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Institute of Computer Science

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Automatic Decoding of Honeybee Identification Tags from Comb Images

Balduin Laubisch
Student ID: 4362142
balduin.laubisch@fu-berlin.de

1. Reviewer: Prof. Dr. Raúl Rojas
2. Reviewer: Dr. Hamid Mobalegh

Adviser: Dr. Tim Landgraf

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Abstract

Although honeybees, with their complex social structure and behaviour are well researched, many details of colony bottom up organization is still unknown. Therefore a tag system is developed to track and identify hundreds of bees inside their hive and investigate individual worker behaviour. This tag system consists of the recording setup, the tags and the respective software decoder. The decoder is evaluated accordingly.

Declaration in Lieu of Oath

I hereby declare in lieu of oath that this bachelor thesis is original and the result of my own investigations, except as acknowledged and has not been submitted, either in part or whole, for a degree at this or any other university.

12th February 2014

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Balduin Laubisch

Contents

1 Understanding Emergent Colony Behaviour

A honeybee (*Apis mellifera*) colony can consist of tens of thousands of worker. To sustain so many individual insects the labour is divided among the hive-bees. Tasks, which need to be allocated, include caring for the brood, building or repairing the combs, foraging for nectar, pollen or water and defending the hive site. How are the bees behaviourally solving this problem of establishing a social structure? Ultimately, what is the underlying informational system composed of?

For example individual age of worker is decisive for job transition in bees [1]. However, much still remains unknown, because as opposed to colony-level observation individual-level observation is difficult to conduct, while many properties emerge from individual behaviour.

A tag system, in which a large portion of colony members can be marked, automatically localized and identified for several weeks can give rise to further studies and extend knowledge and understanding of honeybee colonies.

2 Existing Marking Techniques

There are numerous different insect marking methods[2] available. They vary in resolution of time, i.e. number of times the tag can be read in a given time frame and spatial resolution, but also the quantity of unique tags.

Common bee markers are paint and tags, which have up to two digits on the plate. Both have a very low resolution of time, as they are often manually decoded. The tag system in need requires high resolution in all dimensions mentioned above.

3 Tag System Development

To automatically decode bee markers, a suitable recording setup, a bee tag design and a decoder were developed.

3.1 Recording Setup

For easier bee keeping, domesticated bees are given prepared, planar combs, which facilitated surveillance of a comb with cameras as pictured in Figure 1. An aluminium scaffold was built to hold the hive, cameras and lamps. Two cameras[1] per comb covered the whole side. The scene was lit with red LED lamps, because bees cannot visually perceive red light and are less disturbed by it.

