Pose Estimation of Free-Flying Fruit Flies

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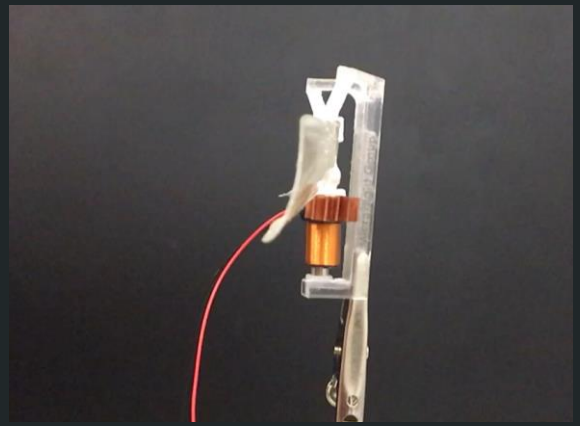
Our goal is to understand the mechanisms of insect flight and implement them in robotic systems



Experimental setup

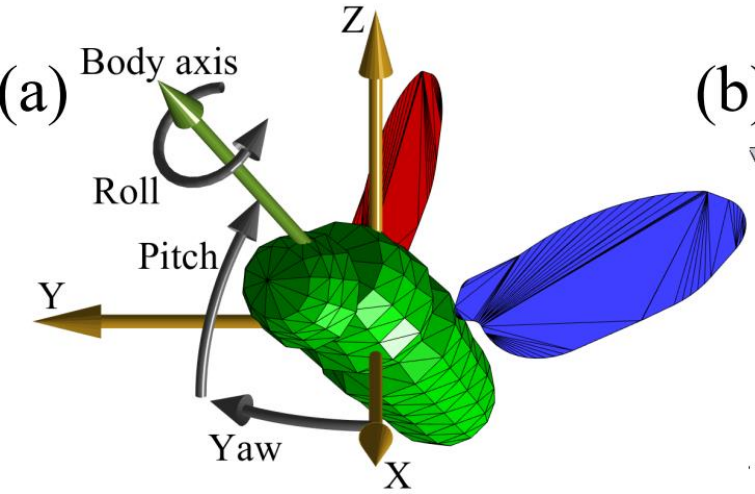
3 cameras, 20,000 frames/sec at 1280x800

