

Spectral Angle Mapping

Many of the automated methods used in Maritime Domain Awareness (MDA) systems to detect vessels in satellite imagery are spectral signature based (McGowen, 2018). MDA is the effective understanding of anything associated with the global maritime domain that could impact the security, safety, economy, or environment of the United States. NRL's MDA system, Proteus, uses Spectral Angle Mapping (SAM) to assess vessel spectral signature profiles in commercial satellite imagery. SAM compares an input target spectrum with the spectrum of each pixel within an image. If the pixel spectrum is close to the target spectrum, the output is a high pixel value.

Whale annotations from Cubaynes and Fretwell 2022 were used to test whether marine mammal pixels are spectrally distinguishable from background pixels using SAM in a WV2 image taken over Southern right whales in Peninsulas Valdes, Argentina (Catalog ID: 103001001C8C0300). The Basic All Bands TIF from G-EGD). The Basic All Bands product is critical to this analysis because it is the rawest form of the image and does not have any correction applied to the image that would distort the spectral signature values.

The entire image was divided into two groups: whales and background. In this scenario, the target group is the "whale" group. This concept can be further expanded by separating the target group into two subgroups: submerged and surface whales. A group consists of N pixels, x_i . For each group a mean vector m and the covariance matrix C is calculated:

$$m = \frac{1}{N} \sum_{i=1}^N x_i, C = \frac{1}{N} \sum_{i=1}^N (x_i - m)(x_i - m)^T$$

If an 8-band multispectral image (i.e. WV2 and WV3) was manually annotated and 100 whales were found. The "whale group" would be an 8×100 matrix, where each of the 8 columns represent the various WV bands: red, red edge, coastal, blue, green, yellow, near-infrared 1 (NIR-1), and near-infrared 2 (NIR-2). The mean of this 8×100 matrix would be an 8×1 vector and the covariance matrix would also be 8×100 . If the pixel resolution is less than a meter,

multiple pixels may represent one whale. For this proof of concept, only the brightest pixel is selected such that there is one 8x1 vector of spectral information describing each whale.

Let subscript t refer to the whale/target group and b to the background. The likelihood ratio test on pixel x (using a multivariate Gaussian model) is the difference of two Mahalanobis distances:

$$(x - m_b) C_b^{-1} (x - m_b)^T - (x - m_t) C_t^{-1} (x - m_t)^T$$

Thresholding the Mahalanobis distance will distinguish the target group from the background. Large, consistent Mahalanobis distances would prove separation between groups and the capability of spectrally detecting whale pixels in a sea of non-whale pixels. All annotated whale's band statistics were meticulously assessed through ENVI as submerged or at the surface. Recommendations include viewing the RGB TIF in a coastal blue, red, and NIR2 band trio. In the event multiple pixels make up a whale, the brightest pixel was used for each whale. Spectral values for all 8 bands of the WV2 image for surface (non-submerged) and submerged whales are shown in Figure S1.

