ASIA-PACIFIC
SOLAR RESEARCH CONFERENCE

Camera-based measurement of reflection and emission from complex receiver shapes

Ye Wang, Wojciech Lipiński, John Pye

The Australian National University, Canberra, Australia

In a solar thermal system, reflections and themal emissions occur all the time in the receiver system where the concentrated solar radiation is converted into thermal energy of the working fluid, which then drives the power cycle. It is important to be able to quantify these radiative losses in order to get an understanding of the optical and thermal performance of the receiver. In design stages, optical modelling methods (e.g. Monte Carlo ray-tracing) can be used for predictive purposes. However, conditions in real operations may vary from the simulations. For example, the surface properties vary with temperature and change over the time of operation, e.g. aging and degradation of the surface coating. It is desirable to have a method to physically measure the surface properties during operations.

The camera-based measurement of reflection and emission has a lot of advantages. Firstly, it is portable and convenient for on-site operations. It does not need additional sensors. In addition, it is capable of capturing the local behavior on the receiver, eg. flux distributions without calorimeters or flux gauges. In Ho and Khalsa (2011), the PHLUX method was developed for this purpose. However, methods reported in the literature have not been demonstrated for measurements used for complex shaped receivers, eg. the promising concept of multi-cavity receiver, bladed receiver (Ho et al., 2014; Wang et al., 2016; Pye et al., 2016), where shading, blocking and light trapping occur greatly, and where the reflection and emission would not be uniformly distributed in the hemisphere outside the aperture (see Figure 1). How to deskew and unwind images and integrate the energy in all directions is a big challenge.

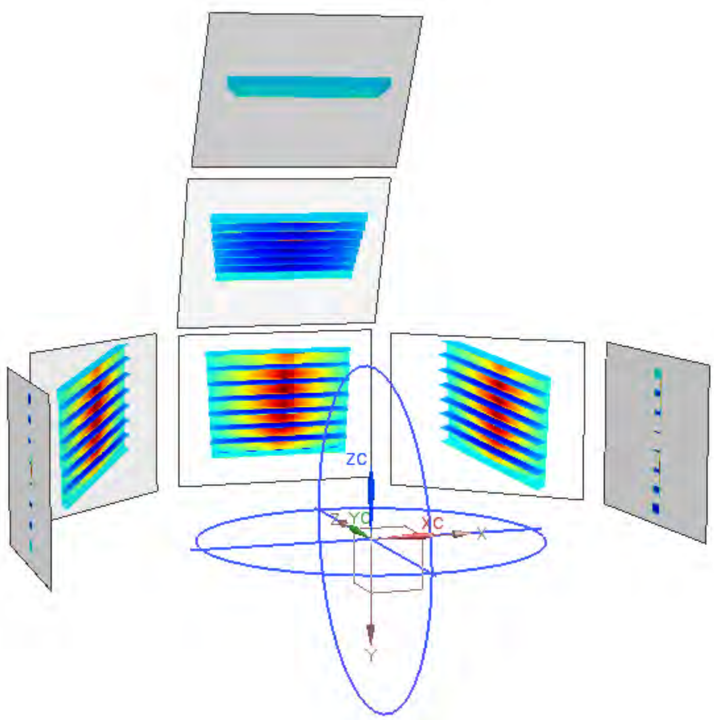

Figure 1. Radiosity distribution from a multi-cavity receiver, bladed receiver, which is viewed in different directions that cover the hemisphere

In this presentation, the photographic method of measuring reflection and emission from complex receiver shapes will be demonstrated. In this method, images are captured through a set of intervals in the domain that cover the entire hemisphere above the aperture of the receiver. The interval independent study is carefully investigated. The reflected and emitted energy can be photographed by a DSLR camera (for visible light) and an infrared camera (for infrared radiation) from a range of directions. A method similar as PHLUX (Ho and Khalsa, 2011) is applied to calibrate each pixel value from each image to an energy value. The 3D reconstruction method is applied to integrate the energy from all the directions to establish the total radiative losses from the receiver aperture. The method is carefully validated through three stages of investigation.

Stage I: Diffuse Flat Surface Model

Initially, the method is validated through comparison with the traditional camera-based measurement (Ho and Khalsa, 2011) of radiation from a diffuse flat surface, from which the radiosity is independent of direction. Instead of taking one image and integrating the intensity through the whole hemisphere in the traditional way, the method takes a set of images from all directions and combines them together. This stage ensures that the camera calibration and energy calibration are correct, and also the energy extracted from multi-images is consistent with the energy that is integrated from just one direction.

Stage II: Obscured Surfaces Model

In the second stage, complex arbitrary obscured surface geometries are investigated. It focuses on developing the flexible 3D reconstruction method, which converts a set of 2D images from limited different directions to the 3D object. The independent interval of image taking in azimuth and zenith special positions is carefully studied in this stage.

Stage III: Bladed Receiver Model

The method is eventually applied to measuring the radiative losses from the bladed receiver, as shown in Figure 1. The radiosities are captured by DSLR and infrared cameras from a set of directions. The image data is converted to energy by the method validated in Stage I and integrated by the 3D reconstruction method that is validated in Stage II. The total radiative losses and the spatial distribution are compared with ray-tracing simulation.

This method is not only valid for complex shape objects but also applicable for measuring the total radiations from non-diffuse surfaces, where the radiosity varies with directions. Besides, based on the previous stages, it is possible to apply this camera-based measurement in the upcoming on-sun test for the bladed receiver at CSIRO in September this year. The progress will be updated in the presentation during the conference in December, 2018.

References

Ho, C. and Khalsa S. S., 2011, ‘A flux mapping method for central receiver systems’, Proceedings of ASME 2011 5th International Conference on Energy Sustainability and 9th Fuel Cell Science, Engineering and Technology Conference, 2011, Washington, DC, USA

Ho, C., Christian, J. M., Ortega, J. D., Yellowhair, J., Mosquera, M. J., Andraka, C. E., 2014, ‘Reduction of radiative heat losses for solar thermal receivers’, In Proceedings of the SPIE Optics and Photonics Solar Energy Technology High and Low Concentrator Systems for Solar Energy Applications IX, San Diego, CA

Wang, Y., Asselineau, C.-A., Coventry, J. and Pye, J., 2016, ‘Optical performance of bladed receivers for CSP systems’, Proceedings of the ASME 2016 Power and Energy Conference

Pye, J., Coventry, J., Ho, C. K., Yellowhair, J., Nock, I., Wang, Y., Abbasi, E., Christian, J., Ortega, J. and Hughes, G., 2016, ‘Optical and Thermal Performance of Bladed Receivers’, SolarPACES 2016, Abu Dhabi, UAE