FTrack v0.9.3
User's Manual

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April 7, 2008

1 Introduction

FTrack is a suite of functions written in Matlab for the purpose of single-object video tracking. Specifically, the "single-object" is assumed to be a fruit fly, although this need not be the case. The current version (v0.9.3) uses the videoIO toolbox[1] to read the videos into Matlab. At this point FTrack, does not allow for multiple fly tracking and has no analysis functionality. The analysis functionality is contained within the accompanying program FAnalyze[2]. If need be, with small modifications, the FlyTracker function (which is the backbone for FTrack) will most likely be able to track multiple *well-separated, non-colliding* flies. FTrack provides the user with the raw tracked data, along with the ability to view the data, clean any obvious false tracks, and correct for camera tilt. It is up to the user to smooth and segment the subsequent data anyway that the user sees fit.

The functions were written as generally as possible to locate a moving object and track the position of that object in each frame. The algorithm that FTrack employs is relatively basic and was optimized for the fly tracking application with the video setup used by our lab. It has only been tested in videos with very simple, unchanging background conditions (namely a black fly on a white background or a white fly on a black background). FTrack is not guaranteed to work in videos of higher complexity or with different setups, although it should have a reasonable amount of versatility.

FTrack functions are relatively modular, so the overall structure of the program can be maintained if changes to any particular function are required. Those who are Matlab-savvy are encouraged to modify/replace functions as you see fit. Those who are not Matlab-savvy should refrain from manipulating the `.m` files, and contact the author with any suggestions for additions or subtractions to the program. Please note, however, that only the most relevant, pressing changes will be made.

[1] `http://sourceforge.net/projects/videoio/`
[2] See FAnalyze documentation for details

2 Overview of the FTrack algorithm

The algorithm behind FTrack is relatively rudimentary and is described in detail in Ref. [1] and Ref. [2] The underlying assumption is that the object moves from frame to frame, and so subtracting a background image will highlight pixels that are different from this background. FTrack creates a background, subtracts it from the current frame, and squares each resulting pixel to increase the signal to noise ratio. Then, the brightest pixel in this image is found and the center of mass (really, center of *intensity*) of a subset of pixels around this point is calculated. This center of intensity is used as the object's location.

There are two caveats to this method, and both have to do with the calculation of the background image. First, in order to find the object in the first frame, a static background image must be calculated. This background is an average of the first N_B frames, where N_B is a user-defined parameter. N_B should be relatively small so that the algorithm does not take an exorbitant amount of time to read the video and calculate the average, but needs to be large enough to ensure at least some variation in the image.[3]

After the first two frames, the background is calculated by taking a weighted running average

$$I_B(n+1) = \alpha I_B(n) + (1-\alpha)I(n)$$

where I_B is the background image, I is the current frame, α is the weighting parameter (between 0.90 and 1.00), and n is the frame index. The entire image is updated *except* for a square region that includes the fly. This allows the algorithm to work effectively even when the fly remains stationary for a long period of time.

The body axis of the object is also calculated as the tracking algorithm proceeds. To do this, pixels in the difference image with intensities greater than 20% of the maximum intensity define a 2D projection of the object. This projection is effectively a scatter plot, with points placed at the locations of the pixels that define the object. A Principle Components Analysis (PCA) is then performed on this data. Since a fly is typically longer than it is wide, the component with the largest variance is used to calculate the orientation angle ϕ_1. The orientation angle is somewhat ambiguous, since $\phi_2 = \phi_1 + \pi$ defines the same axis. For ease of use, the program divides up the orientation angles into two groups, ϕ_{UHP} and ϕ_{LHP}. ϕ_{UHP} is defined as the orientation angles that lie in the upper half plane $(0 < \phi < \pi)$ and ϕ_{LHP} are angles that lie in the lower half plane$(-\pi < \phi < 0)$. For each frame, both angles are available to the user. By comparison of these angles with the direction of velocity, one can reasonably estimate in which direction the object is moving. It is up to the user to decide which orientation angle to choose.

[3] We have seen that 100-500 frames gives reasonable results, depending on frame rate and activity of the fly.

3 Placing FTrack in the Matlab path

In order to use FTrack, the FTrack folder must first be placed in the Matlab path. It is also recommended to remove any previous versions of FTrack from the Matlab path.

