A Versatile High-Resolution Scanning System and its Application to Statistical Analysis of Lizards' Skin Colour Time-Evolution

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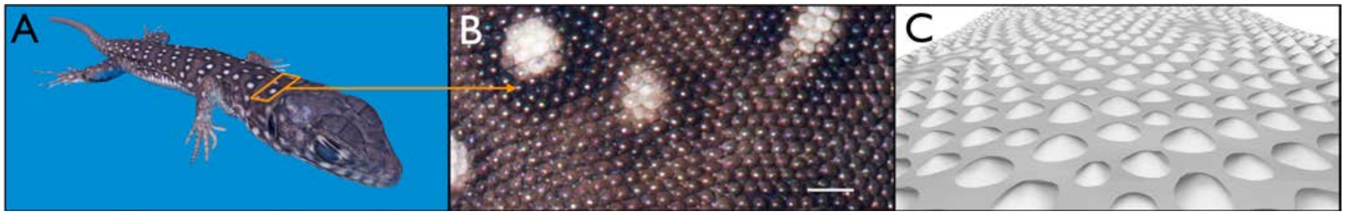

Figure 1: *(A) Rendering of the textured Structure-from-Motion (PMVS) reconstruction of a juvenile Lacerta lizard. (B) Close-up picture of small skin patch. Scale bar 0.5mm. (C) Overlapping of the PMVS reconstruction (flat) and hybrid PMVS+PS mesh (bumpy).*

1 Introduction and Motivation

Numerous methods and systems exist for 3D objects scanning. Each application area uses different types of hardware and software setups, requiring application-specific fine-tuning. Robotic scanning systems are usually used in manufacturing and reverse-engineering (e.g., for inspection of parts in a production line). For safety reasons, robotic systems are complicated to use. However the aim of our project was to develop high-quality, fast and versatile hardware for automated scanning small-sized (from 2cm to 100cm long) living animals under anaesthesia for investigating the evolution and development of morphological features. Two reconstruction approaches, Structure from Motion (SfM; [Furukawa and Ponce 2010]) and Photometric Stereo (PS; [Papadhimitri and Favaro 2014]) are of particular interest to us, as they can be performed fast, do not require additional complicated hardware and are scalable. PS acquires high-frequency micro-geometry information, but often generates a low-frequency bias, while SFM provides low frequency unbiased geometry. Our robotic system allows combining the two methods, yielding enough resolution and completeness to investigate the time-evolution of single skin appendage (scales) colour change during animal growth (see Fig. 1.)

2 Technical Details

Our system is based on an industrial six-axis robotic arm (Fanuc M10iA), a high-resolution DSLR camera (Nikon D800), an in-house built mechanical extension and illumination basket system with 30 high-intensity LEDs (2100 lumen each), and different stand and suspension configurations. The mechanical interface, connecting the camera and its illumination basket to the robot flange, was designed to optimise camera scanning envelope and minimise vibrations while keeping the payload as low as possible. The camera focus and triggering, the LEDs and the turn-table are all electronically and independently controlled from the Robot digital inputs/outputs (IOs). In addition, we incorporated a USB/Digital-IO interface that allows interaction between the robot and a computer, thus extending the scanning capabilities. The hybrid reconstruction, combining SFM and PS approaches, is performed by taking a sets of 30 PS pictures at certain positions, which are part of the bigger set of SFM scanning positions. After constructing the SFM model, it is being ray-traced from PS camera positions in order to get normal and depth maps, which are then combined and optimised with normal maps generated by PS reconstructions, using the technique described in [Nehab et al. 2005].

3 Application

Our scanning system was designed to allow researchers in our laboratory to generate digital 3D models of reptiles under anaesthesia to investigate biophysical mechanisms at the origin of skin morphological complexity and diversity. We use the hybrid mode for analyses involving the geometry of skin appendage such as small body scales. One example of such analysis includes investigation of the shift in colour patterns occurring between juvenile and adult forms of two species of lizards (from the genera Eublepharis and Lacerta). For each individual investigated, we perform high-resolution 3D geometry and colour texture reconstructions at different time points during development from the juvenile to the adult stage. The different time points are aligned after semi-automated scale detection based on local variations in geometry (dome-shaped structures). The time evolution of colour patterns is then recapitulated on the 3D geometry. These analyses form the basis for characterization and numerical simulation of pattern evolution in squamate reptiles.

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