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Compensation strategy for positioning inaccuracies in robot-based laser structuring

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Abstract

Laser structuring is used to texture complex 3D geometries, such as moulds for plastic injection moulding. However, due to the complex plant technology, common machines for laser structuring are very expensive and require lots of space. We developed a laser-structuring module which can be held by an industrial robot for large-area structuring. This can reduce the investment costs in the technology by up to 80%. The precision of the handling system is of major importance for laser-structuring. We developed a strategy to compensate for system-related positioning inaccuracies of the robot. For this purpose, an inline camera is used for a target-actual comparison. The camera system is able to detect reference markings as well as features of the texture itself. During the structuring process, the position error of the robot is compensated adaptively by determining the difference between the target and actual position in the region of interest and applying the difference to modify the toolpath accordingly.

Keywords: Laserstructuring; Robot; Large-Parts

1. Introduction

Laser structuring is used to repeatedly mark or engrave complex 3D geometries. For this purpose a focused, pulsed laser beam scans a target surface using a high precision galvo-scanner [1]. The scanning field is limited, therefore large surfaces must be divided into sufficiently small patches which are then sequentially processed. In order to avoid visible transitions between the processed patches, precise repositioning of the structuring system is of critical importance. Deviations of even a few micrometers lead to optically recognizable seams. This high demand on positioning accuracy requires reliable high precision system technology. Processing e.g. large moulds in the automotive industry like moulds for bumpers, instrument panels or centre consoles, requires complex and cost intensive plant technology [2]. Investment costs for systems with a working volume of 6 m³ quickly exceed 1.5 million €. In contrast, only a fraction (approx. 50k-75k €) of the costs are accounted for by the actual laser system. Robot systems therefore present a cost efficient alternative for laser processes. Today, such systems are mainly used in laser material processing for laser welding or laser cutting [3]. Their commercial application in laser ablation is limited, as the positioning accuracy of robot-systems is not sufficient for this purpose. Currently, even high precision robot-systems - within the relevant range of working volumes – cannot exceed positioning accuracies of approx. 0.3 mm [4].
There are several ways of dealing with robot positioning inaccuracies. For example, path and positioning deviations can be compensated for using external laser trackers or stereo cameras [5]. Such systems increase the total costs by 100k to 150k €. Unfortunately, the resulting increase in accuracy is still insufficient for the purpose of laser structuring.
We developed an approach that accepts the system-related inaccuracies of positioning the laser structuring module using a robot system, and then compensates the resulting error using an inline-camera based optical reference system.

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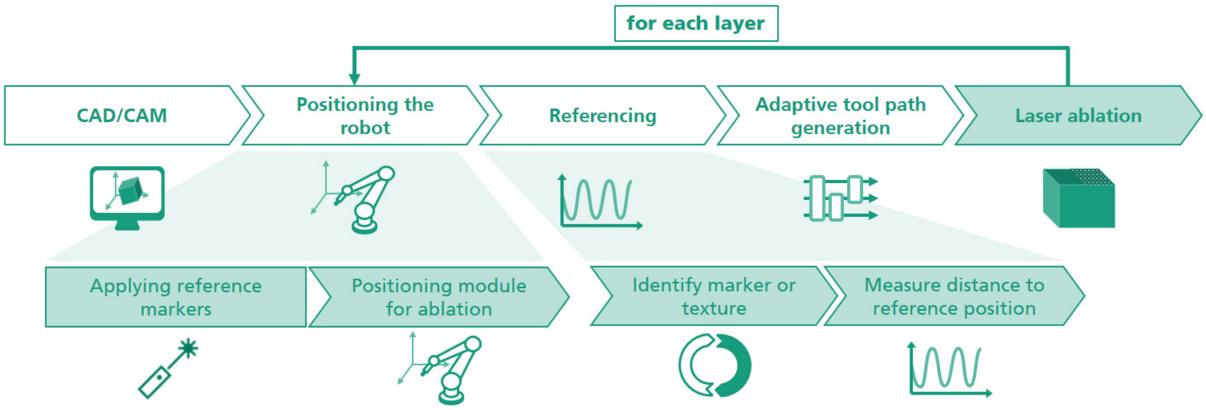
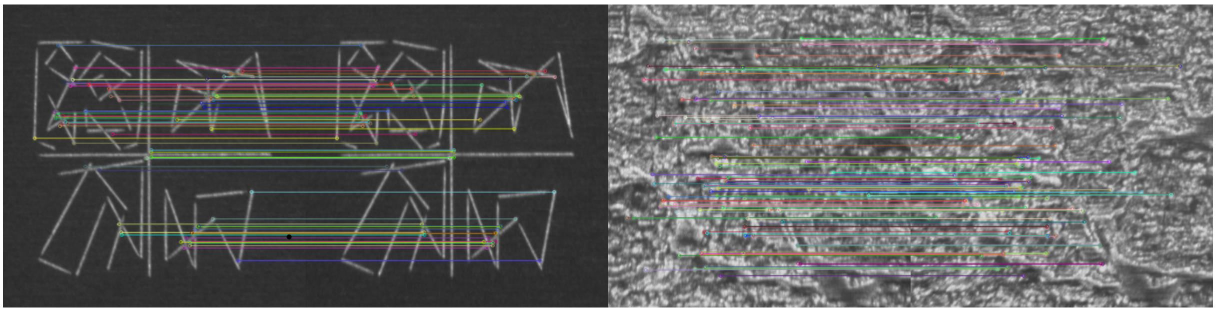


Fig. 1. Process chain for robot based laser structuring.

