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This paper describes a study conducted in the spring of 1996 in the waters off the western coast of the Hawaiian Island of Maui to evaluate the utility of an airborne Hyperspectral Imaging (HSI) Sensor to detect and recognize whales. This paper gives a detailed discussion of the sensor, describes the spectral image processing used to detect and enhance the whale images, provides sample imagery products, and finally discusses the potential utility of the method to conduct a rapid and accurate whale population survey at sea.

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THE POSSIBILITY OF PASSIVE WHALE TRACKING WITH THE USE OF AN HYPERSPECTRAL SENSOR

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ABSTRACT

According to the 1972 Marine Mammal Protection Act, the National Marine Fisheries Service has the responsibility to monitor and protect marine mammals including the great whales. To effectively implement this act NMFS must routinely observe whales to measure the size and health of their population. The Act further stipulates that observations of whales be done from a distance far enough away to ensure that the whales not be disturbed. Thus a need exists for an accurate method to sense the whales from an airplane at an altitude sufficient to not trouble the animals while still making accurate measurements of their size and other features. This paper describes a study conducted in the spring of 1996 in the waters off the western coast of the Hawaiian Island of Maui to evaluate the utility of an airborne Hyperspectral Imaging (HSI) Sensor to detect and recognize whales. This area serves as a spring mating and calving area for a population of humpback whales who winter in Alaskan waters. A Science and Technology, Inc. (STI) Hyperspectral Imaging (HSI) camera was mounted in a Piper Aztec aircraft moving at a ground velocity ranging from 80 to 100 miles/hour. The aircraft flew at an altitude of 1000 m above the whales. The HSI camera was operated in a "pushbroom" mode and was framed at a nominal 40 frame per second rate to image in each downtrack frame a strip on the sea surface beneath the aircraft. The strip was of width 190 m wide with a 1 m down track extent. The frame rate of the camera and the altitude and speed of the aircraft ensured that successively framed downtrack strips were contiguous in space. A spectral dispersion element in the camera divided the white light strip image into 72 contiguous spectral bands that fell on a Charge Coupled Device (CCD) array located in the focal plane of the camera. The system had sufficient data storage capacity to be able to image an ocean area of width 190-m by 2 km in length. The size of a single pixel imaged on the ocean surface was $1 m^2$. An internal Global Positioning System was used to reference the image of the sea surface and the whales to the local navigational charts The paper gives a detailed discussion of the sensor, describes the spectral image processing used to detect and enhance the whale images, provides sample imagery products, and finally discusses the potential utility of the method to conduct a rapid and accurate whale population survey at sea.

I. INTRODUCTION

In 1972 the public interest in marine mammals was expressed by the Marine Mammal Protection Act (MMPA) passed by congress. This act stipulates that the National Marine Fisheries Service (NMFS) is obligated to manage and protect all marine mammals. In order to do this effectively the NMFS requires an accurate population count of the different marine mammals. This study focuses on a possible new counting technique for large marine mammals such as humpback whales.

Besides the MMPA there are other reasons, why it is important to know how many marine mammals are in certain areas. One reason is that many experiments are performed in the oceans today. These experiments have no intention of harming animals. A not so obvious problem is to understand what processes harm different animals. In the case of marine mammals there is a great uncertainty if noise generated during an experiment affects the animals. To reduce possible harm it is better to perform all experiments in areas where the natural marine mammal density is low. A problem is to determine the location of these sparsely populated areas.

Most whale census methods presently used are visually based counting methods. The bulk of these surveys are conducted from ships or small aircraft that cover the oceans according to a statistical line transect ensuring proper sampling. These methods are to a certain degree uncertain since they assume that the whales are randomly distributed in the oceans, which is not always the case. Whales seeking food are usually distributed somewhat randomly in a large area. This natural random distribution is a close approximation to the assumption of randomness needed for the statistical line transect method. During other behaviors, such as migrations, whales congregate in herds for travel. They move large distances at fairly high speed making them difficult to detect with the statistical line transect method.

Another problem with visually based methods is that the observer relies on the animals being visible from the observation platform. This type of observation excludes times when the animal is submerged and not detectable from the observing platform. Additionally whales submerge for a longer time than they breathe on the surface. The ratio of surfacing to submersion differs for each whale species and from animal to animal depending on individual behavior. During food searches some species spend over one hour submerged with only a few minutes on the surface between deep dives. During migration periods some whales prefer to breath frequently, while others prefer to travel long distances underwater. Altogether this behavioral diversity make whales difficult animals to detect with the presently used statistical line transect method.

