Using WorldView 2 Vis-NIR MSI Imagery to Support Land Mapping and Feature Extraction Using Normalized Difference Index Ratios.

SUBMITTED BY:
Mr. Antonio Wolf
Sr. Spectral Analyst
Ball Aerospace & Technologies Corp.
2875 Presidential Drive
Fairborn, Ohio 45324

SUBMITTED FOR:
Digital Globe
8-Band Challenge
1601 Dry Creek Drive, Suite 260
Longmont, CO 80503

December, 2010
Executive Summary

Multispectral imagery (MSI) provides information to support decision making across a growing number of private and industrial applications. Among them, land mapping, terrain classification and feature extraction rank highly in the interest of those who analyze the data to produce information, reports, and intelligence products. The 8 nominal band centers of WorldView 2 allow us to use non-traditional means of measuring the differences which exist in the features, artifacts, and surface materials in the data, and we are able to determine the most effective method for processing this information by exploiting the unique response values within those wavelength channels. The difference in responses across select bands can be sought using normalized difference index ratios to measure moisture content, indicate vegetation health, and distinguish natural features from man-made objects. The focus of this effort is to develop an approach to measure, identify and threshold these differences in order to establish an effective land mapping and feature extraction process germane to WorldView 2 imagery.

1.0 WorldView 2 Specifications

The WorldView 2 sensor is the first commercial MSI sensor of its kind. Advancing from the spatial advantages of WorldView I, it has remarkable 46cm panchromatic optics on-board at nadir. Each swath measures 16.4km and can store up to 2199GB on solid state drives, complete with EDAC. WorldView 2 can register objects on the ground within 6.5m, and register ground control points within 2m accuracy. The temporal revisit time of the sensor is 1.1 day at 1m ground sample distance, giving users an advantage of having changes detected within any scene in a mere matter of hours. Each band has a dynamic range of 11bit radiometric resolution, and data is transferred to the ground station over the 800mbps X-band downlink.

The 8 spectral bands of WorldView 2 offer a unique perspective of the data within each scene. Unlike traditional MSI systems, WorldView 2 captures the coastal, yellow, red edge, and NIR 2 wavelengths, as illustrated in Figure 1-1.

Figure 1-1: The 8 spectral bands (and panchromatic band) of WorldView 2.
2.0 Analysis

The WorldView 2 multispectral imager is the first sensor of its kind to capture the ‘yellow’, ‘red edge’, ‘coastal’, and 2 separate NIR spectral ranges in a single focal plane, coupled with traditional visible wavelengths. These unique channels will grant the analyst access to spectral regions where distinguishable differences exist between multiple classifications within the scene, which may be overlooked by more traditional MSI systems. Those classifications become more well-defined once they are transformed along a new axis, and WorldView 2 has the advantage of using non-traditional wavelengths, which may foster more specific results from this transformation.

Index ratios are typically used to classify a particular material or feature, and are dictated by the difference in reflectance values between the bands used in the ratio. Traditionally, water and vegetation have been the primary focus of normalized index ratios because they are easy to identify by the difference in reflectance values between the 0.45µ, 0.65µ and 0.75µ channels. WorldView 2 provides us with a coastal region band (0.427µ) which could be used to produce a more accurate index ratio to represent areas of subtle moisture within the scene, as opposed to complete saturation or standing water. This allows the ratio to classify areas of “in-between” response values, such as soil and surface moisture levels, which are not exploitable by traditional V-NIR MSI systems.

With regard to land mapping, index ratios can be used to establish the foundation of classifications, from identifying the most abundant surface materials, to drawing discrete differences in the health, condition and variety of other natural and man-made features. Systems such as Landsat 7 ETM have provided the capability to distinguish characteristics in the data which foster a high-level land use analysis, using standard Vis-NIR wavelengths. WorldView 2 could provide an exponential number of more characteristics than traditional systems such as Landsat based on the product of indexing the ‘coastal’, ‘yellow’, and multiple NIR bands.

The product of each index ratio is considered an independent element of the land map, and together the elements comprise a composite image which describes the classifications of the scene. In essence, ratios are individual nodes along the processing chain, which contribute to the overall mosaic of land mapping. The objective of this study is to assess the unique utility of WorldView 2 imagery with respect to utilizing multiple index ratios to produce a more accurate land mapping method than that of traditional MSI.