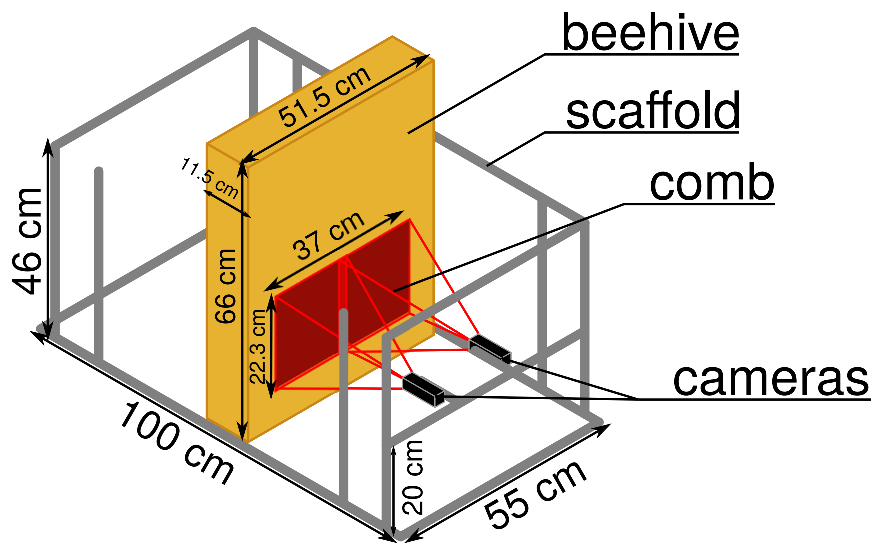

Figure 1: The recording setup, which was indoors, is schematically shown here. The wooden hive (light brown) with a was placed into the middle of an aluminium scaffold (grey). The cameras (black) were mounted on the flank side of the scaffold with ≈ 29 cm distance to the cameras and the view angles (red) of the cameras were perpendicular to the comb under observation. The red LED lamps (not depicted) were also attached to the aluminium scaffold. The comb frame measured 370 mm × 223 mm ("Deutsch Normalmaß"), while the cameras had a 4000 px × 3000 px resolution. The overlapping field of view was partially needed to detect tags close to the border.

3.2 Tag Design and Tags

On the one side the tag had to meet requirements concerning the bees such as fitting to their thorax, minimizing the resulting behavioural impact and

[1]Camera: Point Grey Flea®3, Model: FL3-U3-88S2C-C

preventing the tags from loosening too soon. On the other side the decoder had to be able to process the images generated by the recording setup.

3.2.1 Tag Design

The base tag was circular to suit the thorax of the bees. Hence, a circular matrix was chosen to spatially fill the tag and still be able to detect the contour of the tag reliably (Fig. 2).

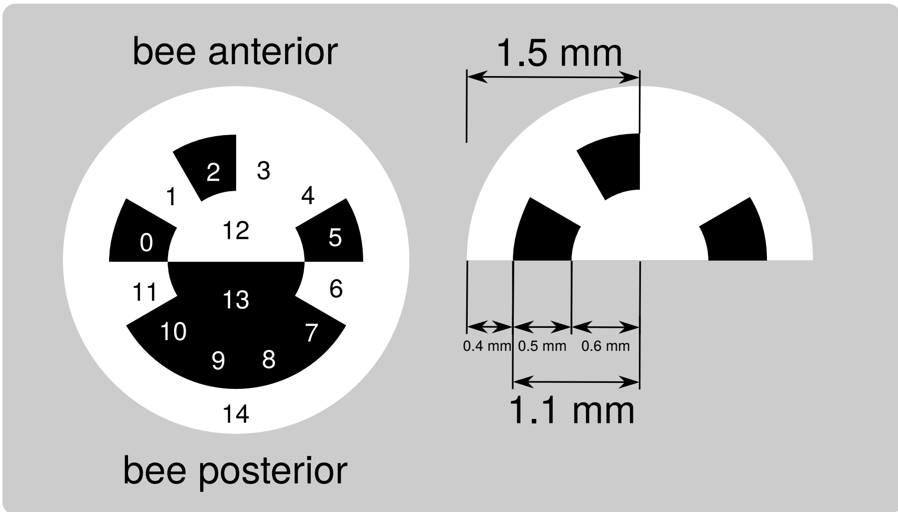

Figure 2: The matrix (or grid) of the tag was circularly partitioned into inner circle (cell 12 and 13), middle ring (cell 0–11) and border ring (cell 14). Each of these cells was coloured either in black or white, whereas cell zero to 11 represented the information bits, such that there were $2^{12} = 4096$ different grid configurations. Cell 12 (white) and 13 (black) were designed to determine the angle of the tags as well as the facing of the bees. Cell 14 was white.

3.2.2 Tags

The actual tags were printed out onto paper and covered with a layer of scotch tape, to prevent the bees from easily detaching the markers. Furthermore a modified punch tool was used to cut out a single tag at a time and give it a slight roundness, which adapted to the thorax of the bees.

A bee to be tagged was caught in a small acrylic glass tube (~ 3.5 cm in diameter and ~ 10 cm in length) with a wide meshed gauze on one and a piston on the other side. Then it was carefully squeezed between the piston and the gauze. Now the dorsal thorax of the immobilized bee was right in a mesh of the gauze and the glued tag was put on the thorax from the outside, thereby leaving it unhurt and still able to fly. A bee tagged in this manner can be seen in Figure 3.

