THE UTILITY OF VIDEO IMAGE SEQUENCE COMBINED WITH MULTISPECTRAL OCEAN IMAGING

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INTRODUCTION

The goal of our research is to detect underwater targets using reflected sunlight. The challenge is removing the pervasive background of light reflected from the ocean surface, from the atmosphere above the ocean, upwelling from the water column, and from the ocean bottom, so as to render the underwater targets, more visible. (The underwater targets are generally of very low contrast relative to the background.) Our companion paper in this conference[1] discusses two algorithms using multispectral image data. The spectrum of the background light is subtracted pixel-by-pixel. The targets are then recognized as deviations from the background light spectrum. One algorithm (“de-glinting”) models and estimates the spectrum of background light as the sum of light reflected from the surface and light backscattered from above and below the surface. The second algorithm models only one component but includes spatial correlation information. Both algorithms were successfully applied to data from hyperspectral imaging sensors. With both algorithms we were able to subtract a substantial amount of the background clutter and improve the visibility of underwater targets.

Most of ocean clutter is due to light reflected from the surface. Ignoring other clutter components for the moment, another way to filter clutter is by temporal integration. In practice, temporal integration is accomplished in one of two ways. In the first method, one uses a video camera and stacks a sequence of images. This method is especially convenient from a moving platform because one can correct frame-to-frame perspective, and make translational, rotational, and magnification changes before stacking. The second method is using a fixed camera and long exposure time. In both cases, the integration works because surface light is modulated at the frequency of surface waves. Integrating over a time period of twice the wave period eliminates most of the surface reflected light. Long wavelength (order of 100 m) waves can be filtered with 20-second integration. Short wavelength (order of 1 m) waves can be filtered just as well in as little as 3 seconds. Longer integration time is generally better for averaging out background noise, but one can get by with an integration time appropriate to the scale of targets of interest: long integrations for large underwater features such as reefs, and short integrations for small targets such as mines.

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[1] D. Silva and R. Abileah, “Two Algorithms for Removing Ocean Surface Clutter in Multispectral and Hyperspectral Images,” in this conference.

Thus, there are two radically different ways of “de-glinting” an ocean image. One exploits multiple spectral bands as we show in our companion paper, and the other uses time integration. The choice of which is used leads to radically different sensor designs—one is a multispectral or hyperspectral imager, the other is simply a long exposure or video camera (possibly with a select narrow spectral band filter). The question then is how well time integration works relative to a multispectral approach. Is one approach superior to the other in performance, complexity, or cost—or is there some optimum way of combining multispectral and temporal data?

We are now at the initial phase of investigating these issues and have very preliminary experimental results. The most straightforward experimental approach would be to process the same data twice—first using multi-spectral information, then using time integration—and compare performance. Unfortunately, this could not be done with the data used in the first paper. The data used there was from the AAHIS hyperspectral sensor, which is a pushbroom imager, so there is no temporal information.

PRELIMINARY EXPERIMENTS

In place of the AAHIS data, we collected new data with a three-color video camera. This gave us temporal and some spectral (e.g., the standard R-G-B channels) information. A scientific grade video camera, Hitachi model HV-C20U, with 24-bits per sample, was used. We collected data frames at 15 Hz. The target was a set of color tiles (red, green, blue, black, and white) mounted on a black panel and immersed in the ocean to a depth of 1 m.

We processed the data to determine if temporal integration did what we expected. We also compared it with the same data processed with the spectral de-glinting algorithm described in the companion paper. We then evaluated the combination of temporal integration and spectral de-glinting.

The following are typical results. Figure 1a is a single video frame in the blue channel in which we can clearly see surface waves and the guys attached to the submerged panel and tiles. The tiles are obscured by the intense surface reflection. Figure 1b is the same image area after time integration. Here the surface reflection is eliminated and the panel and three of the five tiles are visible. Figure 2 is a wave number-frequency power spectrum of the video data showing that strong energy is concentrated in two places: in the phase-speed of surface waves, and on the frequncy=0 axis. The temporal integration eliminates the surface waves but leaves the energy at frequency=0, as expected. The frequency=0 clutter is now the limiting factor for detection of the submerged tiles. Note that all features on frequncy=0 must be stationary in the image. They can be features on the ocean bottom, slicks on the ocean surface (assuming that there was no appreciable ocean surface current), or camera pattern noise. In this case, there are clear indications that most of the frequency=0 noise are characterized by real features in the ocean environment. The exact source or mechanism is a subject for future investigation.