2.1 Index Ratios

In order to exploit specific features which can be used to support land mapping applications, you must first derive the information using index ratios which are germane to each classification included in the land map composite. For instance, regions of soil moisture are derived using a ratio using the coastal band and the second NIR band, whereas regions of standing water are derived from a ratio using the blue band and the first NIR band. The same logic applies to mapping vegetation (scaled by health), man-made features, regions of dense soil, and other natural features identified by their unique spectral content. Ratios to be used for the practice of establishing effective land mapping means using WorldView 2 imagery are listed in table 2-1.
<table>
<thead>
<tr>
<th>Index Ratio</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized Difference Water Index (NDWI)</td>
<td>Identify areas of standing water in size greater than one pixel</td>
</tr>
<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>Identify areas of vegetation and determine the health of each vegetation class.</td>
</tr>
<tr>
<td>Normalized Difference Soil Index (NDSI)</td>
<td>Identify areas where soils is the dominant background or foreground material</td>
</tr>
<tr>
<td>Non-Homogeneous Feature Difference (NHFD)</td>
<td>Classifying areas which contrast against the background, which can be identified as man-made</td>
</tr>
</tbody>
</table>

**Table 2-1**: The index ratios proposed to support land mapping methods using WorldView 2 imagery

The difference which exists between the response values in the ratio will dictate where the respective classifications lie in the scene. Once these areas are identified, the detection threshold values can be set to capture only the feasible regions of classification. After the thresholds are set, the regions can then be classified as areas having specific characteristics with respect to the land map. Each region is then overlaid onto a single projected image, and annotations will identify each region being a particular class (i.e. water, soil, healthy vegetation etc.), generating the land map. Each of the new unique bands is used in the ratio in order to provide context to the utility of these wavelengths with respect to traditional analysis techniques.

### 2.1.1 NDWI

\[
\sum \frac{(\text{Coastal} - \text{NIR2})}{(\text{Coastal} + \text{NIR2})} = \text{NDWI}
\]

Traditionally, a blue band is normalized against a NIR band, since the difference in response is very obvious. In this case, we take the coastal band, and normalize that against the NIR2 band, since the difference that each of these unique bands gives us, is even greater, hence will provide an even more discrete threshold for detecting areas of standing water.

### 2.1.2 NDVI

\[
\sum \frac{(\text{Red} - \text{NIR2})}{(\text{Red} + \text{NIR2})} = \text{NDVI}
\]

Given any other MSI system, a red band is used to represent the low level of reflectance from vegetation and a broad NIR to represent the higher reflectance values. The red band stays true to lower reflectance levels than the NIR2 band, which has a higher value than traditional broad NIR bands, hence should produce a higher NDVI value.

### 2.1.3 NDSI

\[
\sum \frac{(\text{Green} - \text{Yellow})}{(\text{Green} + \text{Yellow})} = \text{NDSI}
\]
Normally, SWIR and NIR bands are used to represent the difference in reflectance values in soil areas. Since there is no SWIR band, but there are unique differences in the response values of soil between the green and yellow bands, this artifact can be exploited to represent soil.

2.1.4 NHFD

\[
\sum \frac{(\text{Red Edge} - \text{Coastal})}{(\text{Red Edge} + \text{Coastal})} = \text{NHFD}
\]

Non-homogeneous features tend to stand out brighter in response than the background. To exploit these features, the difference between the red edge and coastal bands will provide an effective means of segregating these features.

This type of analysis is indigenous to each collection, and the data must be calibrated and atmospherically corrected prior to classification. To do this, the ENVI WorldView Calibration algorithm will be used to convert the raw digital numbers to radiance values, ensuring that each response is free of most scattering and artifacts. It is important to use sanctioned correction methods such as the ENVI WorldView correction, and not arbitrary techniques such as IARR, or QUAC, to ensure that the results are consistent and valid. This study does not assess the quality of the radiometric calibration of WorldView 2 imagery, nor will it compromise any integrity of the data by attempting to base classification on the result of any dimensional transformation of the data.

Furthermore, once this analysis is complete, a further analysis will compare the attributes of this study to that of other commercial assets including Quickbird 2, and Landsat 7 ETM, in order to provide perspective on the advantages of using WorldView 2. This is to shed insight regarding the utility of this sensor in other civil applications.

2.2 Description of Data

All data used in this study is standard WorldView 2 collection file format (raw digital number, .Tiff), including all geo-registration information and full 8 spectral band data. The calibration metadata used in order to convert the raw digital numbers to radiance is also necessary. This information is adequate to produce the most accurate and effective land map applications. Included with this data package is the corresponding EO panchromatic data that will provide spatial context for further analysis. Figure 2.2-1 provides details of the data which is used in this analysis.

Data used for this analysis is full integrity 8 band WorldView 2 MSI, and the corresponding EO panchromatic imagery.

