Investigations on the techniques for development of high resolution optical systems for earth observation

A thesis submitted
in partial fulfilment for the Degree of

Doctor of Philosophy

by

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JULY 2014

ABSTRACT

Optical system is one of the major elements of a sensor for remote sensing. Remote sensing is acquiring of information about an object or phenomenon without making physical contact with it. A large number of missions carrying variety of sensors have been launched providing priceless information leading to the establishment and operationalization of a large number of applications of the remote sensing technology. Earth observation satellites are categorized as low (> 100 m), medium (10-100 m) and high (< 10 m) spatial resolution. Over the years with the advent of newer technologies, there is a growing demand for higher spatial resolution optical system for the earth observation. The limiting resolution for observing the earth through atmosphere i.e., from space is estimated as 4.6 cm. One can expect that the demand for the spatial resolution of a classical earth observation sensor may extend till the limiting resolution.

The performance metric of an imaging system is, in general, defined by the product of the modulation transfer function and the signal to noise ratio. The desirable goal of a sensor design is to achieve a near photon noise limited signal to noise ratio and a diffraction limited modulation transfer function at nyquist spatial frequency. The modulation transfer function, more pertinent to optical systems, mainly depends on the optical system aperture ratio. In the past, smaller F-number (typically F/4) optical systems were adopted to have adequate margin for the modulation transfer function and the signal to noise ratio with respect to the final specification. Increase in spatial resolution demands for longer focal length optical system. However the commensurate increase in the aperture to meet the practised F-number is constrained by issues pertaining to fabrication and testing, assembly and alignment, retention of optical elements position in the instrument structure, launch load and envelope. Therefore, the margin in the modulation transfer function available for various stages of development of a high resolution optical system to meet the final specification is less and becomes critical.

The critical nature of the modulation transfer function which is one among the performance metric of the optical system needs to be addressed at

various stages of development of a high resolution optical system. The development of an optical system is basically categorized as (1) design, (2) components fabrication, (3) assembly and alignment and (4) test and evaluation stages.

In the design stage, we have developed a baffle design method based on a combination of the results of optical design software and analytical relations formulated herein. The method finds the exact solution for the baffle parameters of a modified Ritchey–Chretien telescope by iteratively solving the analytical relations using the actual ray coordinates of the telescope computed with the aid of an optical design software. The baffle system so designed not only blocks the direct rays of stray light reaching the image plane but also provides minimum obscuration to imaging light. Based on the iterative method, we proposed a baffle design approach for a rectangular-image-format telescope. We have verified the performance of the baffle design method through a numerical experiment using a realistic modified Ritchey–Chretien telescope model with a standard light analysis tools. Also the baffle design method is implemented in the planned next in series optical system of cartography satellite of Indian Space Research Organisation.

The optical elements (mirrors) are held in position in the telescope using mechanical mounts/structures. Flexure mounts are being used to reduce the distortions on the mirror surface that arise due to deformations of mechanical interfaces. The mirror and the flexure called *mirror assembly* are held together with an adhesive. To investigate the procedures in the assembly stage, we have prepared samples and carried out experiments in detail, for the known space qualified adhesives, to understand the adhesive-induced stress and other effects on space-borne optical components. Cases and parameters that are not reported elsewhere for adhesives Epotek-301 and 3M 2216 B/A gray are experimentally studied and discussed here. We have also attempted from the results, with the known properties of various space-qualified adhesives, to establish an empirical relation that helps to identity adhesives for space borne high resolution optics.

It is necessary not only to evaluate but also to understand the degradation of performance of a space borne optical system that occurs during various tests and operations. We have proposed and designed a wavefront analyser based on

Shack-Hartmann wavefront sensor to test the optical system in an electro optical module. We have analysed the effect of parameters of the wavefront sensor on the accuracy of wavefront determination. During the development of wavefront sensor, while addressing experimentally the effect of parameters on wavefront retrieval accuracy, we have proposed and demonstrated new methods of determination of focal length of microlens array using (1) spherical and (2) plane wavefronts. Those methods also facilitate in the axial positioning of the microlens array in the wavefront sensor configuration; hence improves the determination accuracy of wavefront. The wavefront sensor which is developed is demonstrated by evaluating the wavefront that emerges from a simulated-telescope and the results are compared with that of the standard interferometer which is configured for an *in situ* measurement. The comparison of results after calibration showed a close match between the two methods and hence supporting the utility of the proposed wavefront sensor for the testing.

The work reported here in terms of methods, hardware development and experimental studies demonstrate that there is an overall improvement on the development of high resolution optical systems for earth observation.