RAPID HELIOSTAT SURFACE MEASUREMENT USING RECONSTRUCTION FROM CAMERA IMAGES

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1. Introduction

The modelling of a solar concentrator is central to its design, operation and evaluation. Increasing sophistication in modelling requires more detailed information about the nature of the concentrator to predict its performance accurately. In particular, the profile of an image from a heliostat is important for understanding and predicting the energy that can be collected at a receiver. As the heliostat image is a direct result of its curvature, the only way of universally characterizing this image is by measurement of the heliostat reflector curvature itself. Conventional surface measurement techniques cannot be applied to large heliostat mirrors at mass production scale because of cost, practicality and accuracy limitations. This study demonstrates how the curvature of a heliostat can be calculated from two digital camera photos of the reflector surface. The setup is inexpensive and can be easily implemented in a heliostat assembly line.

2. Background

Common process and quality control methods such as scanning laser/ultrasonic distance measurement are not easily adaptable to the specific requirements of rapid heliostat mirror surface profiling. Instead, surface characterisation by reconstruction from camera images draws on the image processing techniques used in Particle Image Velocimetry (PIV), to calculate the shape of the mirror surface. PIV uses two dimensional cross-correlation to determine a vector shift between regions of two images that have similar structure. The two dimensional cross-correlation function returns a maximum when the similar regions of the two images are aligned, and a minima everywhere else [1]. The translation vector associated with the alignment condition is the key to accurately mapping the light source to its reflection.

3. The Method

The setup was constructed as shown in Fig. 1. The source of light was chosen as a textured and coloured vertical sheet, illuminated by a conventional light source. The domain size of the texture and colour areas on the source object was set just above the resolution of the camera detector, such that different areas of the source could easily be recognised in a photograph. The digital camera was mounted on the other side of the heliostat such that an image would capture both the source object as well as its reflection. Images were captured with the source in positions 1 and 2, with the second position 0.5m closer to the camera (Fig. 1).

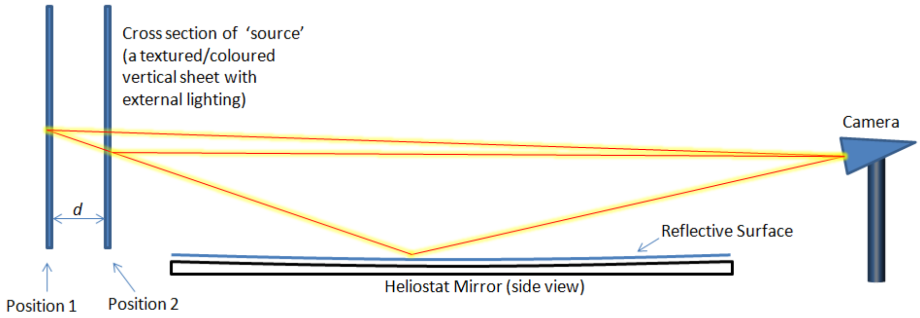

Fig. 1. The basic setup required for optical measurement of a 3m x 3m heliostat mirror.

Each pixel associated with a point on the source was mapped to a corresponding pixel in its reflection using the two dimensional cross-correlation method with the inverted image. A simple calculation based on camera internal parameters was then made to convert pixel pairs (a pixel on the source, and its corresponding reflection pixel) into vector pairs associated with each pixel in the reflected image. The length of each source vector was known from measurement, and the length of the reflection vector was arbitrary.

From one image, each vector pair (source and reflection) define an infinite number of possible reflection points along the reflection vector. As demonstrated in Fig. 2, the reflection plane (black line) becomes more inclined towards the camera if the reflection point occurs further from the camera.

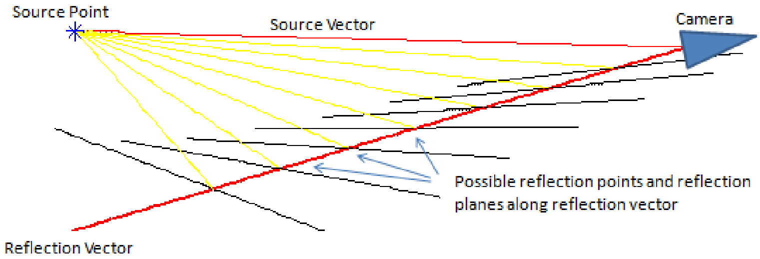

Fig. 2. For any given source vector, and reflection vector, there are an infinite number of possible reflection points (and reflection planes) that could produce the image seen by the camera.

With the help of a second image, captured with the source in another location, the exact position of the reflection point is defined uniquely on the surface of the mirror (Fig. 3). This was repeated for all reflected rays to obtain a full set of points lying along the mirror surface.

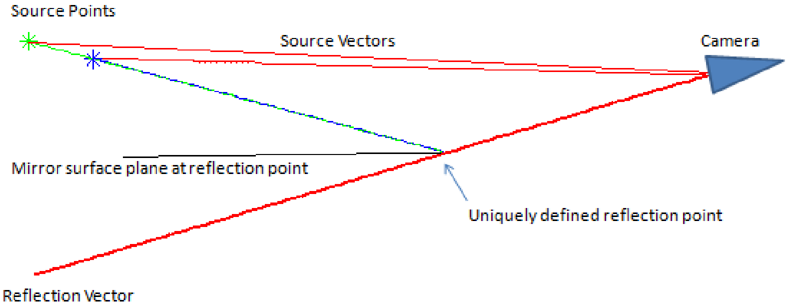

Fig. 3. Images from two source points allow a reflection point and reflection plane to be defined uniquely.

4. Accuracy and Speed

The accuracy of the technique is dependent on the distance separating the source sheets (*d*), and the resolution of the camera. As the heliostat is highly reflective and the reflected image clarity is very high, the cross correlation method accurately maps regions of the images to within a few pixels. By assuming that the mirror curvature is smooth (ie. smooth vector fields), it is possible to further improve the image correlation performance. The mirror surface curvature measurement was within the accuracy of other available optical and mechanical measurement techniques, and is estimated to be approximately ±0.5mm at this stage.

As the two photos can be captured in a very short time, the speed of the measurement is generally limited by the time taken to manipulate the heliostat mirror into the appropriate position for measurement. If this were implemented on a production/assembly line, this time would be significantly reduced. Image processing speeds are improving as the processing algorithms are streamlined. Improved camera to processing software integration is necessary for further improvement.

References

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