II. MATERIALS AND METHODS

The data for this study was obtained in February and March of 1996 in the ocean basin off the West Coast of Maui, Hawaii. This area is a winter calving and breeding grounds for Alaskan Humpback Whale ensuring that whales would be in the area of the experiment. The sensor was mounted on a Piper Aztec airplane, which flew at speeds of 80 to 100 miles/hour and an altitude of approximately 1000 m. The sensor operated in a push broom mode recording 72 spectral bands simultaneously. A typical track segment was about 2 km long and 190 m wide. The area resolved on the sea surface was approximately 1 m^2 per individual pixel.

Fig. 1 shows a schematic representation of the sensor used. The upwelled and reflected sunlight enters the sensor through the entrance slit. The light is then reflected by a mirror element, and passes through a dispersing element. The dispersing element diffracts the light into different wavelengths. These diffracted wavelengths are then reflected by a second mirror element and passed onto a detector array, with the spatial axis vertical and the spectral axis horizontal. The detector array is a Charged Coupled Device (CCD) located in the focal plane of the camera.
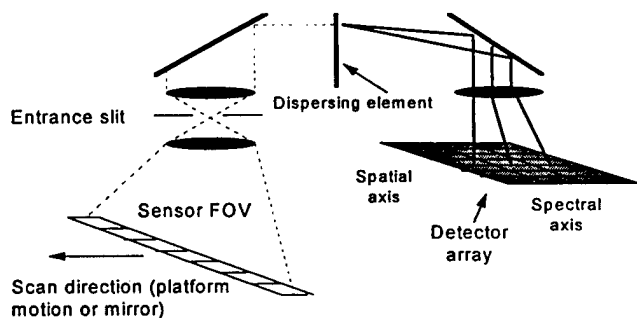
Hyperspectral Imaging Sensor Technique

Fig. 1: A schematic representation of the sensor showing the path of a light ray. The light is reflected from the scan area, then passes through the entrance slit and is further reflected by the mirror element. The ray is then passed through a dispersing element. The resulting rays are reflected again by a second mirror element and collected onto a detector array which records the intensity which separates according to a spatial and a spectral axis.

A geographical positioning system (GPS) incorporated into the system obtained images, which could be referenced to a known latitude and longitude.

III. IMAGE ENHANCEMENT

Data was processed on both PC and UNIX systems with the ENVI 3.0 program. A processing method used to remove the sea surface reflection effects from the image was color subtraction. This method notes that water absorption affects blue and green light differently, i.e. the presence of phytoplanktonic chlorophyll will absorb blue light and reflect green light while the absence of phytoplankton will produce the opposite effect. A consequence is that the covariance between blue and green light coming from the sea will be dominated by the Fresnel reflection of the wavy air-sea interface and not the water. This fact is used to form a composite 2-band spectral image from which the sea surface induced variance is removed. Generally sea surface induced variance in each band is much larger than any variance induced by the seawater itself. The removal of the sea surface induced variance greatly improves the possibility of seeing objects in the water itself. The removal operation chooses one blue and one green band, finds the covariance between the two bands, i.e. the sea surface effect, and forms a weight as the ratio of the covariance of the two bands divided by the variance of the green band. Subtracting the weighted green image from the blue image gives a two-band image with sea surface removed. This method minimizes the effect of sea surface and hence enhances subsurface features such as whales. For every image a separate weighing factor was calculated and used in the processing.

Fig. 2 is an example of the image enhancement through color subtraction. Fig. 2 top represents the unprocessed image with the whales barely visible. Fig. 2 bottom is the processed image with the whale silhouettes quite visible. It can be seen that while the color subtraction method enhances the whale silhouettes it is still difficult to see them clearly due to their relative positions to the sunlight. The whales can be seen best when they are parallel to the reflecting light when their white flukes show up extremely well due to the higher reflectivity of white to gray. Deeper whales are harder to see. Fig. 2 also shows the problem of white cap clutter as seen in both images. Fig. 3 top and bottom also demonstrates the before and after of this enhancement technique. This method is still based upon visual inspection.
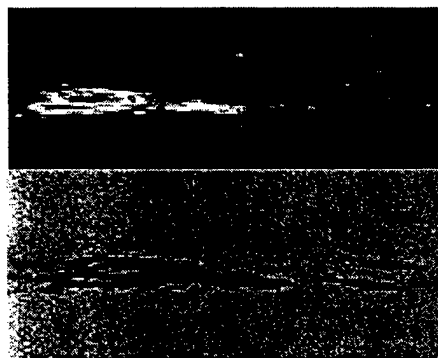