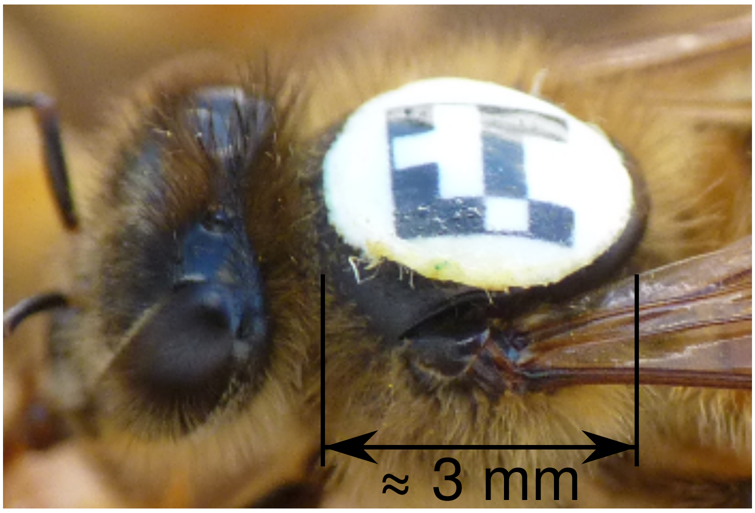

Figure 3: Markers were glued and quiet accurately fit to the dorsal thorax of the bees. This was done cautiously as to retain their ability to fly. (Note: The tag shown here is old.)

3.3 Decoder

A software decoder with was implemented in the OpenCV framework to locate and decode the tags described above from the images taken with the recording setup.

3.3.1 Tag Localization

The grayscale comb images taken from the recording setup contained several tens of tags. To filter the regions of interest (i.e. small subimages, where presumably a tag is fully contained in) a Sobel operator with thresholding was used to detect the comparably sharp edges at the border and the inside of the tags. Erosion and dilation both in circular shape were used to generate a binary contour, which approximated the contour of the tag. These contours were filtered by dimensional size and area to get a reasonable bounding box for each tag and reject non-tag contours. This procedure is illustrated in Figure 4.

3.3.2 Tag Contour Extraction

For each identified region of interest an ellipse detection[3] was attempted on the Canny edge map[4] to extract the outline of the tag (Fig. 5).
Accounting for possible rolling or pitching of the tag was done by inverting the approximate, perspective transformation (see Eq. 4 and also Fig. 6). First the image was translated by the center of the found ellipse (Eq. 2), then rotated by the angle of the ellipse (Eq. 1) and scaled up on the y-axis

by the ratio of major to minor axis (Eq. 3). The rotation and translation are then reverted (Eq. 4). Interpolation between pixels was done linearly.

$$R = \begin{pmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (1)$$

$$L = \begin{pmatrix} 1 & 0 & -c_x \\ 0 & 1 & -c_y \\ 0 & 0 & 1 \end{pmatrix} \quad (2)$$

$$S_y = \begin{pmatrix} 1 & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{pmatrix} ; s_y = \frac{a}{b} \quad (3)$$

$$L^{-1} \cdot R^{-1} \cdot S_y \cdot R \cdot L \quad (4)$$

3.3.3 Grid Scoring

To actually decode the tag and receive the ID, a specific grid was assessed by a scoring method (Eq. 7), which was based on Fisher's discriminant analysis[?]. The main assumptions arising from the tag design (see Fig. 2) were used in the process.
Given a grid (its center, size and angle) and the respective region of interest, a two-class k-means clustering was performed on the μ_i (arithmetic mean of all pixel intensities of cell i) where $0 \leq i \leq 14$ to estimate $c_\bullet$ (blackness) and $c_\circ$ (whiteness). This allowed for the calculation of $\sigma_\bullet^2$ (Eq. 5), the variance to $c_\bullet$ among the cells, which were classified as black. Similarly $\mu_\bullet$ was the arithmetic mean of all black-labeled cells ($\sigma_\circ^2$ and $\mu_\circ$ analogous). Additionally, the score was linearly scaled with β (Eq. 6) to possibly include as much black (information) in the encoding cells.

