Interference-Free Identification of Honey Bees at the Hive Entrance Based on Infrared Illumination and Data Matrix Markers

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***Abstract*—In this paper, we describe a method for detecting and identifying honey bees under infrared light using data matrix code markers, specifically the ECC200 code. The identification of the bees allows to automatically monitor the individual departure and entry behavior of the honey bees. Material costs per stainless steel platelet as marker are estimated at 0.5Ct. Therefore the process is suitable for marking a large number of individual bees. The bees are individually provided with a data matrix code. During the motion of the bees from the center to the hive entrance, the marker is read using an infrared-sensitive camera and a corresponding infrared light source. As bees do not see infrared light, the monitoring is interference-free and does not affect the behavior of the bees. On live bees, the procedure was successfully tested. The results show that it is possible to reliably identify bees under infrared light and read the associated code.**

***Index Terms*—image processing, honeybee, behavioral science, data matrix code, decoding**

I. Introduction

Keeping honey bees is of high economic importance: in the European Union, f. e. 207 thousand tons of honey were produced in 2018 [1]. There are 650 thousand honey beekeepers there. China is the world's largest producer of honey (540 thousand tons). However, beekeeping is a high art [2]: Bees are threatened by parasites such as the Varroa Mite and pathogens. It always comes back to the mass extinction of bee colonies. Therefore, beekeepers are supported by bee research.

HOBOS (Honey Bee Online Studies) e.g., is a research platform at the University Würzburg and has beehives with sensors such as light barriers and measuring units such as scales and cameras.

Tracking [3], [4] and identification of individual bees at the beehive entrance allows the investigation of their behavior. For example, it can be used to determine how often and how long worker bees leave the hive to collect honey. RFID technology is the standard method for identifying bees at the entrance [5], [6]: A millimeter-sized Ultra Small Package RFID transponder is glued to the dorsal thorax of bees. The costs per transponder (for example, Hitachi IM5-PK2525) are in the order of 1€. A bee colony consists of up to 60 thousand bees. Worker bees gather honey for just a few weeks until they often die off the hive. Therefore, the marking of a high number of worker bees with RFID transponders leads to high material costs.

This paper shows a cost effective method of identifying bees at the hive entrance:

A laser marker is used to apply data matrix codes to millimeter-sized stainless steel foil platelets. These are glued to the dorsal thorax of the bees. By reading the data matrix codes using a camera and image processing, the marked bees are identified. For illumination infrared light is used. The method has 3 advantages:

Material costs for the platelet made of stainless steel foil are negligible. Laser inscription is weather-resistant, so that the labelling is not destroyed when the bees are flying. Compound eye of bees are blind in the infrared range, and therefore the bees are not disturbed by the illumination.

II. Materials and Methods

A. Overall System

In a passage between the entrance and the center of the beehive, marked bees are identified. A data matrix code on the thorax of the bees serves as a marker. The data matrix code contains a number for each bee. As the bees pass through this opening, they are illuminated with infrared light (Fig. 1) while an infrared camera takes pictures. The width of the passage is 15mm. An image preprocessing algorithm extracts an image section with the code tile out of each camera picture. The image section is fed into the decoding algorithm for reading the code number. Finally, a text file is generated containing the code with the associated timestamp.

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In LabVIEW, the image preprocessing and the decoding algorithm are implemented. The source code is available from the corresponding author.

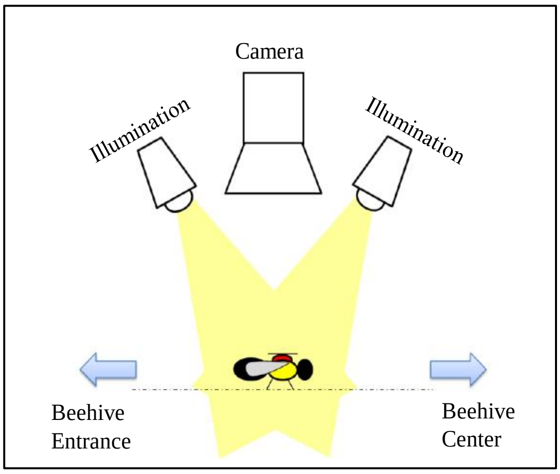

Figure 1. Schematic setup of the optical system.

