MEASUREMENT OF STRUCTURES (SURFACES) UTILIZING THE SMART 310 LASER-TRACKING-SYSTEM

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Abstract

Coordinate measuring devices such as CMM machines, Photogrammetry Systems, Manual Theodolite systems have been introduced already some years ago. To get 3-D coordinates from the objects they have to be dislocated to the CMM machine or have to be measured from at least two different stations with photogrammetric or manual Theodolite systems. A laser Tracking system has been developed for 3-D-measurements of object points with a single sensor-head.
Principles of the Laser Tracker function will be explained in this paper. Accuracy is derived taken into account the resolution of the interferometer and of the angle encoders. Typical positioning accuracy of a static point is better than 10 ppm. Physical limitations of the measuring unit (Laser Tracker) have to be taken into consideration as well.
Comment and conclusions will conclude the paper.

1 Introduction

The basic technology of the SMART 310 Laser Tracker was developed by a small group at the National Bureau of Standards in the USA. The further development was continued at ‘Automated Precision Inc.’

Leica improved and redesigned completely the Laser Tracker and presented the SMART 310 Laser Tracker at the 1990 Quality Show in Chicago.
The advent of new 3-D metrology systems that can measure huge amount of points on an object has created both new opportunities and new problems. The resulting measurement files may contain up to thousands or even tenthousands of points. This gives us the possibility to describe surfaces with a large amount of points. The disadvantage is, that the most common CAD programs are completely overwhelmed by the file size.

2 Technology

2.1 The Sensor

A single beam laser interferometer to measure distances, and two high precision angle encoders to determine vertical and horizontal angles, are used. The system gives as results distances and angles. The laser beam is used as well for the detection of the directions. A two-axis photosensor is used to receive the reflected laser beam and is responsible for the tracking facility of the SMART 310. The Trackers 'Home Point' supports a retroreflector and sets the laser interferometer's initial distance.

2.2 The Controller

The controller contains the main electronics and treats all signals to and from the tracker head. Component are:

- Motor Amplifiers
- Encoderelectronics Boards
- Interferometer Board
- Power Supplies
- Furthermore all signals will be transferred to the TP.(Tracker Processor)

2.3 The Tracker Processor (TP)

Consists the following parts:

- 486 Main Board
- Analog / Digital Boards
- Encoder Boards
- LAN Board
- ROM disk Board

The hardware related software (firmware) is downloaded from the AP (Application Processor = PC) after each system's start.

2.4 The Application Processor

The application processor is a common PC 486 or Pentium used to run the SMART 310 software.

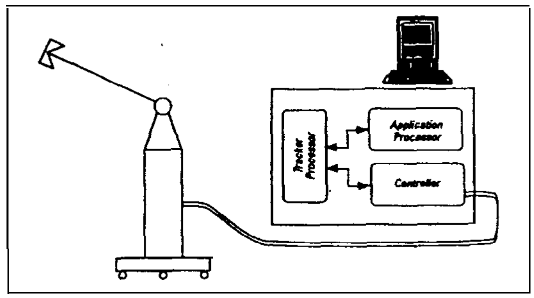

Figure 1
System configuration

3 System

3.7 System preparation

A very short preparation of the measuring system is needed. After switching on all components, the laser must heat up for approx. 20 min. In the meantime preparations to perform the necessary measurement can be done. The following procedure is needed:

- Position the tracker near the part you wish to measure. Ensure that the entire part or surface is visible from the desired location. Relative stability is very important.
- Power on all components and allow at least half an hour warm up.
- Measure control points (if existing).
- Perform transformations (axis alignment, least square, translations or rotations)(if needed).
- Measure structure (surface)

3.2 System *description*

The principle of the SMART 310 Laser Tracker is described in chapter 2.1. Because the laser beam is also used to determine the direction (movement) of the target it is absolutely necessary that this laser beam has a high accurate stability in direction and, regarding the beam diameter, an intensity according to Gauss. The speed of the target (Retroreflector, see chapter 5) is influencing the measurement capability and the accuracy as well. The sensitivity of the photodiode is essential for the measurement of the direction. The biggest influence of all optical component is on the retroreflector's side. Figure 2 is showing the schematic construction of the SMART 310.

