Next generation in-water radiance distribution camera system

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ABSTRACT

A new electro-optic radiance distribution camera system is described. This system is based upon cooled CCD array cameras and includes a multi-channel irradiance meter, tilt and roll sensors, flux-gate compass and several auxiliary channels. The system is controlled with an internal '386Sx computer and includes a 450 MByte hard drive for image storage. Data archiving is performed through a SCSI interface to an external 1.4 GByte DAT tape drive which is attached when the instrument is on deck. Some preliminary calibration data on the system is also included.

1.INTRODUCTION

The radiance is defined as the radiant flux per unit solid angle per unit projected area from a given direction while the radiance distribution is the collection of radiance information for all angles.[1] When combined with spectral filtering a profile of the radiance distribution provides the most complete set of data on the ambient underwater light field. Other measures of the underwater light field such as the downwelling and upwelling irradiances, E_d and E_u, and the scalar irradiance, E_o, can be obtained from the radiance distribution with simple integrations.[2] Apparent optical properties such as the diffuse attenuation coefficient, K, can be obtained from a profile of the radiance distribution. With knowledge of the radiance distribution, Gershun's law may be used to obtain the absorption coefficient.[3] Finally it has been demonstrated theoretically that the radiance distribution can be used to determine the scattering phase function.[4]

The radiance distribution is not commonly measured due to the difficulty in collecting the large quantity of data required to adequately describe the distribution in a short period of time. The data must be collected quickly enough so that the incident radiance field (predominantly solar radiation) does not change significantly during the measurement process. Initial measurements of the radiance distribution were performed with Gershun tube radiometers (e.g., see Tyler[5]) where each angle required a different angular orientation of the instrument. The problem with this type of radiometer is that because of a lack of azimuthal symmetry in the underwater radiance distribution, measurements must be performed over ranges of azimuth combined with zenith angles. If only 10 degree intervals of zenith and azimuth angles are required then more than 600 measurements must be made to measure only one depth and wavelength.

The major advance that made measurement of the radiance distribution possible in the open ocean was the use of cameras and fisheye lenses. The first effort in this direction used photographic cameras with photopic broadband filters centered at about 550 nm.[6] While the data collection was vastly improved, lack of narrow band filters and the difficulties associated with photographic radiometry made data reduction a difficult and time consuming operation. The first generation electro-optic radiance distribution camera (RADS-I) improved this technique by having electro-optic cameras and spectral filters.[7] This system was used to look at ship shadow problems,[8] investigate approximate solutions of radiative transfer problems,[9] and in other investigations.

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The first generation system used CID cameras (GE-2509) and Poynting frame grabbers which had a limited dynamic range (8 bits). The system also suffered due to the communication between the instrument and the controlling computer at the surface. Data in this instrument was digitized in the underwater instrument and transmitted at 9600 baud to the deck computer where it was archived. This limited the speed at which profiles could be obtained, and thus the optimal depth resolution of the in-water profile. The limited dynamic range also restricted operation near the surface, where the radiance distribution changes rapidly and has a large variation from zenith to nadir. Because of these limitations the second generation of electro-optic camera was built and will be described here.

2. INSTRUMENT DESCRIPTION

A block diagram of the new instrument (RADS-II) is shown in Figure 1. The central feature of this new camera is the use of cooled CCD arrays (First Magnitude, Starscape II) in the imaging plane. These cameras are 480 x 542 arrays and are cooled to approximately -30 degrees C. The cooling reduces the dark noise significantly thus increasing the allowable integration times. Camera images are digitized by a 16 bit frame grabber thus significantly increasing the intrascene dynamic range. The optical layout of this system is similar to the first generation system. The light collected by the fisheye lens is transmitted through spectral and neutral density filters before being imaged on the surface of the array. The spectral filters which allow 4 different spectral wavelengths to be investigated. The 4 neutral density filters allow the overall scene intensity to be varied as the radiance field increases or decreases due to depth or changes in the incident light field. The filters may be changed remotely at the surface

Inside the underwater housing, a single board '386Sx 16 MHz computer (Diversified Technology, CAT 970) controls the camera and frame grabber. A 450 MByte hard drive (Seagate, ST1480N) is also enclosed in the underwater housing. Since the computer controlling the camera and the storage device are contained in the housing, data communication to the surface is greatly reduced. Only subsampled low resolution images are needed at the surface to check data quality and set exposure times. Data communication between the surface and the underwater unit is performed using serial 9600 baud transmission using standard "commercial" software (Dynamic Microprocessor Assoc. Inc., Run PC). This allows the surface computer to display the complete operations of the underwater computer without additional complicated software.

Since each image is approximately 500 Kbytes, a complete radiance distribution is 1 MByte per wavelength (upwelling and downwelling images). Therefore approximately 400 distributions may be obtained and stored on the internal hard drive during a cast. Between casts an external SCSI port is provided through the housing to allow the hard drive to be archived on a 1.4 GByte DAT tape (Archive Python 433).

Another improvement of RADS-II over RADS-I is the inclusion of integral irradiance collectors for upwelling and downwelling irradiance. These collectors (Biospherical Instruments, MER-2040) allow the calibration of the cameras to be checked by comparing the integrated radiance distribution with the irradiance data. Thus calibration drift can be monitored. The irradiance data may also be used to set exposure times for the camera system. An automated routine using this data will be implemented in the future. While the camera is limited to 4 wavelengths of radiance distribution data, upwelling and downwelling irradiance is collected at 8 wavelengths to better monitor the spectral distribution of the underwater light field.

