A Low-Cost Airborne EO Oceanographic Measurement System

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LONG-TERM GOALS

The long-term goal of this project is the development of an electro-optical imaging system that can be mounted and flown in an aerial photography airplane to produce time-series imagery of the ocean surface suitable for scientific research. The system will be designed for low-cost production through the use of commercial-off-the (COTS) components and low-cost operation through the use of commercial single-engine airplanes.

OBJECTIVES

The primary goal of the Phase 1 SBIR effort is to provide justification that technology developed by Arete Associates for a UAV surrogate payload, the Airborne Remote Optical Spotlight System (AROSS), can be transferred to a portable system capable of being mounted on commercial aerial photography airplanes while maintaining data quality. A further objective of the new sensor is to reduce the cost to build and operate the system as compared to AROSS costs. Use of commercial aircraft can reduce the operating cost by a factor of 3 to 4 from the approximate cost of $2000 per hour for AROSS. The specific tasks for the Phase I effort are:

1. Determine the effects of restricted viewing geometry which result from collecting data through the downward looking viewport of an aerial photography airplane;

2. Develop preliminary design of gimbaled positioner system for mounting in aircraft; specifically determining technical issues which must be addressed in a Phase II development effort;

3. Determine necessary requirements for integration of system with avionics for GPS signal.

APPROACH

The effects of a restricted viewing geometry are being studied using archived AROSS data and computer simulations. Data collected by AROSS typically is at a grazing angle (GA) of 26° for the center of the image. However a small fraction of data has been collected at higher GA. Reductions in the signal-to-noise ratio (SNR) expected at higher GA and the utility of a reduced footprint on the ocean surface will be examined from analysis of the high GA data.

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14. ABSTRACT
The long-term goal of this project is the development of an electro-optical imaging system that can be mounted and flown in an aerial photography airplane to produce time-series imagery of the ocean surface suitable for scientific research. The system will be designed for low-cost production through the use of commercial-off-the (COTS) components and low-cost operation through the use of commercial single-engine airplanes.

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Spectra from the emulated data set will provide insight into the projected system's response to various wave conditions. From the 3D ω–κ spectra, the reduction in SNR as a function of GA is being determined by the ratio of signal power on the dispersion surface to the nearby background spectral noise. The directional spectra obtained from viewing the same sea with various GA will be analyzed for loss in fidelity and sensitivity to wavelengths of ocean waves as a function of GA.

Bathymetry and current estimates from the emulated data set will be compared to the results obtained from the nominal AROSS viewing geometry. In addition to the response of the system for various GA, these retrievals will determine the feasibility of the reduced ground coverage for operational purposes. Bathymetry and currents are typically derived from overlapping subpatches of mapped, time-stacked imagery. Reducing the footprint on the ocean surface from the normal AROSS collection scheme reduces the number of subpatches that can be obtained from a single aimpoint. The footprint reduction for a single image can be calculated from the viewing geometries, but a realistic estimate for an image stack must include camera motion and can only be truly determined from real data. The ability of the new system to provide reasonable coverage and the reduced coverage rate, utilizing multiple aimpoints, will be determined from this analysis.

The engineering constraints and requirements to mount the system on commercial aircraft are being investigated using a variety of information sources. Conversations and meetings with local aerial photography professionals are being used to provide information on FAA regulations, operational requirements, mounting constraints, interface with avionics for GPS signal, and general design considerations. Technical specifications on standard aerial cameras were obtained through a literature search. This information, along with blueprints and engineering drawings for the viewports of a commercial, aerial photography aircraft, is being used to address key technical issues.

WORK COMPLETED

A data set for the restricted viewing geometry study has been compiled, mapped to geodetic coordinates and analysis begun. Spectra from two collections taken within a span of one hour on March 30, 2001 near LaJolla, CA with GA of 26° and 45° have been produced and studied. In addition, a computer model based on the Arete Associates RenderWorld ocean wave simulator has been constructed. RenderWorld is a collection of software modules for producing a physics-based rendering of an ocean scene as seen by an optical sensor. This capability was originally developed for visualization by the human eye, and it has been very successful, but it is equally suited for providing high-quality ocean wave data for evaluating future EO sensors. Simulated data from a variety of GA and wave conditions are being generated and analyzed.