2. Technical approach

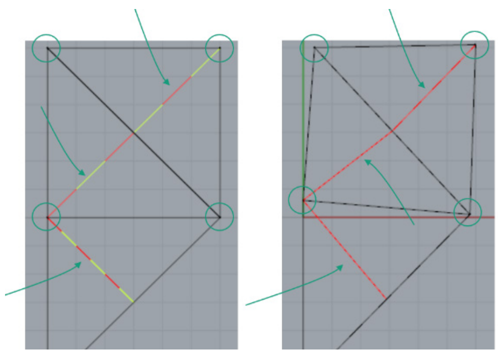
The compensation method is mostly based on system components which are already required for laser structuring. Figure 1 shows the developed process chain for the compensation of positioning inaccuracies and the subsequent adaptive toolpath planning. The first process "CAD/CAM" pre-calculates tool paths for the laser module as well as the robot that positions it. The latter tool path is checked for collisions. In the next step, “Positioning the robot”, markers are applied by the laser system at defined positions on the surface, see Figure 2a. These markers serve both as anchor points for the texture and as a mean for position determination of the robot system in the following steps when applying the structure. The marker positions are approached individually by the robot system and



a) b)

Fig. 2. calculated displacement vector for (a) a marker and (b) the texture itself.

positional inaccuracies of the system are deliberately tolerated. The integrated camera system then takes a reference image of each marker, enabling successive comparisons with images taken using the high precision galvo-scanner. Now the robot successively positions the laser system above each segment, such that the optical axis is located in its center. Before the structuring process starts, the actual position of the robot in the current segment with respect to the applied markers is determined using the stored reference images. Each segment contains three associated markers, which enable triangulation of the current position. Acquisition of the comparison images is carried out by the high-precision scanner. Each recorded image of the actual position is then compared with the corresponding reference image.



(a) (b)

Fig. 3. (a) Pre-calculated toolpath consisting of a simple line crossing intersections of segments. (b) Adapted toolpath regarding the measured displacement vectors.

For this purpose, Zertrox GmbH has developed a library based on MSER [6] for the identification of identical features in images. Figure 2 shows the position shift of the features for (a) a marker and (b) the structured texture itself and the

corresponding calculated shift vectors. Using that information, a displacement vector for each marker is calculated. This information is now used to adapt the pre-calculated tool path for the respective segment on the fly. This adaption technique was implemented by ModuleWorks GmbH. An extreme example of toolpath adaptation is shown in figure 3. Figure 3(a) shows a pre-calculated toolpath consisting of a single line crossing the intersections of several segments, the green circles represent markers. Figure 3(b) shows the adapted tool path with respect to the displacement of markers caused by positioning inaccuracies. It can be seen, that the resulting toolpath - the red line - is without any discontinuities despite drastic changes to the perceived segment geometries.
The corrected toolpath is now executed, resulting in no recognizable seams between the segments.

3. Results

For evaluation, both the individual process chain components and the process chain in the aggregate were examined.

