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An imaging system for monitoring the in-and-out activity of honey bees

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ABSTRACT

This study aimed to develop an imaging system for monitoring and analyzing the in-and-out activity of honey bees as they pass through the entrance of a beehive. As such, the daily in-and-out activity of a beehive could be automatically recorded with minimum interference with the regular behavior of the bees. The components of the imaging system include: (1) an infrared LED light source; (2) an infrared CCD camera and a personal computer for image acquisition and processing; and (3) an acrylic passageway to temporarily confine the bees within the image-capturing range of the camera. In operation, this imaging system was affixed to the outside of a beehive at the entry/exit point. To identify each forager of bee workers individually, circular character-encoding tags were attached to the dorsum of the bees' thoraxes. To locate individual honey bees in a video frame, a circular Hough transform was used to detect the presence of the circular tags. A black positioning dot on the tag was used to identify the orientation of the characters in order to facilitate the reading of the symbols on the circular tag. The extracted character symbols were further segmented and a support vector machine (SVM) classifier was deployed to recognize the characters and identify the individual honey bee. The system developed in this study was used in experimentation to identify each of the tagged bees and to record the timing of the entries and exits. The character symbol recognition and identification accuracy rates of the system were about 98% and 86%, respectively. Based on the in-and-out records, daily foraging behavior of honey bees were analyzed and presented. These experimental results demonstrate that this imaging system is feasible and can be used as an efficient tool to study honey bee behavior.

1. Introduction

Honey bees are social insects and the polyethism of worker bees provides the whole colony continuous labors with different tasks according to their age. While the foragers fly out from the beehive in search of food sources, others stay behind and wait for the results of the search to be communicated (Kolmes et al., 1989). The in-and-out activity of honey bee workers, especially the foragers, provides critical information about the *super organism*. Thus, a better understanding of their activity is important not only in the context of the individual forager but also in regard to the whole colony.

Previous studies using manual methods to observe the beehive activities are not only labor-intensive but also present difficulties in producing tracking records in longitudinal studies. Because it is almost impossible for human eyes to differentiate among hundreds of individual bees, manually monitoring particular bee castes, such as foragers, is extremely difficult. Therefore, developing an automatic monitoring system to analyze the in-and-out activity of honey bees is a critically important technical issue in this particular field of study. With the aid of an automatic monitoring system, quantitative information about honey bee behavior can be efficiently obtained which allows modeling and analysis of foraging activity of honey bees (Adeva, 2012). Furthermore, it will provide an efficient tool for experimental studies to compare various factors affecting honey behaviors such as homing abilities (Pahl et al., 2011; Henry et al., 2012).

Among the automatic monitoring systems so far used, the most effective method has been shown to be a passive radio frequency identification (RFID) system. In these kinds of systems, an RFID reader is placed on the entrance of a beehive to detect the miniature tags attached to the dorsum of bees and is used to interpret the data stored on the tags (Streit et al., 2003; Decourtye et al., 2011; Henry et al., 2012); this system records the in-and-out activity of the bees. However, as the weight of the RFID tags is about 2.5 mg and the average weight of an adult honey bee is approximately 70 mg, the tag is almost 3.6% of the weight of the honey bee. Additionally, the power source of the passive RFID tags comes from the induced current produced by the strong electromagnetic

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waves emitted by the reader. Importantly, whether the heavy tags and electromagnetic waves affect the regular behavior of honey bees is still unknown.

Following the increasing accessibility of imaging technology, in this study, we developed a novel monitoring system for recording the in-and-out activities of honey bees. To identify each of the bees, a printed circular tag was attached to the dorsum of each bee's thorax. The characters printed on each tag served as the identification number of each honeybee. Because the weight of each tag is only 1.0 mg and no electromagnetic waves were emitted from the device, our system is considered comparatively less influential to the honey bee behavior. An imaging system was specifically designed to match the entrance of the beehive and an image processing method capable of real-time processing of images and identifying the bee tags was also developed and tested.

