



Coastal Processes Research
Passive VNIR Detection of Objects in the Surf Zone

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Multispectral measurements in the surf zone

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ABSTRACT

Over the past year an index has been defined which quantifies the surf zone with respect to an electro-optical (EO) system's ability to find targets. The purpose of this index is to both normalize the EO Mine Counter Measure (MCM) systems performance expectations to the environment in which it is tested and to assess the value of its performance in an operational environment. For example, if a given system has a Probability of Detection (P_D) requirement of 90% in a clear water surf zone and is tested in murky waters the surf zone index of the murky water is used to determine what P_D is required in the murky water to yield the 90% P_D clear water requirement. The surf zone index is defined in this paper and expanded from the deterministic contrast transmittance as reported in earlier papers⁽¹⁾ to a probabilistic approach. Examples of how to measure the index using readily available low cost spectral imagers such as PAR Government Systems Corporation's Mission Adaptable Narrowband Tunable Imaging Spectrometer (MANTIS) system are given. Finally, the surf zone index usage is discussed and demonstrated.

Keywords: Multispectral, Surf Zone, Remote Sensing, Mine Counter Measure

1. OBJECTIVE

To quantify the impact of surf zone environmental factors such as wave height, sediment load, and water clarity on electro optical imaging systems in surf zone mine hunting operations.

2. BACKGROUND

Research activities have been on-going to characterize the dynamic surf zone environment with respect to the performance of passive and active electro-optic (EO) mine hunting systems. In support of these research efforts, PAR Government Systems Corporation (PGSC) has performed multispectral and digital video data collects over beaches in Southern California and North Carolina. Two series of airborne collections were conducted over White Beach, located on Camp Pendleton in Southern California and a third series of airborne collections was conducted at the US Army Corps of Engineers (USACE) Field Research Facility (FRF) at Duck, NC.

Multispectral data was collected by employing several of the multispectral sensors developed by PGSC under research and development efforts funded by NAWC and OSD. These multispectral sensors, termed MANTIS (for Mission Adaptable Narrowband Tunable Imaging Spectrometer), were configured for remote sensing collections and mounted in a Quicksilver GT500 Ultralite, shown in Figure 1. The MANTIS sensors simultaneously image, acquire, and digitally record four narrowband spectral images at frame rates greater than or equal to 30 Hz. The narrow band filters used to determine the spectral images are user selectable and selected prior to flight testing. Complementing the MANTIS sensor suite, a COTS Sony 3-CCD video camera was also flown. Data collected from the Sony camera allows for situational awareness due to its larger field of view than the MANTIS sensors and also provides a means by which the performance gains achieved by narrow band imaging can be measured.

All of the data acquired during the collection exercises were collected during daylight hours but at different points in the tidal cycle. Figure 2 shows an example of the Sony video imagery collected during one collection over White Beach, Camp Pendleton from an altitude of 250 meters. Figure 2 also shows the series of calibration panels deployed on the beach during each data collection. The calibration panels, shown in Figure 3 and discussed in Table 1, are required to convert the collected imagery to radiance units and also to measure and verify system MTF performance.



Figure 1. Quicksilver GT500 Ultralite aircraft employed for surf zone imagery data collections



Figure 2. Sample imagery from White Beach, Camp Pendleton

		
Blue Tarp	MW	MTF2
		
LG	LB	MTF1
		
SB	SG	SZ1-4

Figure 3. Selected targets and calibration panels employed during surf zone multispectral image collections at Duck, North Carolina and White Beach, Camp Pendleton, Southern California

Table 1. Detail of beach and surf zone targets and calibration panels

Target	Size	Reflectivity	Purpose
MW	3 m X 3 m square	85 % spectrally flat	Radiance to reflectance conversion of data
MTF1	3 m X 3 m square with 1.75 m diameter center circle	4 % with 95 % center spectrally flat	System MTF and registration control point
MTF2	3 m X 3 m square with 90 cm diameter center circle	4 % with 95 % center spectrally flat	System MTF and registration control point
LG	5 m X 5 m square	15 % spectrally flat	Radiance to reflectance conversion of data
LB	5 m X 5 m square	4 % spectrally flat	Radiance to reflectance conversion of data
SB	1.2 m X 1.2 m square	4 % spectrally flat	Radiance to reflectance conversion of data
SG	1.2 m X 1.2 m square	15 % spectrally flat	Radiance to reflectance conversion of data
Blue Tarp	2.8 m X 4.6 m		Gotta have a blue tarp
SZ1	60 cm diameter, circular	90 % spectrally flat	Registration control point and water clarity
SZ2	60 cm diameter, circular	90 % spectrally flat	Water clarity, contrast transmittance
SZ3	60 cm diameter, circular	90 % spectrally flat	Water clarity, contrast transmittance
SZ4	60 cm diameter, circular	90 % spectrally flat	Water clarity, contrast transmittance