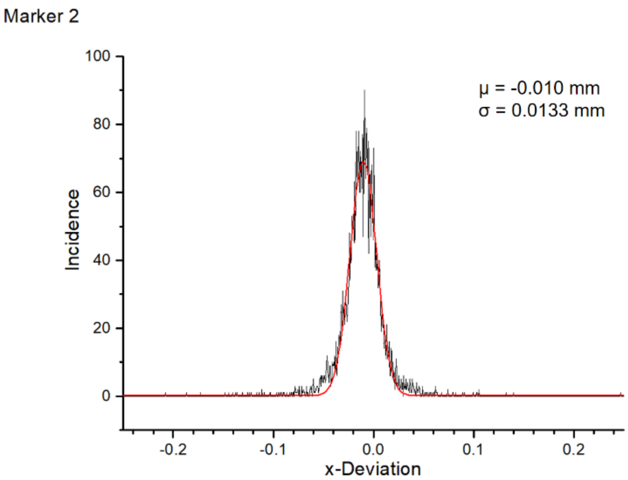


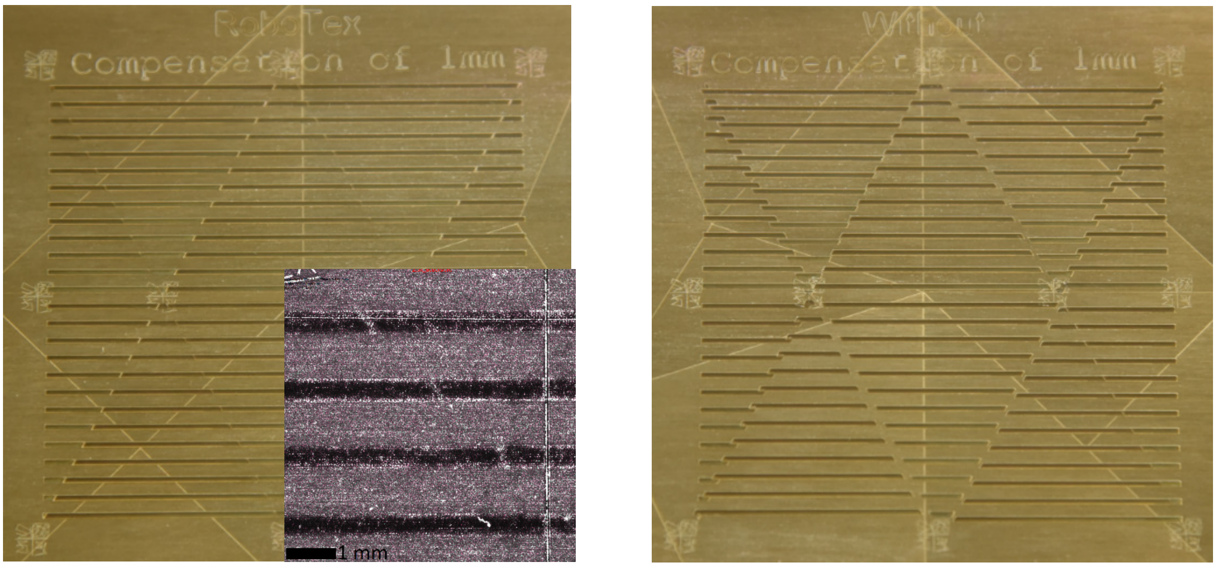
Fig. 4. x-value of the displacement vector for n=5000 images of one marker.

3.1. Laser Settings

Laser ablation results are significantly influenced by the choice of laser process parameters. Here a good balance between volume ablation rate and resulting surface roughness must be found. The following settings were chosen using an IPG G4 laser: Power $P = 70\,W$, frequency $f = 350\,kHz$, pulse length $\tau = 20\,ns$; the used scanning speed read $v_s = 2\,m/s$. Using these settings, volume ablation rates of 0.02 mm^3/s with roughness (R_a) of less than 0.5 µm are achieved. For a leather texture with dimensions 80 mm^2 and a depth of 150 µm those settings resulted in a processing time measuring approximately 13 hours.

3.2. Referencing

Determination of the displacement vector for the respective markers is subject to statistical errors. Figure 4 shows the statistical distribution of the x component of the displacement vector for one reference marker. The sample size is n = 5000 with a standard deviation of σ = 13 µm. In order to minimize propagation of error, 10 image acquisitions are taken for each marker and evaluated by means of arithmetic mean values



(a) (b)

Fig. 5. (a) Resulting surface applying the compensation strategy to a random position uncertainty of 1mm. (b) Resulting surface with the same setting but compensation method switched off.

3.3. Complete process chain

Fig. 6. Ablation result for a leather texture.

Evaluation of the compensation method was based on a test geometry consisting of horizontally arranged beam geometries distributed over the structural surface. The surface was divided into 10 triangular segments. For purposes of visual clarity, an initial random positioning uncertainty of up to 1 mm is being artificially induced into the positioning of the laser module. Figure 5 shows the laser result of 5 (a) structuring with the compensation method switched on and 5 (b) without correcting the toolpath before structuring. Results show that even high position inaccuracies can be compensated with the developed process chain. Figure 6 shows the boundary section of a leather texture with a depth of 0.15 mm. The developed system managed to structure 300 layers while adapting the tool path for each layer keeping the boundary at the cross section of the markers. There are no seams noticeable between the segments.

4. Summary

Within the research project, a low-cost industrial robot with novel technology is used for the first time for the purpose of large-area laser structuring. The system-related inaccuracies of the robot are being compensated using components native to standard laser structuring systems. A very robust and cost-efficient large-area laser system, shown in Figure 6, has been developed avoiding additional cost intensive technology to increase the accuracy of the robot.

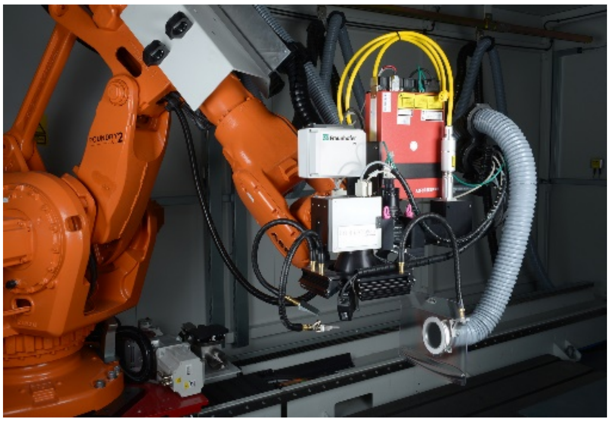


Fig. 7. Robust and cost efficient large area laser structuring system

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