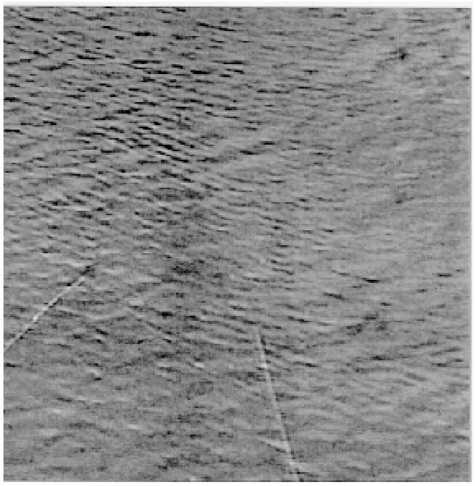

Figure 1a. Blue channel image.

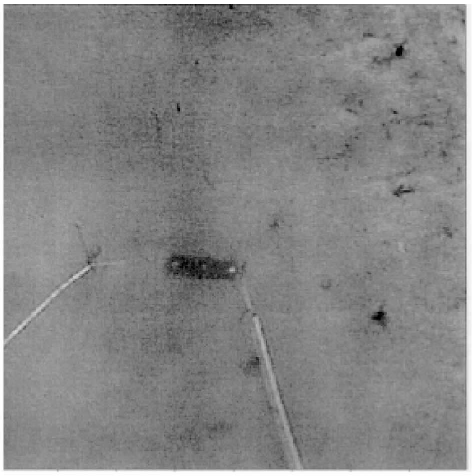

Figure 1b. Time-integrated image

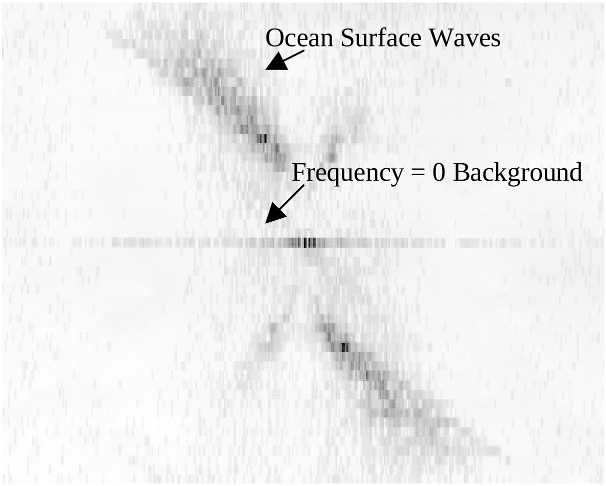

Figure 2. The wave-number and frequency spectrum of the data in Figure 1.

The next example, with a different data set, compares temporal averaging and the spectral de-glinting algorithm. Again we use the blue channel for illustration. Figure 3a is a single image frame showing the predominance of surface waves. The guys are also faintly visible in the upper right. Figure 3b shows the time-integrated image where the surface waves are almost (but not entirely) filtered out, and the panel and some tiles are now more visible. This result is very similar to the case in Figure 1.

Figures 3c and 3d show the result of the “de-glinting” algorithm. In both cases, the de-glinting algorithm estimated the clutter spectrum as a function at three points at the three primary colors. This is a very coarse spectral resolution compared with the 10 spectral bands used in the result shown in the companion paper.

Figure 3c shows spectral de-glinting applied to a single frame. One of the panels is just barely visible above the clutter—a result that is not as good as temporal integration. Figure 3d shows the result of spectral de-glinting applied to the temporally integrated three-color images. This result is the best because there is more contrast associated with the three tiles, and a faint hint of a fourth tile. Thus, this example shows that the combinations of temporal integration and spectral de-glinting is promising.

