Fast 3D Shape Measurement of Transparent Glasses by Sequential Thermal Fringe Projection

Martin Landmann[1,2*], *Henri* Speck[1], *Patrick* Dietrich[1,2,3], *Stefan* Heist[1], *Peter* Kühmstedt[1], and *Gunther* Notni[1,3]

[1]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany
[2]Friedrich Schiller University, Institute of Applied Physics, Abbe Center of Photonics, Albert-Einstein-Str. 6, 07745 Jena, Germany
[3]Ilmenau University of Technology, Department of Mechanical Engineering, Gustav-Kirchhoff-Platz 2, 98693 Ilmenau, Germany

Abstract. We present an approach for measuring the shape of transparent glasses, which enables us to significantly reduce the comparatively long measurement time while increasing the measurement accuracy. Instead of using area-like patterns, we irradiate the object to be measured successively in a locally strongly restricted area with considerably higher irradiance.

1 Introduction

Pattern projection-based 3D measurement systems are widely used to measure objects quickly, contactlessly, and non-destructively. However, the necessary condition of diffuse reflection of the projected patterns is strongly limited or not fulfilled for transparent, translucent, shiny, or absorbing materials. In recent years, we have developed a two-step optical method [1–5] for the measurement of such uncooperative objects based on the scanning from heating approach [6]: 1. projection of area-like thermal patterns onto the measurement object and 2. stereo recording of the thermal radiation that is absorbed and re-emitted by the object surface.

In this contribution, we present an approach that allows the significant reduction of the comparatively very long measurement time (> 20 s) while increasing the measurement accuracy. Instead of using area-like patterns, we irradiate the object to be measured successively in a locally strongly restricted area with considerably higher irradiance. This allows significantly shorter irradiation times and reduces contrast decrease due to thermal diffusion. Despite a higher number of individual projections, this results in a substantially lower total measurement time.

2 Sequential Fringe Projection Principle

The measurement principle is similar to the one presented by Brahm et al. [3] but with an improved projection method. The temperature contrast between dark and bright fringes is the key quantity for the thermal 3D measurement quality. It is induced by the irradiance of the projection pattern. However, while a longer irradiation period can lead to a higher temperature contrast, thermal diffusion usually counteracts a temperature contrast build-up. Hence, in order to improve the contrast, we increase the irradiance while we reduce the time until recording the camera images. Higher irradiance can be easily achieved by shaping the laser beam into locally strongly restricted areas, e.g., few fringes or even a single fringe per projection, instead of using a diverging laser beam in combination with a mask. Theoretical considerations show that in our setup, the irradiance can be increased by a factor of about 30. In order to achieve a temperature contrast, which is similar to that of the reference method, the irradiation period can be reduced drastically. In this way, thermal diffusion has very low influence on the temperature contrast. At the end of the projection of a single fringe, we record a pair of camera images. After that, the projection unit directs the laser sheet onto the next position and the irradiation and recording process is repeated. The high irradiance allows us to reduce the irradiation period so far that we can operate the cameras at their highest frame rates. This leads to a substantially lower total measurement time despite a higher number of individual projections.

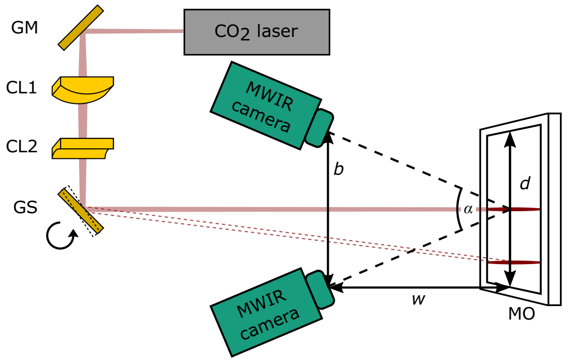

Figure 1. Schematic setup of our MWIR 3D system based on sequential thermal fringe projection consisting of projection unit (CO_2 laser, gold mirror GM, ZnSe lenses CL1 and CL2, galvanometer scanner equipped with gold mirror GS), measurement object MO, and MWIR cameras.

