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Published in:
SSIAB8

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Durey, M., Paulsen, R. R., Matessi, G., & Dabelsteen, T. (2010). Semi-automated tracking of behaviour of Betta splendens. In B. K. Ersbøll, & G. Guillot (Eds.), SSIAB8: The 8th French-Danish Workshop on Spatial Statistics and Image Analysis in Biology

Semi-automated tracking of behaviour of *Betta splendens*

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Abstract. In this paper, a novel software system for animal behaviour tracking is described. It is used for tracking fish filmed in aquariums using a low quality acquisition system. The tracking is based on a multiscale template matching technique that finds both the position and the orientation of the tracked fish. The template is matched in the background subtracted frames, where the background is estimated using a median based approach. The system is very stable and has been used in a large behavioural study design to the use of the behavioural pattern known as *mate choice copying* in *Betta splendens*.

1 Introduction

In modern behavioural studies, a common practice is the observation of subjects using recorded video. The video can be recorded during a fixed test setup and analysed immediately or at a later stage if the observer is already busy with the experiment. This avoids the experimental subjects to be disturbed by the experimenter and allows a safe-keeping of the experiment. Traditionally, the observation and annotation of events in the video is done by a human observer, which can be tedious, error prone, and time consuming. Obviously, some of this work can be performed using image processing techniques and several commercial products exist [14]. These packages are generic and can normally be used for well-controlled experiments. However, in our case, specific light conditions were needed for the setup to function. This in combination with a low quality video capture device, caused the output video to be to difficult to handle for the generic packages. The problems are mostly due to interlacing, inconsistent light, low resolution, and noise. It was therefore necessary to develop a custom image analysis tool that was customised to the quality of the video and the setup of the experiment.

2 Data

The data consists of video recordings of experiments with the Siamese fighting fish, *Betta splendens*. The overall goal of the experiment is to verify whether Siamese fighting fish use the facultative mate choice strategy known as *mate choice copying* [2, 5, 9, 3, 8]. This strategy has been observed in different species, and also in fish [13, 4], but never in *Betta splendens*.

A large series of experiments was designed and carried out to test the hypothesis. The main subject is a female, which is a placed in a choice situation between two males. After being allowed to express her preference for one of these males, another female is shown together with the non-favoured male to mimic a courtship interaction. If female fighting fish use mate-choice copying, we expect our subjects to reverse their preference, thus favouring the male they previously rejected after seeing him engaged in courtship with a female. *Betta splendens* are known to extract and use information from others' interactions [6, 7, 1], so we would also expect them to be able to use information from witnessed courtship interactions. In our experiment, the females' position was analysed directly by the observer, and therefore not recorded. The two males' behaviour, though, was recorded in order to investigate female mate choice preferences and the effect of male behaviour on mate choice copying. It is necessary to track both the position of the male and four types of behaviours, which are used in agonistic contexts, but also for courtship [10]. They are *lateral displays*, *gill cover erections*, *tail beats*, and *biting*. The design of the experiments was not optimised for automated video tracking as post-processing and therefore neither the light, the setup or the background are designed for image analysis. Leading commercial tracking software was tested, but was not able to perform the tracking due to the limited video quality. It was therefore decided to develop a custom software package.

3 Methods

The overall goal of the image analysis is to be able to track the position of the fish and allow the user to annotate specific behavioural patterns, such as bites, lateral displays, and gill cover erections. Optimally, the image analysis software should be able to detect these movements. However, the quality of the video material is not sufficient for this. The solution is therefore to make a semi-supervised system, where the system tracks the position of the fish and the user presses a key when the fish is for example biting.

The tracking is based on the commonly used technique of background subtraction. Therefore, the first task is to robustly estimate a background. However, this is further complicated by the fact that no pure background frames have been captured prior to the experiment. The background estimation should therefore also *remove* the fish. One popular approach is to use a mixture of Gaussians to model the distribution of every pixel in the image [11]. However, in the given experiments it proved sufficient to use a per pixel median filtering of a set of 100 frames to estimate a good background.

Prior to the actual tracking, the user manually selects the region of interest (also called the arena). During the tracking, the absolute difference between the background estimate and the current frame is computed. Furthermore, a simple routine to correct for jitter and interlacing is applied. Each scan line is shifted to maximal correlation between the line and the corresponding line in the background image before the subtraction. After the jitter correction and background subtraction, the fish is seen as a bright and elongated shape in this difference image. This can be seen in Fig. 1. In the next step, a multiscale

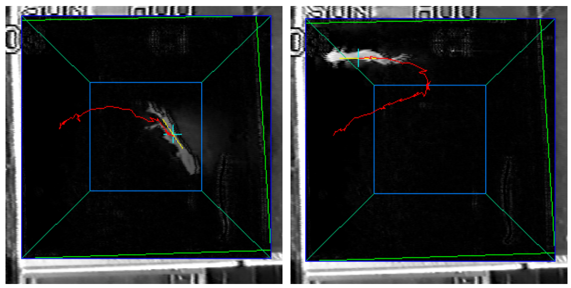

Fig. 1. The absolute difference between the current frame and the estimated background frame. The fish is seen as a bright region. The red line is the tracking from the last 100 frames and the cyan cross is the current estimate of the fish centre.

