SCOTS: A Quantitative Slope Measuring Method for Optical Shop Use

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Abstract: Software Configurable Optical Test System (SCOTS)[1], a computerized "reverse Hartmann test", can rapidly quantitatively measure highly aspherical shapes such as solar collectors, Giant Magellan Telescope (GMT) primary segment with accuracy to micron rms or better without complex calibration. Implementation of SCOTS needs only hardware like a laptop computer. It illuminates test surface/system with patterns from a LCD screen and use reflected/refracted image to determine surface/system wavefront slope variations.

OCTS codes: (220.4840) Testing ;(080.4228) Nonspherical mirror surfaces

1. Introduction

Low cost and rapid measuring of relatively low accuracy large scale concentrating solar concentrators [2], was the original need that spawned the Software Configurable Optical Test System (SCOTS) at University of Arizona. SCOTS is a simple, inexpensive yet highly flexible optical test that can be configured with software for almost any specular surface. It uses the same basic test geometry as the fringe reflection technique or phase measuring deflectometry (PMD) [3, 4]. However, the data collection and reduction algorithms used by SCOTS are designed for testing surfaces at the caustics [5], or for testing complex surface shapes, such as low accuracy optics or freeform surfaces. For these kinds of specular surfaces, the common fringe reflection method, which utilizes phase shifting method for data reduction, will have phase unwrapping ambiguity issues.

In this paper, we explain the basic principle of SCOTS and give the algorithms to solve the phase ambiguity issue. Some initial experimental results for the measurements of a solar reflector and the GMT primary segment are presented.

2. Basic Principle

The test is analogous to do a Hartmann with the light going through the system in reverse. In the case of the SCOTS and an appropriately small mirror, a laptop computer can be used as the entire test device. The screen of the laptop is placed at the center of curvature of the concave mirror being tested. Under computer control, a line is created on an otherwise dark screen and the built-in camera takes a picture of the mirror. The mirror will appear bright in the region where the bright pixels reflect off the mirror and enter the camera aperture. The line is rastered and another picture taken, etc. Knowing the coordinates of the bright lines and where they reflected from the mirror and entered the camera it is possible to know the slope of the incident and reflected rays, and thus the slope at each position on the mirror surface as the line is rastered across the screen in two directions. Figure 1 schematically shows how the surface slope is measured and calculated. The slopes can then be integrated using polynomials fit to the slopes or by zonal integration methods to give the surface shape.

The PMD method uses the same test geometry as SCOTS and lights up sinusoidal fringes horizontally (H) and vertically (V) on the screen, and the camera takes multiple images while the fringes are phase shifted. Slope data can be derived from standard phase shifting algorithms. However, the PMD method will have phase unwrapping ambiguity issue when the test happens in the caustic or when surface under test has a complex shape, because the mapping is many to one between the test surface region and the screen pixel. Multiple regions on the test surface can be lit up at once by the same pixel on the screen as shown in Fig. 2 for testing a trapezoidal shape solar reflector panel with sinusoidal fringes. We resolve this issue by illuminating the test surface with a single line of pixels per camera frame. A bright strip of pixels is rastered H and V, separately, while an image of the reflection from the surface is taken for each rastered line. To find out the mapping relation between region at the test surface and the pixel at the screen, each computer stored horizontal (or vertical) line are compared with all the vertical (or horizontal) lines. If there are common regions at the test surface from horizontal and vertical line, then the intersection pixel is the pixel lighting up the common regions at the test surface. In this way, the mapping relationship is precisely known. Fig. 2 (c) and (d) shows this cross line concept. In reality, the horizontal and vertical lines will scan separately and be compared in the computer memory.

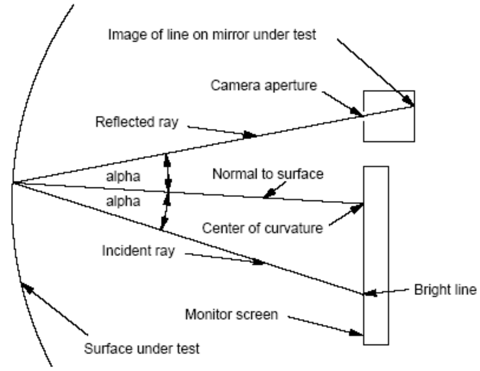
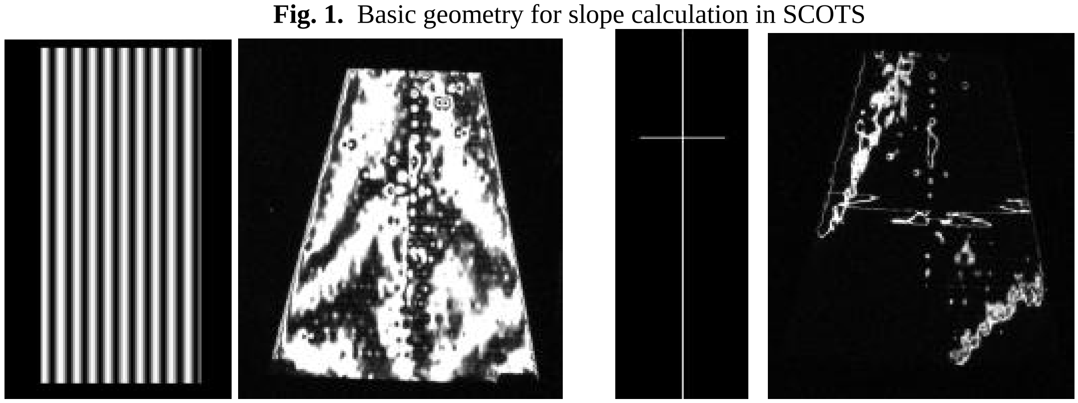
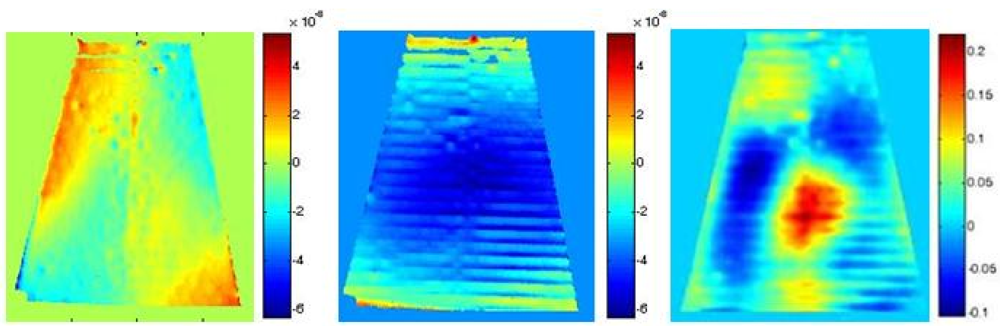