3. SURF ZONE INDEX

The surf zone index (SZI) is discussed in detail in Gilbert (2003) and is summarized in Schoonmaker *et al.* (2003). The basis of the index is the concept of contrast and, in general, the SZI is the contrast transmittance of the surf zone from the depth of a potential target. That is

$$Y(z) \equiv C_z / C_0, \quad (1)$$

where $Y(z)$ is the SZI for a target at depth z , and C_z is the apparent contrast of the target at depth z as seen by the sensor and C_0 is the inherent contrast of the target against the expected background. In Schoonmaker *et al.* (2003) the SZI is measured using the apparent and inherent contrasts of targets deployed in the surf at Duck, NC. In this paper the analysis is expanded to predict the probability that the SZI exceeds a given critical value (Y_c) throughout the surf zone or $P_{|Y>Y_c|}$. An expectation of the SZI can then yield an expectation of system performance. That is, if a sensor system is characterized by its minimum detectable contrast (as is possible given the appropriate resolution) then the probability that the SZI exceeds a given value becomes the fraction of the surf in which the system in question can detect a mine and can then be used as a probability of detection environmental normalization factor. For example, if a system has a required P_D of 0.9 in an optimum environment (no breaking waves, fairly clear water and thus a high SZI) and is tested in an environment such as Duck, NC which is not optimum (lots of breaking waves, muddy water and thus low SZI) then $P_{|Y>Y_c|}$ can be used to normalize the required P_D to the environment in which the system was tested. As determined from the data collected at Duck, NC on September 18, 2002, it is likely that $P_{|Y>Y_c|}$ may be about 0.2. Thus, in the September 18 Duck environment, the system would need to achieve a P_D of 0.2 times the required 0.9, or a P_D of 0.18, to demonstrate the ability to meet system requirements.

Gilbert (2003) showed the SZI (or contrast transmittance, Y) for a target at some depth, Z_B , could be written as:

$$Y = \left(1 + \frac{E^* + E_s}{\rho_b E_o T_s^2 \exp(-[k + c]z_B)}\right)^{-1}, \quad (2)$$

where E^* and E_s are the water column and surface irradiances, ρ_b is the bottom reflectivity, E_o is incident irradiance, T_s is the transmission of the water surface, z_B is the depth to the bottom and k and c are water clarity parameters. This can be simplified and rewritten as:

$$Y = \frac{1}{R} \rho_b T_s^2 e^{-(k+c)Z_B}, \quad (3)$$

where R represents the total reflectivity and the other parameters are defined as above. R , ρ_b , k and c are functions of wavelength and hence the SZI is wavelength dependent. k and c , measured *in-situ* at Duck by both SPAWAR System Center (SSC), San Diego and the Coastal Systems Station, Panama City, are considered to be Gaussian distributed random variables with mean and variance given by the *in-situ* measurements. Z_B has both a mean depth component and a Gaussian random component with a variance given as a function of mean depth. The depth variability has a wind wave component and a gravity wave component and is normalized to wave staff measurements taken by SSC at Duck, NC. T_s , the transmission of the surface, can be determined by the reflectivity of the surface measured in a spectral band in which we expect a negligible water column reflectance. Thus, spectral data at 700 nm is used to calculate T_s by $T_s = 1 - R_{700}$. The reflectivity, R , can be taken directly from the spectral imagery at each point by converting the digital number values to reflectivity using the calibration panels placed on the beach and shown in Figure 3. Figure 4 shows an example of reflectance data collected at Duck, NC on September 18, 2002 with the PGSC MANTIS-1 sensor. The composite reflectivity map of the surf zone at Duck in Figure 4 is constructed by registering and mosaicing several frames of calibrated multispectral image data. The reflectivity data shown in Figure 4 corresponds to the reflectance along the red line in the image. This reflectivity data is the reflectivity at 550 nm only. The reflectivity curve clearly identifies the small black calibration panel and illustrates the variation in reflectance from the beach out past the breakers on the sand bar.