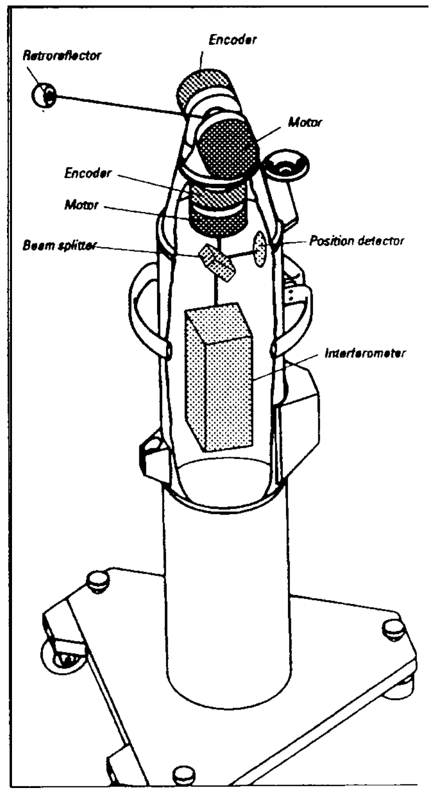

Figure 2
Principle of the optical
way of the laser beam

4 The measurement principle

The mechanism for the beam-steering allows to read horizontal and vertical encoders. Together with the distance measurement from the interferometer this will result in a spherical coordinate system. The measured data are azimuth, elevation and distance. See figure 3

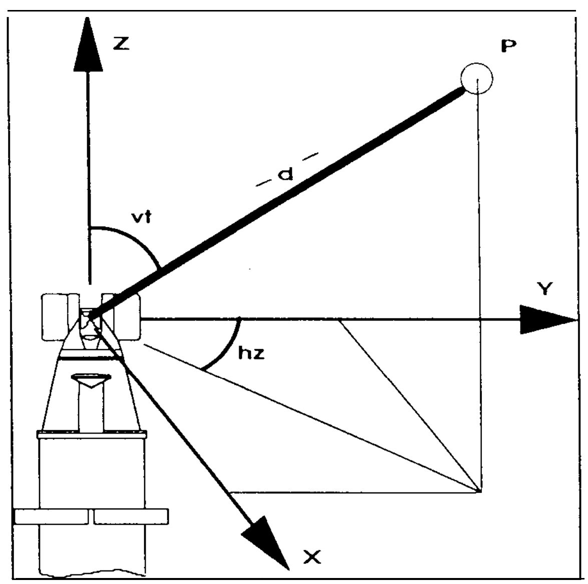

Figure 3
Principle of Distance
and Angle Measurement

4.1 Resolution and Accuracy

The interferometer resolution is 1.26 µm (micrometer). An accuracy of about 1 ppm can be achieved with a linear interferometer. Angular encoders deliver a resolution of 0.7” (arcseconds). The angular resolution for both the azimuth and the elevation is the same, but the resolution for the elevation is double the azimuth’s resolution because of the measurement principle of the tilting mirror. (See figure 4).
An overall reproducibility of a point Coordinate (X,Y,Z-values) of ± 5 ppm (µm) can be achieved.
A typical absolute accuracy (coordinates) for a non-moving target will be ± 10 ppm (µm)
A typical absolute accuracy (coordinates) for a moving target will be ± 20 - 50 ppm (µm) as a function of the acceleration.

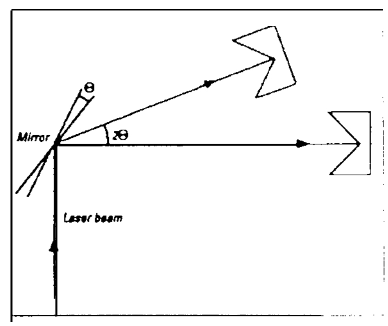

Figure 4
Double Angle Reflection

5 Hand held Retroreflector (Targets)

Two types of hand held retroreflectors are existing. The Corner Cube Ø 1½ ” and the Cateye Ø 75 mm. Beside of the different principles of the below described retroreflectors both types are manufactured with the same high precision to guarantee an absolute accurate measurement of the center of the target.

5.7 Corner Cube

Corner Cubes (Figure 5) are used for very high precise measurements for shorter distances (< 2m). A reception angle of ± 20 Deg. describes the working range of the corner cube.