$$\sigma_\bullet^2 = \frac{1}{n_\bullet} \cdot \sum_{j_\bullet} |x_{j_\bullet} - c_\bullet|^2 \quad (5)$$

$$\beta = \frac{\text{\# black pixels inside of cell 0–13}}{\text{\# black pixels of the whole ellipse}} \quad (6)$$

$$S = \beta \cdot \frac{|\mu_\bullet - \mu_\circ|^2}{\sigma_\bullet^2 + \sigma_\circ^2} \quad (7)$$

3.3.4 Tag Decoding

The decoding was done by taking the region of interest, the detected ellipse and assuming the grid, scoring it in all discretized centers and angles and accept the grid with the highest score.

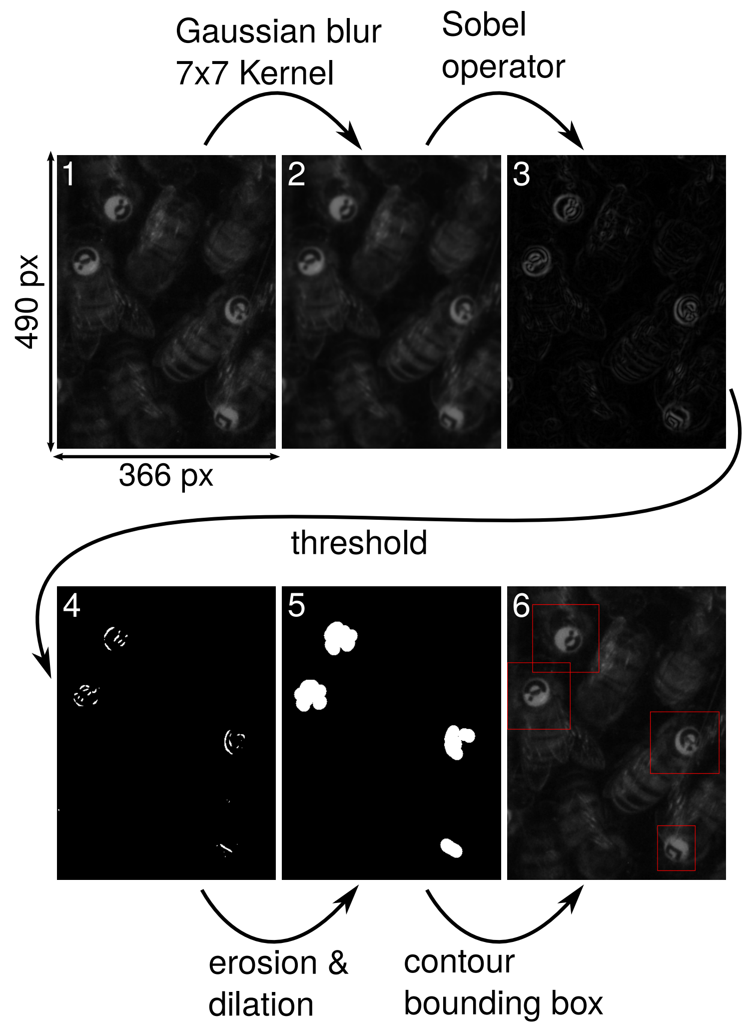

Figure 4: The grayscale 4000 px × 3000 px input image (detail in 1) was smoothed and denoised with a 7×7 kernel Gaussian blur (2). The Sobel operator was then used to detect edges (3). A constant threshold was applied to the Sobel map to filter reflections and other lower-gradient areas (4). Morphological operations (3×3 kernel erosion and 21×21 kernel dilation) further highlighted the tags and formed a binary contour (5), from which the bounding boxes were inferred (6).