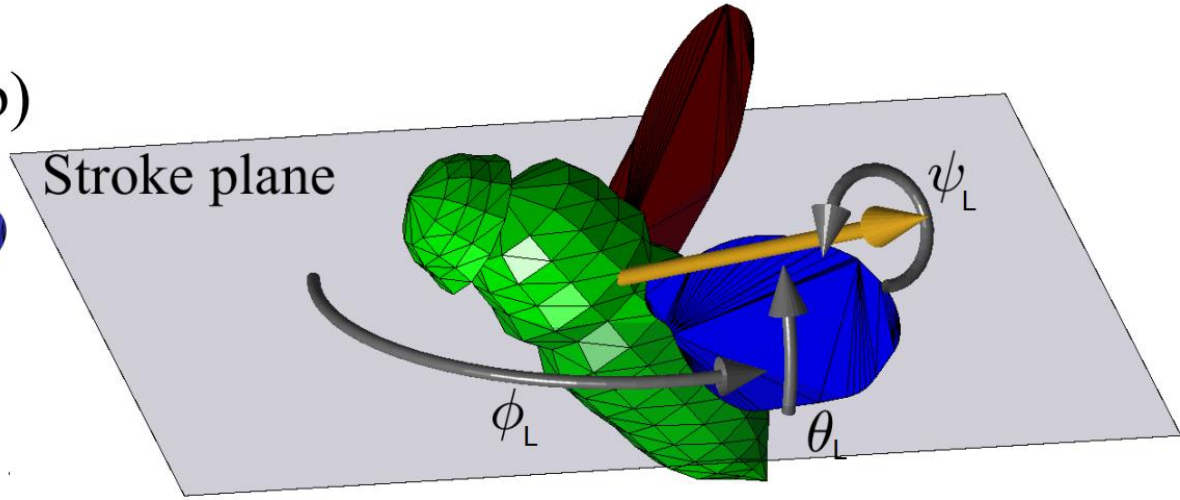
Automated trigger and saving

100’s of ms / 15-20GB per flight event

100’s of events per day

Parameters of interest



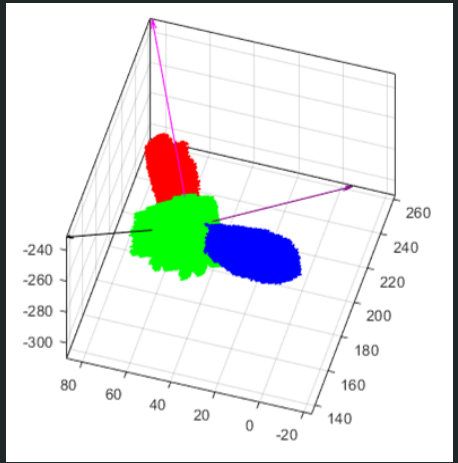


3 Body position parameters	+	3 Body rotation parameters	+	2X3 Wing rotation parameters	=	12 parameters

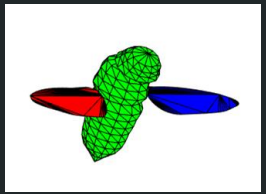
Common approaches

- Manual
  - Extremely laborious
  - Human error
- Hull reconstruction
  - Projecting images into 3D → 3D point cloud hull
  - Susceptible to wing occulsions
  - Difficult to extract wing deformation and body roll
- Model-based
  - Generate a 3D model from kinematic paramters
  - Project the model and fit it to the data images

Hull reconstruction

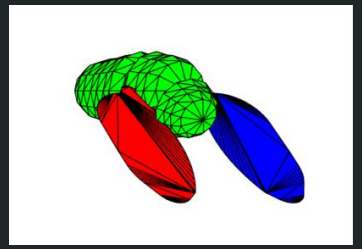


Model

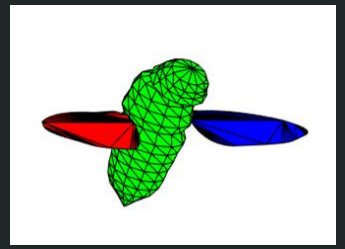


Loss function - single camera

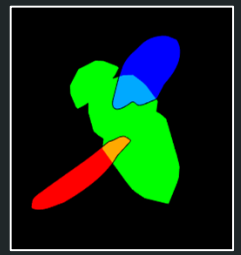
Neutral pose



Rotation & translation



Projection & Polygonization

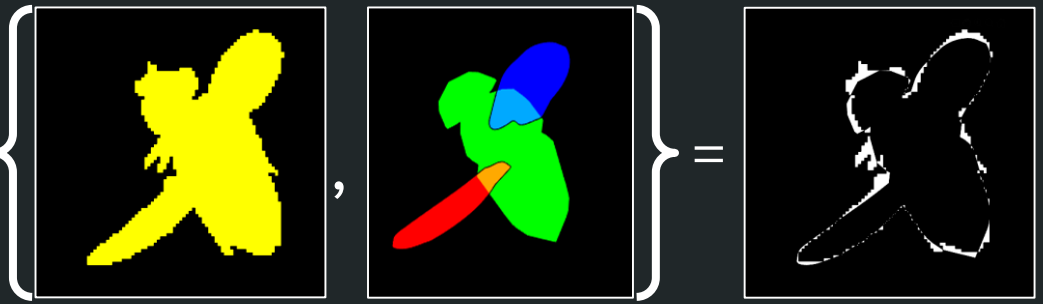


Data polygon
(image binarization)