1. Open Matlab.
2. Select **File** >> **Set Path...** from the toolbar. The Set Path dialogue will open up.
3. Click on the **Add Folder...** button.
4. Find the FTrack directory and select the **functions** folder. Click **OK**. The path and name of the FTrack functions folder should show up in the Matlab search path window.
5. Find the videoIO folder that fits your Matlab release. FTrack has only been tested for R2006a, R2006b, and R2007a. For other releases, you will need to recompile the videoIO functions (see the videoIO documentation if you need to do this).
6. Repeat Step 4 with the appropriate **videoIO** folder.
7. Click **Save**, and then click **Close**. FTrack is now ready to use. To test if it is installed correctly, type `help videoReader` and then `help FTrack` in the Matlab command window. If an error is obtained upon either of these commands, the folders were not correctly installed, so try to re-install. If the installation worked, you will be able to open the program or use any of the functions regardless of what directory you are currently in.

4 The FTrack GUI

The FTrack graphical user interface (GUI) was written to facilitate use of the tracking functions. It is specifically intended for users who have minimal-to-no experience with programming in Matlab. Because it provides an accessible interface for loading and tracking, use of the GUI is recommended for all applications unless the user prefers to incorporate specific functions into his/her own scripts.

The interface is shown in Fig. 1 and is divided into two general sections: Tracking and View & Clean Data. The functionality of these sections is described below.

Instructions for Tracking

The first section of the GUI is the "meat" of the program, so to speak. In this section, the user inputs all of the necessary information and parameters required to initiate the tracking.

1. Open Matlab.

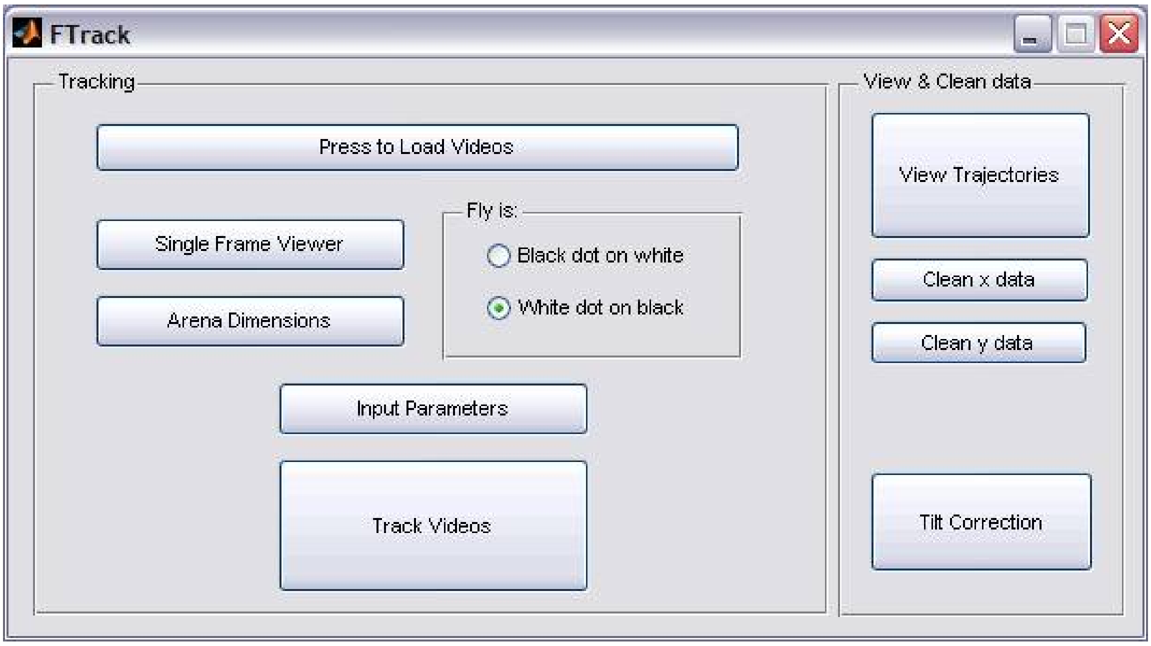

Figure 1: The FTrack GUI

2. Type `FTrack` to start the program. The FTrack GUI should appear.

3. Click the **Press to Load Videos** button. The user can select one or more videos to track (.avi, .mpg, mp2, etc.). The name of the videos will appear in Matlab Command window. If multiple videos are selected, they will be tracked in succession, and necessary information from each video will be saved as a .mat file (see below).