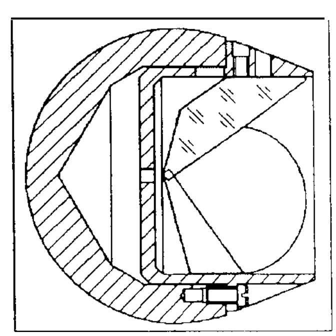

Figure 5
Corner Cube

5.1.1 Surface Target

A combination of the above described Corner Cube and a special device will lead to the ‘Surface Target’. The specialty of this target is to measure a virtual point on a surface without any offset !

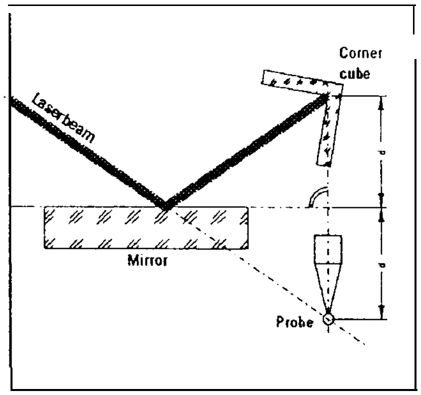

Figure 6
The Principle of the Surface Target

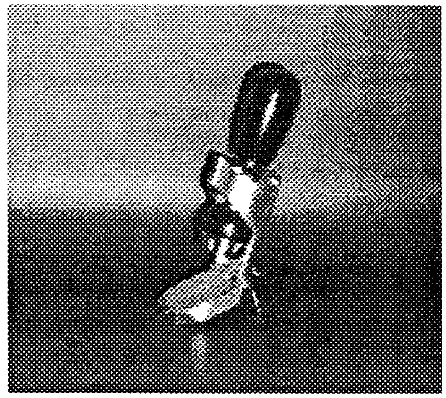

Figure 7
Surface Target

5.2 Cateye

Cat Eyes are mainly used for distances > 2m. They are easier to handle because of the bigger working range of ± 55 Deg.

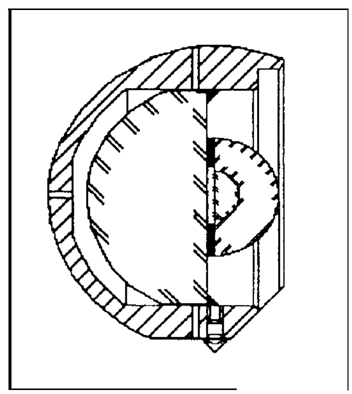

Figure 8
Cat Eye

6 Measurement

6.1 Methods

A variety of measuring methods are possible. Each method has its advantages. Because the tracker’s control software it is capable to measure hundreds of points within a second.

Tooling balls are standard targets to measure control points. To rapidly measure a contoured surface or any other large amount of points, a hand held retroreflector can be used. The collection rate can be defined in different ways by the user.

Tooling balls as standard targets are used as control points. Special adapters (Flush Mount Bolts) are used to measure the center of the tooling balls. Mathematical methods utilizing least-squares transformation are used to calculate the transformation and its parameters such as rotations, translations and scale.

To be able to measure surfaces with a high data collection rate, the retroreflector (each of the above mentioned types) can be moved by hand (see figure 7) over the entire surface while the tracker is measuring and storing permanently points into the database.

Point separation can be decided from the user either by time- or distance separation.

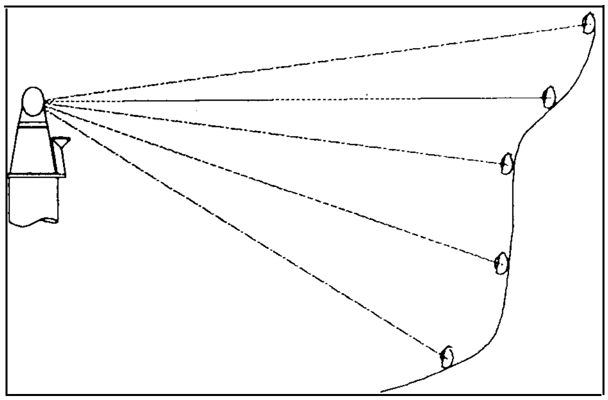

Figure 9
Principle of target movements

6.2 Cautions to the measurements

The following actions must be considered when using the SMART Laser-tracker:

Don't collect too much data. Too much data can cause problems in analysis.

