Peregrine: help

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1 Introduction

Peregrine is an automated tracking system developed to analyse and study animal behaviour. Versions of this tracking system have been used/developed as part of [1, 2, 3, 4, 5, 6]. Please refer to those for technical details. This document describes basic steps to get started and use peregrine.

2 Preferences and initial setup

3 Tracking

3.1 Position and velocity tracking

Position and velocity tracking uses a Kalman filter [7], and global data-association [8] to track multiple targets in a video.

3.2 Shape tracking

The shape tracking follows the approach described in [6]. Briefly, the measurements consist of a centroid, orientation, and two shape parameters that represent a parabola in the body frame. The parabola and corresponding orientation is found by brute-force search. The final measurements are fed into a particle filter with 200 particles. In the case of Shape tracking the csv file is ordered as:

3.3 Repair mode

The repair mode allows the user to fix the tracks by

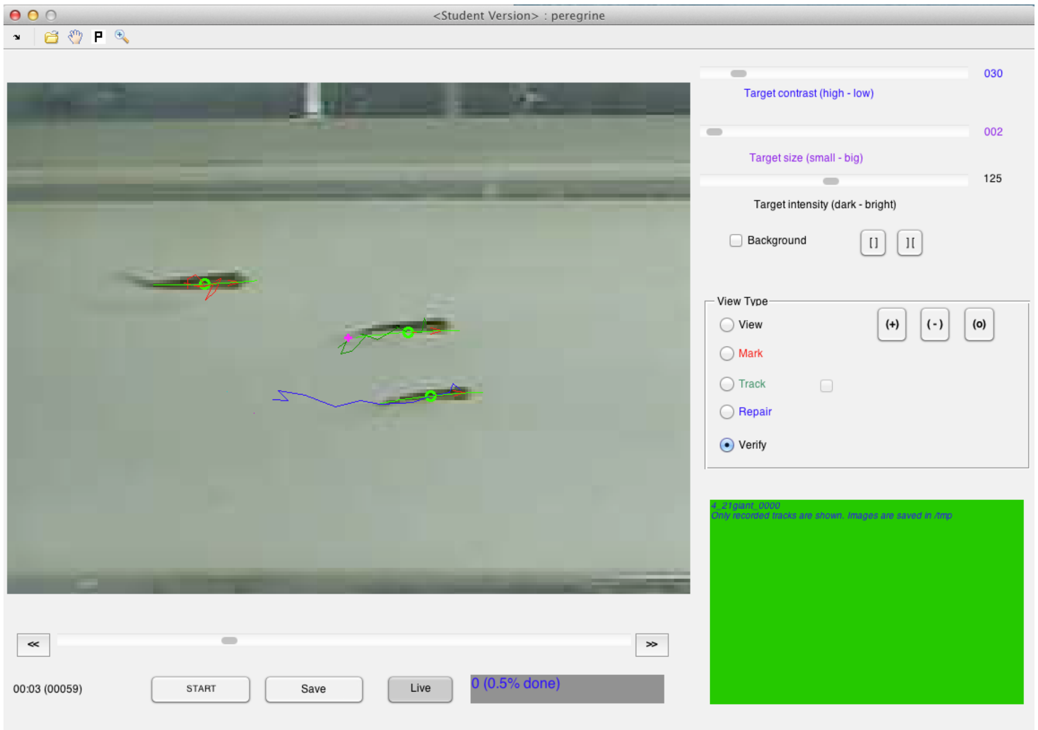

Figure 1: Tracking shape and orientation of three fish in a flow tank. Two fish on the top are occluded

1. Stitch broken tracks
2. Switch tracks before and after an occlusion that was not resolved properly
3. Add a new point for an undetected target

3.4 Command line mode

pg_cmd

4 Global observations

Once trajectory data is available, the command *get_obs* computes the various measures of collective behavior. We assume that both position and velocity of each

