Stereophotogrammetry with active structured illumination for measuring mouse whiskers in 3D

A. W. Stark*, J. Wutke**, S. Weiler***, O. W. Witte**, K. Holthoff**, R. Kowarschik*, ****, M. Teichert**, + and C. Franke*, ****, *****, +

** Friedrich-Schiller-Universität Jena, Institut für Angewandte Optik und Biophysik*
*** Universitätsklinikum Jena, Klinik für Neurologie*
**** Sainsbury Wellcome Centre for Neuronal Circuits and Behaviour,*
***** Friedrich-Schiller-Universität Jena, Abbe Center of Photonics*
****** Friedrich-Schiller-Universität Jena, Jena Center for Soft Matter*

+Contributed equally

mailto:andreas.stark@uni-jena.de

The measurement of three-dimensional (3D) structures using stereophotogrammetry with active illumination (SAI) has been an established method for non-contact measurement for decades. Importantly, this technology is becoming more frequently utilized in addressing clinical and biological questions. Within a collaborative study, using SAI, we recently measured the 3D structure of the mouse whisker array situated on their snout. (Weiler et al., 2022, doi: https://doi.org/10.1101/2022.11.04.515161). This array consists of 24 individual whiskers with lengths ranging from 0.5 mm up to 4.5 cm and diameters < 50 µm. To create a unified representation of nearby objects, mice typically fuse tactile information gathered by the whiskers and visual information gathered by the eyes. Hence, the initial question was to examine whether whiskers are located within the 3D visual space of the mouse and whether this potential multisensory convergence is also represented in specific brain areas. We will show how a functional setup for SAI was created for this purpose and which methodological obstacles had to be overcome in order to serve this specific biological application.

1 Introduction

Optical 3D measurement traditionally serves the field of industrial applications, such as shape measurement of components, face recognition or the archiving of art-historical objects. In recent decades, rapid development has taken place in this area, which has sometimes left behind potential users who neither come from a technical-optical nor the industrial background. By opening up areas of application that were previously only considered peripherally, biological and medical scenarios can increasingly benefit from the now well-developed optical technologies that enable precise and correct recordings of macroscopic objects ≥ 5 x 5 x 5 cm^3, which can be resolved at an axial 3D resolution of less than 50 µm. In the context of the present work [1], we built a specialized setup for measuring the 3D shape and position of mouse whiskers using SAI. Thus, we combined 3D measurement technology with biological and clinical inquiries to open up novel quantitative avenues in the related fields.

2 Starting point and basic principal

Mice, like other mammals, perceive their environment with different senses. Their ability to correctly identify an object in the nearby space crucially depends on the orchestration of vision and tactile sensation via the whiskers. We investigated in the past years how this precise orchestration functions within the 3D proximity space around the mouse head and where and how in the brain these sensory inputs converge. We demonstrate that both whiskers and visual space are profoundly overlapping, suggesting that mice sense nearby objects with these two senses simultaneously. We further identified the visual cortex as an area where both tactile and visual inputs converge at the level of individual nerve cells. Interestingly, this brain area represents the space in front of the mouse where whiskers and visual space display their strongest overlap. Taken together, these data demonstrate that tactile sensation and vision are deeply bound in both proximity space and the brain to finally generate a coherent view of objects touched and seen simultaneously. This study further demonstrates that mice represent an ideal model organism for investigating principal features of sensory interactions which might be important to ultimately develop treatments and therapies for humans suffering from sensory disorders. However, to initially investigate the association of whiskers and visual space, a morphologically accurate 3D model of the mouse whisker array needed to be generated. Previously, mouse morphology has been measured in 3D with computer tomography (3D CT) [2], but

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because of insufficient resolution without the whiskers.

3 Experimental setup

Here, we overcame the limitations of spatial resolution by using high-resolution SAI. This technique is based on illuminating an object of interest with a sequence pattern while two calibrated cameras image the same object from different angles (**Fig. 1**). The image sequence from each camera is stored and used for subsequent calculations.

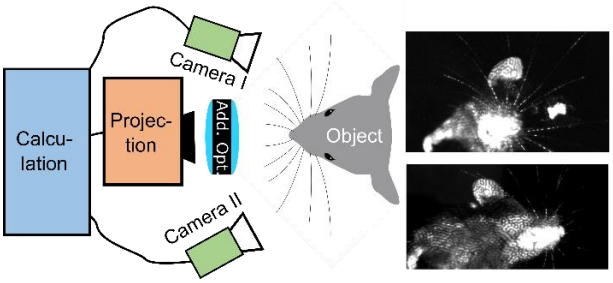

Abb. 1 *Left: Schematic of the setup for stereophotogrammetric 3D-measurments with active SAI, Right: Pair of measurement images with structured illumination.*

Corresponding image areas can be assigned to one another by searching for correlations between the image stacks produced by both cameras. 3D points can then be calculated using triangulation and prior knowledge about the relative camera positions from the calibration process [3,4]. Due to the poor scattering cross-section of the whiskers caused by their shape, several modifications were necessary to optimize the system. First, the number of patterns used was increased to 90 per reconstruction and an integration time of up to 3 s per image was applied. Second, the patterns were greatly reduced in size by additional projection optics, so that they fit into the field of measurement of roughly 5 x 4 cm^2. Third, not only 1 but up to 6 reconstructions from slightly different angles were made from a single mouse in order to measure all the whiskers at least once. In total 5 mice have been measured and reconstructed to generate the presented data.

4 Results

The final 3D reconstructions and additional microscopic scans of individual whiskers were converted into usable formats and assembled using *CloudCompare* and *Blender*. These data were then combined with the 3D model of the mouse head from [2] to finally generate the first morphologically accurate 3D model of the mouse whisker array (**Fig. 2**).

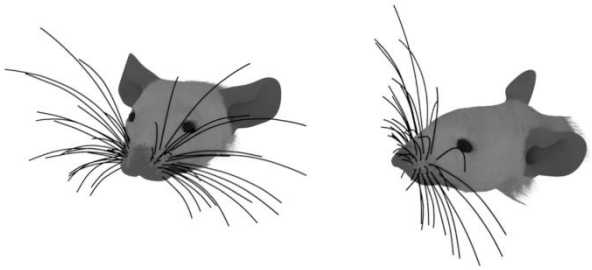

Abb. 2 *The completed model was generated by J. Wutke and M. Teichert.*

5 Conclusion

Utilizing the optimized setup for SAI presented here, high-resolution 3D reconstructions of the mouse whiskers could be generated. Using this model, we could demonstrate for the first time that the space covered by the whiskers substantially overlaps with the visual space. Current and future research will focus on expanding and improving the set of 3D point reconstructions. In the long run we also plan to apply the here presented technique on moving mice and other biological and clinical objects of interest.

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