This paper however is focused on the Pan Sharpening tools within RemoteView.

Panchromatic data

In contrast to the multispectral image, a **panchromatic** image contains only one wide band of reflectance data. The data is usually representative of a range of bands and wavelengths, such as visible or thermal infrared, that is, it combines many colors so it is “pan” chromatic. A panchromatic image of the visible bands is more or less a combination of red, green and blue data into a single measure of reflectance. Modern multispectral scanners also generally include some radiation at slightly longer wavelengths than red light, called “near infrared” radiation.

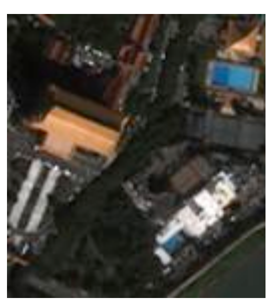
Panchromatic images can generally be collected with higher **spatial resolution** than a multispectral image because the broad spectral range allows smaller detectors to be used while maintaining a high signal to noise ratio.

For example, 4-band multispectral data is available from QuickBird and GeoEye. For each of these, the panchromatic spatial resolution is about four times better than the multispectral data. Panchromatic imagery from QuickBird-3 has a spatial resolution of about 0.6 meters at nadir. The same sensor collects the nearly the multispectral data at about 2.4 meters resolution. For GeoEye’s Ikonos, the panchromatic and multispectral spatial resolutions are about 1.0 meters and 4.0 meters respectively. Both sensors can collect co registered (explained below) panchromatic and four-band (red, green, blue and near-infrared) multispectral images.

The image below is a QuickBird panchromatic image of Taipei, Taiwan with 0.6 meter ground resolution.

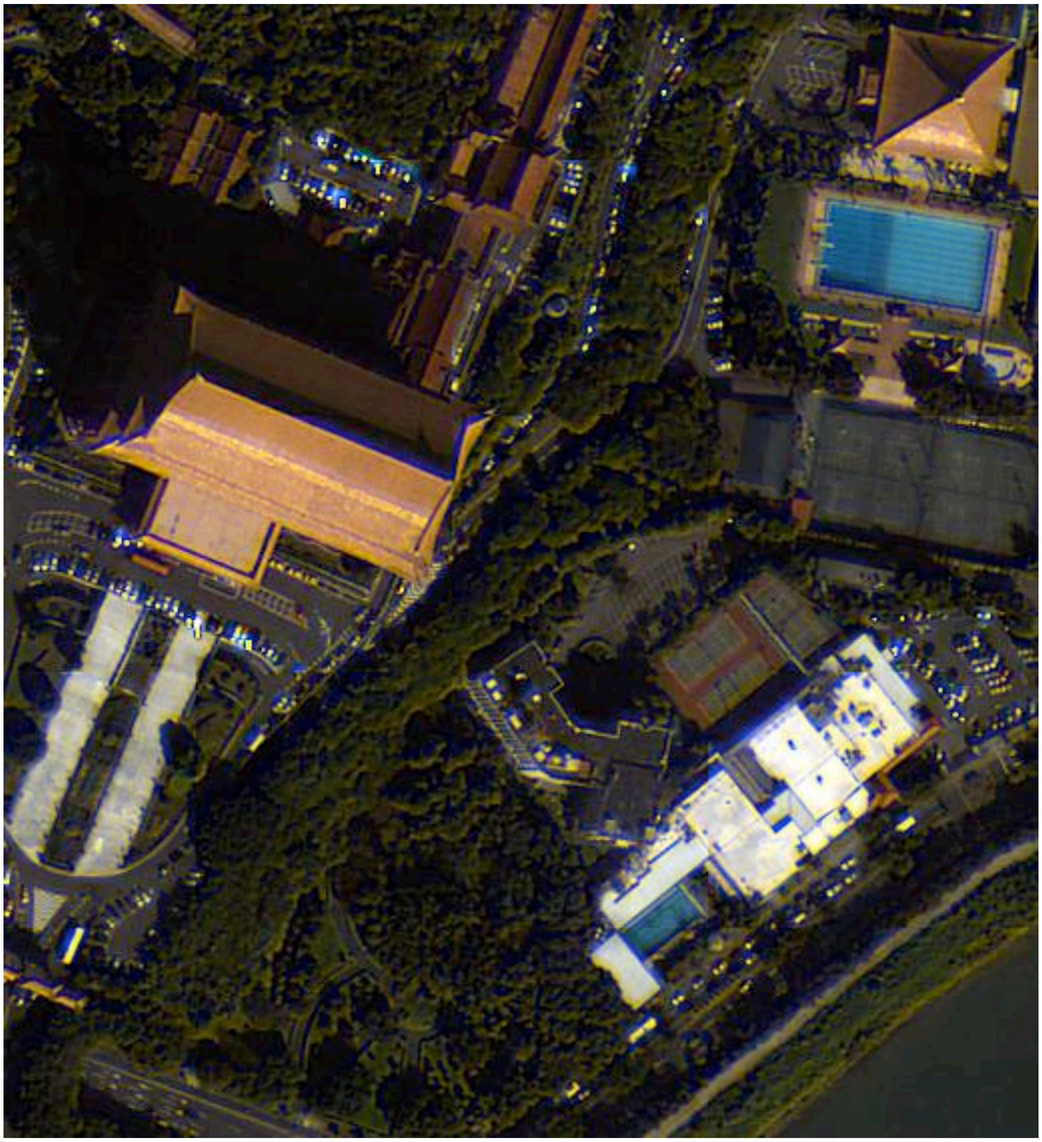
QuickBird panchromatic image, 0.6 meter ground resolution.