Model polygon

XOR result

XOR



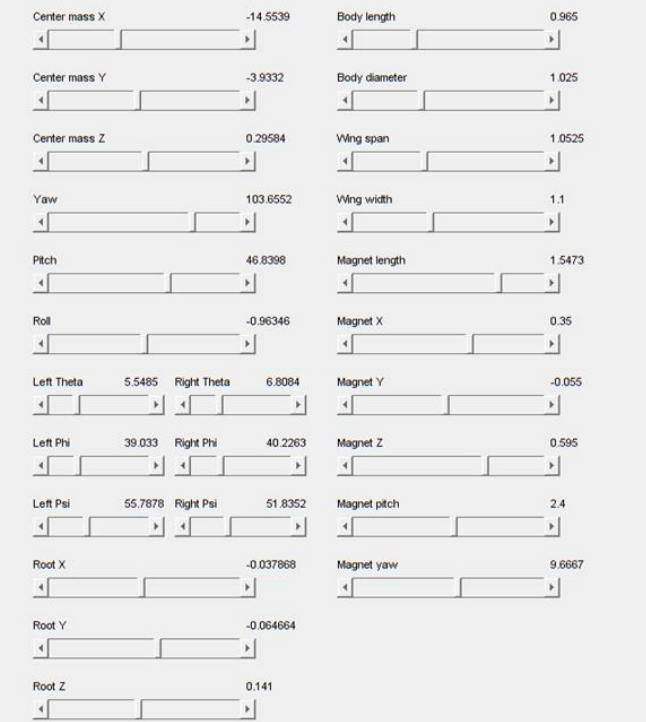
Loss function = data area not covered by model (normalized)

$$L(p) = \frac{\text{Area}\left[\text{camera} \oplus \text{model}\,(p)\right]}{\text{Area}\left[\text{camera}\right]}$$

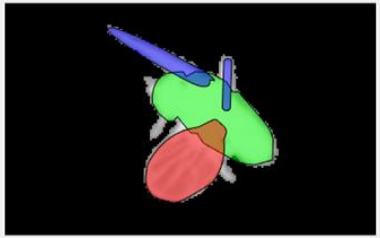
Optimization process

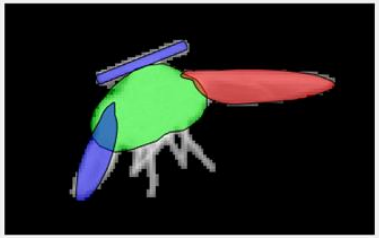
- Multi-view loss function
  - Weighted mean of the 3 single-camera losses
  - Each weight is determined by the un-occluded area of the wings
- Initial condition
  - Taken as the result of the previous frame
  - First frame: determined manually using GUI
- Loss optimization
  - Constrained, gradient-free optimization
  - Parameters constraints are determined from typical kinematics
  - Optimization algorithm: Use either interior-point or active set

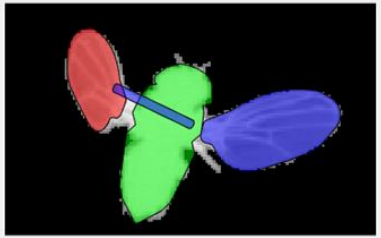
Setting initial parameters and model scaling