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[*]e-mail: martin.landmann@iof.fraunhofer.de

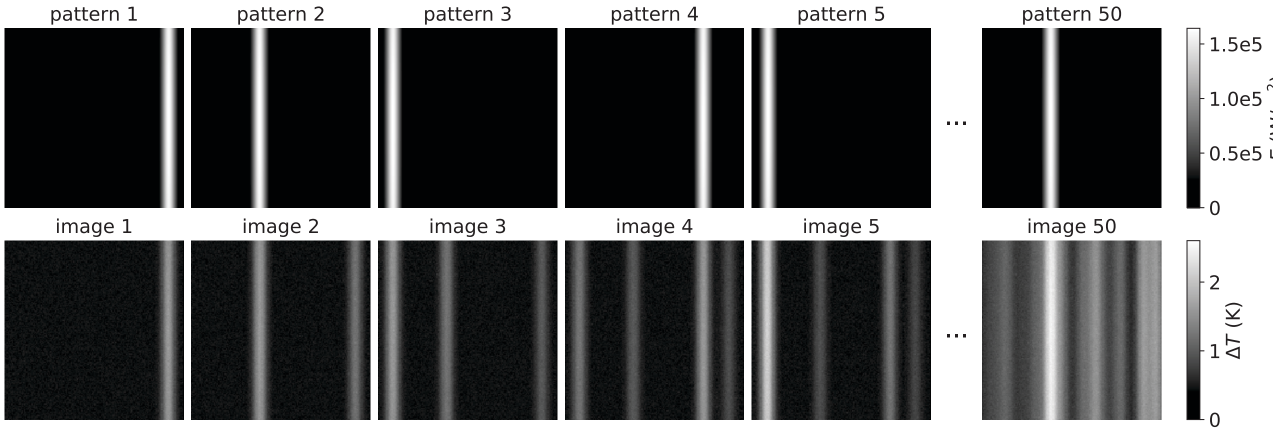

Figure 2. Example projection sequence of single fringe patterns for a sequence length of $N = 50$ and random positioning in the top row and corresponding MWIR camera images in the bottom row.

3 Measurement Setup

The measurement system comprises a projection unit, a measurement object, and two mid-wave infrared (MWIR) cameras. Figure 1 shows a schematic setup. The laser beam is deflected by a gold mirror GM. To obtain a thin laser beam in the horizontal direction on the measurement object MO, a convex cylinder lens CL1 slightly focuses the laser beam. A further concave cylinder lens CL2 provides a stronger diverging beam in the vertical direction. Behind CL2, a galvanometer scanner GS equipped with a gold mirror enables the projection unit to quickly change the fringe position in the measurement field. The central fringe position and a second arbitrary position are depicted. The projected fringe is partly absorbed by the measurement object and converted into heat. Local temperature increase leads to thermal diffusion. The measurement object emits the heat distribution which is recorded by two MWIR cameras.

4 Measurement Process

As we successively project single fringes instead of many simultaneous fringes covering the whole measurement field, we have to perform more projections and camera recordings compared to Brahm et al. [3]. Some example projection patterns for a sequence length of $N = 50$ and a random fringe positioning algorithm are shown in the upper row of Fig. 2. The corresponding MWIR camera images are illustrated in the bottom row. It can be observed that fringes of previous projections are still seen by the cameras. This is not a drawback but leads to additional information in the correspondence search between the two camera views. The entire measurement object warms up slightly during the measurement.

For the 3D reconstruction, we search for corresponding pixels by detecting the maximum of the normalized cross-correlation function [7–9]. Therefore, previous knowledge of the emitted pattern is not necessary. Once we have found the corresponding pixel pairs, we calculate the object point coordinates via triangulation.

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