Fig. 2: The top image represents the unprocessed image where the white cap can be clearly seen. The bottom image represents the processed image. Here the whales can be seen as well as the white cap
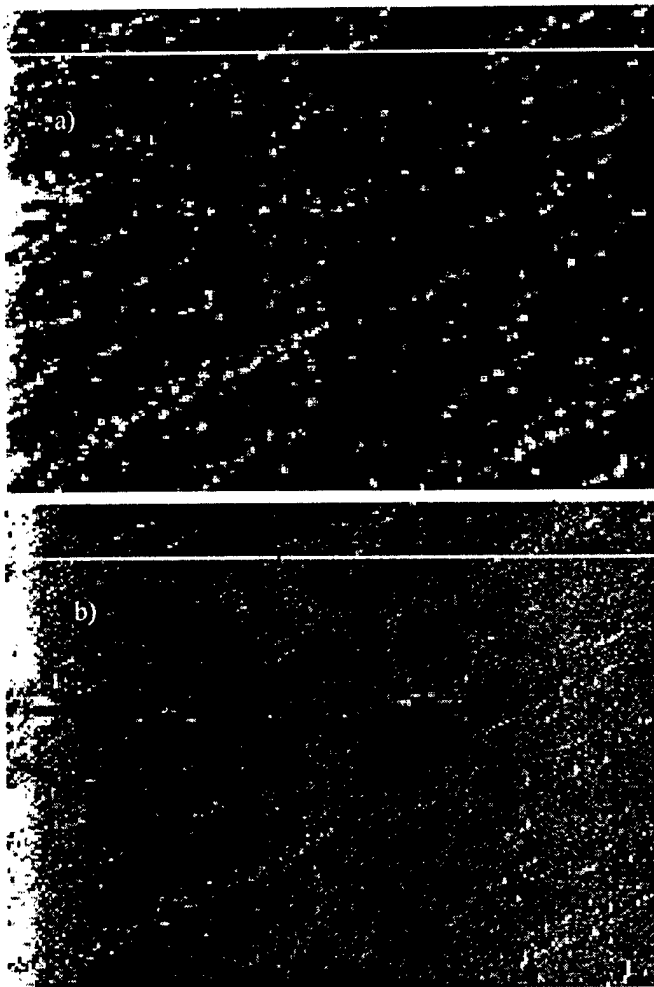
Fig. 3: a) the unprocessed image can be seen. Here the school of whales is barely visible. b) Shows the processed image, where the whale silhouettes are visible.
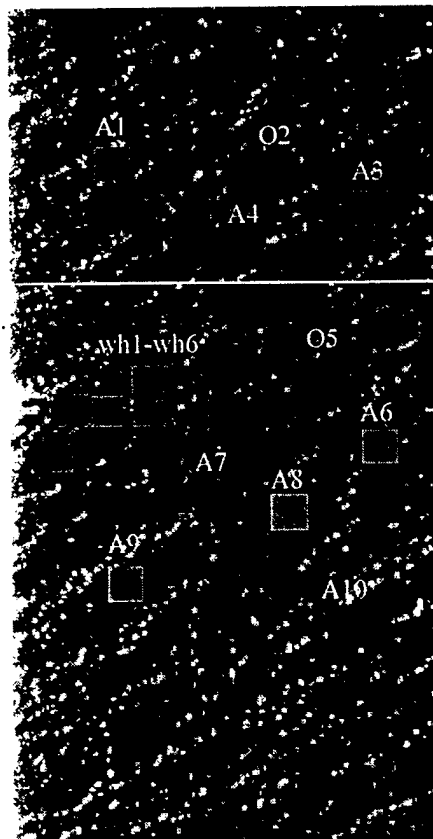

Fig. 4: The initial image from which all samples were collected. The true length of this image is 2000m. It has been cropped for presentation purposes. The image width of 190m was conserved. The new length is 400m. A1 through A10 as labeled, with O2 and O5 as the two water outliers. wh1-wh6 also as labeled from top to bottom, left to right

This figure shows the areas where water-only and whale-only spectral samples were taken. By inspection of several whale image and water image spectra it was determined that spectral differences between the two cases were significant only for the spectral region from 435nm to 560nm. Fig. 5 exhibits the spectra of these samples.