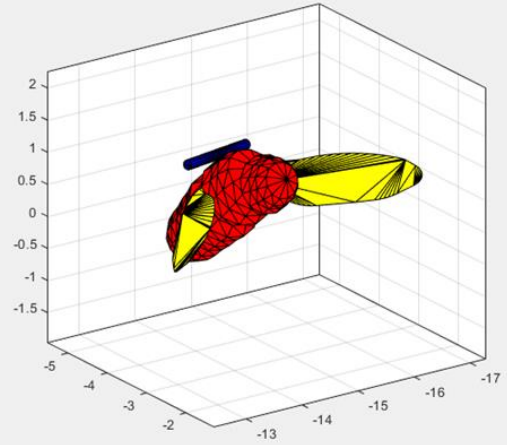


Semi-automatic fitting

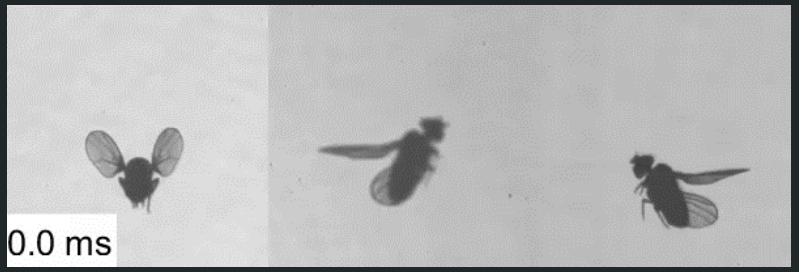


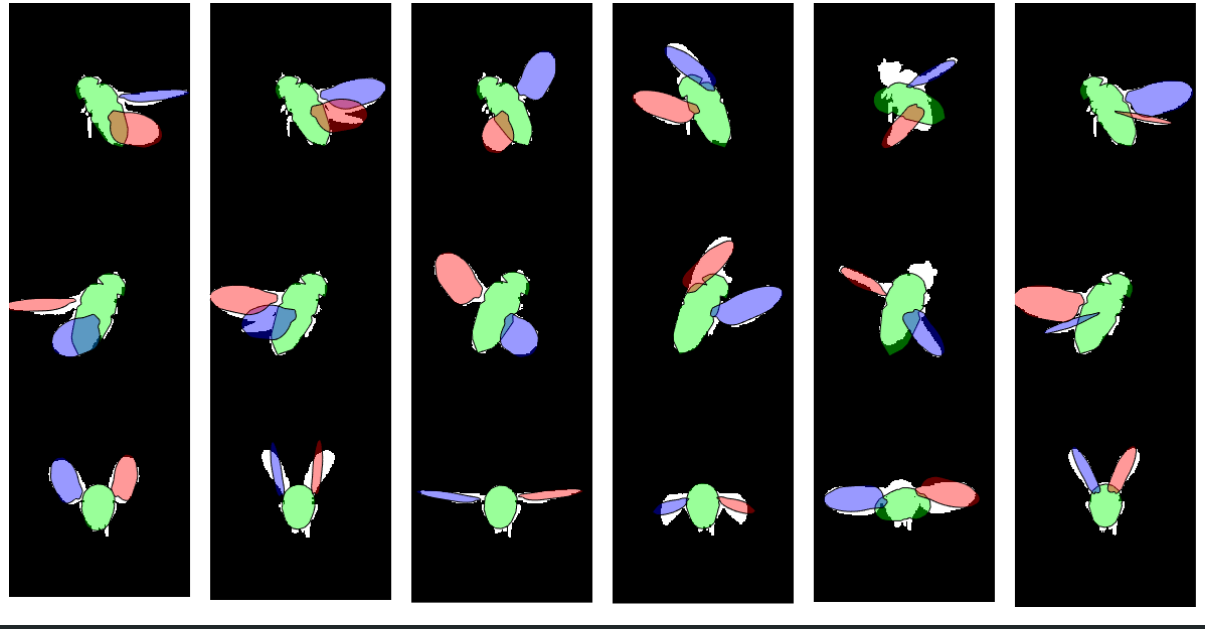


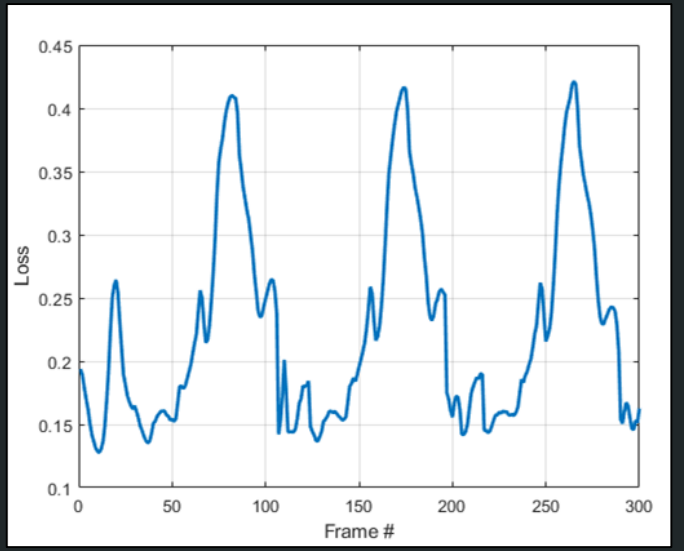




Fitting result: The basic 12-parameter model fails