4. Click the **Single Frame Viewer** button. This will show the first frame of each selected video; the filename of the particular video can be seen in the title bar of each figure window. The purpose of having this button is to extract pertinent information about the specific videos in question and to make sure that they can be read properly by the program. Information about the video will be displayed in the Command Window (video dimensions, number of frames, and frame rate).

5. Click the **Arena Dimensions** button. When this button is clicked, the user is able to select any number of points in the image by left clicking. The user is expected to click points that define the boundary of the arena. FTrack assumes a circular/elliptical arena, so it goes ahead and calculates the best fit ellipse[4] to the selected points when the user hits Enter. FTrack then calculates a mask so that only the portion of the video within the elliptical boundary is tracked. The resulting mask is shown, along with the location of the boundary. Furthermore,

[4]The function `fit_ellipse` is used for this calculation. It can originally be found at `http://www.mathworks.com/matlabcentral/fileexchange/loadFile.do?objectId=3215&objectType=File`

the parameters of the resulting ellipse are displayed in the Command Window. This step *must* be performed if the user plans to employ the Tilt Correction functionality of FTrack.

6. Select the characteristics of the object in your video: black dot on a white background or a white dot on a black background. As of this version, each video must have the same characteristics.

7. Click the **Input Parameters** button. A window will open with several input boxes. The filename of the video that these input parameters correspond to is displayed at the top of this window.

   - Enter the name of the directory where you would like the output files to be stored.
   - Enter the **Start Frame** and **End Frame** of the region of video that you would like to track. Please note that the first frame of a video is indexed as frame 0.
   - Enter the **Initial background size**. The need for this number was discussed in Section 2. The default is 100 frames, and this should be sufficient for most applications.
   - Enter the **Radius of the Arena (in cm)** as well as the **Bounding box half-size (in pixels)**. The Bounding box half-size defines the size of a box around the fly that will not be updated in the background calculations (described above). Make sure this number is slightly larger than the maximum length of your fly.
   - Enter a value for the **Background weight** α between 0.9 and 1.0. The default (0.9) should be sufficient.
   - Click **OK**
   - Repeat these steps for each video that you have selected. Note: it may be helpful to keep the figure windows from the single frame viewer open while you input parameters.

8. Click the **Track Videos** button to begin tracking. The progress of the algorithm will be displayed in the Command Window. After each video is tracked, the raw (x,y) trajectory, time vector, video information (frame rate, size, etc.), and input data are saved in a `.mat` file with the same filename as the video. The variables saved are described in the Appendix. The x,y data are also saved as `.xy` file as a simple two column list of positions, and the upper half plane orientation data are saved as a .ori file. This allows the user to track many videos at once and access the data at a later time for processing. The saving happens *automatically* at the end of tracking, so the user need not worry about it. A message will be displayed in the Command Window validating the saving process and completion of the tracking.

View & Clean Data

At this point, the user can choose to view and/or clean any trajectory data that has been saved in a `.mat` file from a previous tracking session. You may only select one file to view/clean at a time. To load in a previously saved session, click the **View Trajectories** button, and select a file. A figure will be displayed for the chosen video. This figure shows the x-position as function of time (upper left), the y-position of the fly as a function of time (lower left) and the resulting trajectory (right) as if it were drawn on a video frame. See Figs. 2 and 3 for details.

Cleaning the Trajectory

In some cases, the object may leave the frame or hide behind an obstacle in the environment[5]. When this happens, the algorithm is no longer able to locate the object and will result in a false track for that frame. These false tracks are marked by regions of the x or y trajectories that are visibly deviant from the "actual" trajectory. Definitions of such deviations are largely chosen at the discretion of the user, and examination of the data will suggest whether these points are actual outliers or are actual movements of the object. In any case, FTrack allows one to "clean" these outliers from the data and interpolate between known true points. The x and y data must be cleaned separately.

