A Study on the Applicability of Rededge-M Camera for Water Color Observation

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ABSTRACT: The color of water is a great indicator of water quality since it reflects the abundance and the type of organic and inorganic constituents in the water. Analysis on water color also allows synoptic observation of large water bodies such as ocean, rivers, and lakes, making remote observation platforms such as satellites, aircraft, and drones extremely effective for monitoring the water system. This study investigates the applicability of a multispectral camera (Micasense Rededge-M) for the water color observation. A critical aspect of water color observation is that the light intensity upwelling from the water body is usually small compared to that from the terrestrial targets (1/10 ~ 1/100 scale), thereby the radiometer used needs to have sufficient sensitivity for low light intensity. In this study, a simple experiment was conducted to evaluate the usability of Rededge-M camera for water color observations, and an empirical algorithm was tuned and evaluated with field-collected in-situ data to remotely estimate chlorophyll-a concentrations existing in the water. The results showed that the radiometric quality of Rededge-M data is promising in that the spectrum of the four relevant radiometric variables are consistent with those obtained from a hyperspectral radiometer that is commonly used in the water color analysis. The chlorophyll estimation performed for 10 locations in a coastal area showed that the simple band ratio algorithm exhibited a good training accuracy despite of the existence of suspended sediment load in the area.

1. INTRODUCTION

Water color contains rich information on organic and inorganic constituents existing in water. For example, pigments in phytoplankton absorb light selectively for different wavelength, allowing estimation of pigment concentration from the remote observation of the water body. Algal blooms such as green tide and red tide can be effectively detected by observing water color, and the quantitative analysis of the reflectance spectrum of water enables retrieval of the abundance of the constituents. The theoretical framework for water color analysis has been intensively investigated in the ocean color community for decades since the launch of the first ocean color satellite, Coastal Zone Color Scanner (CZCS) (Feldman et al., 1989). While the ocean color research for satellite data is being actively conducted in various institutes, ocean color observation from the low altitude platforms such as drones have received less focus so far (Kim et al. 2019). Although drones have shortcomings of smaller observation areas with a shorter operation duration, they can be operated promptly for customized observation needs, thereby creating new application areas which cannot be fulfilled with high-cost and high altitude observation platforms such as satellites.

This study performs a preliminary investigation on the Micasense Rededge-M, a camera that has been widely used in the remote sensing community for earth observation, to see whether it can be used for the quantitative water color observation. This relatively low-cost and light (~190 g) multispectral camera has 5 spectral bands (475 nm, 560 nm, 668 nm, 717 nm, 840 nm), with an independent downward irradiance sensor (DLS), which apparently satisfies the minimum requirements for water color analysis; ability to measure radiance in the blue (400 – 500 nm), green (500 – 600 nm), red (600 – 700 nm), and two near infrared bands. Irradiance that is required for calculating remote sensing reflectance (R_{rs}) can also be measured by using either the DLS sensor or the reference panel accompanied with the camera. Compared with the typical ocean color sensors on satellites, it lacks bands in the further blue wavelength range (412 nm, 443 nm), but has a green and red bands in a quite similar location with the ocean color sensors (560 nm and 668 nm).

Unlike satellite images, frame-camera images require correction of artifacts such as the Vignette effect and the band alignment between spectral bands to compensate for the displacement of the fore optics of the 5 spectral bands. After the preprocessing, the Rededge-M radiance and irradiance data and the resultant R_{rs} are compared with simultaneous observations made by an independent hyperspectral sensor. The qualitative comparison of the radiometric variables is performed for each spectral band of Rededge-M camera, by comparing the corresponding bands in the TriOS RAMSES hyperspectral sensor. The radiance and irradiance measurements form Rededge-M are then fed to a retrieval algorithm for chlorophyll-a concentrations, and validated with field-measured chlorophyll-a concentrations determined by the filtering of sea water.