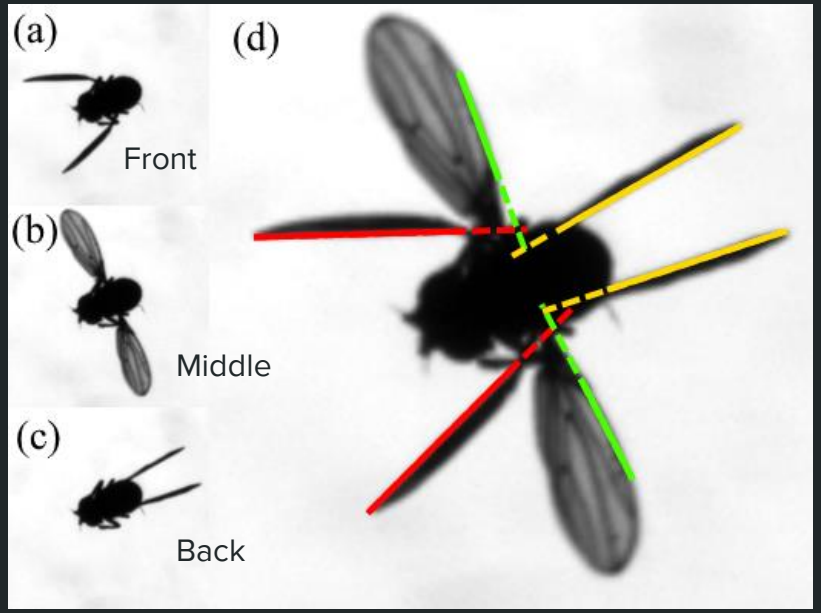






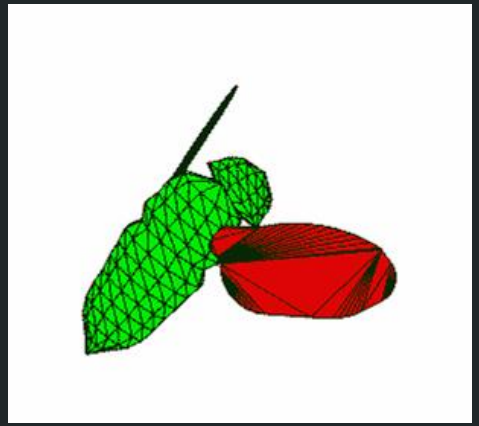
Loss variance also reflect fit errors

Identified problem 1: The wing root is not a fixed point

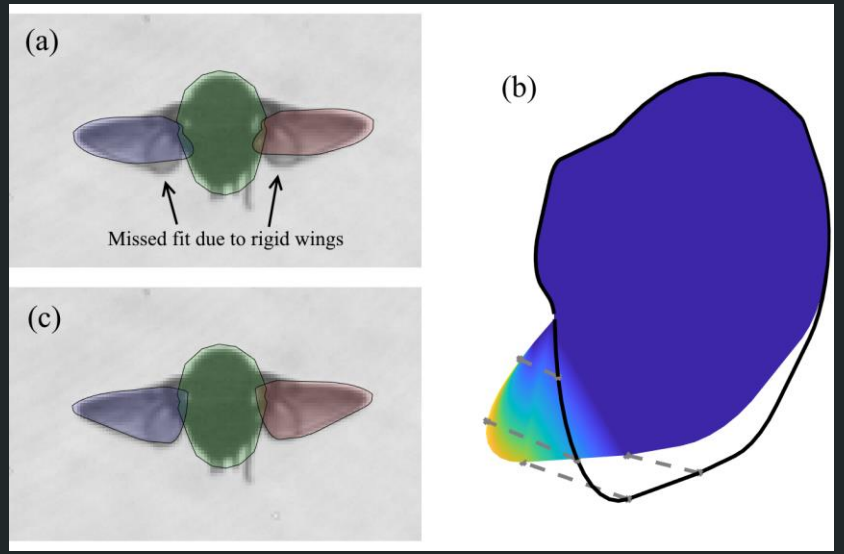


12-DOF model is not realistic enough

