

Review

Laser trackers for large-scale dimensional metrology: A review



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ABSTRACT

Thirty years since their invention, laser trackers are now recognized as the measurement tool of choice in the manufacture and assembly of large components. The general design of laser trackers, i.e., a ranging unit on a two-axis gimbal, has not changed significantly over the years. However, innovations in ranging technology, for example, the emergence of increasingly accurate absolute distance meters (ADMs), are providing users with an alternative to interferometers (IFMs). Hand-held accessories such as touch probes and line scanners are expanding the scope and applicability of laser trackers. In this paper, we survey the literature in all areas of laser trackers as applied to large-scale dimensional metrology (LSDM), with emphasis on error modeling, measurement uncertainty, performance evaluation and standardization.

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1. Introduction

The laser tracker was invented in the mid-1980s by Lau et al. [1–3] at the National Institute of Standards and Technology (NIST) to facilitate robot metrology. Laser trackers are portable coordinate measuring systems (CMS) that measure the three-dimensional coordinate position of a cooperative target such as a spherically mounted retroreflector (SMR). The instrument records the distance to the target along with two angles, providing position data in a spherical coordinate system. Two closely related spherical coordinate systems are a coherent laser radar based system [4] and the laser tracer [5]. The coherent laser radar based system operates without the need for a cooperative target and does not track the target. In that sense, it is more closely related to large volume terrestrial laser scanners and therefore not considered in this review. The laser tracer does require a cooperative target and tracks the target in the same manner a tracker does. The laser tracer, however, only reports range to the target and not angles, and is intended to be used in a multilateration scheme (see Section 3.3).

Much of the research and development activity during the last 30 years has been in the areas of absolute distance meter design, modeling of instrument error sources and estimation of uncertainty, improving accuracy using multilateration, design and testing of hand held accessories, and the development of performance evaluation methods and standardization. These efforts have tremendously increased the scope and applicability of laser trackers. Today, laser trackers are the measurement tool of choice for a multitude of applications (see Section 5). These include robot metrology, manufacture and assembly of large components such as aircraft wings and ship hulls, error mapping of coordinate measuring machines (CMM) and machine tools, providing reference measurements for large volume laser scanners and distributed metrology systems (such as indoor GPS), automotive panel assembly using hand held accessories, and alignment of large optics and structures for astronomy and nuclear industry. In this paper, we survey reported literature in all research areas of laser trackers as applied to large-scale dimensional metrology (LSDM), with emphasis on error modeling, measurement uncertainty, performance evaluation and standardization.

This paper is organized as follows. The principles of laser tracker operation and the major sources of error are described in Section 2. This section includes discussions on ranging technology, opto-mechanical errors, geometrical error models, compensation procedures, targets, and hand-held accessories. In Section 3, we address improvements to measurement accuracy through multilateration measurements such as bundle-adjustment procedures and multilateration. Performance evaluation tests, documentary and material standards, traceability, and measurement uncertainty are covered in Section 4. We provide an overview of some of the applications in Section 5, followed by conclusions in Section 6.

2. Principles of operation and error sources

A laser tracker is comprised of several key sub-systems: the ranging unit, the two-axis steering mechanism, the tracking mechanism, environmental sensors, and targets. We describe the

sub-systems, associated error sources, geometrical error models, and compensation procedures in this section.

2.1. Sub-systems

A laser tracker is an assembly of various mechanical and optical components. A schematic of one design of a tracker is shown in Fig. 1. The instrument has two rotation axes – a standing axis (vertical axis) and a transit axis (horizontal axis). In ideal geometrical configuration, the two axes are orthogonal to each other and intersect at a point that serves as the origin for the spherical coordinate system defined by the tracker. The path of the laser beam from the instrument to the target ideally intersects this origin and is perpendicular to the transit axis. One angle encoder is mounted coaxially with the standing axis to read the horizontal angle while the second encoder is mounted coaxially with the transit axis to read the vertical angle. The encoders are not shown in Fig. 1.

A portion of the beam emerging from the source (laser-head) is retained within the system as the reference beam for interferometric fringe counting. The measurement portion of the beam

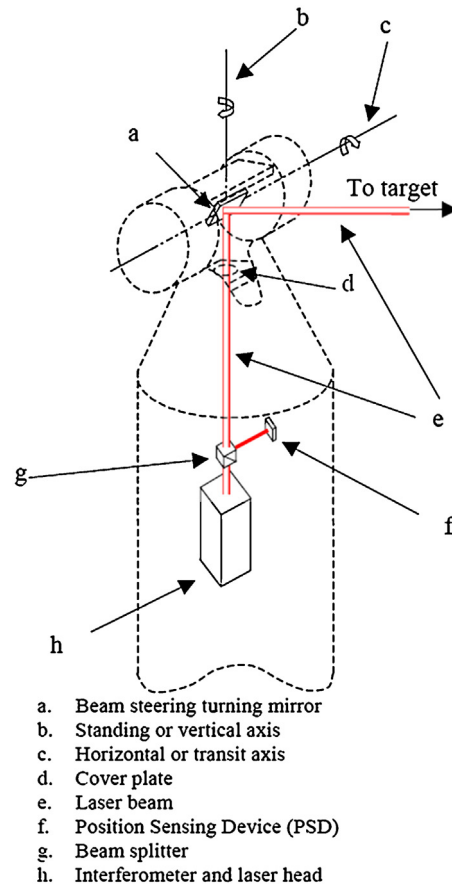


Fig. 1. Construction of a laser tracker with a beam steering mirror (angle encoders are not shown in the figure) [Source: Sawyer et al. [10], reproduced with permission from ASPE].

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