Translation of speckle patterns for highspeed 3D shape measurements

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3D shape acquisition is a broad research field. In close-range scenarios like quality control, demanding high-speed and accurate reconstructions, stereophotogrammetry including structured illumination is a widely used technique. High accuracies are reached by typically projecting and acquiring about 50 patterns illuminating the object under test. Therefore the projection rate is an important factor. We explain and compare three suitable objective laser speckle projection techniques.

1 Introduction

Optical 3D shape acquisition is already a widely used technique. It's made the way into industries giving advantages for special applications. Especially, close-range stereo-photogrammetry approaches with structured illumination are going to be used for quality control within assembly lines. They lead to dense and accurate shape acquisitions for nearly arbitrary objects. But high relative accuracies ($\approx 10^{-4}$) are typically reached by projecting many patterns, commonly about 30, for the illumination sequence. Hence, the projection system as well as the acquisition system (cameras) are the key factors considering high-speed shape measurements. Since high-speed cameras are already purchasable, our workgroup developed several high speed projection approaches to overcome the limitation of commonly used DLP projectors in the past. The general idea of speckle projection proposed in [1] has been extended within this work and the way of projection is modified in terms of simplicity, speed and cost.

After explaining three objective laser speckles projection setups a qualitative and quantitative comparison between them is concluded.

2 Setups for objective laser speckle projection

All setups use the same cameras and geometry to guarantee highest comparability. Two $207\,\mathrm{Hz}$ cameras with $640 \times 480px$ and $17\,\mathrm{mm}$ lenses are used. Base distance for the experiments was $0.68\,\mathrm{m}$. Both cameras acquire simultaneously the object structured with a different objective laser speckle pattern image by image. Concisely, the stored stack of image pairs is afterwards used for temporal correlation to solve the correspondence problem and the corresponding pixels are triangulated to calculate the pointcloud.

2.1 Acousto-optical deflection - AOD

The idea has been proposed in [2] already and makes use of an acousto-optical deflector that is able to deflect a laser beam rapidly. The setup (see Fig. 1) consists of a $532\,\mathrm{nm}$, $2\,\mathrm{W}$ laser, the aforementioned AOD and a lens focussing the first-order diffracted beam onto a diffuser. By changing the frequency of the acoustic wave in the AOD's crystal, the first order beam diffracts with different angles. Therefore, the focus position of the beam behind the lens can be switched with the rate of AOD-frequency changes. This can be done with up to $205.000\,\mathrm{Hz}$ and marks the highest speckle pattern projection rate.

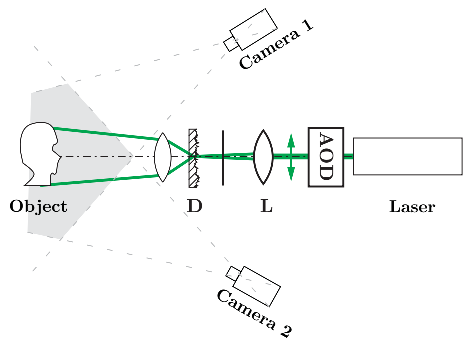

Fig. 1 *Sketch of the experimental setup using laser beam deflection*

2.2 Translation of laser speckle patterns - Transl

Another way of sequential object structuring is not to switch a pattern but rather translate the pattern continuously over the object.

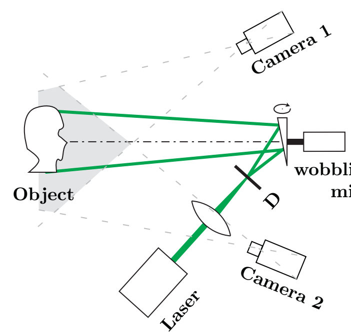

Fig. 2 *Sketch of the experimental setup using statistical pattern translation*

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It inherits from the idea proposed by Grosse et al. in [3]. By snapping into the translation of the pattern with both cameras a good temporal coding of the pixels can be achieved. One static laser speckle pattern is created by focussing a laser beam onto the diffuser. The propagating statistical interference field is then translated over the object by using a rotating motor with a tilted mirror attached (see Fig. 2).

2.3 Continuous speckle variation - CSV

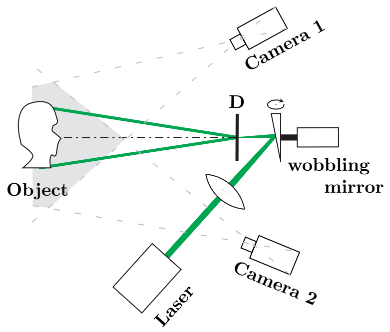

Fig. 3 *Sketch of the experimental setup using continuous speckle variation*

The third idea is to move the focal spot of the laser beam continuously over the diffuser surface (see Fig. 3). This influences the scattering region itself and therefore changes constantly the contributing facets of the illuminated diffuser surface to the diffraction pattern. A constant speckle boiling and speckle translation depending on the wave front curvature can be observed. Low movement speed together with suitable short exposure times achieves good pixel coding and the correspondence assignment and triangulation result in accurate 3D points.

3 Comparison and Conclusion

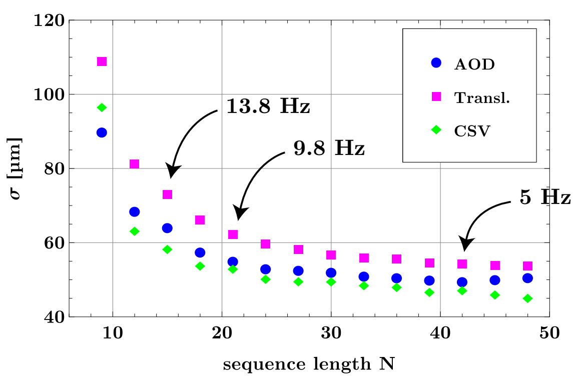

Fig. 4 *Point localisation accuracy versus the amount of images used for temporal correlation.*

We distinguished the achievable accuracy of the three techniques by measuring a certified flat plane and calculating the point noise about a fitted plane. The measurement plane was put in a $20\times20\times20\,\mathrm{cm}^3$ measurement volume. The deviation of the points is denoted as σ (compare Fig. 4). All approaches led to similar quantitative 3D point localisation accuracies. The speed can be adjusted with choosing the desired accuracy $(60\,\mu\mathrm{m} \mapsto 10\,\mathrm{Hz})$. All three concepts would enable higher 3D rates, but the $207\,\mathrm{Hz}$ cameras were limiting. Furthermore, all three concepts have in common that they are less accurate than non-coherent approaches due to parasitically occurring subjective speckles in the camera images. But, due to coherent pattern formation all of the laser powers goes into the pattern. This enables bright illumination and very short exposure times in the range of some milliseconds. Brightness becomes a crucial factor considering high-speed approaches with short exposure times and large measurement volumes.

The proposed setups mainly differ in their versatility, cost and simplicity. While the AOD approach is the most versatile giving the possibility to switch the laser light on and off with high rate, it is the most difficult to set up and cost-intense. On/Off switching is necessary for instance in color 3D measurements. In terms of simplicity the continuous speckle variation setup is hard to beat. It mainly consist of a rotation motor, an attached mirror, lens and diffuser. The laser itself is necessary in any case so cost comparison is made without. The CSV and Translation system using wobbling mirrors are highly shrinkable. Miniaturization could go down to some centimeters whereas the AOD needs free space propagation to separate the first from the zeroth diffraction order.

Concluding, we have presented three techniques that deploy the objective laser speckle projection idea. They lead to dense and accurate results and allow high-speed 3D shape measurements when used in conjunction with high-speed cameras.

References

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