Pitch and roll indicators (Lucas, Accustar) are provided along with a flux gate compass (KVH-1000). These aid in determining instrument orientation, and allow the images to be mapped to a precise coordinate system.

The irradiance information, pitch, roll, and heading are combined with depth and water temperature and stored when images are taken. Additional channels are available for water transmission, fluorescence, conductivity, etc. when this information is desired and the transducers are available.

3. INSTRUMENT PERFORMANCE

At the present time RADS-II has been used in one field experiment and preliminary information is available from this experiment and the calibration procedures performed.

The calibration steps required for the RADS-II are similar to those required for RADS-I and have been detailed elsewhere.[10] Only results specific to this system will be discussed. As mentioned previously we now have 16 bit digitization of the camera images. Figures 2A and 2B illustrate the linearity of both the upwelling and downwelling camera system. The upwelling camera frame grabber is set with much more sensitivity, thus the noise (represented by the error bars in the figure) is much greater (factor of 3). Most of this noise is not dark current but rather CCD readout noise.[11] Steps will be taken in the future to try and reduce this noise source, but overall the system shows good linearity over more than 3 orders of magnitude. Since the lens system of RADS-II is very similar to RADS-I, most of the calibration steps and results specific to the lens are the same.

For field operation, the new computer control of RADS-II has greatly increased the data acquisition rate. Where previous measurements required 2 minutes for data transfer per image, now the time is approximately 10-20 seconds. Software is being developed to speed this rate to 4-5 seconds/image. This will allow for faster casts and greater depth resolution than in the past.

Overall, the system is a large advancement in the capabilities for radiance distribution measurements. The increased accuracy of the data obtained with this instrument will be useful for radiative transfer studies and tests.

4. ACKNOWLEDGEMENTS

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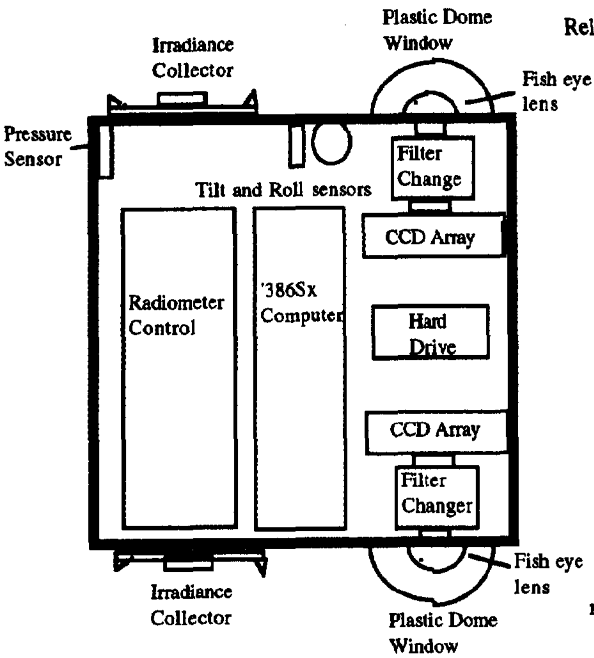

Fig. 1) Block diagram of RADS-II instrument

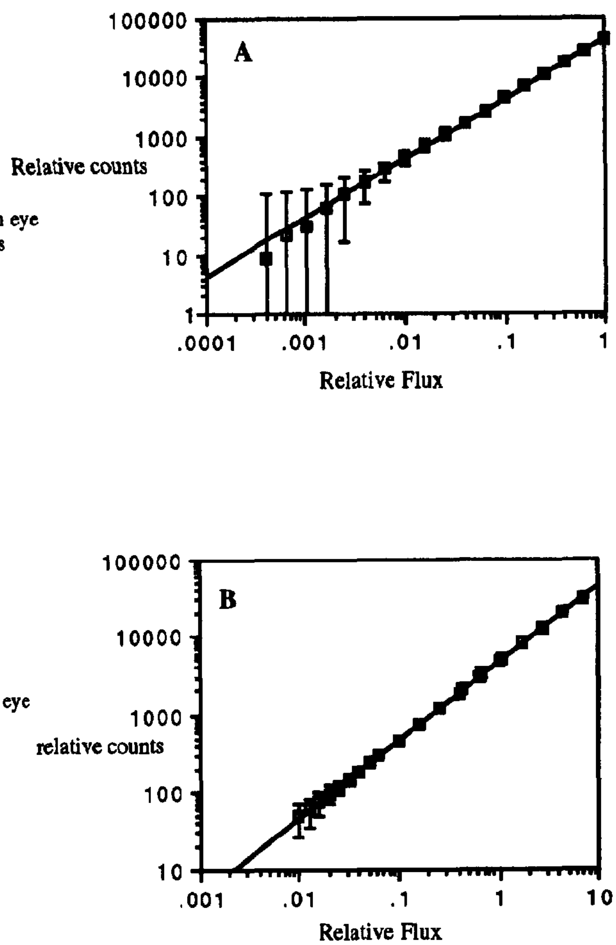

Fig. 2 Linearity calibration results for both cameras. Data points are average of 100x100 pixel boxes. Error bars are std dev. around average. Line is LSF with no constant. A) upwelling camera B) downwelling camera.