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On Detection of Honeybees' Waggle Dances by Space-Time Correlations

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Abstract—Waggle dance is a behavior performed by honeybee workers for sharing information of feeding sources among other workers. It is important to analyze the occurrence timing and spatial distributions of dances in order to illustrate how workers communicate with each other. This paper proposes a scheme for automatically detection of workers undergoing waggle dance from a sequence of images. The performance of the proposed scheme is investigated through the experiments of detecting workers from sets of images obtained by video camera.

1. Introduction

Waggle dance is a well-known behavior performed by honeybee workers (*Apis mellifera*) [1]. This behavior is used for transmitting the information, concerning the direction and distance to a feeding source, to the other workers in their hive, so this is regarded as a kind of "language" [2]. It is important to analyze the timing and distribution for the occurrence of waggle dances, in order to reveal the effects of waggle dances to the collective behaviors of workers.

Traditionally, the analysis is conducted based on the manual extractions from the sequence images taken by video cameras. This tends to be time-consuming task, so automated schemes for detection of waggle dance should be desirable. There are few attempts to detect the workers undergoing their waggle dances from a sequence of the images, but several schemes have been proposed to track and to analyze the trajectories of honeybees [3, 4]. These approaches are effective for extracting and tracking a small number of honeybees each of which can be separated, but are not suitable for crowded group of honeybees. Another approach for detecting workers from crowded group of workers has been proposed [5]. This scheme finds particular patterns occurred by waggle dance from so-called cross-sectional images. It can detect workers with their dance behavior effectively, however, it takes much computational time to produce cross-sectional images from spatio-temporal images obtained by a video camera. A scheme with lower computational cost is necessary to construct a detector for continuous monitoring of honeybee colonies.

This paper proposes an automated scheme for detecting workers in waggle dance behaviors from groups of workers. Space-time correlations for image patches, proposed in [6], are produced as a matrix containing differential vectors on each of patches divided from an input image, then detection of behaviors by honeybees is judged by an eigenvalue of the matrix. A computational cost for this correlation is very small, and honeybees' behaviors including their waggle dances, can be represented by this correlation. The performance of the proposed scheme is explored by using the actual image sequences of honeybees, from the viewpoints of detection accuracy, sensitivity, and computational cost.

2. Preliminaries

2.1. Materials

Figure 1 shows a trajectory of the worker performing a waggle dance. A waggle dance consists of two performances: first a worker goes forward with shaking its body (waggle phase), and after that, this worker turns their direction and circles back to the staring point (return phase). The direction of turning switches on the return phase, to the left or to the right, thus the trajectory by a worker becomes the shape like figure-eight. The angle and distance showing in this dance corresponds to the distance and direction to a feeding source (see Fig. 2).

These behaviors are captured by a video camera (see Fig. 3 for the capturing environment), and then obtained as a set of image sequences with time.

2.2. Calculation for space-time correlation

In this section, we recapitulate the correlation between two space-time patterns proposed in [6]. This correlation uses gradients of pixel intensity for patches of space with time, called ST-patches. A ST-patch is typically small enough, e.g., a small patch consists of 7 pixels width, 7 pixels height and 3 frames, so that it can contain only a single uniform motion. Behavioral property for this patch is

Figure 1: A trajectory of worker in waggle dance.

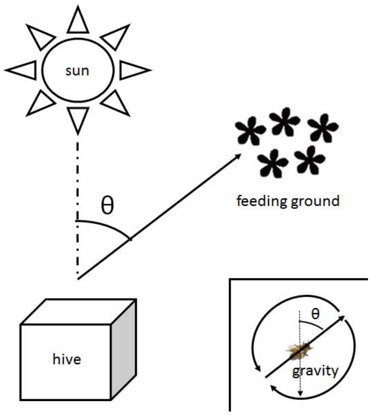

Figure 2: Information indicated by waggle dance.

