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Development of the Sea Color Surface Spectral Radiometer

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Abstract

This paper describes the design, calibration, and deployment of a sea color surface spectral radiometer that accurately measures downward visible wave (solar) irradiance and leave-water radiance. It is diffused on a moving platform, such as a ship on the sea for in situ measurements. The sea color surface spectral radiometer has two channels, one Self-Scanning Photodiode Array(SSPD), and its response wavelength is from 450nm to 800nm. As the instrument can detect two indispensable parameters——water-leaving upward spectral radiance and downward irradiance, we can compute remote sensing reflectance. It can provide sufficient irradiant data to meet the need of scientific study, promising it a bright application prospect. From the calibration and experiment results of the spectral radiometer, we can see the spectral radiometer is fairly accurate and the results satisfactory.

Keywords: ***Sea Color Surface Spectral Radiometer; Self-Scanning Photodiode Array(SSPD); Irradiance; Radiance.***

1. Introduction

The color of the sea, which can be measured from space, reveals information on the presence and concentration of phytoplankton, sediments, and dissolved organic chemicals. By studying the color of the light scattered from the seas, optical sensors can quantify the amount of chlorophyll and other constituents[1]. The optical sensors can be deployed in or on the sea, from aircraft, or from satellites. And the most effective way to observe the sea color is to set the optical sensors on the satellites. But the optical instruments in space tend to degrade, a coordinated measurement program is the only approach (termed a calibration and validation program). We shall design, construct, test, calibrate, document and deliver a two-channel spectral radiometer. The radiometer will be used to measure or verify the spectral

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radiance of radiometric sources, particularly verify the SeaWiFS calibration radiation scale[2], and must have adequate sensitivity to correct for small variations in the scale[3,4,5].

2. Radiometer's Design Scheme

2.1. Mechanical design and configuration

The radiometer is required to have an angular field of view of 1.2 degrees and measure over the spectral range of 450 to 850μm[6], which includes downward and upward light[7]. Fig. 1 shows the overall design and configuration of the instrument. downward and upward light come into the instrument at the same time. Choice of the light is construed by the baffle on a step DC motor. The downward solar light is collected by cosine collector, reflected by the reflector 1, and then comes into spectrophotometer. Thus we can obtain the downward irradiance[8]. The upward leaving-water light is through the bottom class, and is reflected by reflector 2, then comes into spectrophotometer. Thus we can get the upward radiance.

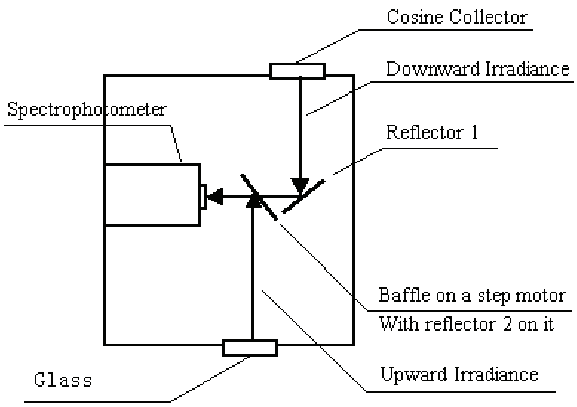


Fig.1 mechanical design and configuration

2.2. Spectrophotometer's Optical system

Spectrophotometer's Optical system is shown in Fig. 2. Light source firstly shines on the collimating mirror and it can produce parallel beam of radiation. Then the parallel light is dispersed by the grating into component wavelengths. At last Focusing mirror focuses separated radiation onto planar detector.