Technical specifications for the two, most-common aerial photography cameras have been acquired along with blueprints for an aerial photography airplane viewport. A site visit to a local aerial photography company has also been performed.

RESULTS

Slices in the direction of the swell from the full 3-D ω–κ spectra of the data collected on March 31, 2001 are shown in Figure 1. The swell peak is clearly evident in both spectra and has a frequency of ~0.11 Hz or a peak period of 8.5 sec, which matches closely with the period of 8.0 sec measured at the

Scripps pier. The SNR for the swell peak are 39 dB and 29 dB for GA of 26° and 45°, respectively. This drop in SNR is close to that expected from the change in reflectivity of the sea surface as a function of GA. Figure 2 shows the reflectivity of unpolarized light incident on a flat, water surface. Although the true reflectivity will depend on the polarization of the incident light and the sea state, this calculation will be representative of the expected signal loss due to the change in GA. From this chart, the reflectivity at 26º is 0.077 and the reflectivity at 45º is 0.028, which accounts for a loss of 8.8 dB in SNR. Despite the drop in SNR for higher GA, an SNR of 29 dB is still high and quite adequate for METOC parameter retrieval and comparison with shoaling wave models.

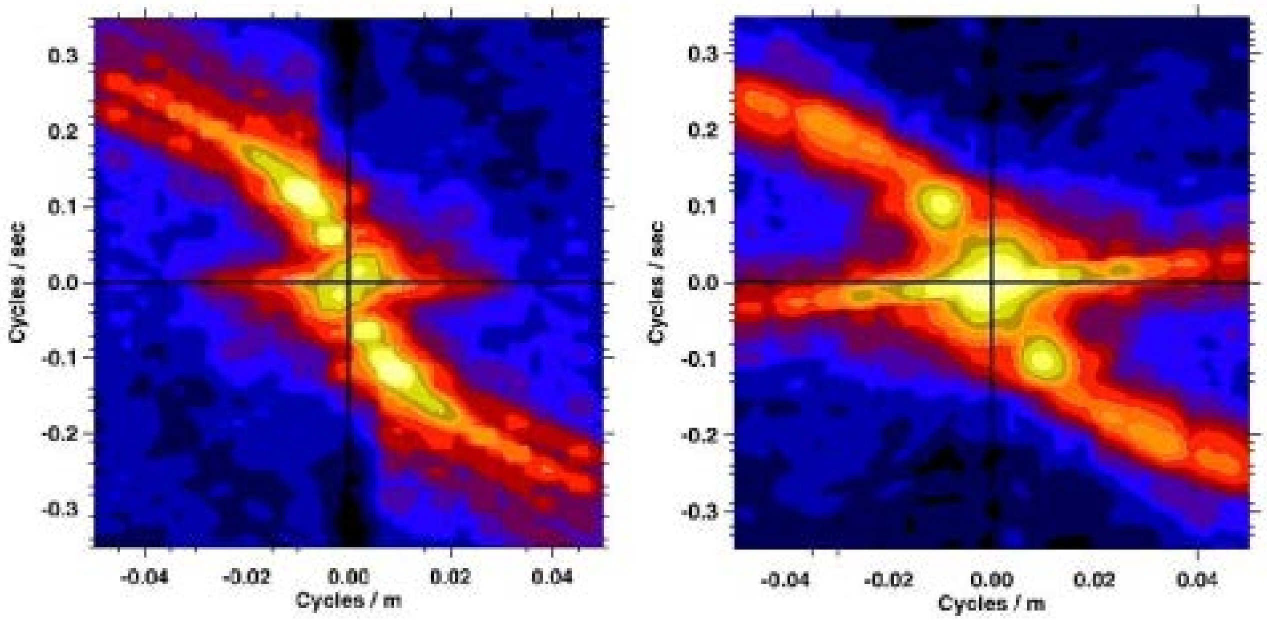

Figure 1: 2-D Slices from the full 3-D spectra
[ω–κ Slices in the direction of the swell propagation for the PSD obtained from data collected at 26° (left) and 45° (right). Each slice has been normalized relative to the noise floor and the scale for each slice has been set from 0 dB to 40 dB.]

