Development of an Imaging Spectropolarimeter Using Liquid Crystal Tunable Filter

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1. Introduction
There exists a potential demand for determining surface conditions from optical properties under the increasing necessity of protecting the Earth’s environment 1). In particular, hyperspectral analysis of solar rays reflected on the Earth’s surface is expected to play an important role in future Earth observation 2). A new type of imaging spectropolarimeter using an LCTF has been developed at NAL for such analysis 3). In order to realize the practical application of this optical sensor, work is currently under way to develop it into a sensor package for airborne Earth environment observation system.

2. Outline of an Imaging Spectropolarimeter
Shown in Fig.1 is a side-view photograph of the LCTF spectropolarimeter developed at NAL. This sensor can sense radiation in the 400–720 nm wavelength band. After passing through an object lens, unpolarized white light from the target impinges upon the LCTF device, which transmits only light with a selected polarization direction and wavelength onto a CCD camera. Two relay lenses can make the parallel incident light on the LCTF. A rotation mechanism driven by a stepper motor is mounted on the LCTF and allows the polarization plane of the transmitting light to be altered within a range of –90° to +90°. Thus, the CCD can detect images of the target irradiated by light with a selected wavelength and plane of polarization.

A number of successive improvements have been made since the first prototype optical sensor was successfully developed in 1999, and Fig.2 shows a schematic diagram of the most recent model.

3. Concept of an Onboard Observation System
Development of an onboard observation system using an LCTF optical sensor for remote sensing has been conducted at NAL. A block diagram of the onboard observation system is shown in Fig.2. This system can automatically acquire spectropolarimetric images of a target from which solar rays are reflected. It consists of the optical sensor (shown by dotted lines) that includes a filter rotation mechanism and a control unit (delineated by solid lines) which comprises related peripheral devices and contains software for sensor operation and data capture. A controller for filter rotation generates the necessary control signal to allow the observation plane of polarization to be changed.

4. Verification of Instrument Functions
Fig. 3 shows the normalized spectral radiance of the CCD output images measured when He-Ne gas laser light with a wavelength of 632.8 nm is incident upon the object lens. The measurement result shows that the spectral resolution of the optical sensor is less than 10 nm at the wavelength of 632.8 nm. However, it is common for the spectral resolution to be higher in the shorter wavelength bands and lower in the longer wavelength bands. The spectral resolution of the optical sensor is thought to be 5 to 15 nm in the 400 to 720 nm wavelength band.

To verify the function of the LCTF filter rotation mechanism, linearly polarized light was shone onto the object lens and the radiance of the CCD output was measured. In such polarization...
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It has been proved that the radiance of the CCD output varies with the relative difference angle between the polarization plane of the LCTF and that of the linearly polarized light incident on the LCTF.

5. Field Observations of Surface Conditions

Preliminary field experiments were conducted beside the Tama River near the NAL in the autumn of 2001 to acquire the images of targets in a real-world environment. The area for field trials is shown in Fig.4, and targets indicated are (a) coniferous trees, (b) grass, (c) water and (d) gravel. The spectral characteristics of solar rays reflected from target points (a), (b), (c) and (d), which were obtained from the analysis of the CCD output of the optical sensor, are shown in Fig.5. The experimental results do demonstrate that solar rays reflected from targets with differing characteristics have different spectropolarimetric properties.

6. Conclusions

Some of the latest results of the present research are summarized as follows:

- An onboard observation system incorporating an imaging spectropolarimeter has been verified to be functionally applicable for airborne Earth environment remote sensing.
- Continuous selectivity of wavelength with a spectral resolution of 5 to 15 nm and operation of the filter rotation mechanism have been verified.
- Spectropolarimetric characteristics of solar rays reflected from targets in an outdoor environment were acquired as spectral radiance in field experiments.

References