2. INSTRUMENTS AND METHOD

2.1 Instruments

Micasense Rededge-M camera has 5 spectral bands, which constitutes of the main camera, downwelling light sensor (DLS), and the GPS module. The weight is around 170 g, and the dimension is 9.4 cm 6.3 cm, 4.6 cm, which are amenable to be operated on drones that is sensitive to the payload weight. The bandwidths are 20 nm, 20 nm, 10 nm, 10 nm, and 40 nm, respectively for the bands centered at 475 nm, 560 nm, 668 nm, 717nm, and 840 nm. Besides the main camera and the connected devices (DLS and GPS), a reference gray panel is accompanied, which can be used for estimating downward irradiance independent of the DLS sensor. The reflectance of the panel is available on the panel case with a QR code.

TriOS RAMSES consists of two types of hyperspectral sensors, ARC-VIS for radiance measurement, and ACC-VIS for irradiance measurement, both of which cover the spectral range between 280 and 950 nm with a roughly 3-nm interval. Two ARC-VIS sensors were operated in a frame that guides the two sensors to 40° down and 40° up in zenith angles, respectively for measuring the water and the sky radiance. An ACC-VIS sensor for downward irradiance was installed in a high position to avoid light intervention around the sensor. RAMSES, being operated simultaneously with the 3 sensors, has no errors caused by the observation time difference between the three radiometric variables.

2.2 Preprocessing of Rededge-M Camera Data

Raw camera data in digital number are converted to radiance based on the radiometric correction equation and the correction coefficients provided in the camera data. In the correction process, the Vignette effect, that is prominent in this type of 2-dimensional sensor, has also been corrected (Kim et al., 2019). After the radiometric correction, image alignment between 5 spectral bands was performed to compensate the positional difference in the 5 bands (Kim et al., 2019).

Remote sensing reflectance (R_{rs}) is derived from the three radiometric variables measured; sky radiance (L_{sky}), total water radiance (L_{wt}), and downward irradiance (E_d) as in

$$R_{rs} = \frac{L_{wt} - \rho L_{sky}}{E_d}$$

, where ρ is the Fresnel reflectance factor which varies with the viewing geometry and the wind speed. In case of Rededge-M, L_{sky} and L_{wt} were measured directly with the camera, and E_d was derived from the radiance measurement of reference panel (DLS measurements were not used in this study).

2.3 Determination of Chlorophyll-a Concentration in Water and Estimation from Optical Data

Chlorophyll-a concentration (denoted as Chla, hereafter) is one of the major water quality variables that can be estimated from the remotely sensed optical data. To train and validate the remote Chla estimation algorithm, Chla in target waters was measured by the spectro-photometric method after the filtering of the water samples in the field.

The field-measured Chla was used to tune the classic band-ratio based Chla algorithm for Rededge-M (O'Reilly et al, 1998). Since the 475 nm band is the only blue band available in Rededge-M, a two-band algorithm (OC2 type) that utilizes the band ratio of 475 nm over 560 nm was used for estimating Chla.

$$\log_{10} Chla = a_0 + \sum_{i=1}^{4} a_i (\log_{10} R)^i$$

$$R = \frac{R_{rs}(475)}{R_{rs}(560)}$$

3. RESULTS

3.1 Radiometric Quality of Rededge-M Camera for Water Color Analysis

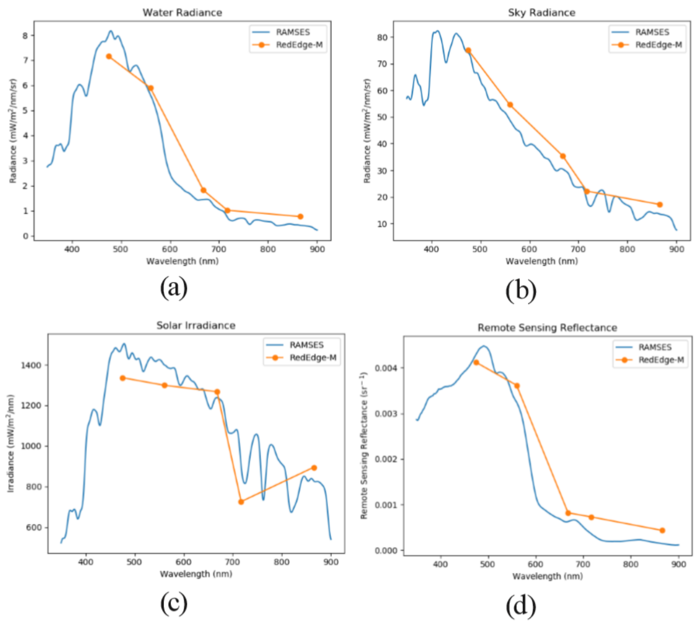

Fig. 1. Spectrum simultaneously measured by Rededge-M and RAMSES for (a) water radiance, (b) sky radiance, (c) downward solar irradiance, and (d) the derived remote sensing reflectance.