The frequency-direction spectra, derived from the full 3-D spectra, for the two cases are shown in Figure 3. From this figure, it is seen that the signal from the swell peak is reduced in comparison to low-frequency, "stationary" clutter. However, despite the reduction in the power of the swell peak, the fidelity of the data is excellent.

Engineering efforts are nearly complete. From the literature search and the site-visit to an aerial photography company, several of the engineering design questions have been answered. First, the mounting scheme for aerial photography airplanes is a standard 4-bolt pattern that will allow for a universal mounting plate to be designed for the system. Also, the system will use the same or less space than the equipment required for a standard, large-format, aerial camera. Power requirements for an aerial camera and supporting equipment are about the same as the system and thus the power requirement will also be met. Inspection of the viewport revealed that restrictions to the range of motion of the system should not be excessively limiting and grazing angles (GA) of 45º and less should be readily achievable. Blueprints of the airplane mounting bracket and viewport are being obtained.

An additional possibility for operation of the system was realized from the site-visit. According to personnel at EarthData, Inc, the side doors can usually be and are readily removed from aerial photography airplanes. Many aerial photographers use this method to take photographs at oblique angles. This new information opens up the possibility of using the system to look out the door as opposed to the downward looking viewport. This option would allow data collection at grazing angles comparable to AROSS, although at some loss of comfort to the pilot and operator.

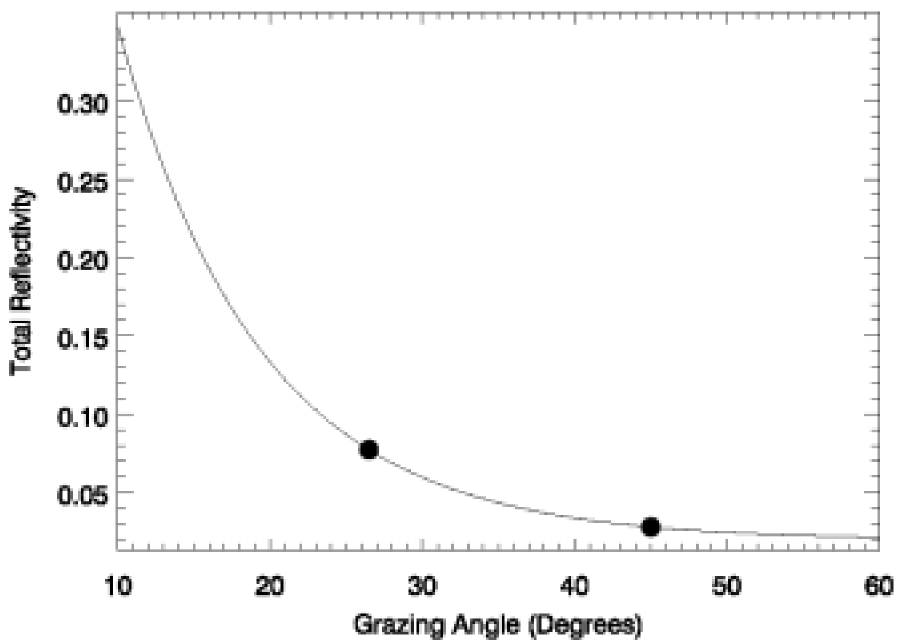

Figure 2: Total reflectivity from a flat surface by unpolarized light as a function of grazing angle.

In light of the findings from the site visit and information gathered from vendors of positioners and skyballs, a yoke (or Y) style of positioner is considered best since it would allow viewing through either a viewport or the side of the airplane (with the door removed).

Quotes from several companies for flight time were also obtained. The average cost quoted for flight time was $500 per hour. This is higher than the initial estimate of $300 per hour, but still much less than the flight cost of AROSS, thus fulfilling the requirement of low-cost operation.