Solution: add 3 parameters for relative and symmetric root position



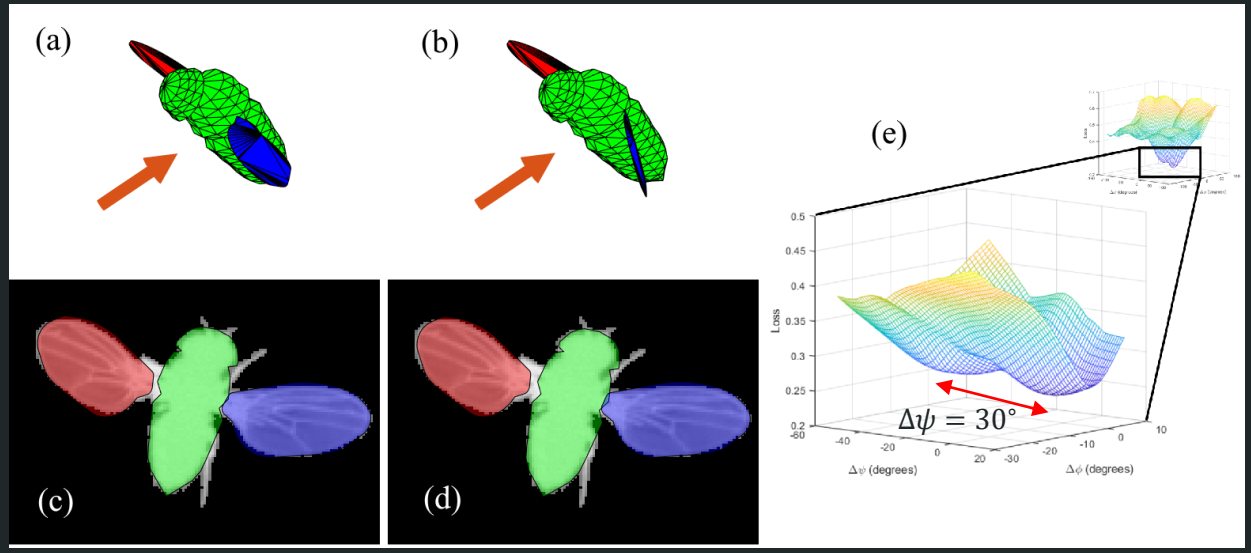
Identified problem 2: The wing is not a rigid plate



Solution: Add a twist parameter per wing.

- Twist the bottom half of the wing
- Twist increases from the tip towards the root