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	1	55.499	-6.7637	0.25673	0.58371	86.339	1	0.000131	-0.0066521	0.38471	0.92304	
2	1	2	56.684	13.985	1.1122	-0.87997	97.442	1	0.0049763	0.030075	0.98755	0.1573	
3	2	1	55.276	-5.0267	0	0	96.389	1	-0.0015587	0.014326	0.46413	0.88577	
4	2	2	57.229	13.226	0	0	103.73	1	-0.0194	0.16096	-0.99754	0.070146	
5	3	1	55.245	-4.6705	-0.42651	-0.49495	99	1	0.00069473	0.0013312	0.44851	0.89378	
6	3	2	57.119	13.164	-1.7882	1.6944	101	1	-0.023058	0.16719	-1	-1.22E-16	
7	4	1	54.878	-4.3277	0.1081	-0.37019	104	1	0.00050186	-0.0006713	0.41687	0.90897	
8	4	2	57.145	12.968	-2.1517	3.7531	101	1	-0.023633	0.13363	-0.99246	-0.12255	
9	5	1	54.953	-4.1089	2.3791	0.75698	95	1	-0.0005307	0.00089688	0.40085	0.91614	
10	5	2	57.063	13.049	-3.6376	3.66	100	1	-0.025411	0.14411	-0.96083	-0.27714	
11	6	1	54.78	-3.4952	0.45362	6.3239	92	1	-0.0012489	0.0034225	0.40085	0.91614	
12	6	2	56.909	12.652	-2.8358	0.61514	106	1	0.027038	0.10735	0.89768	0.44065	
13	7	1	54.574	-2.7577	1.4282	4.8254	97	1	-0.0014674	0.0059003	0.40085	0.91614	
14	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100	1	[illegible]	[illegible]	[illegible]	[illegible]	

Figure 2: Output of the tracker is stored in a csv file where each column corresponds to a single frame and a single target.

target (for example fish) is available at all times during the experiment. We also assume that the each fish identified by a unique number that can be used to quantify the behavior during the trial. Unless specified, we make the assumption that the heading is the same as the direction of motion. (This assumption is dropped, for example, when the fish are in a water tunnel.)

1. *Group cohesion:* The degree of cohesion in groups is described in terms of the average nearest-neighbor distance (ANND) [9, 10]. Given the two-dimensional position $\boldsymbol{r}_i[k]$ of the i-th fish at frame k, the ANND during that frame is [10]

$$\mathrm{ANND}[k] = \frac{1}{N}\sum_{i=1}^{N} \min_{j\in\{1,\ldots,N\}, j\neq i}(\|\boldsymbol{r}_i[k] - \boldsymbol{r}_j[k]\|), \tag{1}$$

   where N is the total number of fish and $\|\cdot\|$ denotes the standard Euclidean norm.

2. *Group coordination:* is captured through the polarization (Pol) that measures the degree of alignment between the directions of motion of the fish [11]. Given the two-dimensional velocity $\boldsymbol{v}_i[k]$ of the i-th fish at frame k, the polarization at that frame is

$$\mathrm{Pol}[k] = \frac{1}{N}\Big\|\sum_{i=1}^{N} \hat{\boldsymbol{v}}_i[k]\Big\|, \tag{2}$$

   where $\hat{\boldsymbol{v}}_i[k] = \frac{\boldsymbol{v}_i[k]}{\|\boldsymbol{v}_i[k]\|}$ is the direction of motion.