Comparison of the 4 radiometric variables measured simultaneously and derived from the two sensors, Rededge-M and RAMSES, showed that the Rededge-M measurements are consistent with RAMSES for all the variables, and the radiometric sensitivity is not inferior in the low radiance levels for the water radiance (Fig. 1). In Fig. (a), the spectral shape was quite robust for the radiance level under 10 $\mathrm{mW/m^2}/nm/sr$, where the intensity in each spectral band do not diverge significantly from that from RAMSES, regarded as the reference instrument in this study.

3.2 Estimation of In-Water Chlorophyll Concentration

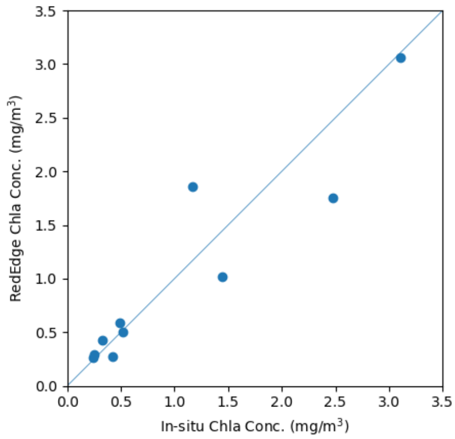

Fig. 2. A scatter plot for the in-situ (x-axis) and the estimated chlorophyll-a concentration by Rededge-M (y-axis) for 10 locations in the study area.

To test the Chla estimation algorithm, in-situ R_{rs} and Chla that were collected simultaneously in 10 locations in southern sea of Korea (near Tongyeong) were used (Kim et al., 2018). Figure 2. shows that the Chla estimation by the OC2 algorithm has high correlation with in-situ Chla (R^2 = 0.93) for a wide Chla range of 0.3 ~ 3.2 mg/m^3. The estimation uncertainty for the 10 stations is around 24%, which is lower than the Chla estimation target performance of the satellite community (35%). Since the performance is for the data used for the training the algorithm, the uncertainty may degrade when applied to independent data having different time and locations. However, for the area has non-negligible suspended sediment loading of around 1 g/m^3, the performance can be said to show promising results for the light-weighted inexpensive multispectral camera.

4. CONCLUSIONS

This study first investigates the radiometric performance of Rededge-M camera for water color analysis by practicing thorough preprocessing for the 2-dimensional data and comparing the 4 radiometric variables, L_{sky}, L_{wt}, E_d, and R_{rs}. The preprocessing processes of radiometric correction, Vignette correction, and the band alignment were applied for deriving radiometric variables needed for the water color analysis. Although the comparison was not practiced for a sufficiently large number of measurements, the simultaneous comparison showed a potential in the radiometric variables derived from Rededge-M.

A simple experiment with field-measured Chla measurements and the corresponding Rededge-M measurements showed that the Chla estimation performance outperforms the target uncertainty in the satellite Chla estimation in the coastal areas in the southern sea having the total suspended sediment loads around 1 g/m^3. Although this experiment was performed for a few selected locations in one day, it is interesting that the simple two-band algorithm can capture the Chla variability ranging from 0.3 to 3.2 mg/m^3 in the wide areas (around 20 km x 20 km).

A further study is warranted for the practical use of Rededge-M camera for the water color analysis. Fresnel reflectance removal for each surface facet in the 2-dimensional image data is the first challenge in the course of using the data. The Rededge-M camera data used in this study were all collected in the ship, where the measurement altitude is lower than 2 m. However, for the use of wide-area observation from the altitude above 200 m, the atmospheric intervention needs to be considered essentially for water color analysis.

5. REFERENCE

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