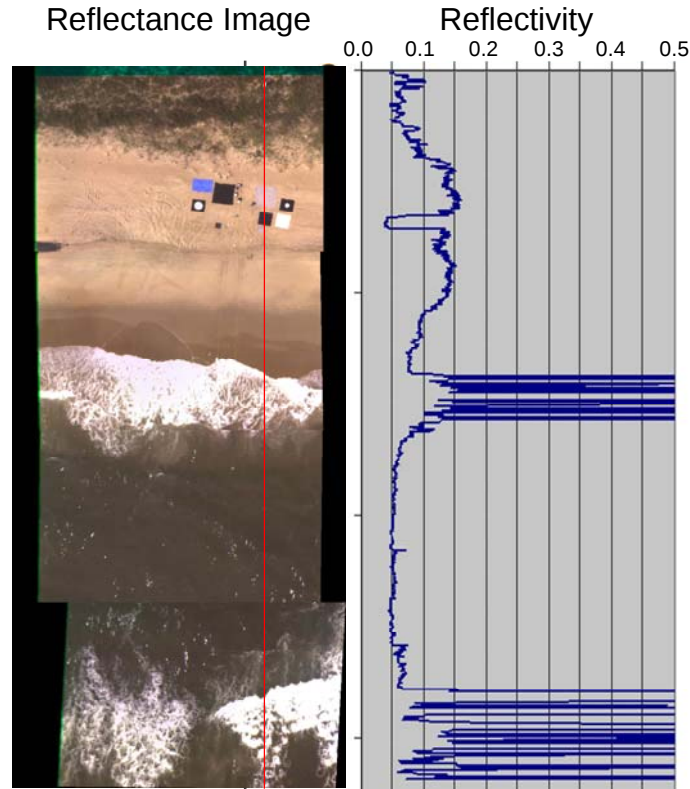


Figure 4. Reflectance image from calibrated multispectral data of the beach and surf zone at Duck, North Carolina and the corresponding reflectance values at 550 nm.

With the measured reflectance data shown in Figure 4 and measured means and variances of surf zone environmental characteristics, the SZI, Y , in Equation 3 can be determined. Figure 5 shows the same surf zone spectral image as Figure 4 and the corresponding SZI map as calculated by Equation 3. The dark areas in the SZI map correspond to regions of foam and, due to high reflectivity, the contrast transmittance is very low resulting in a very low SZI. From this image a simple threshold and pixel counting yields the probability that the SZI exceeds some critical SZI, $P_{Y>Y_c}$ where Y_c , the critical SZI, is used as the threshold.

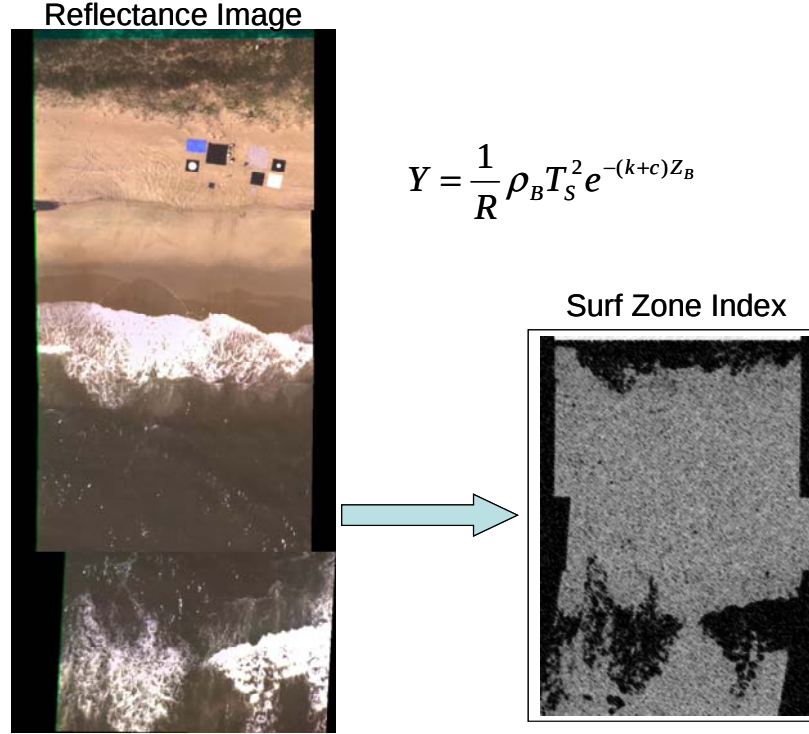


Figure 5. Reflectance image from calibrated multispectral data of the beach and surf zone at Duck, North Carolina and the corresponding surf zone index (SZI) map.