A QuickBird multispectral image of the same area at about 2.4 meter resolution is shown below.



QuickBird multispectral image, 2.4 meter ground resolution showing the same areas shown in the panchromatic image above.

The impact of both the multiple of four decrease in spatial resolution and the enhanced color information available in the multispectral image are readily apparent in these two images. Using RemoteView's projective pan sharpening algorithm to sharpen the multispectral image produces the result shown below.



Pan sharpening example based on the two images shown above. Result has 0.6 meter spatial resolution and 4 multispectral bands.

As you can see from the pan-sharpened image can substantially improve the amount of spectral information in a panchromatic image, conversely it can substantially increase the spatial resolution of multispectral images.

The importance of image co registration

There have been many studies on pan sharpening and many, many algorithms have been developed. Some are slightly better than others at preserving either spatial or spectral information, but there is generally always a loss of one or the other or both. All of the methods depend on the panchromatic and the multispectral image being very closely **co registered**. When images are co registered, you can think of overlaying one on top of the other and examining any pixel in the top image. The pixel in the image below that should be the exact same feature on the ground.

Pan sharpening algorithms depend on the input images being co registered because they all perform operations on corresponding pixels in both images. They all do *something* with the multispectral pixel and the panchromatic pixels to create new pixels. If the images are not co registered, the processing will use the wrong pixels, not the corresponding ones and the result will not look natural.

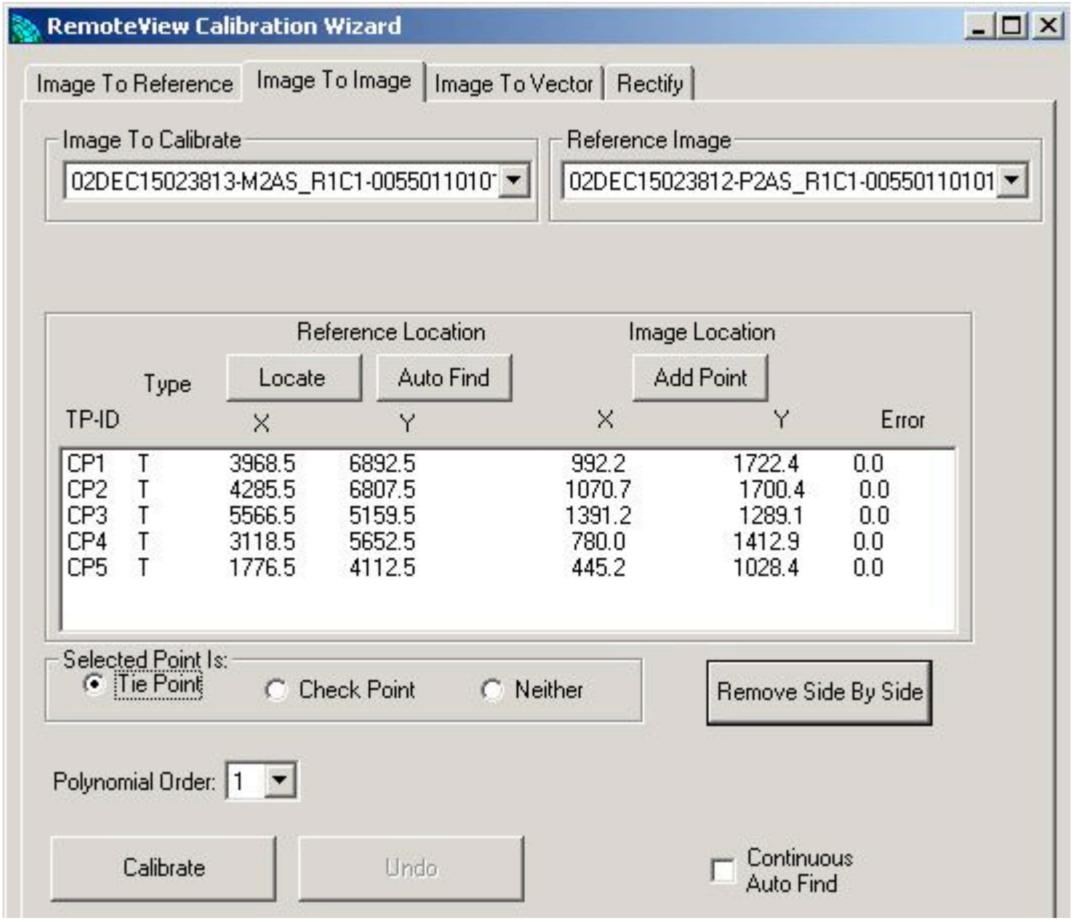
In practice RemoteView uses the georeferencing information in the images to perform co registration "on the fly". That is why images used for pan sharpening must be georeferenced, that is they must have metadata which supports one of the image/ground transformation methods supported in RemoteView. For information on georeferencing see, the *Basic Photogrammetry* white paper available at this web site. Unlike advanced **photogrammetric** operations, the images do not need to have rigorous sensor model support, or RPCs support to perform pan sharpening. Simpler methods such as the ICHIPB or other "4-corner" or map projection methods are also supported.

