ACADEMIC FORUM

Comments on scaling effect of reciprocity in BRDF study*

ZHAO Hongrui** and WANG Jindi

(Research Center for Remote Sensing and GIS, Department of Geography, Beijing Normal University, Beijing Key Laboratory for Remote Sensing of Environment and Digital Cities, Beijing 100875, China)

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Abstract Reciprocity principle is a common theory in electromagnetics and optics. It is also one of the general principles of the radiation transformation theory. However, in many remote sensing studies, this principle cannot be always supported by experimental data, especially when the scaling effect of the remote sensing image pixel is considered. The debate over the issue of whether the reciprocity principle can be used as a fundamental standard in evaluating the effectiveness of remote sensing observations has lasted for years. Using geometrical optics model, Li and Wan proved the existence of the scaling effect in applying the reciprocity principle to a remote sensing image pixel in 1998. In 2002, Snyder challenged Li's proof, and attempted to prove that reciprocity principle is universally valid without any scale limitation. In this paper, we will argue with Snyder's theory and point out that Snyder's theory had neglected an important condition used in Li's proof and, as a result, drawn the wrong conclusion. Here we will restate Li's condition in his demonstration and offer a further proof to verify that reciprocity principle cannot be applied unconditionally to the study of bi-directional reflectance distribution function (BRDF) of land surfaces in field or satellite remote sensing observation scale.

Keywords: **BRDF, reciprocity, scaling effect.**

Reciprocity principle is one of the common theories in electromagnetics and optics, and also a fundamental principle of the radiation transformation theory. Although it was once used as a standard to evaluate the quality of remote sensing observations, it has been questioned by many researchers, because many observed results do not support the unconditionally application of the reciprocity principle on the scale of remote sensing image pixel or the pixel field of view (FOV)[1,2]. The question about whether or not the reciprocity principle can be unconditionally used in the study of bi-directional reflectance distribution function of land surface is concerned seriously, practically and theoretically. The dispute between the two opposite opinions over the issue has lasted for more than 20 years.

First of all, we should make it clear that there are differences between the original Helmholtz's reciprocity principle and the S/D-reciprocity used in remote sensing (Reciprocity of source and detector), which states "when the wave source and a detector exchange positions, the response of the detector remains the same". The main difference is that S/D-reciprocity in remote sensing does not satisfy the strict condition of the Helmholtz's reciprocity principle[1].

After Li and Wan's convincing argument against the mistake made by Siegel and Howell in their thermodynamic proof of the reciprocity principle in 1998[1,3], Snyder insisted on the universality of the reciprocity principle by his so called "photo-path reversal" argument, and reclaimed the unconditional validity of the reciprocity principle on the pixel scale in 1998[4]. Later, Li et al. answered Snyder by demonstrating how uniform incidence can be affected by multiple scattering and how reflectivity can vary inside a structured pixel space. In 1999, Li has also shown that there could be asymmetrical absorption in certain pixel structures, so Snyder's "photo-path reversal" argument could conflict with the law of conservation of energy[5].

Hypothetically, Li designed a pixel structure[5] to demonstrate the scaling effect of the reciprocity principle (see Fig. 1). The valley consists of a blackbody slope laying 45 degree to the left and a perfect concave mirror 45 degree to the right. The valley

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** To whom correspondence should be addressed. E-mail: zhaohongrui@263.net

pixel size is A. The focal point of the concave mirror is located at the center of the A. Incident radiation parallel to the blackbody slope uniformly shining on A will be totally reflected by the concave mirror. A physically small optical system (for example, a lens and a plane mirror system) can be designed and placed near to the focal point of the concave mirror to collect and guide all the reflection light 45 degree up to the right to exit the pixel structure. Apparently, a detector placed in this direction will collect all the reflected photons. If there is N photons out of the M incident photons reflected and collected by the detector, the bi-directional ratio will be $N/M \approx M/M = 1$. After exchanging the positions of the light source and the detector, most of the incident radiation from the direction of 45° to the right and uniformly shining on the pixel structure opening A will be absorbed by the blackbody surface and almost no light can reach the detector. The bi-directional ratio will be close to zero and the reciprocity principle will be invalid in this situation. This simple geometrical optics model clearly shows the scaling effect in remote sensing observations.

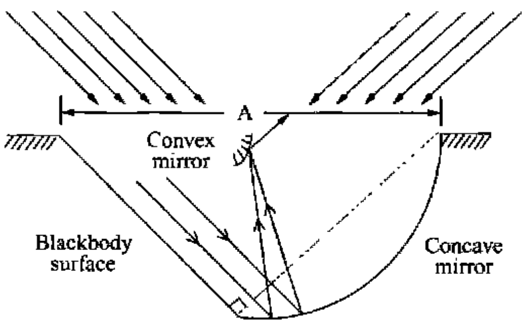

Fig. 1. Pixel structure showing the S/D-reciprocity failure.

Following Li's demonstration, Snyder argued Li's pixel structure and insisted on unconditional validity of the BRDF reciprocity principle in 2002[6]. Fig. 2 shows the picture given by Snyder. It is very similar to Li's pixel structure in Fig. 1 except that the blackbody surface assumption is neglected, and it was this neglect that resulted in his unnecessarily lengthy and complicated proof. Furthermore, Snyder declared that his pixel model shown in Fig. 2 was equivalent to Fig. 3, which completely ignored the scale factor. And so it is the scaling effect of our remote sensing image pixel that provides the foundation of the entire discussion.

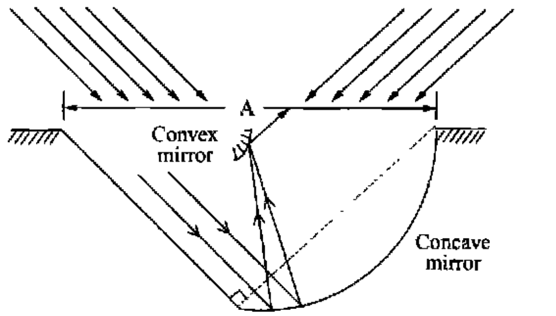

Fig. 2. Pixel structure given by Snyder to prove that reciprocity can be applied to remote sensing unconditionally[6].

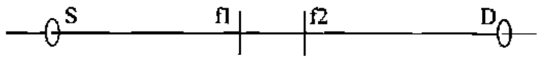

Fig. 3. The picture of telescope structure equivalent to Fig. 2[6].

Li's pixel structure has already provided us with a simple and clear picture to demonstrate the scaling effect of the reciprocity principle. Following Snyder's logic, we can also equivalent Fig. 1 to an optically simplified picture as shown in Fig. 4, in which both the directional blackbody surface and the scaling factor are included. It is very clear that exchanging the positions of the light source and the detector will totally change the readings of the measurements on this constructed pixel. Therefore there should be no further doubt about the existence of the scaling effect of the reciprocity principle in a remote sensing pixel.

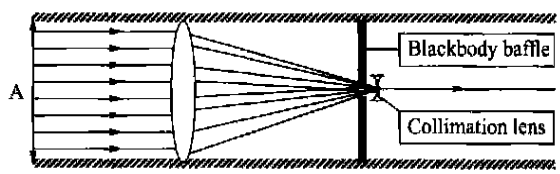

Fig. 4. The optics system equivalent to Fig. 1.

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