IMPACT/APPLICATIONS

The successful transfer of AROSS technology to a system capable of being mounted in a commercial aircraft will provide an inexpensive oceanographic research asset. This asset will directly benefit the Navy wave modeling community who require wide-area measurements of observable parameters, including bathymetry, currents, and directional wave spectra, in the littoral zone. The lower operating cost of the proposed system will be more in-line with the budgets of typical field experiments designed to enhance scientific understanding of coastal processes. Government agencies responsible for coastal waterways, such as the Army Corps of Engineers, and mapping, such as NOAA and NIMA, represent potential customers who can utilize the low-cost rapid bathymetric and current survey capability of the proposed system. In fact, discussions with research and operational personnel at these agencies have uncovered a need for these products on a routine basis. In addition, these agencies expressed a need for accurately geo-located coastlines, a capability AROSS already has already demonstrated. Thus, we expect this additional product to be available without further development beyond what is envisioned for Phase II.

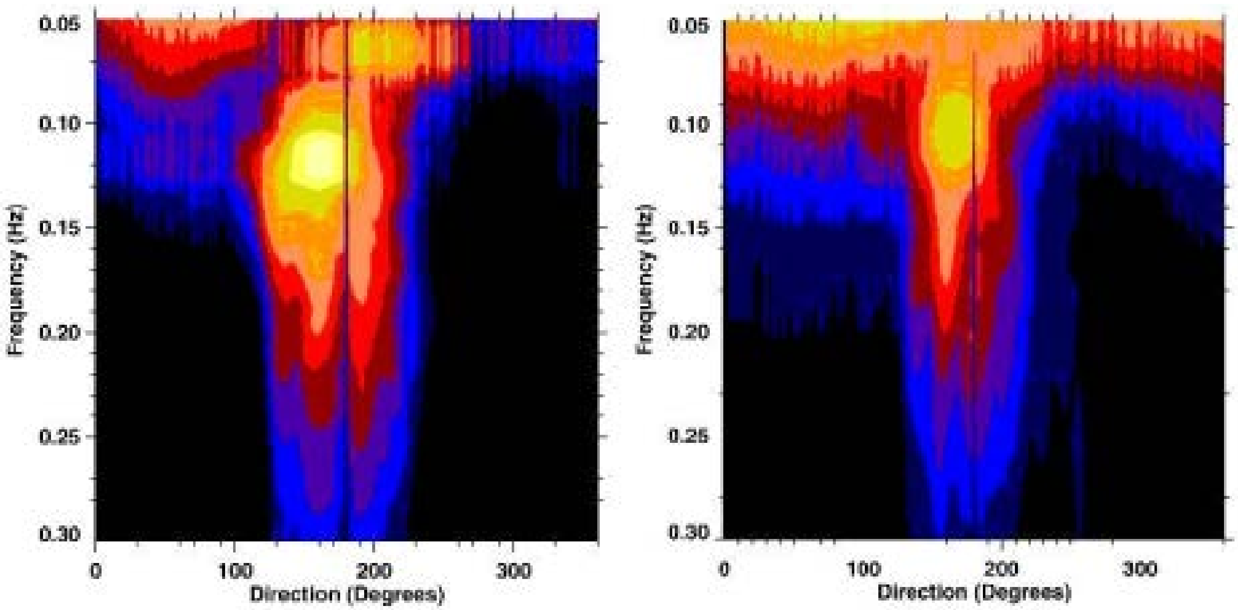

Figure 3: Frequency-direction spectra
[Frequency-direction spectra from data collected at 26° (left) and 45° (right)]

RELATED PROJECTS

The Airborne Optical Spotlight System (AROSS) is a compact, turret-based optical system designed and constructed for passive imaging of ocean waves using a small aircraft. The purpose of the system is to collect time series of images that are mapped to a common geodetic surface in order to extract the space-time characteristics of the waves. This is achieved by staring at a fixed geodetic location, and accurately measuring the imaging geometry. The system was designed to be compact and lightweight for future installation on an unmanned aerial vehicle (UAV), and has been installed on a specially modified, small, manned, single-engine aircraft for testing and experimentation. Initial tests have confirmed successful operation of the staring capability at moderate distances to a fixed target array on land and to the nearshore region with shoaling gravity waves. These capabilities are the result of a successful previous ONR-funded SBIR, and the AROSS technology presently is being transitioned to unmanned aerial vehicles for future use by U.S. Navy and Marine Corps expeditionary forces. More information can be found at http://www.aross.arete-dc.com

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