evaluated by composing the following matrix M:

$$M = \begin{bmatrix} \sum P_x^2 & \sum P_x P_y & \sum P_x P_t \\ \sum P_y P_x & \sum P_y^2 & \sum P_y P_t \\ \sum P_t P_x & \sum P_t P_y & \sum P_t^2 \end{bmatrix}, \quad (1)$$

where P_x, P_y, P_t are gradients for a pixel in an ST-patch for horizontal, vertical, and time directions, respectively. Summation for each component is conducted for all pixels for a patch. The matrix M represents a space-time property for a patch, and the submatrix of M represents a space(appearance) property:

$$M^\diamond = \begin{bmatrix} \sum P_x^2 & \sum P_x P_y \\ \sum P_y P_x & \sum P_y^2 \end{bmatrix}. \quad (2)$$

Remaining elements (elements with the third row and the third column) represents a time(motion) property.

Motions in a patch can be evaluated by calculating ranks and eigenvalues of these matrices. Single/multiple motions is discriminated by Δr_r defined as:

$$\Delta r_\mathrm{r} = \mathrm{rank}(M) - \mathrm{rank}(M^\diamond), \quad (3)$$

where $\Delta r_\mathrm{r} = 0$ and $\Delta r_\mathrm{r} = 1$ are respectively single motion and multiple motion detected in a patch. When two patches are used for evaluation, $\Delta r_\mathrm{r} = 0$ and $\Delta r_\mathrm{r} = 1$ correspond to consistent and inconsistent to each other, respectively.

Figure 3: A view for experiment.

The measurement Δr_r can only evaluate whether the motion in a patch is complex or not, and the degree of motion complexity (or consistency) cannot be evaluated. Consistency of motions in a patch can be calculated by using eigenvalues of matrices. Let $\lambda_1 \geq \lambda_2 \geq \lambda_3$ be eigenvalues for matrix M and let $\lambda_1^\diamond \geq \lambda_2^\diamond$ be eigenvalues for matrix $M^\diamond$. Continuous rank-increase measure Δr_c is defined as

$$\Delta r_\mathrm{c} = \frac{\lambda_2 \cdot \lambda_3}{\lambda_1^\diamond \cdot \lambda_2^\diamond}. \quad (4)$$

This measure takes $0 \leq \Delta r_\mathrm{c} \leq 1$. $\Delta r_\mathrm{c} = 0$ corresponds that the rank does not increase, i.e. $\Delta r_\mathrm{r} = 0$. In this case, there is little motion in a patch. $\Delta r_\mathrm{c} = 1$ corresponds that the rank clearly increases, i.e. $\Delta r_\mathrm{r} = 1$. Complex motions contains in a patch for this case.

2.3. Scheme for detecting waggle dance

We have preliminarily conducted experiments for calculating Δr_c with respect to various space-time segments of honeybee images. From the experimental result, it is found that relatively higher Δr_c can be obtained for the segments where a honeybee worker is in its waggle phase. This can be achieved by high frequencies of pixel values for a worker which is moving forward with shaking its body.

A scheme for detecting honeybees with their waggle dance is described as follows. A sequence of image frames that is obtained by a video camera is prepared, in which an image frame consists of W pixels width and H pixels height and the video camera captures F frames per second. Thus, when an image sequence is assumed to be l seconds long, the number of images is lF.

Each of image frames is subdivided into a set of $w(\ll W)$ pixels width and $h(\ll H)$ pixels height, each of subimages does not overlap each other. By collecting a stack of subimages from t subsequent time frames at the same position, correlation matrices and their measures can be calculated by Eqs.(1)–(4). If a measure Δr_c exceeds to a threshold value, we regard a honeybee in this subimage as being in the waggle phase of waggle dances.