template matching is used to locate the brightest region in the image. Template matching, especially multiscale or hierarchical templates have been widely used in tracking and guidance of for example cars [12]. In our approach, the template is a simple rectangle which size is based on an estimate of the size of an average fish. As an initialisation, the difference image is subsampled by a factor four and a brute force search is performed. A candidate location of the fish is found where the sum of pixel-values under the template has a local maximum. Additionally, the template is rotated 0, 45, 90, and 135 degrees to get a rough estimate of the orientation of the fish. The 5-10 highest maxima are kept as candidate locations of the fish. Secondly, each candidate is refined by matching a higher-resolution template in the original difference image. The template position is seeded in the candidate position and a hill-climbing approach is used to find the position with maximum match in the neighbourhood of the candidate. A set of 64 pre-computed template images with rotations from 0 to 180 degrees are used. The optimal rotation of the current template is found by bi-sectioning. A score is calculated for each found candidate and the fish is determined to be the candidate with the highest score. The score is the sum of pixel values in the template. In conclusion, the result of the multiscale initialisation is the position of the fish and an estimate of its orientation. This information is stored and used as a prior for the next frame. A Kalman filtering approach is used to predict the possible location of the fish in the next frame. The Kalman filter uses the estimated velocity and acceleration. In Fig. 1, the tracking in progress can be seen.

4 Results

The developed software has been used to track 510 sequences of fish behaviours, where the fish were placed in three different types of environments. In most situations, the male could only see its own reflection from a mirror, but in some cases it could interact visually with a female, or it could see an empty tank that was placed beside him. In Fig. 2, some results of full tracking can be seen together with the defined arena. The arena for this experiment is divided into five zones. It can be seen that there are clear differences in the way that the fish has moved and the number and placement of the actions (biting, lateral displays, gill cover etc). For each experiment, a feature vector is calculated. It contains, among others, the time spent in each zone, the number of transitions from the different zones and the number of actions in each zone. These features were linearly combined into a single index characterising the behaviour of the males during the female mate choice experiment. This was included in multivariate statistical analysis of the females' preferences for male characteristics, which were size, color, aggressiveness, and activity. The influence of male behaviour on the use of the mate choice copying strategy was also tested using the data acquired the the video tracking system. A thorough analysis of these results will be published in an additional publication.

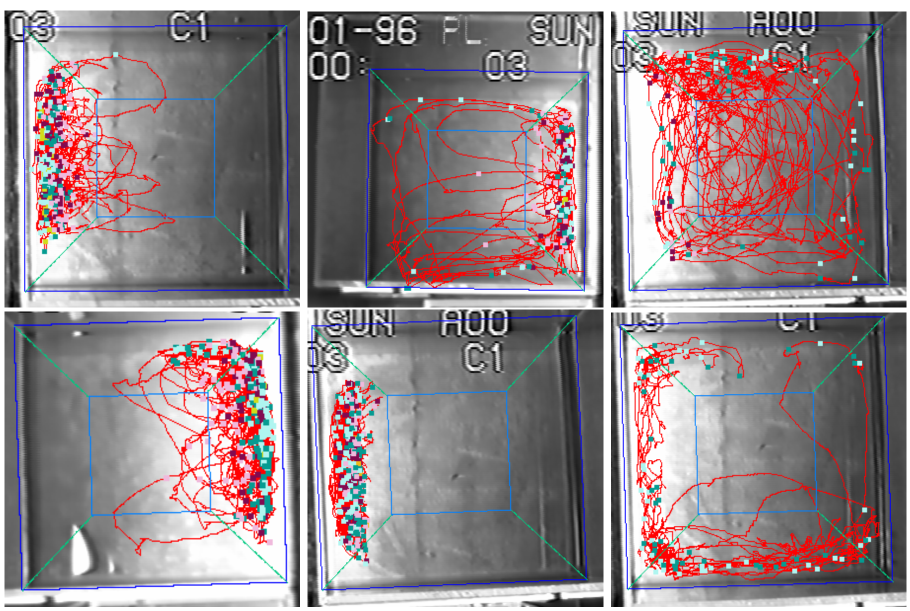

Fig. 2. Tracking results. The red lines are the fish movement and the dots are the different actions that the fish has performed (biting, lateral display, etc.)

5 Conclusion

A stable tracking software system has been developed and used on a large number of recorded video sequences. The method proved stable and is able to track the fish even under severe noise influences and varying light conditions. Preliminary results can be seen in Fig. 2 where it is seen that fish tracks can be very different depending on the individual fish, and independently of the environmental conditions. Some fish are very aggressive toward the mirror and do not leave the adjacent zone, while some other are more patrolling in their tanks. These swimming patterns suggest different personalities in male Siamese fighting fish that can potentially influence female mate choice preferences.

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