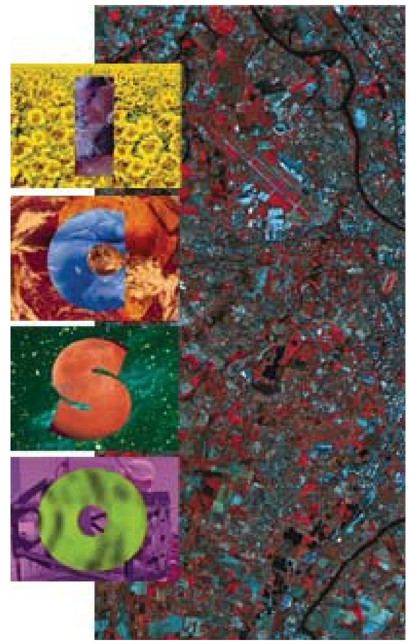
International Conference on Space Optics—ICSO 2000

Toulouse Labège, France

5–7 December 2000

Edited by George Otrio



Large-scale dimensional measurement in the space environment using multi-lateration techniques

Graham Peggs, Ben Hughes, Alistair Forbes

International Conference on Space Optics — ICSO 2000, edited by George Otrio, Proc. of SPIE Vol. 10569
1056907 · © 2000 ESA and CNES · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307949

LARGE-SCALE DIMENSIONAL MEASUREMENT IN THE SPACE ENVIRONMENT USING MULTI-LATERATION TECHNIQUES

Graham PEGGS, Ben HUGHES and Alistair FORBES

National Physical Laboratory, Teddington, UK

ABSTRACT - *Multi-lateration[i] measurement techniques are described which are expected to lead to significant improvements in the accuracy with which large structures, such as optical and x-ray telescopes and radar arrays, could be precisely assembled in space. A high-accuracy system is described, the working volume of which could be significantly extended for use in such applications.*

1 - INTRODUCTION

The assembly of progressively larger instruments in space, such as the next generation of x-ray and optical telescopes and radar arrays, will require advanced techniques, such as multi-lateration, for the precise positioning and alignment needed to achieve the anticipated very demanding performance targets. The technical approach proposed in this paper is expected to have important applications in the construction and/or deployment of space instruments, and also to be applicable to monitoring the long-term dimensional stability of such structures. In the future, new super-lightweight types of telescopes, which may be so large that the primary mirror and the viewing optics are completely separated, will require accurate 6 degrees-of-freedom positioning and station keeping.

Measuring instruments using this approach have been cited in the literature for some years, for example both 2-dimensional [Brow 67], for measuring aerial photographs, and 3-dimensional [Egda 83], for measuring mirrors, systems have been described. Recently, however, technical developments have enabled sub-micrometre accuracies to be achieved using an advanced form of the multi-lateration approach.

In essence, a multi-lateration system comprises four key elements:

- ***a steerable, length measuring, system*** – the critical feature of which is to steer a laser interferometer beam without introducing apparent changes in the beam path;
- ***a target (retro-reflector) with a wide angle of acceptance*** – the key design parameter is the perfection of the geometry of the optics so that the beam is neither distorted, nor are erroneous

[i] Multi-lateration is a way of measuring the position of a target, or targets, relative to several fixed measuring stations. Measurement data associated with the relative displacements of the target with respect to each of the measuring stations is collected as the target is moved through a calibration cycle. General speaking, these positions will cover a large part of the volume encompassing the locations of the measuring stations. From this displacement data the spatial coordinates of the measuring stations can be determined as well as the positions of the target. When a target is subsequently located at or near the key features of the component to be measured the coordinates of the measuring stations are used to determine the coordinates of the target and hence the features of interest.

displacements introduced when lasers beams are incident upon the retro-reflector at different angles. In the past a split hemisphere design has been widely used [Hart 70], but recently glass with a refractive index close to 2 has become available so that perfectly spherical glass retro-reflectors can be made.

- ***algorithms to compute the target and the measuring station co-ordinates and to evaluate the uncertainty of measurement*** – whilst the computational procedures for the multi-lateration approach appear simple, poor algorithms can lead to unacceptable errors in computing co-ordinates.
- ***a self-calibration procedure*** – this enables both target and measuring station co-ordinates to be determined simultaneously, thus avoiding the problems associated with possible system long-term instability.

