Real-time Detailed Video Analysis of Fruit Flies

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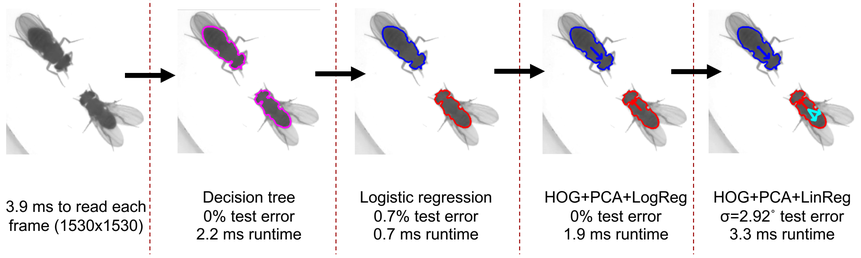
Problem

- Fruit fly behavior (e.g. for neuroscience experiments) is often measured out by analyzing video recordings.
- However, standard tools for this video analysis (e.g., [1]) are often too slow to run in real-time, which is problematic for long-running or closed-loop experiments.
- Goal of the this project: given a video recording of flies, annotate each with its sex, position, orientation, and wing angle in real time.

Data

- Starting point: a 15 min high-resolution 30 FPS grayscale video of the courtship interaction between a male and a female fruit fly. (From Dr. Ryan York of Prof. Tom Clandinin's neurobiology lab.)
- I hand-annotated 326 frames of this video using LabelMe [2] to indicate the positions of heads, abdomens, and a point within the fly body. For male flies, I also annotated wing angles via 3 additional points.

Approach

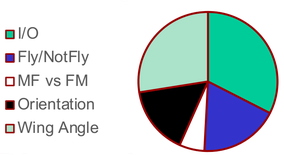


Results Summary

Throughput

84.0 FPS (11.9 ms/frame)

Processing time breakdown



	Train Error	Test Error	Ntrain	Ntest
Fly/NotFly	0.0%	0.0%	759	253
MF vs. FM	0.2%	0.7%	423	141
Male Orientation	0.0%	0.0%	358	120
Female Orientation	0.8%	0.0%	259	87
Wing Angle	σ=2.06˚	σ=2.92˚	354	118

Discussion

- Achieved real time operation (84 FPS processing throughput vs. 30 FPS source video rate)
- Contour classification (FlyNotFly and MF vs. FM) worked well; this was expected because the fly sizes are fairly well-defined.
- Orientation classification using PCA applied to HOG features worked surprisingly well – even using just two components resulted in qualitatively good performance. (I had first tried using keypoint descriptor matching, with less success)
- The wing angle regression worked well because I used image processing techniques (blur, threshold, erode) to reduce feature variance caused everything except wing motion itself.

Future Work

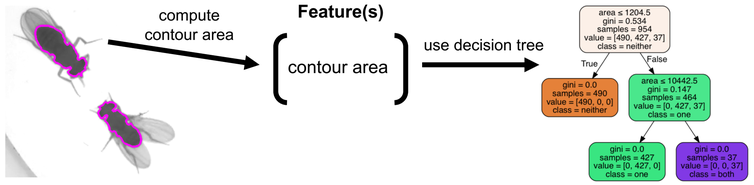
- Improve segmentation when the two flies are in contact.
- Add annotation of female wings (which don't move much) and abdomen (which does)
- Detect male and female wing grooming.
- Investigate the application of unsupervised learning methods (e.g., TSNE [3]) to features produced by the video analysis.

Fly/NotFly

- Type: classifier
- Input: one contour from the raw video after thresholding
- Output: whether the contour represents zero, one, or two flies
- Feature(s): the area of the contour
- Model: decision tree with Gini impurity criterion
- Results:
  - 0% test error
  - 2.2 ms runtime to extract and classify all contours

Gini impurity [4]

$$\sum_k p_k \left(1 - p_k\right)$$



Orientation

- Type: classifier
- Input: the contour of a male or female fly
- Output: the 0-360˚ orientation of the fly
- Data augmented by rotating examples 180˚
- Feature(s):
  - Histogram of oriented gradients (HOG) descriptor
- Model (trained separately for male and female examples):
  - PCA with 15 components, then
  - Logistic regression
- Results:
  - 0% test error
  - 1.9 ms runtime for both flies

PCA [7]

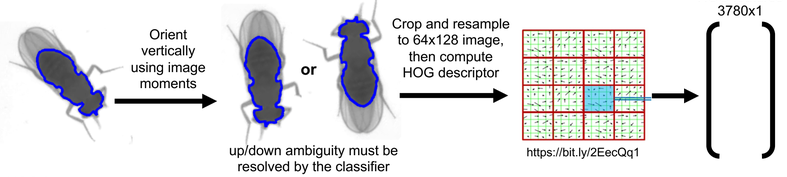
use a basis consisting of the eigenvectors corresponding to the largest eigenvalues of