Identified problem 3: Loss function is degenerate in ψ

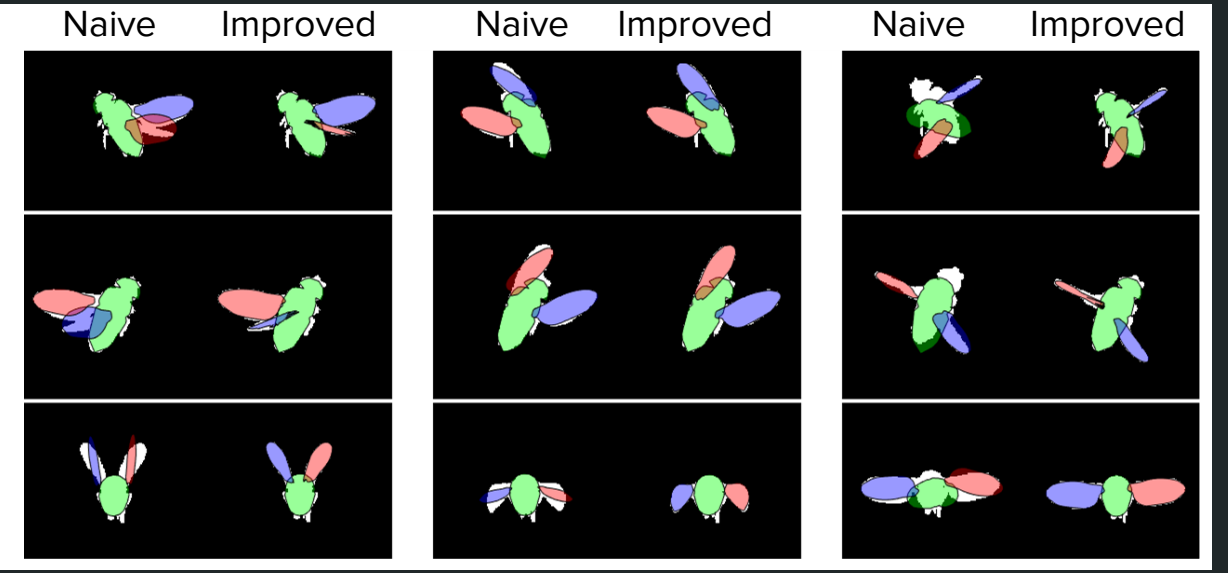


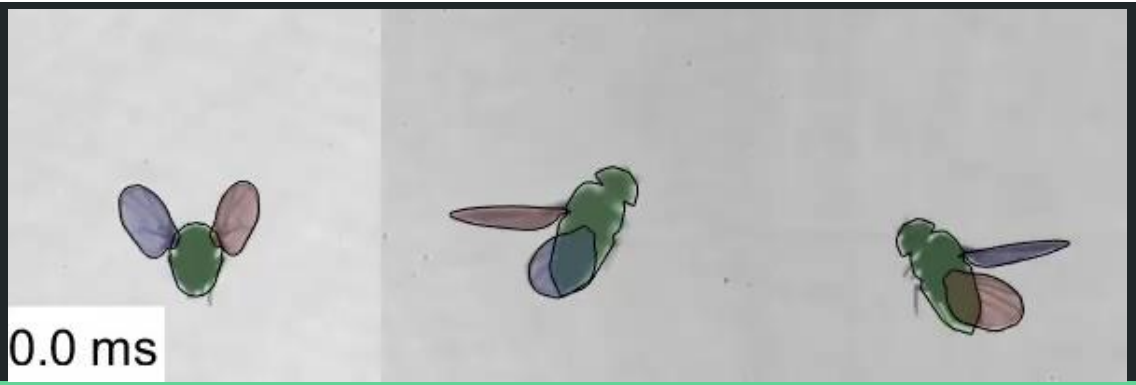
- Different ψ values → similar local minima
- Difficult to distinguish visually
- Optimization might get trapped in the wrong minimum in the following frames

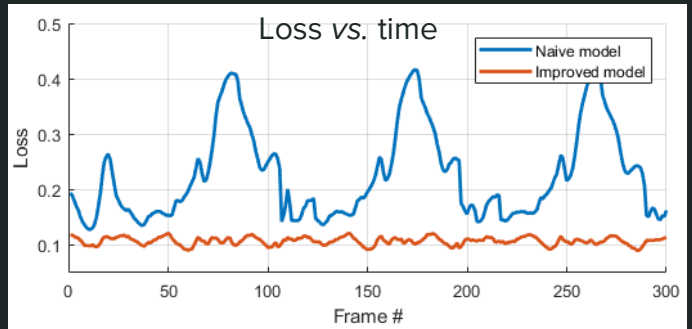
Solution: Use temporal information

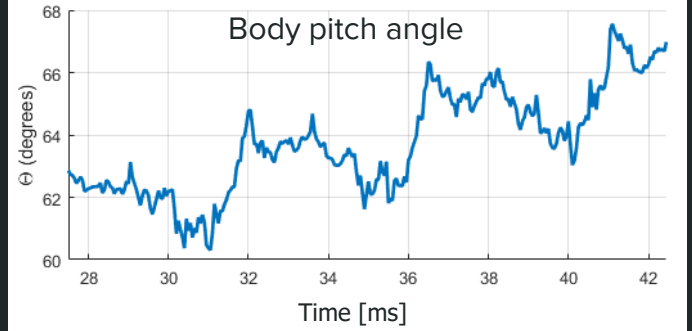
- If a "jump" is detected in ψ or loss:
- Multiple random starts (MRS)
- Re-fit previous frames if necessary