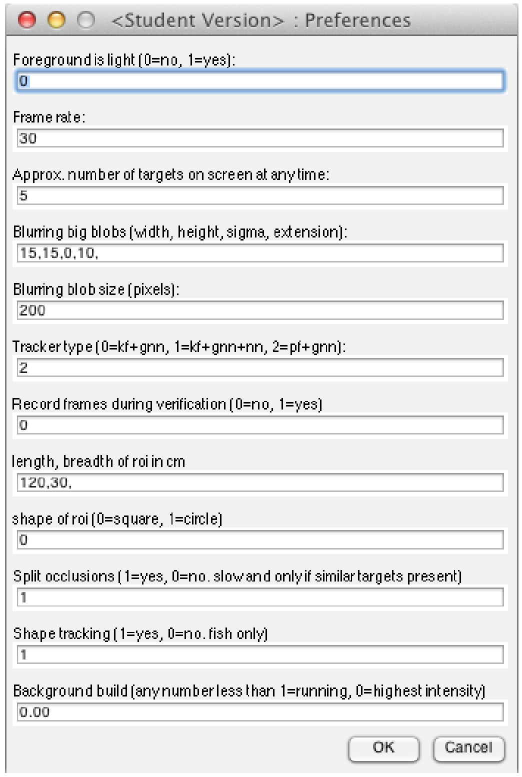

Figure 3: Preferences

3. *Group speed:* is computed to describe average speed of the subjects, and is given by

$$S[k] = \frac{1}{N} \sum_{i=1}^{N} \|\boldsymbol{v}_i[k]\| \tag{3}$$

4. *Group angular momentum*: the normalized group angular momentum $\hat{L}$ is indicative of milling patterns [12, 13], with $\hat{L} = 1$ for single milling formations and $\hat{L} = 0$ for a coherent one-directional formation [12]. Depending on how $\boldsymbol{r}_i$ is defined, the angular momentum can be computed about the group center of mass [14], or about the center of the observation region.

$$\hat{L}[k] = \frac{\| \sum_{i=1}^{N} \boldsymbol{r}_i[k] \times \boldsymbol{v}_i[k] \|}{\sum_{i=1}^{N} \|\boldsymbol{r}_i[k]\| \|\boldsymbol{v}_i[k]\|} \tag{4}$$

Table 1: csv file output for tracking

column no.	variable
1	frame no.
2	target-id
3	horizontal-coordinate (cm)
4	vertical-coordinate (cm)
5	horizontal-velocity (cm/s)
6	vertical-velocity (cm/s)
7	size (pixels)
8	1 (homogeneous coordinate to keep things linear)
9	shape parameter 1
10	shape parameter 2
11	heading (x component)
12	heading (y component)

5. *Group interaction:* with a focal fish (or an external stimulus such as a robot) is quantified in terms of values such as distance, alignment and relative speed. We denote the focal fish or target index with a subscript $\boldsymbol{r}_f$. Specifically the observables are

   (a) *Average distance to the focal fish:* Average distance of all other fish to the focal fish

   $$\hat{d}[k] = \frac{1}{N-1} \sum_{i \in \{1,\ldots,N\}, i \neq f} \|\boldsymbol{r}_i[k] - \boldsymbol{r}_f[k]\| \tag{5}$$

   (b) *Minimum distance to the focal fish:* Minimum distance to the focal fish between all other fish

   $$\tilde{d}[k] = \underset{i \in \{1,\ldots,N\}, i \neq f}{\operatorname{argmin}} \|\boldsymbol{r}_i[k] - \boldsymbol{r}_f[k]\| \tag{6}$$

   (c) *Group relative speed with respect to the focal fish:*

   $$\tilde{S}[k] = \left(\frac{1}{N-1} \sum_{i \in \{1,\ldots,N\}, i \neq f} \|\boldsymbol{v}_i[k]\|\right) - \|\boldsymbol{v}_f[k]\| \tag{7}$$

(d) *Alignment to the focal fish:*

6. *Group behavior:* quantifies on an average the behavior of subjects such as percentage time spent freezing, thrashing, or swimming. These values allow us to determine if the subjects were in general scared or not. The specific observables are:

   (a) *Time spent freezing:* To elucidate the behavior of the subjects, we score the time spent freezing during each trial. This value is computed automatically based on the condition that a fish is considered freezing during a frame if it spends two continuous seconds within a ball of radius of 2 cm [15]. Freezing is recorded if at least one fish satisfied this condition.

   (b) *Excursions of focal from shoal:* To measure the number of excursions from the shoal of a particular fish, we use the definition of shoal membership as described in [16]. In particular, we (i) compute the time series of average nearest neighbor distance of the focal fish,(ii) distribution of ANND for all fish over all frames is computed. Use the mode of this distribution as the threshold, divide the time series into segments where the individual's ANND goes above the mode, and (iii) find the distribution of the maximum ANND of each segment. The upper p=0.05 quantile of the max ANND distribution determines if a segment is an excursion or not.