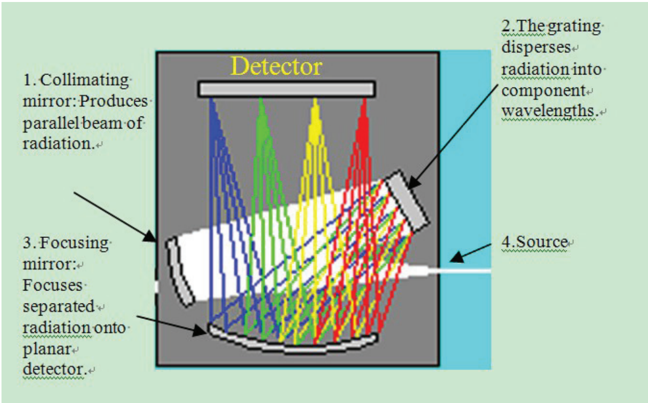


Fig.2 Spectrophotometer's Optical Diffraction Grating system

2.3. hardware system and theory of transduction of the photons into electrons

Hardware system of the sea color surface spectral radiometer is shown in Fig. 3, which consists of circuit controlled by AT89C51 single chip, A/D converter, circuit of integrate Self-Scanning Photodiode Array(SSPD) signals receiving and conversion. Thus it can complete the task from the product and collection of spectral signals to its saving, translation and processing and so on.

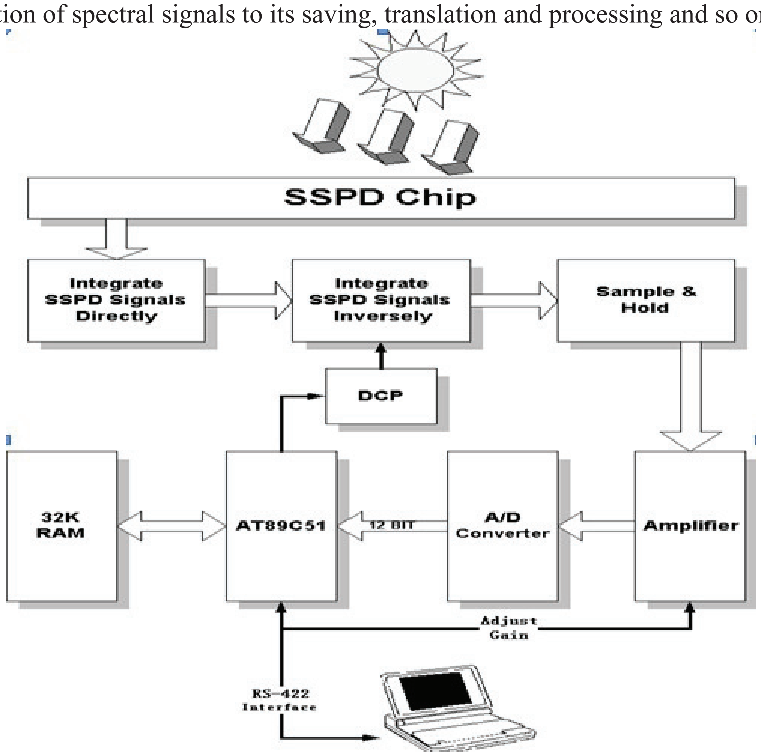


Fig.3 Hardware system flow chart

Its work process is: Radiation from the grating hits the photodiodes, which discharge capacitors. These capacitors contain charges proportional to the photon flux. At the end of the integration period, a series of switches close and transfer the charge to a shift register. While a new integration period begins, and the capacitors are again discharged, the charges on the shift register are digitized and the values are sent to the computer, which plots an absorption spectrum. This detector system has 2048 photodiode-capacitor pairs SSPD, which mainly use visible light absorption theory. It can be described as follow.

First is about Molecular Orbital Theory:

electrons in particle occupy different E-levels. The electrons can be electronically excited by photons:

$$M + h\nu = M^* \quad (1)$$

Different relaxations can occur, most common is:

$$M^* = M + \text{heat} \quad (2)$$

Visible radiation usually excites bonding electrons. The E of the photon has to be equal to the E-difference between the E-levels.

$$A = -\log T = -\log(P_0 / P) \quad (3)$$

where A is the absorption, T is transmittance, P_0 is the source power and P is the throughput power. The absorption spectrum is typical of the molecule. The wavelengths of absorption peaks can be correlated with the types of bonds in the compound. Thus, molecular absorption spectroscopy is good for identifying functional groups. Abs is proportional to conc. Beer's Law:

