

Automated Optical Qualification Method for Position Sensitive Diodes

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This study introduces an automated optical calibration method for position sensitive diodes in context of robot-based laser material processing, achieving a maximum positional error of 15.16 μm . The method optimizes conversion factors between measurements and target positions as well as coordinate system alignment, showcasing significant accuracy.

1 Introduction

Robot-based laser material processing offers significant potential due to its high degree of freedom. With processing heads such as galvanometer scanners, both the control complexity and the degree of freedom increase. A suitable method for evaluating trajectory accuracy in these processes is essential. Additionally, an easy and fast method for measuring laser spot positions is necessary for testing algorithms for online trajectory control.

Robot movements are often measured by absolute laser trackers, which determine the position at a fixed point on a mechanical part. However, to evaluate the entire kinematic chain, consisting of the robot as the mechanical component and the optical part based on galvanometer mirrors, an optical evaluation method must be used to measure the actual laser spot position on a surface. This can involve using a camera or a position sensitive diode (PSD). For evaluating trajectories in laser material processing, a time-resolved measurement capability with high read-out speed is required.

2 Fundamentals

A position sensitive diode is based on a semiconductor. An exposure, e. g., by laser spot, leads to a local change of resistance on the semiconductor surface, resulting in an electron flow I . On each side of the sensor the electron flow, defined as $I_{1\dots 4}$, is measured. The amount of current flow is dependent of the exposure position relative to the electrode. The conventional position estimation is based on the current ratio as stated in formula (1) and (2) for both directions, multiplied with a constant k [1].

$$x = k_x \frac{I_1 - I_2}{I_1 + I_2} \quad (1)$$

$$y = k_y \frac{I_3 - I_4}{I_3 + I_4} \quad (2)$$

State-of-the-art approaches for estimation improvement offer more accurate predictions and effectively

address nonlinearities [2]. A parameter optimization is mandatory for both approaches.

3 Experimental Setup

The setup consists of a Universal Robot UR5e with a Scanlab ScanCube7 galvanometer scanner mounted on the robot's tool flange. A fiber laser is connected to the galvanometer scanner. Below, a PSD mounted on a PI M-824 hexapod is placed (see Fig. 1). The qualification method is evaluated with a Hamamatsu S2044 PSD.

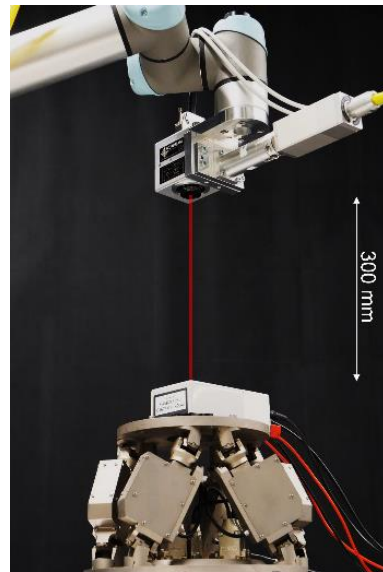


Fig. 1 Experimental setup of scanner-enhanced robot and position sensitive diode mounted on a hexapod. Robot and scanner are positioned once, hexapod execute calibration pattern.

The sensor output signals are scaled, shifted to 0 V to 5 V and converted by a 16-bit analog digital converter ADS1115 with maximal readout of 860 samples per second.

For calibration purpose the scanner mirrors point exactly downwards. Robot position and orientation is set up such that the laser beam is orthogonal to sensor surface. The distance between scanner and sensor surface equals the focal length of the

scanner's lens (300 mm). Robot and scanner mirrors are not moved in further procedure.

4 Methodology

This approach is used to be able to generate data for calibration purpose automated. The coefficients k_x and k_y as well as the orientation error between sensor and hexapod coordinate system should be optimized. This approach can be easily and quickly adapted for more elaborate estimations. The focus of this study is not on achieving the most accurate estimate, but on the degree of automation.

The hexapod is intended to perform a spiral-like movement as shown in Fig. 2 starting at the center. Advantages of this movement procedure are low time for movement as well as the opportunity for easy expansion. At each position a measurement is done.

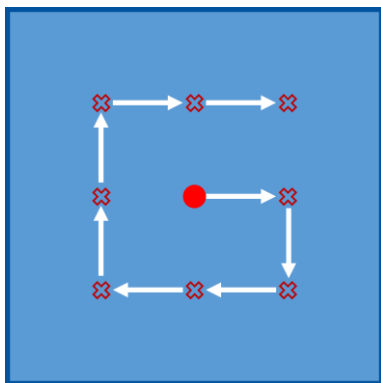


Fig. 2 Schematic of the calibration pattern. The red dot symbolizes the laser spot and white arrows the relative movement based on the sensor movement.

After data acquisition optimization is carried out. The conversion factor between the measured voltage and the target position for hexapod is optimized due to minimize the maximum error. Due to orientational inaccuracies of the mountings and coordinate systems the measurements are done iteratively with different rotations around z-axis of the hexapod. A step width of 0.05° is used for tests but can be adapted due to demands. The minimal error of all steps leads to the best fitted orientation.

A repeatability investigation is also carried out by doing the same measurement procedure several times. The configuration with smallest error is done ten times to check reliability of founding.

5 Results

Measurements show that the used PSD does not have major distortion effects based on its design. The calibration is focus on finding optimal conversion factor. The optimization of the conversion factor based on 81 measurement points leads to a maximal error $15.16 \mu\text{m}$ with an orientation correction around z-axis of -0.6° by step width of 0.05° .

Repeatability test leads to a combined repeatability of $9.38 \mu\text{m}$, defined by the sum of the standard deviation in x- and y-direction.

6 Discussion

The methodology demonstrates a user-friendly and highly automated approach for calibrating PSDs automatically, eliminating the need for manual and time-consuming adjustments. Trajectory evaluation can be performed quickly at various positions or segments of the trajectory. The sensor undergoes automatic calibration and orientation.

This approach achieves performance comparable to that of commonly used laser trackers in robotics. A key advantage over laser trackers is the ability to evaluate both the mechanical and optical kinematic chains. However, a limitation is the sensor's small measurement area. To investigate additional trajectory segments, the sensor can be repositioned using a hexapod.

7 Outlook

The proposed calibration method can be easily adapted for any device, regardless of the manufacturer. For larger PSDs, nonlinearity is likely to increase; therefore, this approach will be tested on larger sensors. Additionally, the same setup can be used to calibrate galvanometer scanners and verify their accuracy. For future research in closed-loop control, this setup, with its automatic calibration method, can serve as sensory input when moving the scanner-enhanced robot instead of the sensor.

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