Automatic tracking method for multiple honeybees using backward-play movies

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***Abstract*— In recent studies, researchers can easily record the behaviors of animals by digital video cameras, which provide high functionality at reasonable cost. However, it is a laborious and time-consuming manual task for them to extract the useful behavioral data from these videos. We recently proposed a tracking method for unmarked multiple honeybees in a flat arena, named the "K-Track" algorithm. The algorithm can successfully identify and track nearly 90% of interaction cases of targets. In this study, we proposed an improved method for the existing K-Track algorithm by tracking results using backward-play movie. If the tracking results differed between the forward and backward episodes, one of them had probably resulted from correct tracking. Therefore, by comparing the forward and backward trajectories of the same interaction, we assumed that there is the potential for an increase in tracking accuracy. In the experiments, K-Track using backward movies successfully tracked four out of five situations that was failed by original K-Track and we confirmed that the method has the potential of improved tracking accuracy.**

Keywords-video processing, unmarked multi-object tracking

I. INTRODUCTION

In most ethological studies, many researchers popularly have observed insects such as bees [1] and ants [2] to reveal social mechanisms in animals. The waggle dance, was discovered by Karl von Frisch in 1967 [3], is known as social behavior of honeybees. These behaviors are of great interest to ethologists, then the bees has one of popular model animals for studying the behaviors. To understand the social structure and performance of a honeybee colony, the researchers must need to monitor and analyze behaviors of not only individuals but also swarm of bees. In recent, they recorded the behaviors of bees within a circular arena [4, 5], and their behavioral information was gathered by analyzing the trajectories and variation of animal movements. Recording equipment, such as digital video camera, provide high functionality at reasonable cost and they acquire important data on animal sociality. Video recordings can capture the long-term movements of target animals rapidly and easily, but extracting the behavioral data from videos is a laborious and time-consuming manual task.

Recently, many researchers have been developing automatic tracking programs, enabling quick, precise analyses of various animal behaviors [e.g. 6, 7, 8]. Ethological data in video images can now be acquired by the programs. However, they are of limited applicability because the target animals are assumed to move against a constant background with continuous, streamlined, unvarying movements. The software is unsuitable for automatic tracking of honeybee behaviors, which are both complex and unique. The bees frequently contact each other and display many irregular movements, such as resting or stop–start walking within their hive or experimental arena. These behaviors require analysis by a new tracking method such as the RFID (Radio Frequency IDentification) tracking and barcode labeling [9, 10]. In these methods, individuals of bees are identified by part of an RFID chip or by a barcode paper attached to their bodies. However, these methods often have an influence on the behavior of targets. The automatic tracking of unmarked honeybees remains an important challenge in animal behavior analysis, because this method would minimize the experimental interference.

We have already proposed a tracking method for unmarked multiple honeybees in a flat arena, focusing on their interaction events [11]. Based on this proposed method, we developed a prototype software, named "K-Track" [12]. The K-Track program implements three main processes; (A) detecting the object (bee) region by a simple threshold processing on gray scale images, (B) identifying individuals by their size, shape and spatiotemporal position changes, and (C) connecting the centers of mass of the identified individuals through all video frames to obtain the individual motion trajectories. The performance of our software was evaluated on three one-minute movies of 16 young bees walking around a flat circular arena. The software successfully tracked nearly 90% of all recorded interaction events, but failed when interactions occurred near the wall, as edge of working area, of the circular arena [12]. The failures are probably caused by the honeybees' nonlinear movement and the sudden directional changes of their bent bodies as they follow the curvature of circular wall [12].

In this study, we proposed an improved method for the existing K-Track algorithm by tracking results using backward-play movie. In the first, the algorithm detects and numbers all situations of interactions from tracking results by forward-play movies. It apply the K-Track's tracking algorithm to each interaction situation using backward-play movies. At last, we compared two tracking results by both forward and backward movies to confirm the performance of tracking using backward-play movie.

II. Materials and Methods

A. Tracking algorithm

To improve the existing K-Track algorithm [12], our software were tracked using the video recordings that played both forward and backward during interaction events (Fig. 1). If the forward and backward trajectories were very similar, both tracking results were regarded as successful. However, if the two trajectories were different, one of them had probably resulted from incorrect tracking, characterized by sudden changes in the moving distance and direction of the target between two continuous frames. Therefore, by comparing the forward and backward trajectories of the same interaction, we assumed that there is the potential for an increase in tracking accuracy.

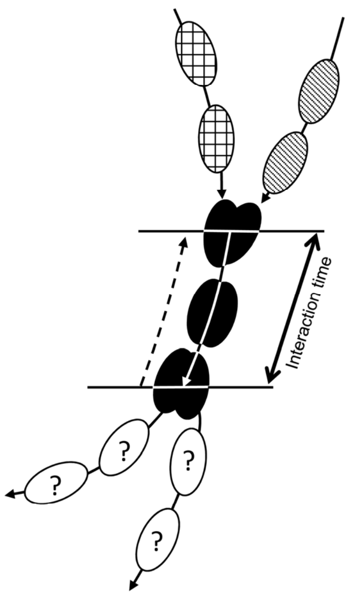

Fig. 1 Tracking directions of forward-play and backward-play image sequences. The solid and dashed line indicate the tracking directions of forward and backward, respectively.