$$\sum_i x^{(i)} x^{(i)T}$$

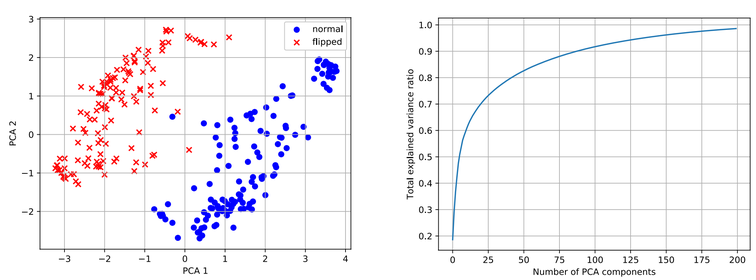
Angle from image moments [8]

$$\theta \approx \frac{1}{2} \tan^{-1}\left(\frac{2\mu_{11}}{\mu_{20} - \mu_{02}}\right)$$

has 0/180˚ ambiguity



Orientation Classifier: PCA applied to HOG features



Male-Female vs. Female-Male

- Type: classifier
- Input: the contours of two flies
- Output: whether the contours are ordered as male-female or female-male
- Data augmented by reversing the ordering of examples
- Feature(s): areas and aspect ratios of both contours
- Model:
  - feature standardization, followed by
  - logistic regression
- Results:
  - 0.7% test error
    - (1.4% without aspect ratio features)
  - 0.7 ms runtime

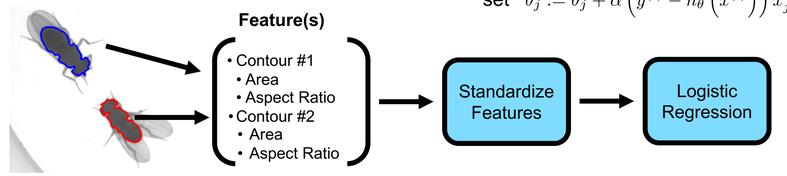
Feature standardization [5]

$$x' = (x - \mu)/\sigma$$

Logistic regression [6]

with $h_\theta(x) = \frac{1}{1 + e^{-\theta^T x}}$

set $\theta_j := \theta_j + \alpha \left(y^{(i)} - h_\theta\left(x^{(i)}\right)\right) x_j^{(i)}$



Wing Angle

- Type: regression
- Input: contour of a male fly
- Output: the 0-90˚ angles of the left and right wings
- Feature(s):
  - Histogram of oriented gradients (HOG) descriptor
- Model:
  - PCA with 40 components, then
  - Linear regression
- Results:
  - σ=2.92˚ test error
  - 3.3 ms runtime

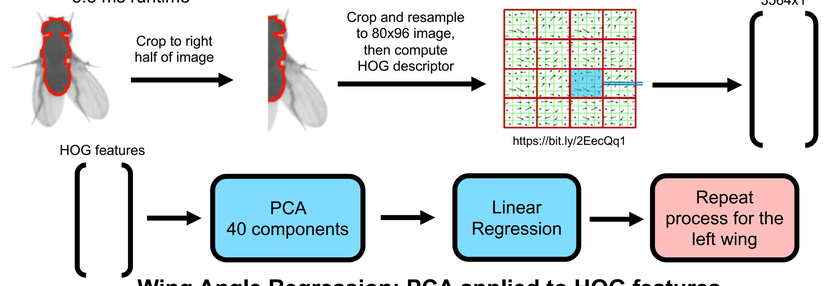
Linear regression [6]

with

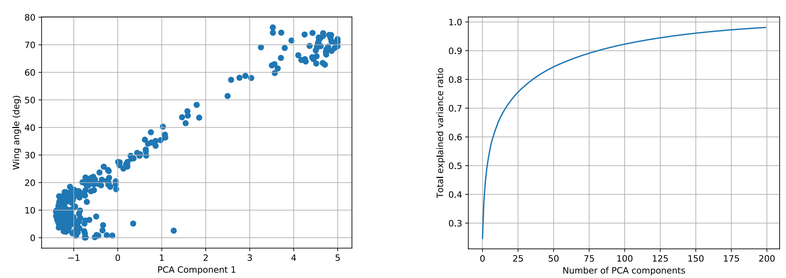
$$\hat{y} = \theta^T x$$

choose

$$\theta = \left(X^T X\right)^{-1} X^T y$$



Wing Angle Regression: PCA applied to HOG features



References

[1] Eyrun Eyjolfsdottir, Steve Branson, Xavier P. Burgos-Artizzu, Eric D. Hoopfer, Jonathan Schor, David J. Anderson, and Pietro Perona. Detecting social actions of fruit flies. In Computer Vision – ECCV 2014, pages 772–787. Springer International Publishing, 2014. [2] http://labelme2.csail.mit.edu/Release3.0/index.php, [3] van der Maaten, L.J.P.; Hinton, G.E. (Nov 2008). "Visualizing Data Using t-SNE". *Journal of Machine Learning Research*. **9**: 2579–2605. [4] https://en.wikipedia.org/wiki/Decision_tree_learning, [5] https://bit.ly/2Lb5XqU, [6] http://cs229.stanford.edu/notes/cs229-notes1.pdf, [7] http://cs229.stanford.edu/notes/cs229-notes10.pdf, [8] https://en.wikipedia.org/wiki/Image_moment