Fig. 1. Basic geometry for slope calculation in SCOTS



(a) (b) (c) (d)

Fig 2. (a) Sinusoidal fringes used in PMD method, (b) corresponding fringe images at the trapezoidal solar reflector, (c) horizontal and vertical scan lines, (d) corresponding fringe images at the trapezoidal solar reflector. The interception point in (c) is the corresponding illumination source for the fringe overlapping regions at the mirror image.



(a) (b) (c)

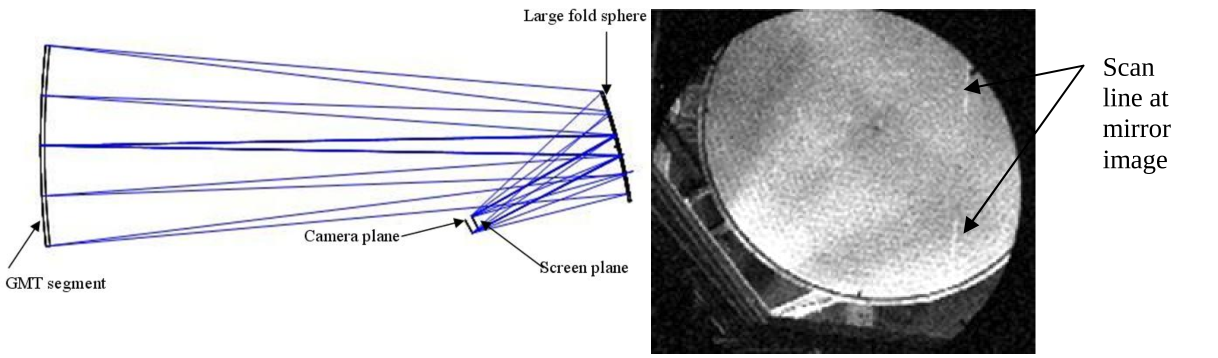
Fig. 3 (a) x slopes for the off-axis piece of a solar concentrator measured with SCOTS (Color scale in milliradians), (b) y slopes, c) integrated surface shape after removing overall parabolic shape (Color scale in mm).

3. SCOTS for solar reflector

We utilized SCOTS to measure the slumped solar reflector panel, which also shown in Fig. 2 is an off axis section of a 3m, f/0.5 parabola. The segment has a trapezoidal shape about 1 m long by 85 cm at the long end. The monitor was set up close to the center of curvature of the segment roughly aligned perpendicular to the normal at the center of the segment. The camera was located at the edge of the screen. A line pattern was scanned across the screen in both directions and the slopes of the surface calculated in both directions. After tilt and focus were subtracted the X and Y slopes are shown in Fig. 3 (a) and (b). Fig. 3 (c) shows the mirror shape errors from slope integration after removing the overall parabolic shape.

4. SCOTS for the GMT segment

SCOTS can also be used to test a system with multiple components. The 8.4 meter GMT off-axis segment is being fabricated at the Steward Observatory Mirror Lab at the University of Arizona. We plan to perform the SCOTS test to check the high slope errors in the surface which can not be well resolved with the interferometric test due to the large departure from the correct surface at early stages of the polishing. The non-null test will be performed with the large fold sphere [6] (a component of the "principal test") as shown in Fig. 4(a). Fig. 4(b) shows an initial concept verification test result where the mirror image shows the corresponding scan line. The line is partially blocked by some mechanical structures and also the background light is not well controlled, however a background image can be removed from the data to reduce this effect. These issues will be corrected in later tests.



(a) **(b)**

Fig. 4 (a) Basic SCOTS setup for testing the GMT system, (b) initial data where the mirror image shows the corresponding scan line. The line is partially blocked by some mechanical.

5. Summary

SCOTS is a computerized surface slope test. It is as useful as a quantitative Ronchi for opticians and it is easy to setup and perform. We show the basic principle of SCOTS and the algorithms for solving phase ambiguity. It overcomes the short comings of PMD so that more complex objects can be measured. SCOTS can have a measurement resolution at the nanometer level the same as the PMD method has. Because SCOTS can work in caustic region of the test surface, it needs a smaller monitor screen which is especially useful for measuring large and fast surfaces.

6. Acknowledgement

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7. References

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