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Automatic behaviour analysis system for honeybees using computer vision

Gang Jun Tu [a,*], Mikkel Kragh Hansen [a], Per Kryger [b], Peter Ahrendt [a,*]

[a] Department of Engineering, Aarhus University, Finlandsgade 22, 8200 Aarhus N, Denmark
[b] Department of Agroecology, Aarhus University, Forsøgsvej 1, 4200 Slagelse, Denmark

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ABSTRACT

We present a fully automatic online video system, which is able to detect the behaviour of honeybees at the beehive entrance. Our monitoring system focuses on observing the honeybees as naturally as possible (i.e. without disturbing the honeybees). It is based on the Raspberry Pi that is a low-cost embedded computer with very limited computational resources as compared to an ordinary PC. The system succeeds in counting honeybees, identifying their position and measuring their in-and-out activity. Our algorithm uses background subtraction method to segment the images. After the segmentation stage, the methods are primarily based on statistical analysis and inference. The regression statistics (i.e. R^2) of the comparisons of system predictions and manual counts are 0.987 for counting honeybees, and 0.953 and 0.888 for measuring in-activity and out-activity, respectively. The experimental results demonstrate that this system can be used as a tool to detect the behaviour of honeybees and assess their state in the beehive entrance. Besides, the result of the computation time show that the Raspberry Pi is a viable solution in such real-time video processing system.

1. Introduction

Honeybees play an important role in agriculture when pollination is required, and in such practices pollination units are regarded as an important factor in agricultural economy. They are clearly the hard working pollinators. For example, only in the United States, the worth of honeybee pollination is estimated at $15 billion (Sagili and Burgett, 2011). However, in recent years, the rates of honeybee colony failure have increased significantly across much of the world because of Colony Collapse Disorder (CCD) (Russell et al., 2013). CDD is characterized by a sudden disappearance of honeybees from beehives, and in the worst case the entire population disappears. The relative contribution of those stressors in CCD events remains unknown (Henry et al., 2012). For this reason, the research of honeybee behaviour in colony has drawn great attentions from both bee-keeper and biologist, and recently also from computer scientist.

The study of behaviour of honeybees under video recordings is still an open challenge in computer vision. Developing an automatic monitoring system to detect the behaviour of honeybees is an important technical issue in the particular field of study (Chen et al., 2012). An automatic monitoring system can efficiently obtain the behaviour of honeybees, which can be used to analyse the activities of the honeybees such as foraging activity (Adeva, 2012). In the past ten years, two technologies have dominated for monitoring honeybees: (1) RFID sensors such as (Henry et al., 2012); (2) video-based surveillance such as (Campbell et al., 2008; Kimura et al., 2011; Chen et al., 2012; Chica, 2012; Chica et al., 2013). There are also other technologies such as capacitance-based sensors (Campbell et al., 2005) and infrared light sensors (Struye et al., 1994; BeeSCAN, 2005).

The video-based surveillance is relatively recent and has aimed at the behavioural analysis from both the inside and outside of beehives. One approach was based on video from the inside of the beehive for identification and tracking of individual honeybees without any markers and employing vector-quantization for image segmentation (Kimura et al., 2011). Another study aimed at counting the number of honeybees outside of the entrance of the beehive (Campbell et al., 2008). In this study, an elliptical shape was fitted to detect a single honeybee and used a motion model to describe various activities such as loitering and crawling as well as flying in/out. Unfortunately, the authors did not show their experimental results in details. In Chen et al. (2012), the honeybees moved in/out through a passageway one at a time. In this system, the in-and-out

* Corresponding authors. Tel.: +45 28825522 (G.J. Tu), +45 41893275 (P. Ahrendt).

E-mail addresses: tujun@eng.au.dk, tuganjun@hotmail.com (G.J. Tu), pah@ase.au.dk (P. Ahrendt).

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activity of the honeybees was restricted because of the passageway.

In order to monitor the behaviour of honeybees as naturally as possible we designed and implemented a video monitoring extension box for the beehive. The honeybees have to pass through the box when they enter or leave the beehive. This allows for markerless unobtrusive monitoring of the bees in their natural habitat. The system is a full real-time video monitoring system with both internal camera, power supply, illumination and computer system. It is based on the low-cost Raspberry Pi (Raspberry, 2012) and succeeds in detecting behavioural parameters of the honeybees such as counting bees, identifying their positions and measuring their in-and-out activity at the beehive entrance.

The rest of the paper is organised as follows: Section 2 describes the materials and methods. The experimental results are shown in Section 3. The discussion is given in Section 4.

2. Materials and methods

2.1. Video monitoring system

In this section, we describe the architecture of our video monitoring system, including the hardware equipment and the software architecture. The Raspberry Pi is a credit-card sized computer that costs much less than an ordinary PC (Raspberry, 2012).