IV. A METHOD FOR AUTOMATED DETECTION OF WHALES

A method employing the dot product cosines of the water and whale spectra was investigated for its potential utility in the automated detection of whales. The ocean away from land presents a much more homogeneous scene than does the typical terrestrial environment. Thus an image of the ocean could be processed with a spatial filter of about the image size of a typical whale. In the simplest case the output of the filter would fall into two sets: scenes that looked spectrally like ocean and scenes that looked like whales. The method used to determine this separation was developed employing the dot product cosines of spectra. All images, i.e. whale or water-only, contained substantial amounts of atmospheric light, sea surface reflected light, and light from the water itself which "cluttered" the "whale signal". Consider the ocean scene in Fig. 4.
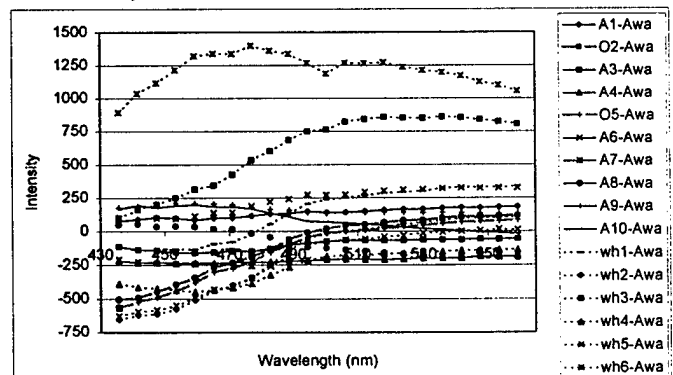

Fig. 5: Legend for graph at bottom right of this page. This graph shows all samples with the average water spectrum subtracted. The first ten samples are the water area, A1 through A10, with A2 denoted as O2 and A5 denoted as O5, as they do not follow the general trend of the other water samples. The next spectra are from the six whales sample areas, which are denoted as wh1 through wh6.

Dotted line spectra represent whales while solid line spectra represent water. Note that whale spectra show markedly less blue light than do the water-only spectra. To initiate the dot product processing a mean water spectrum was formed by averaging a large number of pixels known to be free of whales. This was done using

the water-only data samples from fig. 5. This mean spectrum contained the atmospheric, sea surface, and water light clutter. The average water spectrum was then subtracted from all other samples to remove these mean attributes from all spectra both whale and water-only. This process "demeaned" the data. Dot products were then formed, by dotting each whale size sample whether water-only or containing whales against the average water spectrum. Dot product cosines were determined by normalizing the dot product results by the absolute scalar magnitude of each scene and the mean background. This magnitude resulted from the dot product of a spectrum times itself. The cosines were transformed into arccosines.

The resulting arccosines were then considered to form a statistical distribution. The members of the first distribution were the water only samples. The members of the second were the whale samples.

Statistical moments, i.e. averages-Xave, variances-s^2 and standard deviations–s, were calculated for both groups and are shown together with the sample size, n, in Table 1 below.

Table1: The results of the dot products for the all groups.

Water Analysis		
Xave =	0.025	
n =	8	
s^2 =	0.00032	
s =	0.018	
DF =	7	
Range (min/max) =	0.0074	0.043
Whale Analysis		
Xave =	0.082	
n =	8	
s^2 =	0.0012	
s =	0.034	
DF =	7	
Range (min/max) =	0.048	0.12

From this table is can be seen that the water and the whale groups are distinctly separated from each other. The whale mean of 0.082 is more than three standard deviations from the water only mean, i.e. 0.025 + 3x.018 = .079 < 0.082.

A two-sided Student t-test was used to test the hypothesis that the two sample groups were significantly different from each other and to quantify this significance level. The student t-test was used because of the small sample size. The null hypothesis was that the average water dot product arccosine was equal to the average whale dot product arccosine.

To reject the hypothesis at the 0.005 significance level (i.e. a 1 chance in two hundred of being wrong) that there is no difference between the two populations, the t-statistic should fall outside of the range of -2.98 to 2.98. Since the observed t value is -3.88 well outside this range, the null hypothesis is easily rejected and the alternate hypothesis is accepted that the two distributions are greatly different

V. CONCLUSIONS

It has been demonstrated that the method of hypothesis testing using dot product arccosines shows potential for automating the whale counting process in hyperspectral imagery of the ocean. In a more automated method the mean spectrum of the water only images could be obtained as a moving average. Then each additional whale size image could be processed against this moving average to form the arccosine for hypothesis testing. An advantage is that the moving average will always be close to the environmental conditions, and no extra weighing factor need be calculated for every individual image as required for the color subtraction method. An additional advantage of this technique is that it does not rely on visual inspection for detection and hence can save wear and tear on the census taker.

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