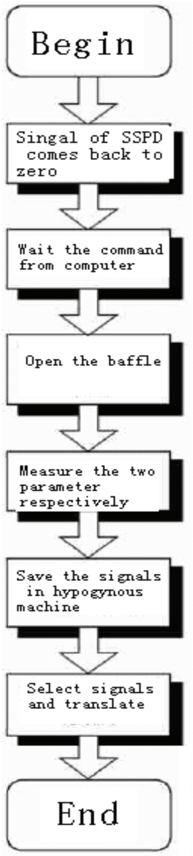
$$A = \varepsilon bc \quad (4)$$

where ε is the molar absorptivity at a certain wavelength, b is the path length (typically given in cm-s),and c is the concentration of the compound

2.4. Software

We use assembly language to write program to drive the hypogynous machine and the program is divided into a few parts and written respectively. The program includes the part of program initialization, the part of data collecting, the part of data translation and the part of anti-jamming. Flow chart is shown in Fig. 4.

The instrument is connected to computer with RS-422 protocol. Computer Interface software is written with Visual Basic language. Operating interface is shown in Fig. 5.



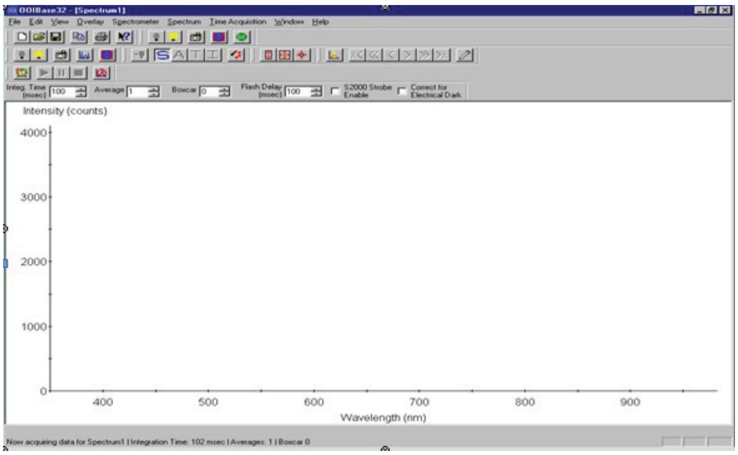


Fig. 4 software flow chart of clien Fig. 5 operating software interface of host

Once running, the program continually updates the spectra. All toolbar icons are also accessible through the command menus.

3. Calibration

After design and manufactured, the instrument needs to be calibrated, which includes wavelength calibration and the absolute value calibration of the irradiance and radiance relevant to the wavelength. We use standard mercury light as source to calibrate.

3.1. Wavelength calibration

Spectral radiance from a low-pressure mercury discharge lamp is used as the standard wavelength to calabrate the wavelength of the instrument[9,10]. We use the spectral radiometer to measure the standard mercury lamp. Fig. 6 shows the spectral radiance from a mercury light source. According to the known wavelength data of the characteristic line, we can easily line out all the wavelenth data of the spectrum which is measured by the instrument[11]. After wavelength calibration, we use HeNe laser whose wavelength is 632.8nm to verify the instrument[12]. Fig. 7 is the instument's spectral radiance from the HeNe laser, which shows us its wavelength response is fairly good.