Recently a multi-lateration measuring system has been developed at NPL that achieves significantly better positional accuracy than previously possible. Although the system is intended as part of the new UK primary standard co-ordinate measuring machine, the generic technique has wider applications in the field of large-scale metrology. The work undertaken at NPL has been aimed at developing a very high accuracy (300 nm uncertainty) measuring system for use in a modest (600 mm cube) working volume [Hugh 00]. The prime purpose of this instrument is to provide a method of measuring mechanical reference artefacts to disseminate the unit of length to industrial CMMs and to provide a means of evaluating ***task-specific measurement uncertainty***.

Several new developments are embodied in the NPL instrument, for example a retro-reflector manufactured from glass with a refractive index of 2 and a special tracking system that significantly reduces the uncertainty due to beam steering; see figure 1 below. Nevertheless, the refractive index of the air in the interferometer paths is the most significant remaining source of uncertainty, and corrections (that are inevitably approximate) are necessary for terrestrial systems in order to deliver high-accuracy measurement. Clearly the advantage of the space environment is that such corrections are not needed, with the corresponding improvement in potential accuracy of the method, particularly over long distances. In the following sections some possible applications are proposed.

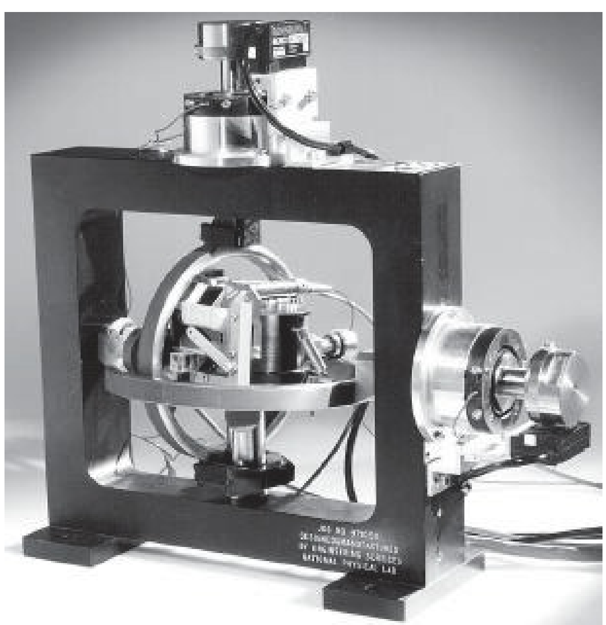


Fig. 1: The measuring station for the multi-lateration system.

2 – FUTURE DEVELOPMENTS

The most suitable applications for multi-lateration are where a large structure needs to be deployed and the final shape and/or size is critical to its functionality, for example a large antenna or telescope. With the future trend towards extremely large, lightweight structures, such as the Very Large Aperture Observatory and beyond, the requirements on measuring the deployed structures will become an important facet of any mission.

In order to achieve yet further versatility from the multi-lateration approach it is expected that absolute length measuring techniques will be used, either with time-of-flight techniques [Park 99], swept frequency, or multiple wavelength techniques. In this case, the complications created by interruptions to the laser beams are eliminated. Moreover, the laser beam could be switched from one measuring station to a multiplicity of targets to enhance considerably the accuracy of the measurements due to the additional data redundancy and extra rigidity in the station-target configuration. Although attractive in principle, the difficulties in providing beam-steering mechanisms for such a system are considerable but technically tractable.

3 - CONCLUSIONS

Multi-lateration techniques offer one of the few viable ways of accurately measuring the relative positions of components in space. The technique will not only open the door to new, very large, telescope designs not depending on a rigid supporting structure to define their geometry, but also be an important phase in commissioning ultra-large telescopes.

REFERENCES:

[Brow 67] D.C. Brown : “Computational trade-offs in the design of a comparator”, *Semi-Annual Convention of the American Society of Photogrammetry*, St. Louis, Mo., October 1967.

[Egda 83] M. Egdall and R.S. Breidenthal : “Large surface measuring machine”, *Applications of Optical Metrology – Techniques and measurements II*, (SPIE) 416, 1983, pp.62-68.

[Hart 70] A.W. Hartman : “A wide-angle retro-reflector”, *NBS Report* 10832, 1970.

[Hugh 00] E.B. Hughes, A. Wilson and G.N. Peggs : “Design of a high-accuracy CMM based on multi-lateration techniques”, **CIRP Annals**, 49, (1), 2000, pp.391-394.

[Park 99] D.H. Parker and J.M. Payne : “Metrology system for the Green Bank Telescope”, *Proceedings of the 1999 Annual Meeting of the American Society for Precision Engineering,* Monterey, California, November 1999, pp. 21-24.