1. Click **Clean x data** or **Clean y data**. A window will appear with the requested data.
2. Use the zoom tools in the toolbar of the figure window examine any areas of interest in further detail. This will help you determine whether points are false tracks or true movements and will ensure that you only clean the regions where false tracks exist.
3. Press any key to continue.
4. Crosshairs will appear in the figure window. These will allow you to select the region of data you wish to clean.
5. Select a point to the left of the false data, then select a point to the right of the false data. This defines the region to clean.
6. Select a point near the apparent actual trajectory. This is called the baseline. Then select a point that defines a threshold for the outliers; that is, a point above or below which any existing data will be discarded. If the threshold is below the baseline, the function will discard data below the threshold; if the threshold is above the baseline, points above the threshold will be discarded. See the example in Figs. 4 and 5.

[5]Assuming, of course, measures were not taken to minimize these events in the experimental setup.

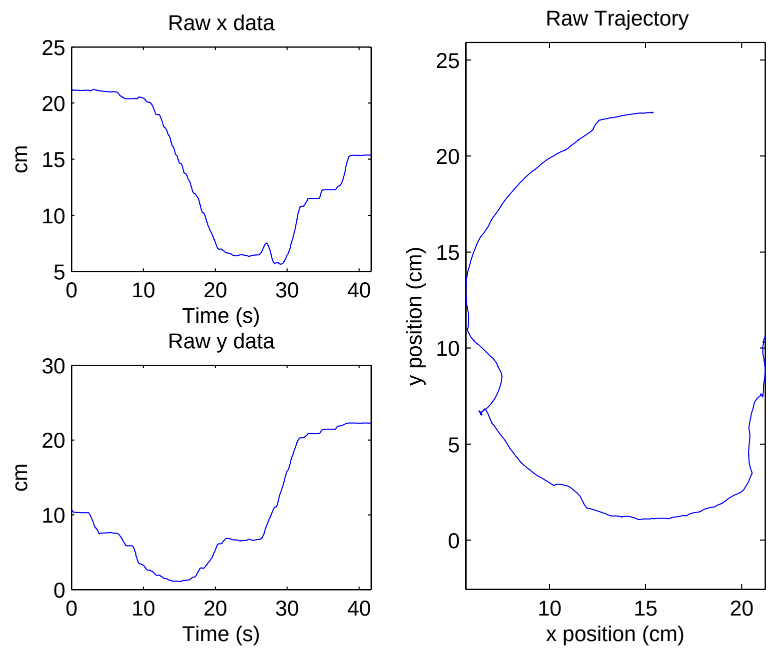

Figure 2: An example figure that will be displayed when the **View Trajectory** button is clicked. The raw x data is shown in the upper left, the raw y data is shown in the lower left, and the raw trajectory is shown on the right.

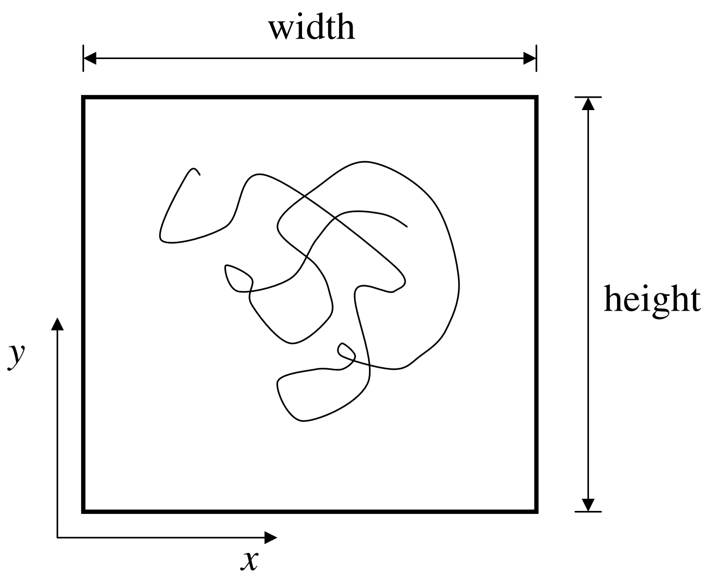

Figure 3: Dimensions associated with a video frame. The origin is defined as (0 cm, 0 cm). An example trajectory is shown.