2. Materials and methods

2.1. Hardware equipment and software

This imaging system was affixed to the exit point of a commercial beehive. The hardware included a specially designed bee passageway, a CCD camera capable of sensing infrared light (DMK31AU03, The Imaging Source Europe GmbH, Germany), an infrared LED light source, as well as a specialized computer used for image acquisition and back-end processing. The shutter time of the CCD camera is adjustable such that each captured video frame can be viewed, so as to prevent blurred images due to bee movement or wing vibration. The primary software used to program the graphical user interface was Borland® C++ Builder 6.0. The program libraries included open source code OpenCV 1.0 and LIBSVM v2.89, which were used for image processing and character recognition, respectively. The computer used for back-end data processing was an Intel Core 2 Duo 2.1 GHz processor with a 4 GB random access memory (RAM) running on an operating system of Microsoft Windows Vista Service Pack 2 (SP2).

The overall framework of the system is shown in Fig. 1. The camera was positioned at the top of the bee passageway. Through the stable light provided by the infrared LED, the camera was able to acquire images with consistent light intensity and send them to the computer via a USB interface. Because the light rays of the infrared wavelength are not visible to honey bees, this method is considered to be less invasive and to have a smaller impact on regular bee behavior (Riley, 1994). The computer was used for various calculations and processing tasks such as identifying the tags on the backs of the bees and recording the conditions of the entries and exits to and from the hive. The dimensions of the system were as follows: the length was approximately 222 mm, the width was approximately 136 mm and the height was approximately 363 mm. This system was affixed outside of the beehive so that honey bees entering or exiting the hive were made to pass through the designed passageway and could be imaged by the camera.

To constrain the movement direction and speed of the honey bees in entering and exiting the hive, this study designed a bee passageway, allowing the images captured by the camera to be clearer and to make the subjects more easily identifiable, thereby increasing the stability of the back-end image-processing system. The passageway was constructed using a 3 mm transparent acrylic material. The dimensions (length, width and height) of the external appearance of the passageway were 145, 80, and 9 mm, respectively. The internal component, which constrained the movement of the honey bees, was approximately 35 mm long, 8 mm wide and 6 mm high, as shown in Fig. 2. Fig. 2A–D illustrate the front view, left view, top view and three-dimensional drawing of the passageway, respectively. The dimensions of this passageway can

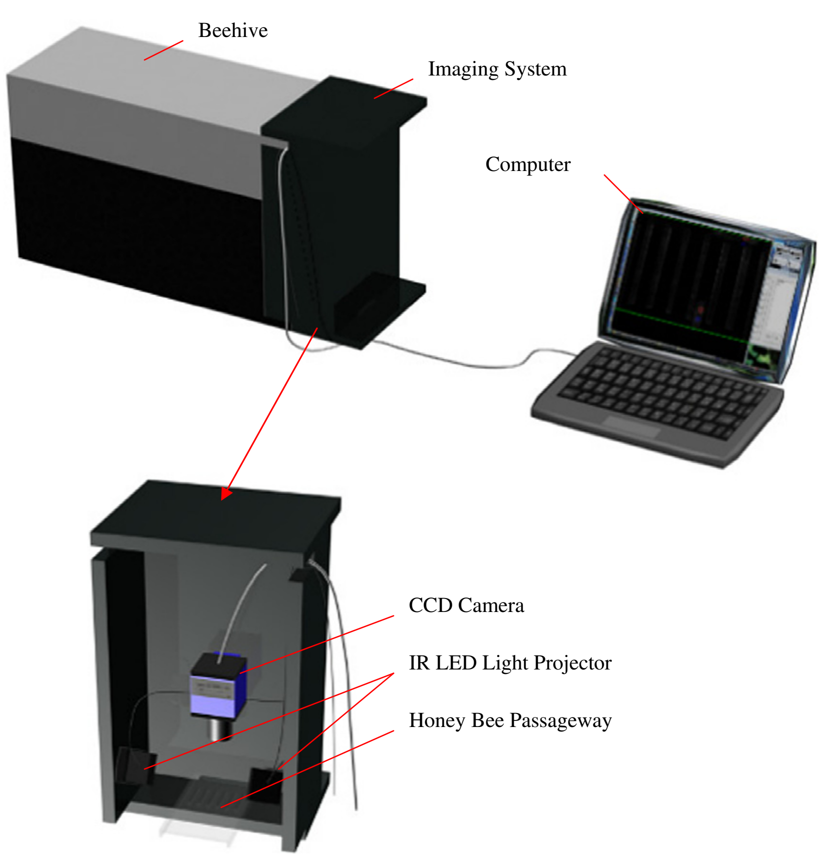

Fig. 1. Schematic drawing of the imaging system architecture.