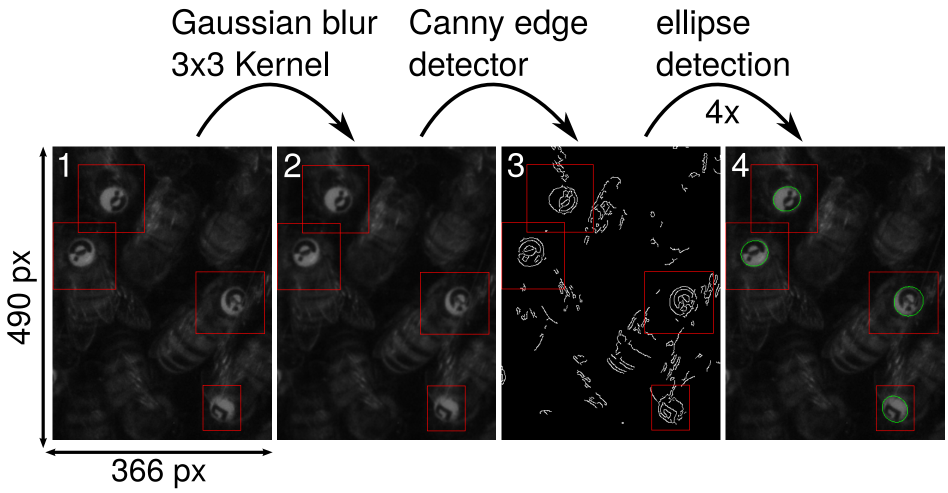

Figure 5: After denoising the grayscale input image (2) with a 3×3 kernel Gaussian blur and executing a Canny edge detector (lower threshold 30, higher threshold 60), an ellipse detection was performed on each region of interest (red rectangles) of the Canny map (3) to find the contours of the tags.

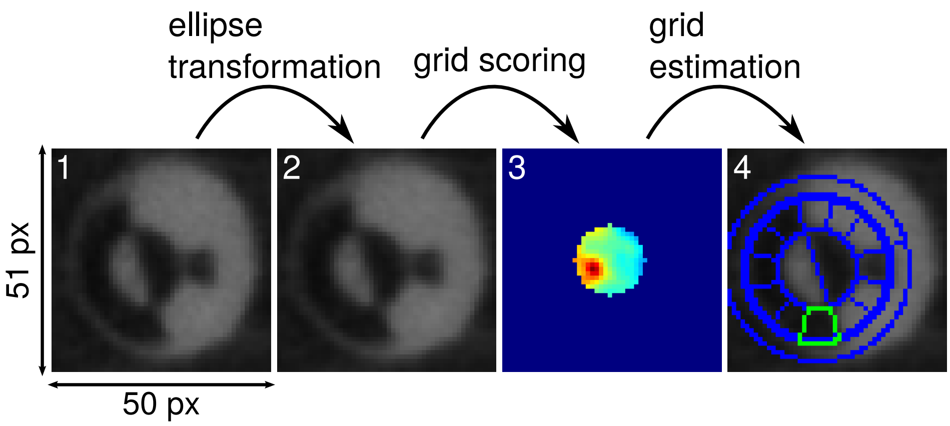

Figure 6: The region of interest (1) supposedly contained a tag and the detected ellipse was utilized to approximately invert the perspective transformation (2), which occured when the respective bee was rolling or pitching relative to the camera angle. For illustrative purpose, the grid score for the assumed centers of the grid, while maximized for the angles is shown in heat map fashion (3). The tag model was then fit to the transformed image (4). Cell zero is bordered in green.

4 Decoder Evaluation

4.1 Test Setup

A test setup similar to the recording setup (Fig. 1), but without any bees was built, because it was winter season and the bees should not be disturbed. 50 different tags were scattered on a black cloth, which was wrinkled to produce differently angled tags. Five images were taken by a single camera and processed by the decoder containing a total of 231 tags.