4. RESULTS

Using the methodology presented in Section 3, the probability that the SZI exceeds a critical SZI can be determined for various data sets and for various wavelengths. We evaluated four separate multispectral data sets from the Duck, North Carolina collection exercise, two data sets were collected on September 19, 2002 at which time the water was relatively clear and two data sets were collected on September 18, 2002 at which time the water was quite murky. The $P_{Y>Y_c}$ is plotted in Figure 6 for each day. The depth, Z , in Equation 3, is the depth of the target or the depth of the bottom, whichever is least. Figure 6 shows curves for the target at depths of 1 and 1.5 meters below the mean surface. We assume the inherent contrast is that of the target against the bottom rather than that of the target against the adjacent water column. This assumption is an approximation but is likely very close in surf zone waters where clarity near the bottom is driven by bottom resuspension. By varying the mean water clarity parameters, k and c , in Equation 3, different coastal environments can be approximated. The approximation would assume the same surface wave condition but clearer or murkier water. In this way, a curve for waters in Hawaii is approximated in Figure 6.

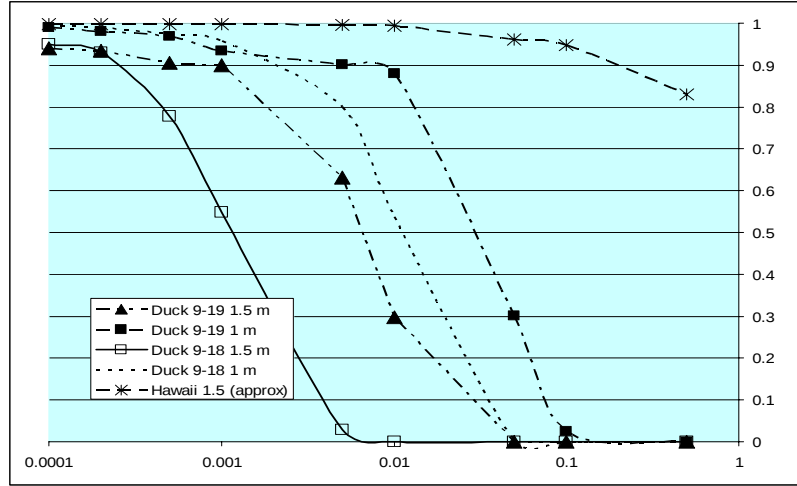


Figure 6. Probability curves, $P_{Y>Y_c}$, for various environments.

On September 19 the water was a bit clearer than on September 18 with mean attenuation coefficient (K_d) very near 1.0 m^{-1} and the waves were higher as well. The result is that there is an elbow in the September 19 curves at about 0.9 indicating the mean foam fraction in the surf. On the murkier day, September 18, the elbow is much less obvious in the data. The reason is that the foam fraction has less impact on the SZI when the water is very murky at the target depths charted in this curve. Figure 7 shows a semilog plot of the histogram of Y for the September 19 data. The bimodal histogram identifies the region of the surf covered by foam. The integral under the mode on the right of Figure 7 shows that 90% of the surface is not covered by foam which is consistent with the elbow at 90 % in Figure 6 for September 19.