7. *Tail-beat frequency:* Tail-beat frequency is computed using the tail-tip position estimated from the body frame location. For a signal x, the *fft* routine implements the following DFT

$$X(k) = \sum_{j=0}^{N-1} x(j)\omega^{jk}, \tag{8}$$

   where $\omega = \exp(-2\pi i/N)$ and $k \in \mathbb{Z}$, and $x(j)$ is the coefficient for the sinusoidal frequency ω^{jk}, which is equal to jk/N. Since matlab returns a double sided spectrum of magnitudes, the amplitude is obtained by doubling the magnitude of $X(k)$. Also refer to the example in `http://www.mathworks.in/help/matlab/ref/fft.html`.

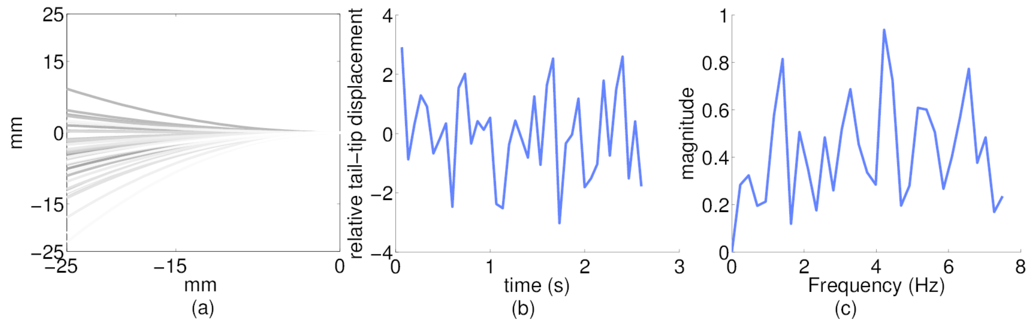

Figure 4: Tail-beat frequency computation: (a) tail end of the fish in successive frames (increasing in time as the color changes from grey to dark, with 0 marking the fish body center) when the fish was not occluded and away from the tank wall; (b) detrended relative tail-tip position during that sequence; and (c) Fast Fourier transform of the tail-tip position for analysis in the frequency domain. The frequency with the maximum magnitude (here 4.2 Hz) is selected as the tail-beat frequency

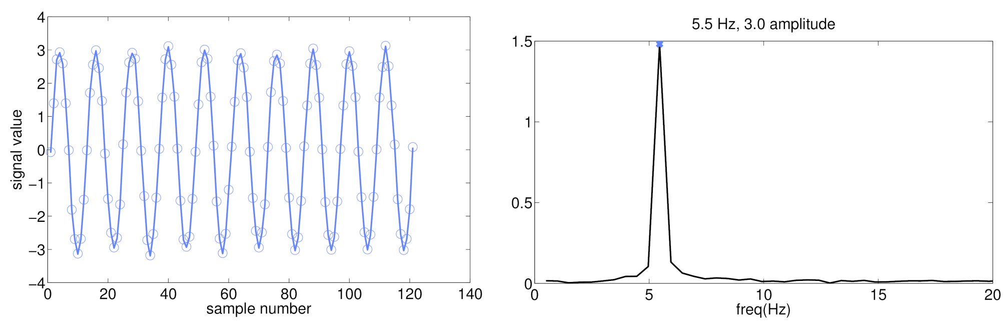

Figure 5: The toy example above shows how FFT is used to compute frequency and amplitude from a given signal. A signal with known frequency (5 Hz) and and amplitude (3 units) is sampled at 60 Hz after corrupting with zero-mean Gaussian noise of 0.1 units standard deviation. The signal is then detrended to remove linear trends. The circles on the left mark the detrended points on the noisy signal. The right plot shows the magnitude after applying the fast fourier transform along the length of the signal. The signal frequency is selected as the one where the magnitude is maximum (5.5 Hz) and the amplitude is twice the magnitude.

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