**Location:** Boulder, Colorado  
**Date:** 08 April, 2010  
**Cloud Cover:** < 1%

- Data in unprocessed state:
  - Raw digital number
  - .Tiff tile images
  - Calibration metadata included
  - Data includes GCPs

*Figure 2.2-1: Description of the data used in the analysis.*
2.3 Processing Chain

A series of pre-processing steps must be performed in order to prepare the radiometric integrity of the data, and spatially mosaic all separated images. Once pre-processing is complete, the index ratios will be calculated against the data, and the results compiled into a land map.

![Processing Chain Diagram]

First, the data must be mosaicked from its original form of 9 separate images (based on GCP information), into a single image that contains undistorted spectral integrity. Some forms of this process will often distort the data, but the ENVI mosaic utility, used in this scenario, keeps all original band information intact. Next, a dark pixel subtraction is run against the data in order to spread the data values evenly in space with regard to dynamic range. This step is often performed on systems that vary in radiometric range among bands, however, since WorldView 2 is uniform 11bit, it is still proficient for providing an equal context for all radiometric data regardless.

The next step is to convert the raw digital number values to radiance factors by applying the ENVI WorldView Calibration utility, available in ENVI v4.6 and greater. This tool takes the factors from the WorldView 2 metadata (provided) and applies the appropriate gains and offsets in order to convert those values to apparent radiance. This will remove enough of the atmospheric artifacts to provide valid intensity levels in the spectra.

Next, the index ratio is calculated against the values in the radiance cube, and an output image is generated. Once each output is produced, the individual result images will be layered into one final land map dataset. This land map will be the final output of this analysis. This processing chain is illustrated in Figure 2.3-1.

Figure 2.2-1: The processing chain for this analysis, from pre-processing through final product generation.

3.0 Results

Results from this study are quite good, and fulfilling to the purpose of this research. Each index ratio performed as theorized, and thresholds were applied to mitigate any false alarms, which were minimal from default threshold settings. Each ratio produced what most analysts would consider feasible results which pass the common sense filter, meaning areas of obvious similarities are apparent in both the true/false color composites of the original data, and the classification regions within the land map.
**NDWI Result**

There are several large bodies of water present in the scene, and each emits a similar response exploited by the NDWI ratio. Figure 3-1 below is the result of the NDWI ratio with a comparison of obvious regions of standing water in the false color composite.

As Figure 3-1 illustrates, the obvious detection of standing water validates the theory that the coastal band is a unique variable in the NDWI equation. As a second phase of validation, the same process was run again, using the blue band in place of the coastal band. As a result, the threshold had to be increased to filter out a larger number of false alarms, making the coastal band an advantageous asset to the NDWI ratio over traditional blue bands. This is not surprising, as in many cases the response of the coastal band was greater than the blue band in areas of standing water.

**NDVI Result**

There are many civil applications which benefit from the use of an NDVI ratio, which has been an industry standard for years. Until now, the use of the red and the NIR bands have provided enough substance to classify areas of vegetation health. The advantage to having the NIR2 band is that the difference in response values between the two regions is even greater, thus widening the threshold for positive classifications of vegetation, and the level of health (varied by intensity). Figure 3-2 illustrates the result of the NDVI ratio.

From the false color composite in Figure 3-2, the areas of bright red response dictate areas of healthy vegetation, represented by athletic fields/venues, parks, and even a golf course (cursor location). The high NIR2 response gives context to the utility of this method of NDVI. Lighter areas in the result image dictate regions where the NIR2 response was not as high, but still apparent, insinuating that the health of the vegetation sample is not as matured or seasoned as the darker response regions.
NDSI Result

As mentioned, typically a soil index ratio requires a SWIR band, since soils tend to stay bright or gain intensity as they are recorded in higher wavelengths. Drawing from a sample of the soil within the scene, a consistent and unique difference between the green and yellow bands was observed. The theory that this is constant for all regions of soil was proven valid, as shown in Figure 3-3.

The NDSI is quite possibly the most impressive result of them all. All detections were validated by cross referencing the signatures in each corresponding region in the true and false color composites with the detections in the NDSI. This is a remarkable, and valid, new method of determining areas of soil content without using a SWIR band. This is the largest sample of the index ratios to be applied to the land map.

Figure 3-3: The NDSI result illustrates areas where soils were detected within the scene.

NHFD Result

Man-made materials are often the most simple to extract from homogeneous backgrounds, but in this scenario, the background consists of many different types of materials. However, the performance of the NHFD was outstanding, detecting not only the most obvious of stand-out materials (building roofs, cars), but paved surfaces (roads) and even obscure static objects such as tennis courts were detected by the NHFD.