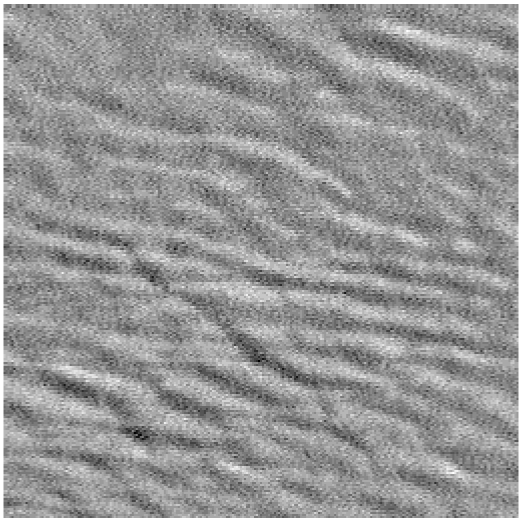

Figure 3a. Blue channel image.

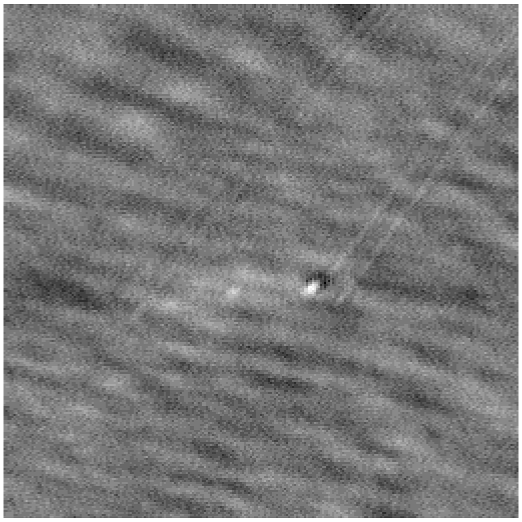

Figure 3b. Time-integrated image.

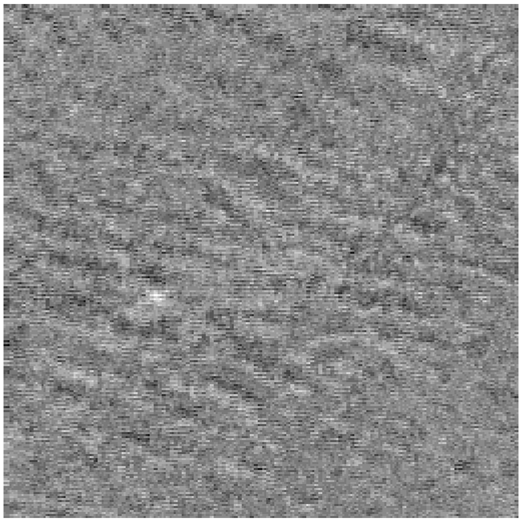

Figure 3c. Single image processed by the spectral de-glinting algorithm.

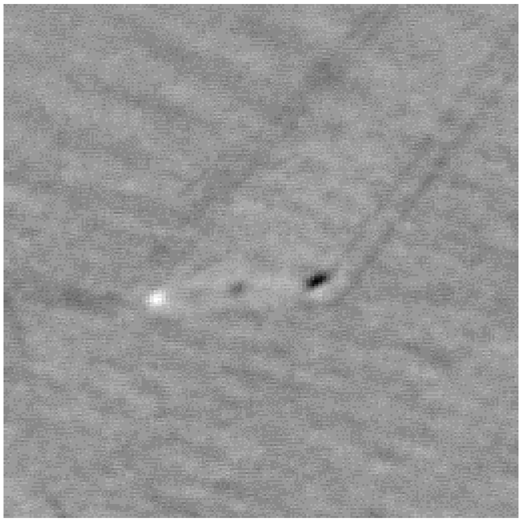

Figure 3d. Time-integrated image with spectral de-glinting.

One point to note in the spectral de-glinted output is that the targets (i.e., the tiles) are detected as either black or white depending on whether their spectrum has a deficit or excess of energy relative to the background. Either case is equally significant as a detection of a local anomaly.

SUMMARY AND CONCLUSIONS

The experiments described here are too preliminary to draw strong conclusions. There is much more to do to calibrate and validate the results. However some interesting indications emerged. Temporal integration works very well at eliminating ocean surface clutter, perhaps as well or better than spectral de-glinting. The combination of temporal integration and spectral processing potentially offers more improvement. If this proves generally to be true, it has important implications for future optical systems used in ocean surveillance. One may want to include some temporal integration in a multispectral imaging system. There may be a tradeoff between using available data bandwidth for more spectral resolution or multiple time frames. And, in some cases multi- or hyperspectral imaging may be combined with longer exposure time to obtain the benefits of both time integration and spectral processing. We hope to investigate these implications in future work.

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