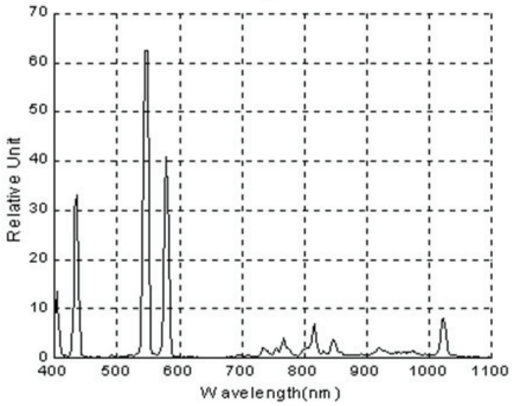


Fig. 6 Spectral radiance from a mercury light source

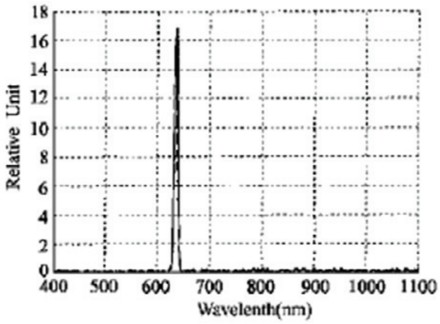


Fig. 7 Spectral radiance from a HeNe laser

B. Irradiance and radiance calibration

The second step of the calibration is the spectral irradiance calibration. Irradiance calibration is to line out the absolute value of the downward irradiance of the spectrometer by measuring the responsibility[13]. Firstly, put the standard lamp whose irradiance has been known beside the instrument wanted to be calibrated. Then use the instrument to measure the irradiance and compare it with standard data. At last, we can get the responsibility from the formula:

$$R=D_N/E_s \tag{5}$$

Where R is the responsibility, and its unit is $10^6W^{-1}cm^2nm$; D_N denotes the measured data; E_s is the standard data of the lamp whose unit is $10^{-6}W/cm^{-2}/nm$. Table I is a few irradiance responsibility of the downward irradiance.

Radiance calibration is to line out the absolute value of the upward radiance of the spectrometer by measuring the radiance responsibility[14]. At first, put the standard lamp before a standard whiteboard with fixed distance. On this condition, distributing function of the whiteboard radiance is known. Secondly, put the instrument near the whiteboard, and make sure that the angle of incidence between normal of whiteboard and that of radiance inputting face is 45°. In the end, comparing the data getting from the instrument and the distributing function of the whiteboard radiance, we can get the responsibility of the upward radiance of the instrument shown in table II.

Tab.1 The Responsibility of Downward Irradiance

Wavelength (nm)	Responsibility
412	0.141530
443	0.058995
490	0.057033
520	0.085678
565	0.145742
620	0.207123
643	0.214866
670	0.244810
683	0.257222
705	0.220074
765	0.304492

865	0.329905

Tab. 2The Responsibility of Upward Radiance

Wavelength (nm)	Responsibility
412	1.440462
443	1.023064
490	1.668280
520	2.176340
565	2.950165
620	3.585012
643	3.382638
670	3.708951
683	3.604963
705	3.031115
765	3.479839
865	2.770691

Finishing design and calibration, we made an measurement upon a pool of water. Fig. 8 is the result.

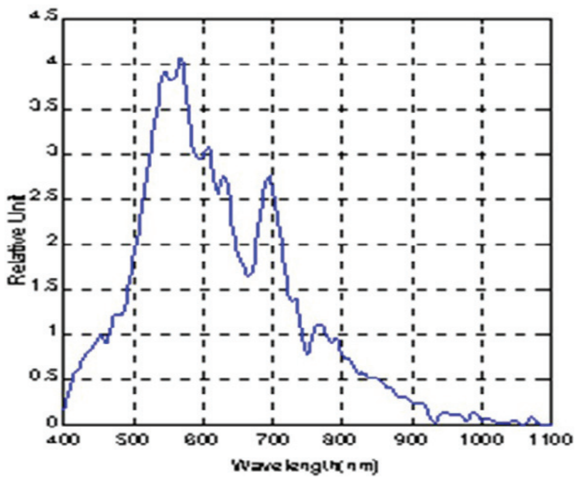


Fig.8 Upward spectral radiance from a pond measured by our instrument

4. Conclusions

The instrument's measurement error is smaller than 3% and its integral cosine error is lower 2.5%. Its sampling speed can be chosen between 3ms to 10s. Its response wavelength is from 450nm to 800nm. The bandwidth is smaller than 0.35nm. All of these promise the instrument a bright application prospect.

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