2.1.1. Hardware equipment

The extension system box (length: 45 cm, width: 45 cm and height: 22 cm) is named video monitoring unit (VMU) and it serves primarily two purposes: (1) it can control the lighting facilities for image capture; (2) the honeybees enter and leave the beehive through the special passage, which does not allow overlapping of the honeybees.

The inside of the VMU is shown in Fig. 1a. In the inside there is a camera, a Raspberry Pi B+ (i.e. processing unit) that is connected to the Internet, some stable LED light sources with diffusers, and a mirror. The camera is a standard low-cost camera module which is sold with the Raspberry Pi (Raspberry, 2012). The camera is directed towards the mirror that is positioned at a 45-degree angle to view the bees from below. Along the sides of the VMU there are four sets of LED strips, which provide a constant illumination with intensity comparable to lightly clouded daylight. The LED array is white and thus a possible annoyance to the honeybees. However, based on our own experience as well as others (Hendriks et al., 2012), it is not the light itself, but rather changes in the light (switching on or off) that cause changes in the activity of the honeybees. The specific LED array can be found in (LED, 2012). The architecture of the inside is shown in Fig. 2.

The sketch of this system is illustrated in Fig. 1b. The VMU connects the inside of the beehive with the outside, thus the honeybees have to pass the VMU in opposite direction when exiting and entering the beehive. The bottom of the honeybee pool is transparent and covers the mirror. Through the mirror, the camera records the entire passage from the bottom.

Fig. 1c shows the VMU with the unmodified entrance of a standard beehive, and the entrance of the VMU covers the whole entrance of the beehive.

2.1.2. Software architecture

Our system runs Linux on a Raspberry Pi, and the primary programming languages for the system are C++ and MySQL. The primary program library is OpenCV, which is open source (OpenCV, 1999) and used for computer vision. Fig. 3 shows the overall framework of the software, which includes the following four phases:

- Recording data: it captures raw data into h.264 video, which is then converted to mp4 format.
- Video processing: it fetches frames from the video (i.e. mp4) and then segments the frames; counts the honeybees and measures their in-and-out activity based on the segmented images.
- Send and Delete: it sends the experimental results to a MySQL database via Internet and then deletes the h.264 and mp4 videos.
- Result database: it saves the experimental results into the database.

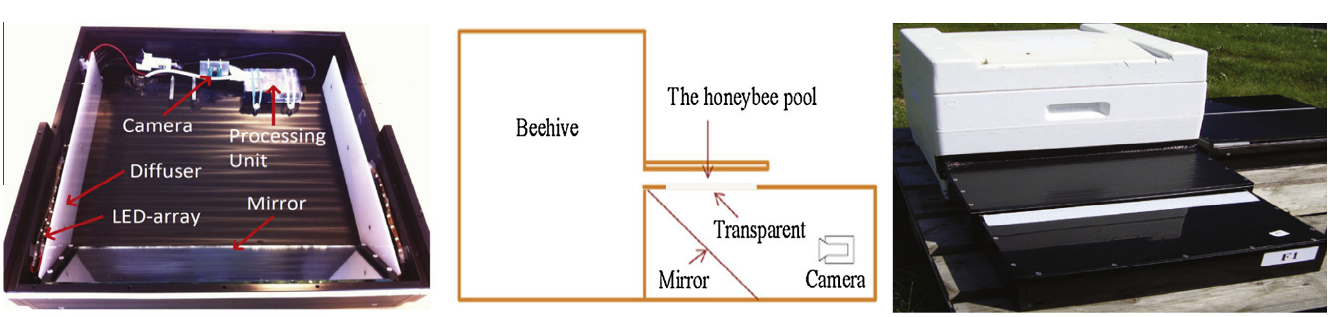
2.2. Material and activity

Two real-time video monitoring systems (see, Fig. 1c) were set up at the research centre Flakkebjerg, Aarhus University, Denmark. Each system recorded 30 s for every thirty minutes (i.e. a video) from Jun. 16, 20l4 to Nov. 24, 20l4. The type of the honeybees and beehives were *Buckfast* and *Segeberger* with ten frames made of polystyrene, respectively.

Each camera acquired colour images of size 1920×1080 at 25 fps. Using the command *raspivid* of Raspberry Pi, the raw data was recorded to video format h.264, which was then directly converted to mp4 format.

2.2.1. Data used in our experiment

In our experiment, two distinct data types were used: training and test data. 25 and 100 videos were selected for the training and test data, respectively. The training data was used to estimate the parameters of our methods and the test data was used to evaluate our methods. The videos were selected to represent five groups with different numbers of the honeybees in a frame. Otherwise, they were selected randomly from the full set of recordings.



a b c

Fig. 1. The automatic detection system: (a) the inside of the VMU, the distance from the diffuser to the bounding box is 4 cm; (b) the sketch of this system, the distance from the entrance of the beehive to the honeybee pool is 3 cm; (c) the VMU connects with a standard beehive.