Our improved program generates the sequential image data in the forward-time and backward-time directions from one original video. In a window of time around each overlap or merger event of two individuals, the K-Track algorithm extracted the both individuals' locations and trajectories from both streams of sequential images by the following steps.

1. Tracking process:
   A) Apply following K-Track's tracking process on the forward image sequences [12].
      i. Extraction of bee's candidate regions using background subtraction and threshold processing
      ii. Detection of bee's regions using bee's body size and sharp
      iii. Identification of bee's regions using a liner moving predication and spatiotemporal context
   B) Detection the time and position of two overlapped animals and number each situation.
   C) Applying K-Track's tracking process on the backward image sequences to each overlaped situation.
2. Outputting tracking results: Output two data of both individuals' locations and trajectories.

Depending on the interaction situation, the overlap or merging duration extended about a few seconds. In this report, we applied the new method to only two-individuals expect for multiple-individual interactions.

B. Image data and computer to develop software

Three one-minute movies were produced at the honeybee laboratory of Karl–Franzens University of Graz [4], Austria, and were also analyzed in our previous study [12]. In those movies, 16 juvenile female worker honeybees were entered into a flat circular arena (60 cm diameter) in a darkroom. A temperature gradient from 32°C on the right to 36°C on the left was imposed on the floor. The behaviors under infrared overhead lighting were recorded by an infrared-sensitive CCTV (Closed-Circuit TeleVision) camera. The movies were recorded in PAL format (25fps), generating (720 × 576)-pixel digital image sequences.

Our software was developed and evaluated on a personal computer (Intel Core i7-3970X, 3.50 GHz, 64 GB memory, 1TB SSD) with Windows 8 Enterprise 64-bit operating system, Visual C++ 2013 as the compiler and OpenCV 2.4.10 as the image processing library.

III. Results

We applied the improved K-Track algorithm to three one-minute movies (Movie1, Movie2 and Movie3) of 16 moving honeybees. The same videos had been previously applied in the evaluation of K-Track [12]. The average computational time of three movie was about 15 minutes in our experiment. By analyzing the backward results, we compared and checked tracking results of all two-individual interactions. In the first, we focused five interactions that the K-Track was failed. We confirmed that the K-Track using backward movies successfully tracked the bees in four out of five two-individual interactions that had failed in K-Track (Fig.2 and TABLE I). In the forward results, K-Track algorithm tracked wrong individuals by exchanged them. On the other hand, in the

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backward results, the algorithm successfully responded to irregular movements and tracked two individuals However, the proposed method could not track the bees in one interaction events in overlapping (2) on Movie-3 (Fig. 3 and TABLE I). In this event, the tracking trajectories of both forward and backward movies were incorrect despite of two tracking trajectories were not similar. The points where two individuals were exchanged were different, but both trajectories were incorrect as a result.

In the second, we checked all two-individual interactions except to above situations. Almost situations are similar tracking results, but two cases are different between forward and backward tracking results. In the cases, forward results are successful to track the bees.

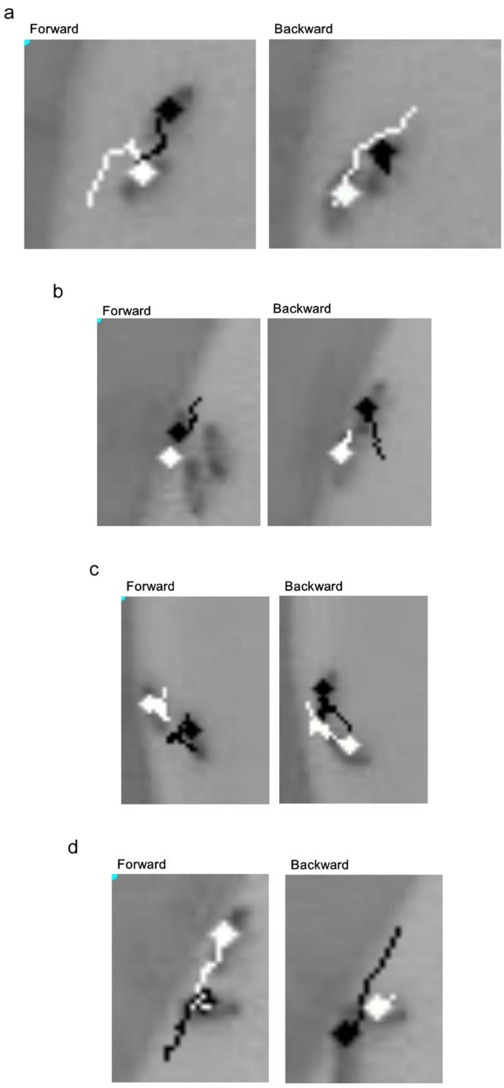

Fig. 2 Tracking results of the forward and backward sequences. a) Waiting on Movie2, b) Passing on Movie3, c) Overlapping (1) on Movie3 and d) Waiting on Movie3. Four situations were successfully tracked by K-Track using backward movies. The points on forward and backward results indicate both end points of tracking.

