Vision Ray Camera Calibration for Small Field of View

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The miniaturization of optical metrology systems like fringe projection and deflectometry requires the downscaling of the calibration techniques. In this article, we present an OLED micro display based setup matching the requirements for conducting a vision ray camera calibration for a field of view of several centimeters.

1 Introduction

Industrial quality control relies heavily on accurate optical metrology systems. As the need for mass produced precision parts is increasing, suitable measurement systems need to be available.

The MEGaFiT project, funded by the European Commission, aims to realize zero-defect manufacturing of complex high-precision metal parts by applying adaptive process control. Within this project, we develop a fringe projection metrology system for measuring micro-formed metal parts, see Fig. 1.

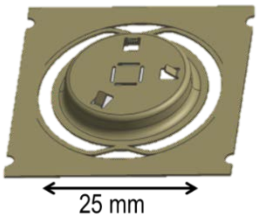

Fig. 1 *CAD drawing of measurement object: Demonstrator of the MEGaFiT micro-forming production line*

To get the best possible accuracy, we use the vision ray calibration (VRC) technique [1],[2] for characterizing the cameras in this measurement system. The VRC has so far only been applied to systems with a larger field of view (0.1 m … 1 m), thus a downscaling is necessary.

2 Vision Ray Model

The VRC models an imaging device as a black box. Every single pixel gets assigned a line of sight, which projects to it. This line can be described by the parameters o_x and o_y denoting the starting point in the aperture plane and the parameters v_x and v_y denoting the direction vector:

$$(o_x, o_y, 0) + \lambda(v_x, v_y, 0) \qquad \lambda \in \Re \qquad (1)$$

With this approach, it is possible to describe optics with local, unknown and exotic lens aberrations, as well as optics which cannot be adequately described with the central projection model.

3 Setup and Reference Object

For traditional camera calibration techniques a calibration reference object with several feature points is sufficient. In contrast to this, the VRC models each pixel independently, which is why a pixel-wise measurement of the reference object is required. This can be achieved by using a fringe-displaying monitor as seen in Fig. 2. When using sinusoidal fringes the monitor does not need to be exactly in focus to get precise measurement data.

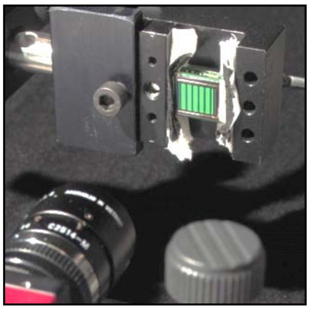

Fig. 2 *Calibration setup. The SVGA micro OLED display is positioned in front of the imaging device.*

However, when the monitor is oversampled by the imaging device, moiré patterns distort the measurement results. Particularly when downscaling, suppressing these moiré patterns is a challenge. For our case the pixel pitch of the monitor needs to be lower than 20 µm. As shown in Tab. 1, this can be achieved by using OLED micro displays.

Monitor	Pitch [µm]	Diagonal [mm]	Pixels
Desktop	222	530	1920×1440
Smartphone	78	89	960× 640
OLED SVGA	15	15	800× 600
OLED SXGA	12	20	1280×1024

Tab. 1 *Properties of selected monitor devices. Only OLED displays have a pixel pitch sufficient for micro-VRC.*

4 Calibration Procedure

To conduct the calibration, the reference monitor is measured in many positions by the imaging device, see Fig. 3. The line of sight for every camera pixel needs to intersect with the monitor in at least three of these positions. To set a well-conditioned numerical problem, not only shifts along z-axis but also tilts around x or y-axis have to be performed.

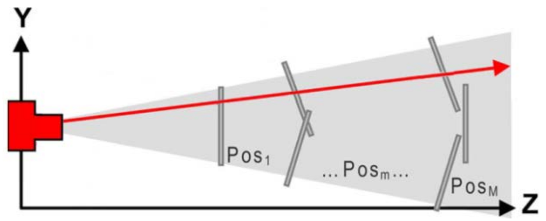

Fig. 3 *Calibration measurements. Each line of sight has to intersect with the monitor in a least three positions.*

The collected data is used in a first step to perform a traditional photogrammetric calibration [3]. This is done to obtain a rough estimate of the monitor positions.

In a second step the actual VRC is performed. It consists of a numerical minimization over the reference object positions. Further free parameters are the coefficients of a polynomial plane, describing a possible deviation of the monitor surface from an ideal plane. Fixed parameters are the monitor cover glass thickness and refractive index for modeling the refraction caused by different incident angles on this glass, see Fig. 4.

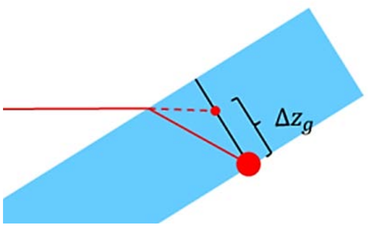

Fig. 4 *Due to optical distortion by the monitor glass cover, the pattern pixels appear shifted by* Δz_g.

Because the reference monitor is usually much smaller than the field of view (FoV), it is necessary to stitch many measurements together, see Fig. 5.

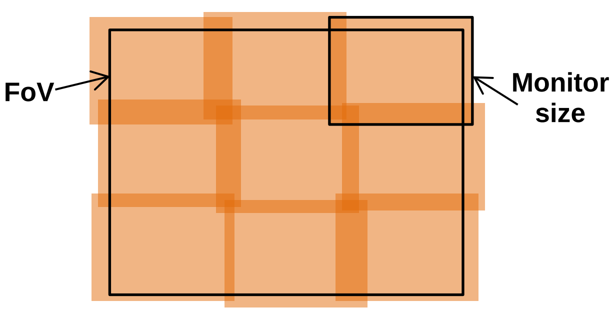

Fig. 5 *Tiling. As the micro displays are small, many measurements are needed to cover the whole FoV.*

As it is a feature of the vision ray calibration to allow for local deviation, special care has to be taken when merging the data. We therefore have developed certain criteria to ensure the stability of the calibration procedure:

- Every sensor area should contain sufficient data for a well-conditioned numerical optimization (shifted as well as tilted positions).
- The individual tiles should overlap substantially to guarantee that they can stabilize each other.

To comply with these criteria, due to the required overlap of the measurement tiles a large number of measurements have to be performed. Running the numerical optimization procedure on such large data sets is a computationally challenging task, but can be tackled by modern hard- and software.

5 First Results and Conclusion

The method was tested with a trial calibration using 99 reference object measurements. The remaining numerical error was less than 1 µm and no edges of the tiles were visible. This shows that the downscaling of the method works well when the developed stability criteria are followed. Furthermore we expect that also the results of vision ray calibrations for larger fields of view improve when using these criteria. The number of necessary measurements could be drastically reduced by using monitors with a larger display area and the same pixel pitch (increased space-bandwidth-product) as a reference, which are currently not commercially available.

The presented calibration technique will be utilized to realize a fast metrology system with improved accuracy for the measurement of small microformed metal parts.

6 Acknowledgements

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References

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