B. Fitting Honey Bees with Data Matrix Code

In addition to the technical component, the honey bee must be considered, on which the data matrix code is applied. The code is lasered onto a conically shaped stainless steel plate with 3mm diameter and 0.1mm thickness (Fig. 2). The code, according to ECC200, contains a six-digit decimal number. So it is possible to distinguish one million bees.

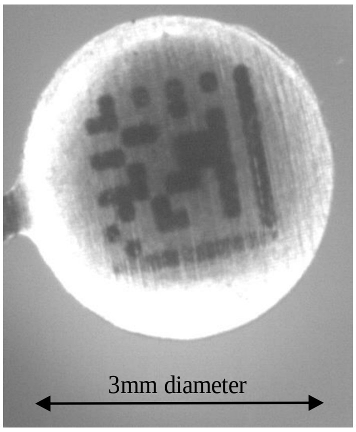

Figure 2. Stainless steel platelet with data matrix code.

For the application of the code platelets, the bees were either cooled down to be momentarily immobilized or stunned with carbon dioxide gas. This immobilization by cooling down is possible because bees, like all insects, are cold-blooded animals. It is harmless for the animals, as they can move again when placed in a warmer environment and do not suffer any damage. The data matrix code platelet is glued to the thorax of the bee using shellac. This procedure is harmless and safe for the bee. It was shown by preparatory work that honey bees with platelets are not rejected by the bee colony.

Stainless steel plates for bees (queen plates, manufacturer Apinaut) are usually varnished in different colors and printed with numbers (1-20 per strip). However, we use unpainted plates. The price for 20 Apinaut lacquered and printed queen platelets is 20€. For large quantities, the material price per plate can be estimated from the material price of the stainless steel foil used and the size of the plate: A square meter of stainless steel foil 0.1mm thick has a cost of approximately 500€. A 3mm diameter plate has a surface of 7.06mm². Now it is assumed that including cutting about 10mm² area per plate is needed. Then 100.000 plates fit on one square meter. The material price per platelet is thus 0.5Ct. Added to this are the processing costs for forming, cutting, and laser marking.

C. Illumination with Infrared Light

Inside a beehive, it is usually absolutely dark. The optical wavelength range in which the honey bees see is between about 300nm and 650nm [7]. Infrared light (IR) with wavelength 900nm is used for illumination because the honey bee can not perceive light of this wavelength and is therefore not disturbed in its natural behavior.

For homogeneous light intensity, the illumination is realized with a flat-dome diffusor and an IR-LED [8]. Image acquisition is performed using an infrared-sensitive camera (uEye CP 3370 NIR-GL Rev.2, manufacturer iDS) at a frame rate of 30 frames per second and a resolution of 2048×2048 pixels. The camera is mounted at the height of 13.5cm above the passage. The field of view has a size of 15mm×15mm.

D. Search for the Code Platelet

The camera takes pictures permanently. However, there is not always a bee with code platelets in the field of view of the camera. Therefore, in the first step, the algorithm looks for the code platelet in the image. The image section with the code platelet is then extracted, processed, and passed to the decoding algorithm.

The code platelet in the camera image (Fig. 3) is circular with a constant radius. It has a higher average brightness than its surroundings.

Figure 3. Camera image of a bee with code platelet (2048×2048 pixels).

The camera image is scaled down to a size of 128×128 pixels to save computing time. For each pixel, the average gray value difference D along two circles around the pixel is calculated according to (1) and (2).

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$$D = \frac{1}{N}\sum_{n=1}^{N}\sqrt{C(n)} \tag{1}$$

$$C(n) = \begin{cases} I(n)^2 - A(n)^2 \; if \; I(n) \geq A(n) \\ 0 \; if \;\; if \; I(n) < A(n) \end{cases} \tag{2}$$

N is the number of input values (typically 20) on two circles around the pixel. *C(n)* is a single gray value difference. *I* stands for the vector of gray values on the inner ring with a radius of 9 pixels.

A is the vector of gray values on the outer circle with a radius of 15 pixels. If a gray value *I(n)* is higher than *A(n)*, the difference in the quadrate of the values is summed up. The result is a matrix of 128×128 gray value differences.

The code platelet is found when one of the values of the matrix (Fig. 4) is above a certain threshold. For 8-bit grayscale image data, the threshold is 85 digits. The center of the data matrix code in the image has the same position as the maximum of the matrix.