The tracker is measuring the center of the retroreflector only (except the 'Surface Target'

Take care about a stable tracker and object place. If there is any movement during measurement, the entire coordinate set moves.

If the laser beam has been broken it must be re-established. A simple process but time consuming if happens frequently.

If a curvature has a small radius the target will not describe the correct surface. To avoid any incorrect measurements in this case, the user should use the 'Surface Target'

6.3 Reflector Offset

For each of the described retroreflectors (see chapter 4) (except the 'Surface Target') a constant offset is existing. This offset can be taken into consideration while calculating surfaces with a CAD program, or by using the 'Surface Target'. For very precise surface measurements the 'Surface Target' is a most welcome tool to avoid any offset and measuring single points or surface points directly on actual positions.

Errors in this process may arise when the measured surface deviates from the actual surface. To avoid the error (see figure 8) the ‘Surface Target’ (see figure 5) should be utilized.

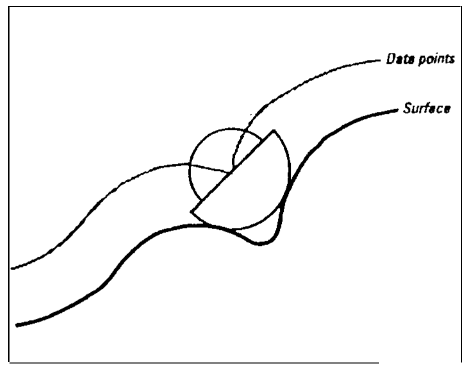

Figure 10
Reflector Offset

7 Data Treatment

A CAD system is required to analyze the data gathered by the SMART lasertracker. The complexity of defining and analyzing surfaces requires a experienced CAD operator. If surfaces are measured with the corner cube or the catseye the handling of the data is even much more complex. Most CAD systems are capable to handle the target offset. If the normal vector is not oriented properly, the results will contain an error. Typical error is about 0.002 mm per degree of angular deviation when the ‘Surface Target’, which creates points on the surface directly, is used. Another method to avoid any error is to create a rough surface from the measured ‘parallel’ surface, and than transfer (shift) the whole measured surface to the correct position.

8 System features

8.7 Portability

The SMART 310 lasertracker is easy to roll from one location to an other. Or can be transported by station wagon to another facility.

8.2 Checking

A simple two hours on site adjustment procedure will ensure system integrity.
(A CMM machine needs an extensive calibration procedure of days or even weeks).

8.3 Data Collection Rate

A high data collection rate provides a decrease of measurement time for large structures with a huge amount of points. Experiments have shown an obvious cost saving and a tremendous increase of productivity. Short measurement duration also guarantees a minimum of thermal influence on the measurements.

8.4 Analysis

When using the Cornercube or the Cat Eye as a target, the analysis of data is more difficult than with common CMM machines because of the retroreflector offset. Using the ‘Surface Target’ or utilizing a high sophisticated CAD software will simplify the data exchange and the treatment of the measurements. Data transfer to any CAD or other programs like statistical analysis by means of ASCII-files is a simple and easy task.

9 Applications

A wide range of measurement tasks can be performed with the SMART 310 lasertracker. Since both static and kinematic measurements can be performed movement of machines can also be measured. Possible applications are:

- Digitizing of surfaces
    - Parabolic Antennas
    - Car Bodies
    - Airplane Wings

- Adjusting and Inspection
    - Aeronautics
    - Automotive

- Kinematic Measurements
    - Robots
    - Welding Machines
    - Cutting Machines

- Calibration
  - Jigs and Figures
  - Robots

- Monitoring
  - Probes in Windtunnels
  - Geometric Structures in Nuclear Power Facilities

10 Conclusions

The tracker holds great promise to measure structures. Single points, contours and surfaces could be measured with an adjustable data collection rate. Surfaces measured on the shop floor can be compared immediately to nominal values. The SMART laser-tracker also allows a great flexibility by not requiring climate controlled facilities.

11 References

[1] Loser R. 1993. ‘Laser-Tracking-System’ tm - Technisches Messen, Heft 5 1993

[2] Mc Kelvey C. 1994. Surface Analysis and Reverse Engineering ‘Coordinate Measurement Newsletter’, Winter 1994