Using the red edge and coastal bands in order to detect man-made materials is 100% germane to WorldView 2 utility, as no other sensor can provide this type of result. As shown in the result image in Figure 3-4, the paved surfaces (even into urban cross-sections) are apparent, as are the larger structures that stand out, such as large buildings and residences. This is the second most abundant layer to be applied to the land map.

Figure 3-4: The NHFD result shows areas and places where man-made objects are located/installed.
Land Map Result

Once the index ratio result layers were compiled to form a single land map, a color map was applied to the scene, giving context to each of the individual results. The greatest attribute to the validity of this analysis is that no layers overlap in this land map. Typically, regions of classification are not set to reasonable thresholds where false alarms still exist, but false alarms in this dataset have been completely mitigated by the previous application of a threshold to the result layer. Figure 3-5 is the result of the land map which was produced.

Transforms such as Principal Components Analysis (PCA) and Minimum Noise fraction (MNF) were created so that this process becomes streamlined, in the instance that an entire scene should be classified. However, these processes redistribute the spectral variance along a new set of axis, with respect to spectral dimensionality. In this case, only specific types of materials needed to be identified, as is the case for most commercial applications that rely on MSI data. Comparing the results of these index ratios with that of a PCA or MNF is not valid for the purpose of this study, it is intended to express the unique utility of these bands when used in context of feature extraction to support land mapping.

**Figure 3-5**: The final product; a land map generated from the index ratios using the unique WorldView 2 bands.

Essentially, the data has come a long way in the essence that each individual scan (9x9) provided enough calibrated substance to support generating a valid wide area land map. In reality, the analysis itself was by no means complex, and required very little pre-processing in order to attain these results. This type of process could become streamlined in order to provide an “on-the-fly” approach to generating this type of product, which is very easy for end-users to understand.

As mentioned previously, these results exceeded the expectations, as they break the norms of all things considered to be textbook rules when it comes to using index ratios to support feature extraction to create land maps. In the further analysis section of this study, other attributes and observations taken from this research are explained, fostering more advantages to using WorldView 2 data over other commercial MSI assets.
4.0 Further Analysis

WorldView 2 and Quickbird 2: Comparison of Pan-Sharpening

A number of observations from this study provide insight to the true utility and robust capability that WorldView 2 brings to the commercial MSI arena. There are a number of techniques that combine two or more processes or transformations to the imagery which place more contexts in the information provided by the data. As an example, a spectral cube fused with EO panchromatic imagery, or Pan-Sharpening, can provide more detailed classification mapping in the scene. The spatial resolution of the EO imagery is the single variable that defines how much context is truly added to the analysis. Until now, Quickbird 2 has provided access to this type of information, with sub-meter panchromatic resolution. WorldView 2 provides even more spatial content, and even more so within the realm of the 8 spectral bands. From this, we can draw that WorldView 2 should be superior for performing this type of analysis, and Figure 4-1 illustrates that this is a valid assumption.

Figure 4-1: Quickbird 2 Pan-Sharpened MSI vs. WorldView 2 Pan-Sharpened MSI

At first glimpse, the two images in Figure 4-1 may not seem so different, until the reader understands what they are looking at. The Quickbird 2 image is of a large chemical processing facility. Although crisp, the resolution does not come close to the level of detail drawn out by the WorldView 2 image of the University of Colorado football stadium, where individual rows of bleachers can be depicted at reasonable zoom levels. Specifications would suggest that WorldView 2 should be sharper at greater zoom levels, and this is a true assumption, as illustrated in this example. WorldView 2 not only exceeds the spatial capability of Quickbird, but also exceeds the spectral resolution with twice as many bands available.

WorldView 2 and LandSat 7 ETM: Comparison of Spectral/Spatial Context

For years, the Landsat 7 ETM has provided spectral context for wide-area coverage, and done so for many purposes. Today, WorldView 2 provides a very large footprint for wide-area coverage, and can provide much more spectral depth.
Though WorldView 2 cannot provide MWIR responses, it is capable of providing very low level scene classification for the entire footprint, whereas LandSat 7 ETM is fixed providing > 10m spectral/spatial context. Take for instance the need to use a Minimum Noise Fraction forward transformation in order to discern materials and objects in the scene. The next step is to fuse that information with high resolution EO imagery, in order to provide even more spatial context to the product. Both systems are capable of providing the necessary data, but WorldView 2 provides a much higher resolution result, for a very wide area of regard. Figure 4-2 and 4-3 illustrate the difference between the two systems when performing the same task. Note, the WorldView 2 sample provides almost as much context after the MNF transformation and pan-sharpening, as when only pan-sharpening was performed in the previous Quickbird 2 example.

