Stereoscopic Motion Analysis of Giant Honeybees

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ABSTRACT

Giant honeybees (*Apis dorsata*) nests display a series of layers of colony members around a single comb and may have more than 1.5 m in horizontal span. Nesting in the open, they have evolved a variety of defence strategies. Against predatory wasps, they produce highly coordinated wave-like cascades termed 'shimmering', whereby a collective of hundreds of bees flip their abdomens upwards simultaneously and in a cascadic way within a split second (see Figure 1). It has been already proved that these Mexican-wave-like traits form signals of antipredatory impact for external addressees and are prone of repelling predatory wasps [1]. However, the question is whether they also contribute for colony-intrinsic information such as reporting the momentary defensive state of the colony. To investigate this colony-intrinsic aspect, we analysed the functional architecture of the bee curtain with high spatial and temporal accuracy using a non-invasive measuring system that enables a 3D reconstruction of position and posture of colony members at the nest surface during shimmering waves [6]. A portable stereo recording setup with two high-resolution cameras (2352 x 1728 px; 60 Hz) acquired image sequences of the shimmering waves in the field on an expedition in Nepal 2009, allowing simultaneous assessment of the individual positions of hundreds of surface bees regarding the three dimensions of space (x,y,z) at the given frame rate and with an accuracy of fractions of a millimeter.

Author Keywords

Giant honeybee, *Apis dorsata*, stereo tracking, stereo reconstruction, 3D position, template matching.

INTRODUCTION

Shimmering behaviour in Giant honeybees is a main component of collective defence and is evoked by visual stimuli of mainly predatory impact [1]. It occurs in the bee curtain which is the changeable and reactive multi-layer cover of the nest (see Figure 1A), and aligns hundreds of colony members to flip their abdomens in a wave-like, highly coordinated reaction within a fraction of a second. Shimmering provides here dynamic visual cues which may confuse and repel predators [1]. The knowledge of how the curtain members are coupled together is fundamental for understanding of proximate and ultimate causes. In this paper we evoked shimmering by dummy-wasp stimulation providing visual cues with standardised velocities and directions. We measured the positional changes of the members of the bee curtain and the motion of the wave in the 3D space during shimmering using stereo tracking as the suitable method. For that, an image acquisition system has been constructed which allowed to monitor a complete nest from one side.

MATERIALS AND METHODS

The shimmering behaviour of the experimental colony was recorded with two high-resolution, high frame rate cameras observing a large part of the experimental nest. The cameras had a resolution of 4 Mpx, and a single pixel corresponded with roughly 0.4 mm length in the real world. The cameras were placed 3 m in front of the colony (see Figure 1B). This distance provided an undistorted view of the whole nest and kept the colony undisturbed.

We stimulated the experimental colony with a dummy wasp which was moved by a miniature cable car device at

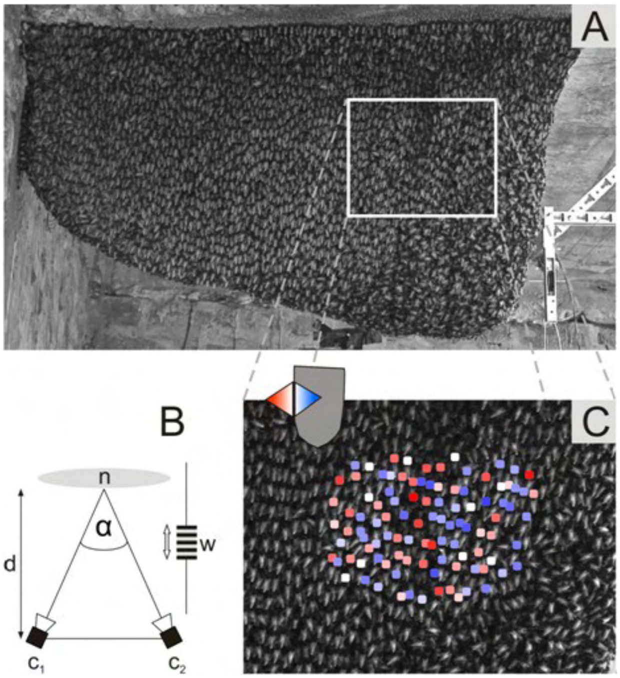

Figure 1. A, a nest attached to a residential house in Chitwan, Nepal. The nest displayed shimmering (see the blackish stripes at the right side of the nest), in particular in its quiescent zone, where the bees hang seemingly motionless and uniformly oriented with the head up and the abdomen down. The sample shimmering was evoked by a dummy wasp on the right side, and spread from right to left. B, the stereo camera setup with the working distance (d), the stereo angle (α), the dummy wasp (w) on the cable car device, the nest (n) and the two cameras (c_1 and c_2). C, magnification of the white frame in A, above the mouth zone in the quiescent zone of the nest. Red and blue colours give the relative z-positions of 100 surface bees assessed by stereo tracking ; red represents positions offwards the nest, blue represents positions towards the nest (see the sketch symbolizing the nest and the two arrows in 14 steps of red and blue shading; maximal amplitude is 5 mm). The sample wave provoked initial z-movements offwards the nest surface (red) which were followed by movements towards the nest (blue).

constant velocities of the dummy along a horizontal line, 10 cm in front of the "sunny" side of the nest. This stimulation method generated shimmering waves under controlled conditions with regard to position, direction and velocity of the dummy wasp [2].

For identification of the colony members at the nest surface during the shimmering waves, individual bees had to be segmented in the single images, tracked over time by matching them over the stereo views by stereo triangulation. One of the challenges in segmentation was due to the fact that the bees cover the comb in multiple layers. Thus the surface bees may overlap each other with their body parts, so the wings mostly cover parts of neighbouring bees. Segmentation of individuals was achieved by template matching using Normalized Cross Correlation (NCC). In a next step we identified the corresponding bees in the twin images of both frame-locked cameras. For that, we formulated the matching process as a discrete optimization problem and used reduced graph-cuts [3] to overcome the particular problem of "repetition" that neighbouring bees look very similar and may confuse the stereo matcher.

The rapidity of the individual abdominal flipping process during shimmering, taking only 100 ms, led to motion and contour blurring which additionally hampered the tracking of identified individuals. NCC was also used here to match the thorax position for a successive frame, based on the tracking data from a defined number of preliminary frames. In contrast to the conventional approach of tracking between pairs of consecutive frames, our method achieved a higher robustness of tracking of individuals in subsequent stereo images because we utilized body symmetry principles enforcing the epipolar constraints by projecting corresponding tracks in the rectified twin images.

RESULTS AND OUTLOOK

The presented framework enables a semi-automatic segmentation of individuals in a roughly two-dimensional matrix of agents. We performed an automated analysis of the individual movements in the three spatial dimensions. Up to now, tracking methods of insects refer mostly to single individuals in the 2D space [4,5]. The presented method [6] allows investigating the dynamics of the positions of hundreds of tightly packed surface bees in the 3D space at resolutions of fractions of millimetres and in time steps of 17 ms (see Figure 1C). This gained greater knowledge of the functional architecture of the bee curtain in Giant honeybees.

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