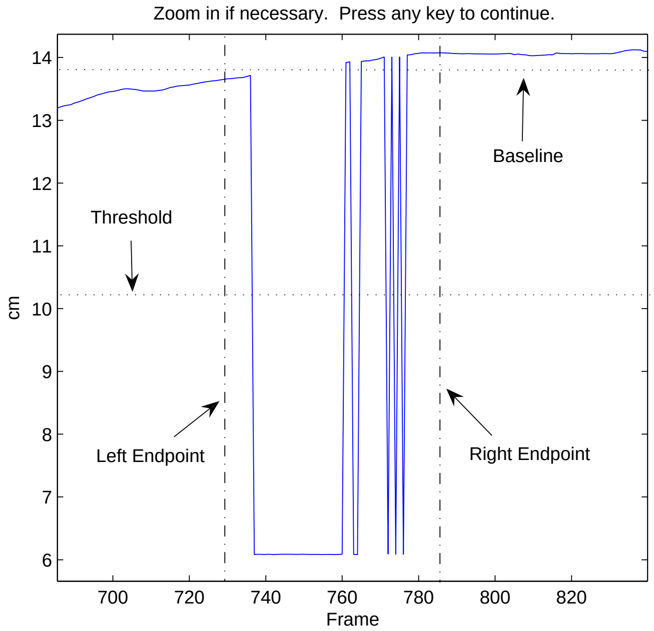

Figure 4: An example figure showing a section of bad tracks. The true trajectory can be inferred from surrounding data. Also shown on the figure are the definitions for the region of data to clean, the baseline, and the threshold to be chosen.

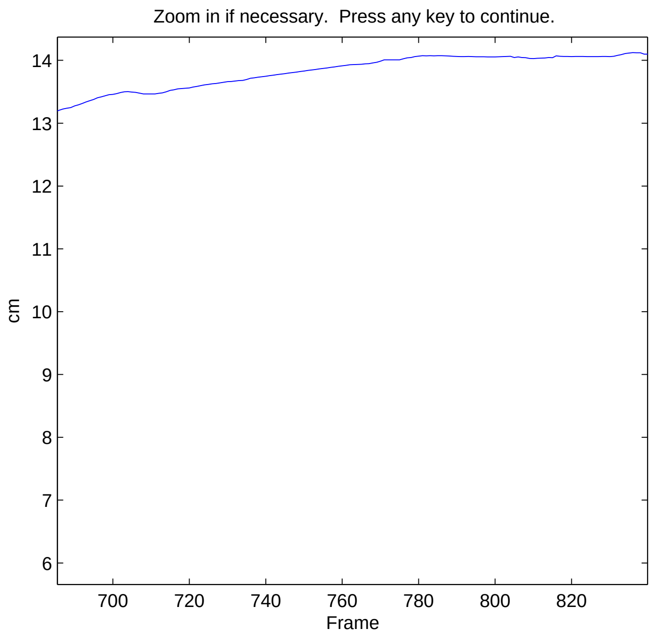

Figure 5: The result of cleaning the region in Fig. 4.

7. The cleaned data will immediately appear. At this point, you can zoom out to clean another section of data, or press Return twice to escape. The figure will automatically close. A message will be displayed in the Message Center letting you know that the data has been cleaned. *DO NOT close the figure window without pressing Return twice!*

Tilt Correction

Note: As of this version (0.9.3), tilt correction is implemented in a slightly different way than discussed in Ref. [1]. The current method should be more robust.

When this button is pressed, FTrack takes the ellipse data from the Arena Dimensions calculation and transforms the data so that the arena becomes approximately circular. First the ellipse is centered at (0,0). Then, the ellipse is rotated such that the elliptical axis closest to the x-axis rotates onto the x-axis. Finally, the semiminor axis of the ellipse is stretched to the length of the semimajor axis, creating a circle.

After the transformation, the data lies within a circle centered approximately at the point (0,0). The data is then converted from pixels into centimeters using the radius that the user has previously input. A figure appears that shows the transformed trajectory with the transformed arena boundary. Finally, the transformed data is saved.

CAUTION: It is recommended to backup the trajectory .mat file before hitting the Tilt Correction button. There currently is no functionality for preventing overwriting of good x,y pixel data if something has gone awry in the transformation process (such as if the user selected bad boundary after hitting the Arena Dimensions button).