**Figure 4-2:** Comparison of MNF results among LandSat 7 ETM and WorldView 2.

A subset of the data is then taken from the MNF result layer and sharpened with the high-resolution EO to produce a very high detailed MNF layer.

From this example, the WorldView 2 imagery possesses a capability unlike any other sensor in its class, and provides further utility in the commercial MSI realm across many civil applications. Although LandSat 7 ETM is still useful for assessing trends in large scale fashion, the short re-visit time of WorldView 2 makes it possible to gather the same amount of large scale information, with greater spectral depth, in a very short amount of time. It is the belief of the author that systems such as WorldView 2 will continue to phase out older systems such as Landsat 7 ETM, due to their growing capabilities, access to data, and ease of processing.
5.0 Conclusion

Results from this analysis are substance that such methods do provide an effective method to support land mapping across a large number of growing applications, who would benefit from exploiting the unique capabilities of WorldView 2 data. It was the intent of the author to comprise a number of unique normalized difference index ratios to provide accurate analysis of the data, and foster new capability using WorldView 2 imagery. Thus, the resulting product, a simple land map, proves that these ratios do in fact validate the integrity of the unique index ratios with respect to WorldView 2 MSI.

Further, utilizing the unique bands of WorldView 2 offers a contextual foundation for land mapping and scene characterization unlike any other commercial MSI sensor. The unique bands push the spectral resolution of commercial MSI, and foster new feature extraction methods to support land mapping. This analysis proves that these new and unique index ratios are a valid means of performing feature extraction. This information, fused with other types of image and data processing, could grow the commercial user base, as this approach proves that using this data is simple. Very little pre-processing is necessary in order to perform advanced analysis techniques, and that is something that the everyday remote sensing data analyst can appreciate.

6.0 Summary

The objective of this study was to establish effective index ratios using the unique spectral bands of WorldView 2 imagery to enhance land mapping methods. Identifying such methods would standardize an efficient way to support land mapping across a large number of growing applications, which could benefit from the unique capabilities of WorldView 2 data. The intent of the author was to provide new means for analysis of WorldView 2 data, by comprising unique normalized difference index ratios, and foster new utility of the imagery. Each ratio comprised of at least one unique band from the arsenal of newly available wavelengths (coastal, yellow, red edge, and NIR2) which are not common of any other platform in the commercial MSI realm.

The results are valid and optimistic. Each ratio provides a unique method of extracting features from within the scene to create a solid approach to generating land maps. From the results of this study, it is clear that the number of civil applications which rely on traditional MSI should consider acquiring WorldView 2 imagery to support their mission and achieve greater objectives.
Contributions

Several individuals have made this study successful, and the author wishes to thank them for their support and contributions to research.

- Mr. Ian Gilbert, DigitalGlobe Inc.
- DigitalGlobe 8 Band Challenge Committee
- Mr. Thomas Jones, Mr. Mark Bowersox, and Mr. Christopher Jengo, ITT Corp.
- Ms. Peggy Irwin and Mr. Vance Saunders, Ball Aerospace and Technologies Corp.
- Mr. Kip Streithorst, Mr. Gary Welch, and Mr. Trevor Clarke, Opticks Development Team

About the Author

Antonio (Tony) Wolf has 8 years of experience as a multi/hyperspectral data analyst and sensor utility assessor, working at the National Air and Space Intelligence Center. Mr. Wolf has specialized in standardizing processing techniques for a broad number of spectral imaging systems including LandSat ETM, Quickbird 2, ASTER, and now WorldView 2. During his Masters studies at the University of Colorado, he has focused his efforts on benchmarking sensor specific methods for transforming, calibrating and processing changes within Vis/NIR data. Today, Tony supports the systems, architecture and analysis side of HSI sensor development, and provides training at the Advanced Technical Intelligence Center for using Opticks, an open-source remote sensing software platform.

Other publications have included:

- Spectral binning optimization for the ARTEMIS real-time processor
  (Wolf, Petrick, Wamsley, Johnson, Buswell, Ewald, Pachter, Grigsby)

- Utility Assessment of the Advanced Change Detection and Thematic Mapping Classification Algorithms to Support Urban Development
  (Wolf)

- Sub-Pixel Target Detection Performance of a Novel Panchromatic Sharpening Technique for Hyperspectral Image Data
  (Borel, Wolf, Ewald, Wamsley)
  Submission 2010 IEEE Aerospace Conference

- Spectral Registration Utility Assessment of the Compact Airborne Spectral Sensor (COMPASS)
  (Wolf, Johnson)
  Submission and presentation 2005 Spectral Analyst Exchange Forum