| Group 1: Not Submerged | | | | | | | | | Group 2: Submerged | | | | | | | | |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Whale ID | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 6 | Band 7 | Band 8 | Whale ID | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 6 | Band 7 | Band 8 |
| 1 | 48 | 29 | 27 | 29 | 11 | 26 | 14 | 15 | 3 | 28 | 14 | 15 | 14 | 4 | 11 | 8 | 5 |
| 2 | 96 | 76 | 62 | 54 | 33 | 41 | 26 | 16 | 4 | 25 | 21 | 22 | 22 | 10 | 22 | 14 | 14 |
| 6 | 38 | 23 | 24 | 24 | 12 | 22 | 17 | 14 | 5 | 23 | 17 | 17 | 15 | 6 | 8 | 5 | 2 |
| 7 | 43 | 26 | 24 | 22 | 11 | 18 | 15 | 12 | 8 | 31 | 21 | 22 | 18 | 9 | 14 | 11 | 5 |
| 10 | 32 | 25 | 23 | 21 | 11 | 17 | 12 | 7 | 9 | 23 | 14 | 15 | 13 | 7 | 13 | 8 | 16 |
| 12 | 97 | 68 | 58 | 57 | 36 | 44 | 37 | 26 | 11 | 21 | 11 | 12 | 12 | 5 | 12 | 9 | 9 |
| 14 | 59 | 38 | 35 | 34 | 4 | 28 | 6 | 16 | 13 | 36 | 18 | 20 | 23 | 8 | 17 | 10 | 8 |
| 16 | 117 | 94 | 76 | 72 | 38 | 46 | 11 | 16 | 15 | 25 | 14 | 15 | 15 | 3 | 11 | 6 | 6 |
| 17 | 50 | 50 | 48 | 28 | 22 | 22 | 12 | 10 | 20 | 27 | 15 | 15 | 13 | 6 | 11 | 5 | 5 |
| 18 | 46 | 40 | 39 | 37 | 13 | 33 | 8 | 20 | 23 | 23 | 16 | 17 | 18 | 3 | 15 | 6 | 10 |
| 19 | 43 | 33 | 32 | 25 | 7 | 21 | 5 | 10 | 24 | 23 | 13 | 15 | 14 | 3 | 14 | 6 | 10 |
| 21 | 65 | 54 | 52 | 41 | 24 | 35 | 20 | 25 | 25 | 39 | 18 | 21 | 28 | 4 | 32 | 6 | 24 |
| 22 | 86 | 57 | 53 | 44 | 24 | 33 | 11 | 19 | 26 | 42 | 32 | 30 | 29 | 17 | 27 | 24 | 18 |
| 28 | 83 | 85 | 72 | 50 | 39 | 41 | 34 | 24 | 27 | 38 | 33 | 31 | 25 | 14 | 20 | 24 | 16 |
| 30 | 51 | 37 | 37 | 35 | 19 | 30 | 22 | 15 | 29 | 31 | 32 | 31 | 16 | 9 | 12 | 10 | 5 |
| 33 | 59 | 42 | 43 | 38 | 23 | 34 | 27 | 16 | 31 | 30 | 14 | 15 | 15 | 5 | 11 | 6 | 5 |
| 35 | 25 | 25 | 33 | 24 | 21 | 23 | 23 | 13 | 32 | 38 | 32 | 29 | 25 | 16 | 25 | 16 | 19 |
| | | | | | | | | | 34 | 30 | 25 | 23 | 18 | 11 | 16 | 14 | 12 |
| | | | | | | | | | 36 | 21 | 12 | 15 | 14 | 7 | 13 | 10 | 6 |

Figure S1: Brightest pixel spectral values for surface (non-submerged) and submerged whales found in the 2012 WV2, Peninsulas Valdes, Argentina image (Catalog ID: 103001001C8C0300)

The non-whale pixel group was created by randomly sampling the background pixels over water. Pixels containing land were not chosen because we plan to apply a land-mask as a would be part of the preprocessing step

| Group 3: Background | | | | | | | | |
|---------------------|--------|--------|--------|--------|--------|--------|--------|--------|
| ID | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 6 | Band 7 | Band 8 |
| 1 | 18 | 9 | 11 | 8 | 2 | 7 | 6 | 3 |
| 6 | 12 | 7 | 8 | 6 | 2 | 7 | 6 | 2 |
| 7 | 17 | 11 | 11 | 7 | 3 | 7 | 6 | 3 |
| 8 | 14 | 6 | 8 | 6 | 2 | 6 | 5 | 2 |
| 9 | 14 | 7 | 11 | 8 | 3 | 6 | 5 | 3 |
| 10 | 17 | 9 | 11 | 7 | 3 | 7 | 5 | 2 |
| 11 | 15 | 6 | 8 | 7 | 2 | 5 | 5 | 4 |
| 12 | 15 | 9 | 11 | 7 | 3 | 7 | 5 | 3 |
| 15 | 14 | 8 | 11 | 8 | 4 | 7 | 5 | 3 |
| 16 | 15 | 5 | 7 | 6 | 2 | 5 | 5 | 2 |
| 17 | 15 | 8 | 8 | 7 | 2 | 7 | 5 | 3 |
| 18 | 20 | 7 | 8 | 7 | 3 | 7 | 5 | 3 |
| 20 | 17 | 10 | 10 | 7 | 2 | 6 | 5 | 3 |

Figure S2: Background pixel's spectral values in the 2012 WV2, Peninsulas Valdes, Argentina image (Catalog ID: 103001001C8C0300).

The Mahalanobis distance between the surface whales and background pixels had orders of magnitude ranging from 3 to 4: 1226 to 20,178. The Mahalanobis distance between the submerged whales and background pixels were on the 3rd order of magnitude ranging from values of 233 to 60,891. The threshold for submerged whales is lower than the surface whales and this is likely due water distorting the wavelengths received by the sensor. These consistently high Mahalabois distance values provide an existence of proof to distinguish target groups from the background. The minimum distance could be used as a threshold for detecting anomalous pixels across an image.

The following products are best for spectral detection methods because these products contain 4-8 bands of spectral information: Maxar's Worldview Basic Imagery (1B), Standard Imagery (2A), and Ortho All Bands (3D).