The software uses the georeferencing information in one image to identify the ground point associated with each pixel, then uses the georeferencing information in the other image in the reverse direction, to convert the ground location to image space in order to locate the corresponding image pixel in the other image.

To a large degree, the results that you obtain from pan sharpening will depend on how well co registered the two images are and how closely their georeferencing methods agree, that is how good their **relative georeferencing** is.

If the images are not well co registered, you can fix this situation using the RemoteView **image to image registration tool**. This tool is explained in the white paper *Basic Photogrammetry*. By manually identifying a small number of "tie points" on the two images, you can achieve much better co registration and pan sharpening results in some cases.

Using this tool, designate the panchromatic image as the reference image and the multispectral image as the image to Calibrate as shown below.



The RemoteView Image To Image Calibration tool. Here 5 "tie points" have been identified on the two images. Push the ***Calibrate*** *button to perform the co registration of the two images.*

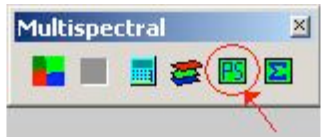
There are also special cases where the panchromatic and multispectral images are already exactly co registered. Such is the case for both the DigitalGlobe level 2A product and standard Ikonos panchromatic and multispectral bundled products from GeoEye.

The DigitalGlobe 2A product can be identified from the file name. In the illustration above which shows the image to image calibration tool, the multispectral image file name contains the string "M2A" and the panchromatic image file name contains the string "P2A". Other image types, including the QuickBird level 1B product, might actually be registered closely enough for successful pan sharpening, and in other cases you might need to perform the image to image calibration steps outlined above.

Note that there is also another registration issue with the multispectral data alone. That is, the individual bands of the image must also be co registered. For nearly all modern sensors, this is not an issue, the bands are precisely co registered because they are collected with the same sensor at the same instant in time. For some older remote sensing data such as SPOT or Landsat, it might also be necessary to perform image to image registration on the individual bands using the technique described above.

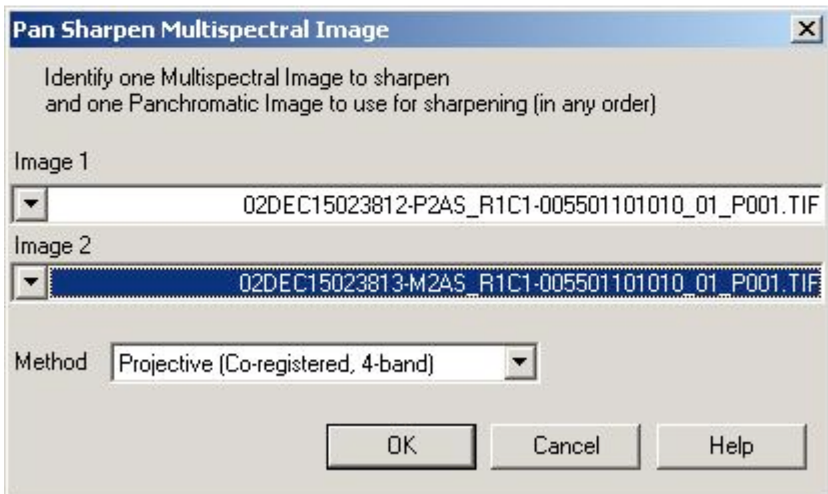
User Interface

To access the RemoteView pan sharpening algorithms, push the "PS" button on the multispectral toolbar, shown below.