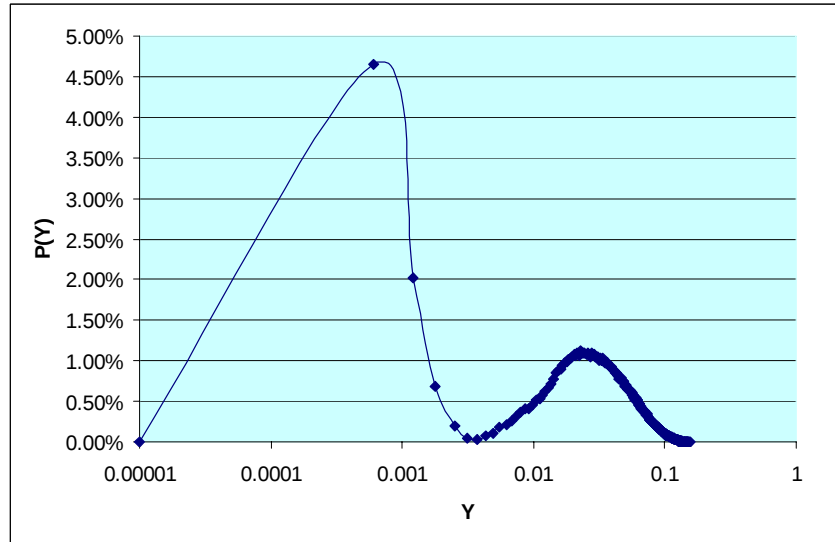


Figure 7. Histogram of Y for September 19 Duck, NC data at target depth = 1 m

There were many flights each day over the surf zone and beach targets. These passes were just a few minutes apart so the mean conditions remained the same even though an entirely different wave pattern was present. Processing these many datasets with similar mean conditions revealed that $P_{Y>Y_c}$ remains relatively constant. When onshore waves are coming from various directions with slightly different wave periods, as is usually the case, the waves will periodically interfere constructively or destructively. $P_{Y>Y_c}$ will thus oscillate with the ‘set’ frequency of the incoming waves. This behavior in Y will not be observed however until many additional datasets have been processed.

The probability that the SZI exceeds some critical value, Y_c , has been computed, as shown above, for various environmental conditions using remotely acquired data and a computer model. Once the probabilities are determined,

they can be incorporated into a nomograph which will yield the probability that the surf zone in a given environment results in a SZI that allows for the detection of a specific target. To construct the nomograph, we need two curves in addition to the probability that the SZI exceeds a critical value. First, we need information regarding the expected target and the expected beach and/or background environment. With this information, we can construct a series of curves showing inherent contrast as a function of background and target. Second, we require information regarding sensor systems as to what minimal detectable contrast is required to detect a target. This data is independent of environment and is simply an overall sensor assessment. With this data, inherent contrast can be converted to a necessary SZI required to detect the target. Finally, with the environmental data presented above, we can determine the probability that a given environment yields a SZI required to detect that specified targets. These three curves are combined to produce the nomograph shown in Figure 8.