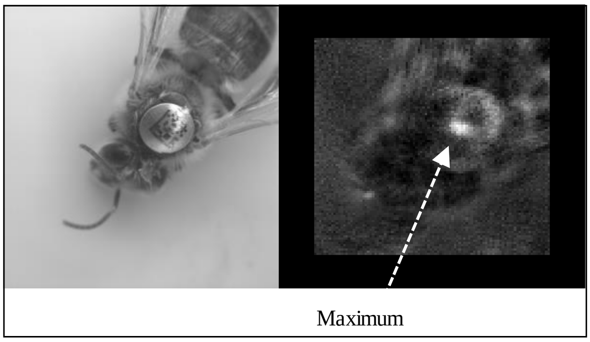

Figure 4. Image of the bee with code platelet and matrix of gray value differences.

The values of the matrix at the edge of the image are set to zero in order to avoid erroneous detection of the code platelet.

E. *Extraction of the Image Section*

In the following step, the section with the code platelet is extracted from the original image (Fig. 5).

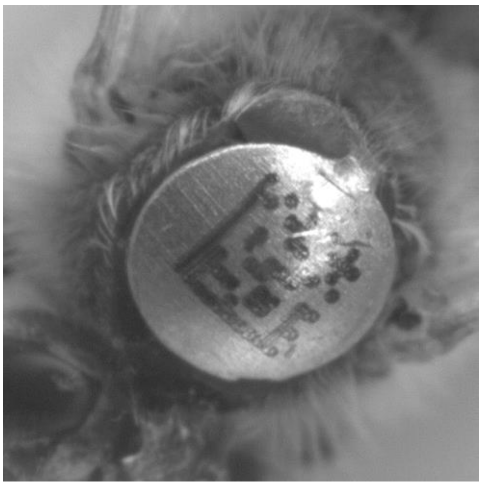

Figure 5. Extracted image section with data matrix code.

720×720 pixels is the size of the image section. This corresponds to a reduction of the data volume of the image by a factor of 8. So the computation time for the decoding algorithm is significantly reduced.

F. *Contrast Adjustment*

The extracted image is subjected to further image processing in the subsequent step. This is necessary because the code platelets under IR light have a lower contrast than in the visible spectral range. As a result, there is no sharp contrast between the data matrix code and the carrier medium. There are only slight differences in the greyscale levels, which make decoding difficult.

The brightness of the image fluctuates due to the sun's rays and darkening clouds. So the average intensity of the image is determined. Depending on this value, the brightness, contrast, and gamma value are adjusted by a look-up table.

G. *Decoding Algorithm*

For decoding, the Reed-Solomon algorithm is used, which is part of the LabVIEW Image Development Module [9]. This makes the software available to all LabVIEW users and allows quick adaptation to newer versions of LabVIEW. Through several series of tests, the best parameters have been statistically selected to enable a high level of error safety and at the same time, a high decoding rate. If the data matrix code is decoded correctly, a timestamped image and a text file with the decode result and timestamp are stored.

If the data matrix code can not be decrypted due to heavy pollution (for example, pollen due to the bee collecting activity), the image is discarded.

III. Results

Fig. 6 shows a picture of a bee with data matrix code and the decoding result with time stamp.

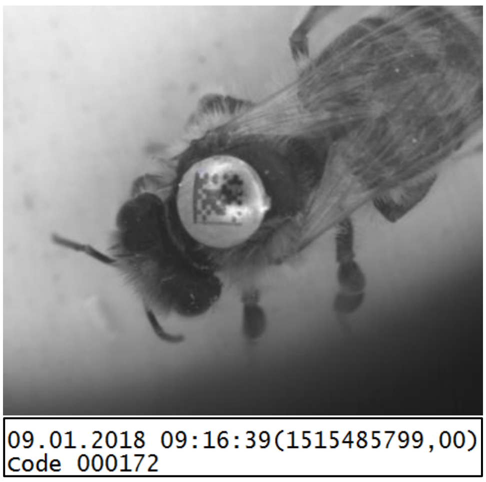

Figure 6. Data matrix code on bee and decoding result. The code has the number 000172.

Partially dirty data matrix code can be correctly decoded by the Reed-Solomon algorithm (Fig. 7) due to the redundancy contained in the ECC200 code.