The Multispectral Toolbar and the Pan Sharpening Tool button (red circle with arrow)

The dialog shown below will be started.



The Pan Sharpening Dialog. Choose one multispectral and one panchromatic image from the dropdown lists. The images can be chosen in either order. Select a method. The default method (projective) is suitable when you have well co registered data and a 4-band multispectral image.

This simple dialog begins the process of pan sharpening. In RemoteView, pan sharpening, like most processing algorithms such as Orthorectification or multispectral classification happen "on the fly". That is, the sharpening occurs only on the pixels which are actually viewed by the user. As the user roams or zooms to other parts of the image, those pixels are processed at that time.

By not forcing the user to wait until the entire image is pan sharpened, RemoteView allows real-time pan sharpening and other processing, removing the need for the "hour glass" user interface of other software packages. Immediately upon selecting the OK button, the pan sharpened image is produced and is ready for exploitation. The sharpened image can also be saved to a new file or saved as part of a RemoteView folder so that the steps used in creating the sharpening do not have to be repeated.

Algorithms

RemoteView provides five algorithms for pan sharpening, as shown below. By far the best method, in terms of the appearance of the output, is the Projective method used in the example of the Taiwan images above. The other algorithms are summarized below.

Algorithm Name	Features
Projective	• Four-band multispectral image • Complete Spectral overlap
Hue, Saturation, Intensity	• Computes a three-band result • Color shift, especially when IR is included in the panchromatic data.
Hue, Saturation, Intensity	• Computes a three-band result • Compensates somewhat for the color-shift of the method above.
High Pass Filter	• Result has the same number of bands as the original multispectral image. • Slightly more loss of spatial detail than either of the H-S-I algorithms.
Multiplicative	• Result has the same number of bands as the original multispectral image.

Pan Sharpening algorithms available in RemoteView.

The results of performing pan sharpening using the High Pass Filter and Hue, Saturation Intensity methods are shown in the images below. As you can see, the projective method shown above produces much better results in terms of preserving the color of the multispectral image. The other algorithms all cause a color shift of one type or another from the original multispectral image. The main advantage of the High Pass and Multiplicative methods are that they produce the same number of bands in the output as the original multispectral image contained.

High Pass Filter, sometimes produces slightly better _spatial_ *resolution than the other methods. Creates the same number of bands as the original multispectral image.*

Hue Saturation Intensity, color shift due to inconsistent *<u>spectral ranges</u>* *of the panchromatic and spectral bands in spectral space. The effect can be somewhat improved using the NIR Adjustment method available in RemoteView. Produces a three-band output (R, G and B).*

The projective pan sharpening algorithm in RemoteView takes advantage of the fact that the panchromatic image used covers the exact same **spectral range** as the multispectral data. The four spectral bands cover the electromagnetic spectrum from the blue through the near-infrared regions. The panchromatic image covers the exact same spectral range. A mathematical model which relates the panchromatic and multispectral images is formed and the parameters of this model are determined by least squares.

The other methods might be necessary when the input multispectral image does not represent full spectral overlap with the panchromatic image, or when it is not possible to accurately co register the two images. The High Pass Filter and Multiplicative methods also have the advantage of producing images with the same number of bands as the original multispectral image.

Benefits of Pan Sharpening

By increasing the spatial resolution of the high spectral resolution multispectral image, many other image processing tasks which are performed on the multispectral image are enhanced. This includes simple visual image interpretation and visual exploitation, as well as product generation and advanced methods such as Orthorectification and ortho mosaic.

Summary

This paper has presented the reasons why pan sharpening is a popular feature in RemoteView and image processing tools and some of the theory of this technology. There are many additional sources of reference on Pan Sharpening available from Photogrammetric and remote sensing journals. The most widely respected of these include, *Photogrammetric Engineering and Remote Sensing, IEEE Transactions on Geoscience and Remote Sensing, Journal of Geophysical Research,* and *International Journal of Remote Sensing.* For additional information, please contact Gene Rose at gene.rose@overwatch.com..