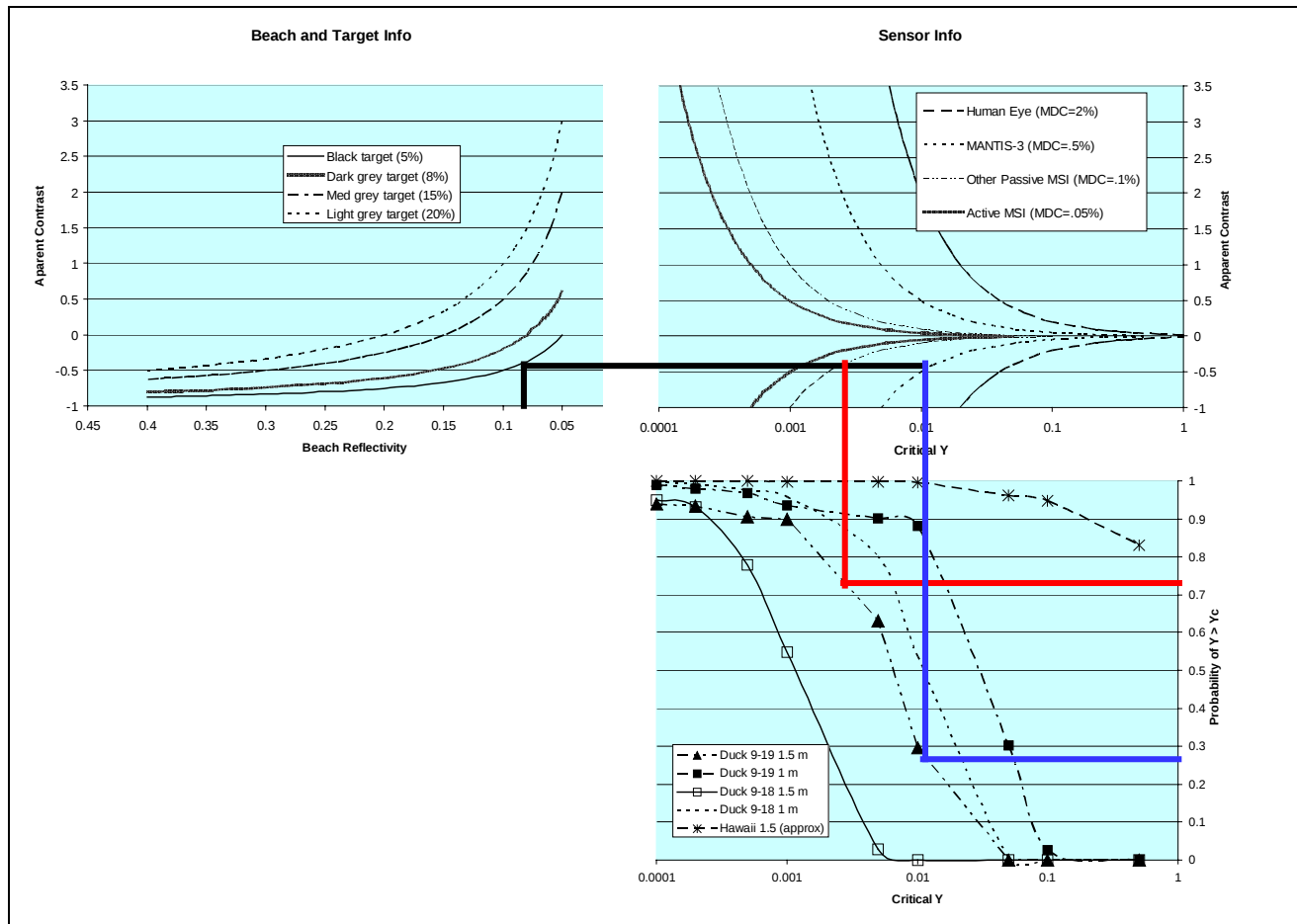


Figure 8. SZI nomograph indicating the probability that the SZI exceeds the requirements to detect a specified target with a specified sensor system.

The use of the nomograph in Figure 8 starts with the reflectivity of the sand in the water (x axis of the Beach and Target Info chart). Once a beach reflectivity is selected, the intersection with the curve corresponding to the target reflectivity determines the target inherent contrast (y axis of both the Beach and Target Info chart and the Sensor Info chart). The line then intersects with the curve identifying the minimum detectable contrast (MDC) of a specific sensor to determine the threshold contrast transmittance needed to detect the target of interest (the x axis of both the Sensor Info chart and the Critical Y chart). Finally, the line intersects with the curve describing the environment to determine the fraction of the surf in which a mine can be seen, $P_{|Y>Y_c|}$. Figure 8 traces a 8% sand reflectivity and a dark target (5% reflectance) using both the PGSC MANTIS-3 system (MDC=0.5%) and another representative passive multispectral sensor (MDC=0.1%) estimates giving surf zone fractions of 0.28 and 0.72 respectively for a target at 1.5 meters deep in a Duck-like (as seen on September 19, 2002) environment.

5. CONCLUSIONS

We believe this SZI will be both valuable in describing the environment in which an EO system is to operate and well as determining how the system has performed relative to expectations and requirements taking into account environmental variability. The differences between the days in this test in this limited study shows how this concept can be used to normalize data taken in one environment to that taken in another at the ROC curve performance level.

Our use of random variables for depth and clarity is clearly an approximation. One error comes from the assumption that the two are independent. In reality the depth minimum just before the break is also a maximum in water clarity. It would be fairly straight forward to make clarity a function of depth and use a single random variable for water clarity. It may also be fairly straight forward to build a surface realization consistent with both the wave staff measurements taken by SPAWAR and the positions of the breaks in the imagery and thus use no random numbers in the calculation of $P_{|Y>Y_0|}$.

The ability of narrow band video to adequately assess the environmental conditions of the surf zone is important. The low cost of this technology and the small size and weight means that narrow band video could be deployed on any or all military platforms for very little cost and without adversely impacting current capabilities. This added information will support important decisions required to deploy sensor assets in mine hunting application.

6. REFERENCES

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