3. Experimental results

This section describes experimental results for the space-time correlation-based scheme applying to sets of image sequences obtained by a video camera. Three sets of sequences, called Image-A, Image-B, and Image-C, are used. These have 512 pixels width, 384 pixels height, and 32 seconds long with 30 frames per second (960 frames in total). An ST-patch used in experiments have 30 pixels width and 30 pixels height, which corresponds to the size of a honeybee in the image. The period of duration for a patch is set to 20 frames so that waggle phase of a honeybee contains in a duration. A threshold value of Δr_C for detecting a waggle phase in an ST-patch is set to 0.9, which is determined from the preliminary experiments. If Δr_C for an ST-patch exceeds to this value, this patch could contain a dancing honeybee with its waggle phase.

Figures 4(a), 4(b), and 4(c) illustrate examples of detections for waggle phase in the images, where red rectangles in the images represent patches containing honeybees in their waggle phase. The judgment for their correctness is evaluated manually, and in these cases, there are honeybees in their waggle phase in these red rectangles. Though the images are not clearly obtained due to low illumination (for not affecting honeybees' activities), the presented scheme can detect waggle phase.

More quantitative evaluations are performed for these image sequences with compared to the previous scheme in [5]. Let N_{ans} be the number of waggle phases in a set of image sequence that are manually measured. Let N_{det} be the number of patches detected as honeybees being in their waggle phase by the presented (or previous) scheme, and let N_{cor} be the number of patches that are correctly detected. From these numbers, sensitivity (r_S) and accuracy (r_A) indices are defined as

$$r_S[\%] = \frac{N_{cor}}{N_{ans}} \times 100, \quad (5)$$

$$r_A[\%] = \frac{N_{cor}}{N_{det}} \times 100. \quad (6)$$

Tables 1, 2, and 3 show the performances of the presented and previous schemes for three image sets, where 'time' denotes the computational time for processing a set of image sequences by a personal computer (CPU:Corei7, 3.40GHz, memory:8GB). The detecting performance for these schemes are similar to each other, but the computational costs for processing by the presented scheme is much less than those by the previous scheme, as shown in these tables. This can be achieved by requiring a small number of image sequences for calculating correlations by the presented scheme.

Table 1: Detection performance for the Image-A

	Presented scheme	Previous scheme
N_{ans}	30	30
N_{det}	44	46
N_{cor}	28	27
r_S [%]	93.3	90
r_A [%]	63.6	58.7
time [sec]	102.2	283.2

Table 2: Detection performance for the Image-B

	Presented scheme	Previous scheme
N_{ans}	34	34
N_{det}	46	40
N_{cor}	32	33
r_S [%]	94.1	97.1
r_A [%]	69.6	82.5
time [sec]	99.3	276.3

Table 3: Detection performance for the Image-C

	Presented scheme	Previous scheme
N_{ans}	29	29
N_{det}	45	57
N_{cor}	25	26
r_S [%]	86.2	89.7
r_A [%]	55.5	45.6
time [sec]	95.4	280.0

4. Conclusion

This paper presents and explores detections of honeybees in their waggle dance (waggle phase) from a set of image sequences. The presented scheme makes matrices with correlations for small patches of images, and its changes are described by eigenvalues of these matrices. The performances are evaluated by three sets of image sequences obtained by a video camera. The presented scheme and the previously proposed scheme based on making sectional images have similar performance with respect to accuracy and sensitivity for their detections, but the computational cost by the presented scheme is much lower than by the previous scheme. The presented scheme sometimes makes misdetection of honeybees in shaking their bodies without their waggle phase and in suddenly showing their bodies from a crowd of honeybees. This is due to the use of single measure (Δr_C) to judge whether the motion in a patch is in waggle dance.

For our future work, it is necessary to improve the accuracy for detections. It can be achieved by the combination of obtaining properties for patches and machine learning, such as support vector machine, for the discrimination of behaviors in high-dimensional vector space spanned by the obtained properties. Parameter dependencies for the presented scheme, such as a threshold value for the detection, should also be explored. Another challenge for the presented scheme is to demonstrate the effectiveness of this scheme with comparisons to other detection schemes, such as the scheme presented in [7], from the viewpoints of de-

(a) (b) (c)

Figure 4: Examples of detection for honeybees' waggle phase

tection accuracy and computational cost.

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