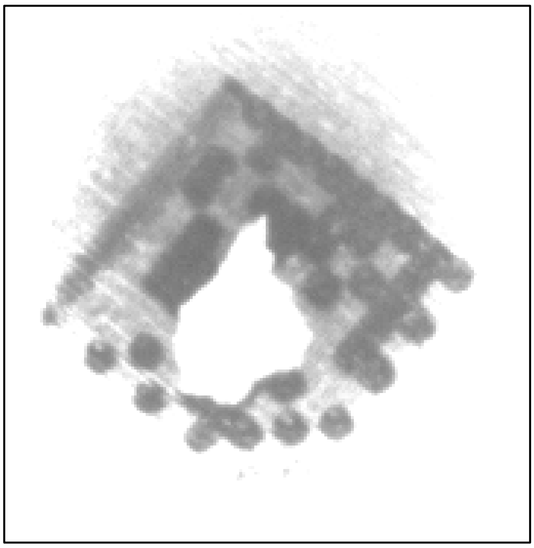

Figure 7. Partially polluted code.

The image preprocessing is robust to brightness differences in image acquisition, and the algorithms work fast and effectively: The calculation time for the search for the platelet is 50ms (LabView 2015, Intel Core i7). Calculation time for the decoding is a maximum of 200ms.

On one of the beehives of the HOBOS Group in the municipality of Aura an der Saale, the procedure was tested: 5 live bees were marked with the data matrix code. The bees walked 55 times through the corridor between the fly hole and the center of the beehive, and they were safely identified.

IV. Conclusions

This paper describes a procedure for individually identifying honey bees under infrared light illumination and assigning them individual departure and entry behavior. Using a data matrix code containing 6 decimal digits, the distinction of up to 1 million marked bees is possible. The method was successfully tested on live bees in the hive.

The pure material costs per stainless steel platelet are about 0.5Ct. Therefore, the marking of a very high number of bees is now possible. To get a more extensive verification of the procedure, we propose larger series of tests with a higher number of marked bees.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Marius Schlereth and Thomas Depner carried out the research as part of their master's thesis; the measurement setups were carried out with the help of Hartmut Vierle, Konrad Öchsner and Gerhard Vonend; Jürgen Tautz and Gunther Bohn supervised the master theses and gave scientific input; Gunther Bohn and Marius Schlereth wrote the paper; all authors had approved the final version.

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Jürgen Tautz was born in 1949 in Heppenheim, Germany. He passed the state examination in Biology and Geography in 1973. In 1977 he received his Ph.D. at the Technical University of Darmstadt, and in 1986 he received his habilitation in Zoology at the Faculty of Biology at the University of Konstanz. He is professor at the Biocenter of the University of Würzburg since 1990. In 1994 he founded the BEEgroup at the Biocenter of the University of Würzburg. In 2008 he started the development of HOBOS. He is involved in over 140 peer-reviewed and over 300 non peer-reviewed scientific publications. In 2008 he was nominated by Popular Science as one of the best popular science writers of recent decades.

His research interests are in monitoring using RFID, behavioral biology of bees and health research on bees.

Gerhard Vonend was born in 1956 in Schweinfurt, Germany. In 1978 he received Diploma in Electrical Engineering at the University of Applied Sciences Würzburg-Schweinfurt (FHWS). From 1978 to 1982 he worked as a Development Engineer for military radar systems at Siemens in Munich. In 1982 he changed to the University of Würzburg (Department Animal Ecology and Tropical Biology – Zoology III). There he developed special electronic devices for scientists for use in Tropical Forests in Africa, Malaysia and South America. From 2002 to 2019 he was Chef IT-manager for the Biocenter of the University of Würzburg. Since 2009 he was team member and project manager at HOBOS.

Gunther Bohn was born in 1967 in Ludwigsburg, Germany. In 1995 he received Diploma in Electrical Engineering at the Friedrich Alexander University Erlangen. In 2002 he got Ph.D. at the Department of Optics at the Friedrich Alexander University Erlangen. He was team leader and project manager from 1999 to 2004 at the Robert BOSCH GmbH, the world's largest automotive supplier. During that time, he developed optical test systems for the production of components for energy-saving automotive diesel engines and driver assistance systems. Since 2004 he is professor for electrical engineering at the University of Applied Sciences Würzburg-Schweinfurt, Germany. Gunther Bohn conducts research in the fields of image processing, optical measurement and inspection systems and lithium ion batteries.

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