4.2 Decoder Performance

The results obtained from the decoder were analysed manually and are illustrated in Figure 8, Figure 7 as well as Figure 9.

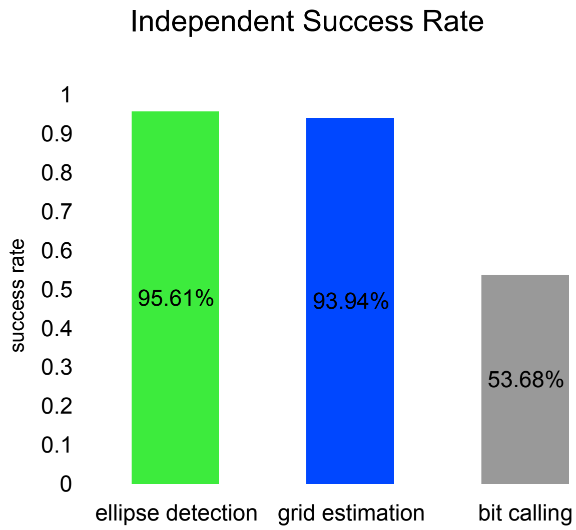

Figure 7: The success rate of the different steps of the decoding procedure are shown here. Global scaling was applied, such that the next step can be at most as good as the previous step.

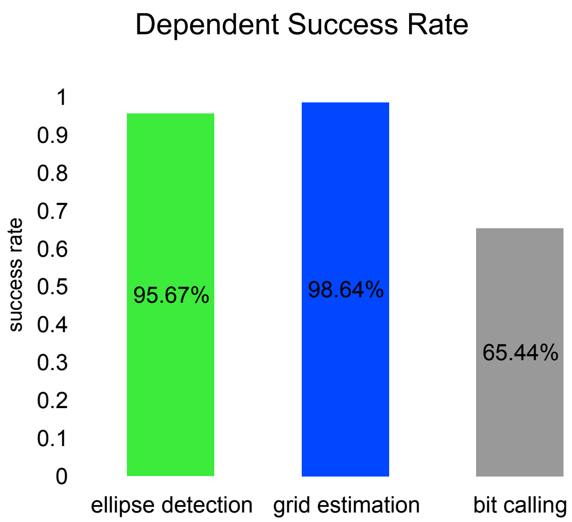

Figure 8: dependent Locally scaled success rates. For a single step only the number of successes are relevant for the next step.

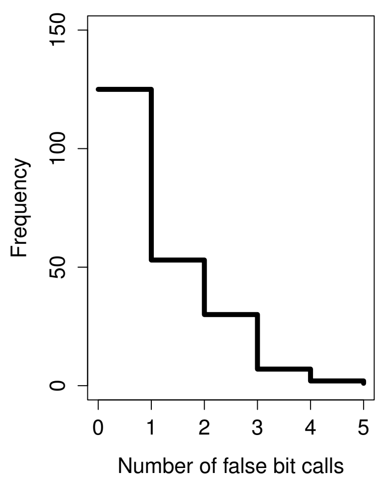

Figure 9: The distribution of false bit calls within the information bits of the tags is shown here. More than half of the tags (124 of 231) were decoded correctly. Also no more than four bit errors occurred at the same time.

5 Discussion

The software is able to detect nearly all ellipses in the test images correctly and fit the grid, too. The decoding (bit calling) is still lacking accuracy.

5.1 Hardware Errors

The tags are still manufactured by hand. This is an error-prone process and should be avoided.

5.2 Software Errors

The ellipse detection should be more dynamic such that a falsely detected ellipse does not disconnect the decoding of the respective tag.

Acknowledgement

I want to thank Fernando Wario for developing the recording setup and the tags (full credit goes to him) and helping me frequently. Thanks goes also to Simon Wichmann, Felix Lange, Juan Purcalla Arrufí. Thank you for your ideas, inspiration and critique. Last but not least I thank my adviser, Dr. Tim Landgraf for his feedback and guidance.

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