5 Known Problems

The only problem encountered so far in v0.9.3 is that the reading of a frame sometimes fails towards the end of very long videos. This means that the numFrames field in the VideoInfo structure does not actually correspond to the number of frames that you can successfully track with FTrack, and FTrack will crash before finishing and saving. The current solution to this is as follows: Download the video-editing program VirtualDub (http://www.virtualdub.org/). Load the video into VirtualDub and notice what the last frame is (move the time slider all the way to the right). This corresponds to the last frame that FTrack will be able to read as well. We are currently working on making FTrack able to catch the error before it crashes.

6 Concluding Comments

For those who wish to use the functions from the Matlab command line, complete descriptions of their use and workings can be found in the Matlab help files; simply type `help function_name`. Describing them in detail here would be superfluous.

The scripts are also highly commented, and as such, they should be relatively easy to follow. Suggestions for improvements to the algorithms, the GUI or the coding style are highly encouraged! Comments on the ease of use of the GUI and functions are also important for refining this program. Since this is v0.9.3, FTrack needs a little more testing in order to find all of the bugs (pun intended). Once sufficient testing has been performed, we hope to release an honest to goodness v1.0. Until then, please check and double-check any results that you obtain from this program, and make sure that they make sense!

Enjoy!

7 Appendix: Variables saved in the `.mat` file

The following is a list of the variables saved to the .mat file with the same filename as the tracked video (minus the extension!).

`t`	Time vector in seconds
`x`	x-position of the fly in centimeters
`y`	y-position of the fly in centimeters
`orientation`	2 x N vector, where N is the number of frames. The first row contains the UHP orientation data; the second row contains the LHP orientation data.

`arena` — structure that defines the best fit elliptical boundary of the arena (see `fit_ellipse` help file. The arena structure has the following fields:

- `a`: sub axis (radius in pixels) of the X axis of the non-tilt ellipse
- `b`: sub axis (radius in pixels) of the Y axis of the non-tilt ellipse
- `phi`: orientation in radians of the ellipse (tilt)
- `X0`: center at the X axis of the non-tilt ellipse (in pixels)
- `Y0`: center at the Y axis of the non-tilt ellipse (in pixels)
- `X0_in`: center at the X axis of the tilted ellipse (in pixels)
- `Y0_in`: center at the Y axis of the tilted ellipse (in pixels)
- `long_axis`: size of the long axis of the ellipse (in pixels)
- `short_axis`:size of the short axis of the ellipse (in pixels)
- `status`: status of detection of an ellipse
- `epsilon`: the eccentricity of the ellipse
- `psi`: angle of tilt of the camera (radians)
- `semiminor`: the semiminor axis of the ellipse (in pixels)
- `semimajor`: the semimajor axis of the ellipse (in pixels)
- `boundaries`: N x 2 vector of points describing the boundary (x,y) (in pixels)

`VideoInfo` The VideoInfo structure has the following fields:

- `url`: the filename of the video
- `fps`: the frame rate of the video
- `width`: the width of the video (in pixels)
- `height`: the height of the video (in pixels)
- `bpp`: See videoIO documentation
- `type`: See videoIO documentation
- `numFrames`: number of frames in the video
- `fourcc`: See videoIO documentation
- `nHiddenFinalFrames`: See videoIO documentation

`InputData` The InputData structure has the following fields:

- `OutputPath`: the name of the directory where output files are to be stored (.mat, .xy, and .ori files).
- `StartFrame`: the frame where tracking begins.
- `EndFrame`: the frame where tracking ends.
- `NBackFrames`: the number of frames in the initial background calculation
- `pixels_in_cm`: the number of pixels in 1 centimeter (only saved if tilt correction performed)
- `sqrsize`: the bounding-box half width (described above)
- `alpha`: the background weighting parameter (described above)

References

[1] Valente, D., Golani, I., and P.P. Mitra, "Analysis of the trajectory of *Drosophila melanogaster* in a circular open field arena." PLoS ONE 2(10), e1083 doi:10.1371/journal.pone.0001083, (2007)

[2] Valente, D., Wang H., Andrews P., Saar S., Tchernichovski O., Benjanimi, Y., Golani I. and P.P. Mitra, "Characterization of animal behavior through the use of audio and video signal processing." IEEE Multimedia, 14 (2), 32-41, (2007)