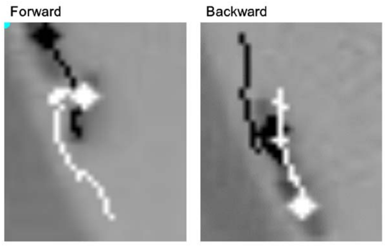

Fig. 3 Erroneous K-Track-kai results when the wrong trajectory is selected from the trajectories yielded by the backward and forward analyses. The points on forward and backward results indicate both end points of tracking.

TABLE I. COMPARISION OF TRACKING RESULTS IN THE FILED CASES OF ORIGINAL K-TRACK

Movie-tag [12]	Interation stuation [12]	Start frame (frame)	Duration (frames)	K-Track using forward movie	K-Track using backward movie	Figure
Movie2	Waiting	134	32	×	○	2a
Movie3	Passing	140	26	×	○	2b
	Overlapping (1)	723	79	×	○	2c
	Waiting	761	34	×	○	2d
	Overlapping (2)	470	48	×	×	3

To summarize these results, there were all 74 situations of two-individual interaction in all three movies. 68 cases were similar between forward and backward results and one case of all was incorrect result. Six cases were different results. In the six, two forward and four backward results were correct. In short, 73 of all 74 tracking cases included correct trajectories. By choosing good results, the method using backward movies would improve the tracking success number.

IV. DISCUSSION

We found that K-Track using backward movie has the potential of improving the tracking accuracy of original K-Track using forward movie. In our previous study, the K-Track failed a total of seven interaction events. All of those events occurred near the wall of the circular arena [12]. The results of tracking two-bee interactions by K-Track using backward movies were categorized into three types: (1) correct in both forward and backward results (2) incorrect in both results and (3) correct in either forward or backward results. New K-Track algorithm needs to compare the two trajectories obtained from the forward- and backward- played image sequences of a video in a window of time around an interaction event, then select the trajectory with an effective method such as the maximum distance in each frame, the average or sum of the moving distances. If we choice an effective trajectory-selection process, new method would improve the tracking accuracy of original software. It is very importance to decide the trajectory-selection process.

We assumed a tracking target as a solid object with a linear movement when we developed the K-Track algorithm for multiple bees. In bee experiments, the infrared light is a necessary requisite. We recorded the bees' motions by an infrared-sensitive camera in this condition. However, the resolution of an infrared camera is not high and the contrast in the produced images is poor. The infrared light degrades the image quality, rendering the tracking effort significantly more difficult. Improving the resolution and contract of recording images would enable more precise detection of the target individuals. More advanced image acquisition equipment would yield finer images for extracting precise data on animal behavior. However, many video data have been already acquired under poor conditions in laboratories around the world, and most data remain raw data ever now. Quantitative measurements from these raw data are important to utilize the existing scientific resources, effectively.

Even in our current situation, our tracking method could be improved in several ways. We assumed that an individual is solid object; in reality, an object's shape often changes during and after collisions. An elastic object model would further improve the estimations of shape and center of gravity of each object [13]. Furthermore, we could consider the irregularity of movement near the edge to improve the tracking accuracy. Tracking methods would not entirely remove all tracking errors in complex interactions and collision cases. Thus, in practical applications of our software, the manual tracking function, in which automatic tracking results can be edited and corrected by human operators, could be developed in future. By admitting a human into the loop, new K-Track might achieve perfect tracking results (100% tracking accuracy) with minimum involvement of human handwork.

In ethological experiments, automatic tracking methods such as our proposed method are powerful tools to reveal various behavioral properties, such as aggregation, scattering and avoiding. Such behaviors can be further quantified by considering factors such as the number of animals in an aggregation or the moving directions preferred by animals. Moreover, the energy consumptions of such behaviors could be estimated from the measured moving distance, speed and observed acceleration. The methods can obtain the movement trajectories of plural animals from video data, enabling new ethological analysis and quantitative evaluation of animal behavior. Such studies will improve our understanding of the complex interaction-based self-regulation of social insect colonies, which have led to significant bio-inspired algorithms and robotic applications in past studies [14, 15, 16].

V. Conclusions

In this study, we proposed an improved method for the existing K-Track algorithm by tracking results using backward-play movie. We confirmed the potential of improving the tracking accuracy of original K-Track by comparing two tracking results by both forward and backward movies. We found that most cases that could not track by existing K-Track were successfully tracked by K-Track using backward-play movies. Therefore, it is very importance to decide the effective trajectory-selection process. If we choice a good process, new K-Track would improve success number of tracking from 77 to 81 out of all 84 situations in our experiment. An automatic tracking is useful for various behavioral experiments, but the development of the method and technique depending on image quality is not easy. So, it is important that we use and improve software in the experiments.

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