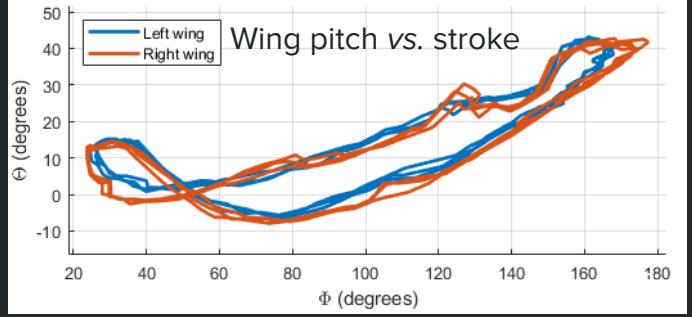
Naïve *vs.* improved 17-DOF model



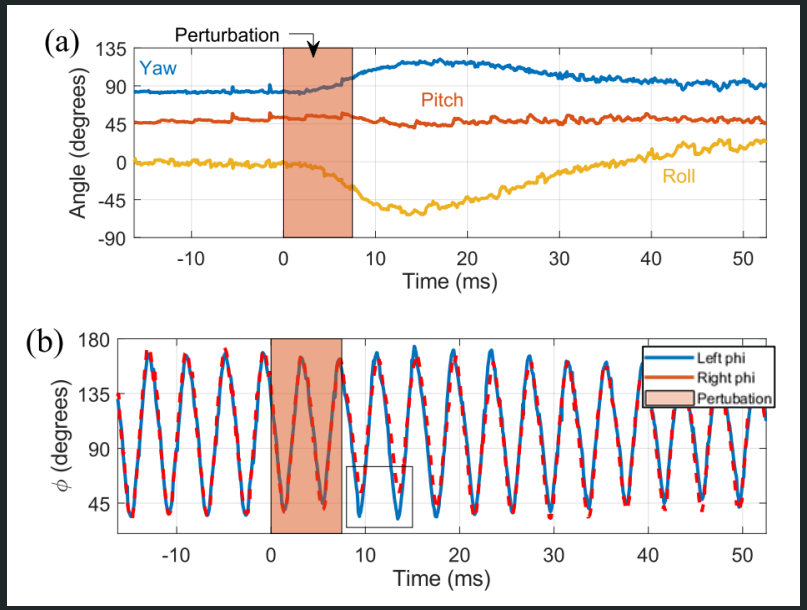


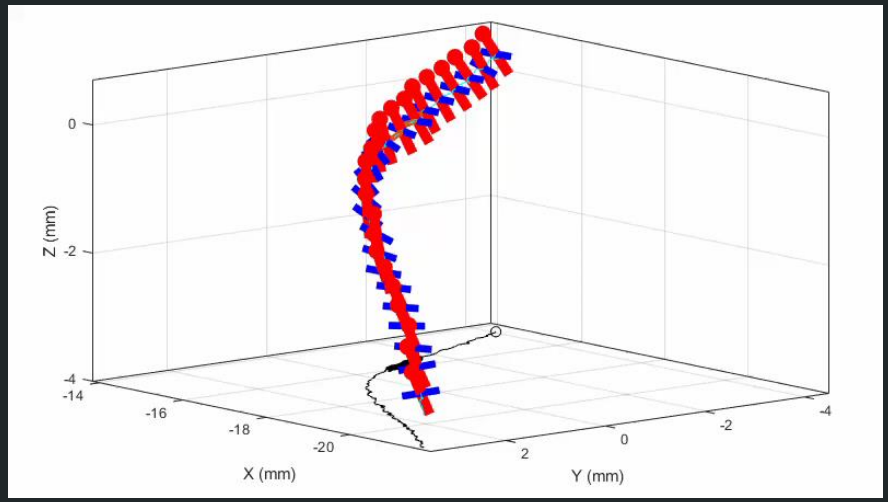




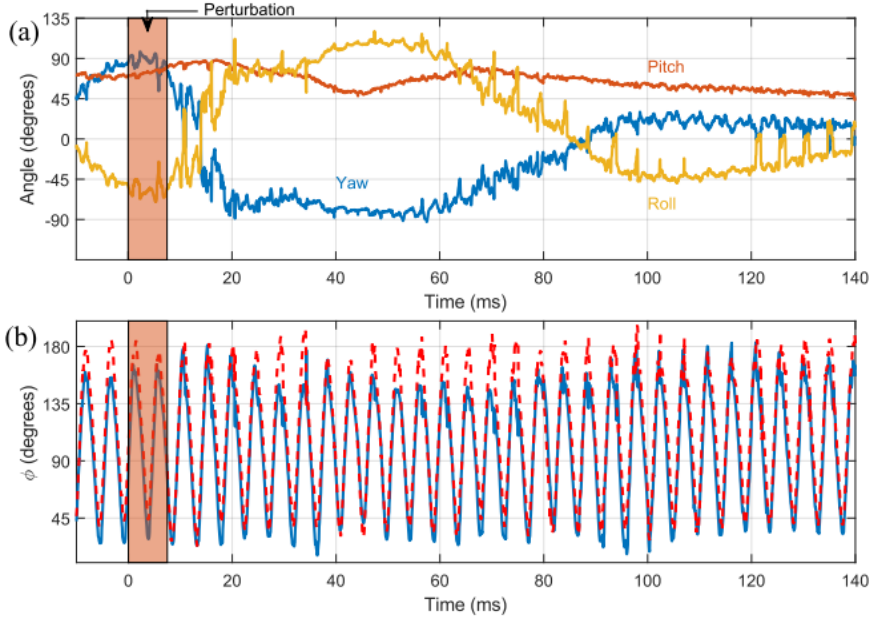


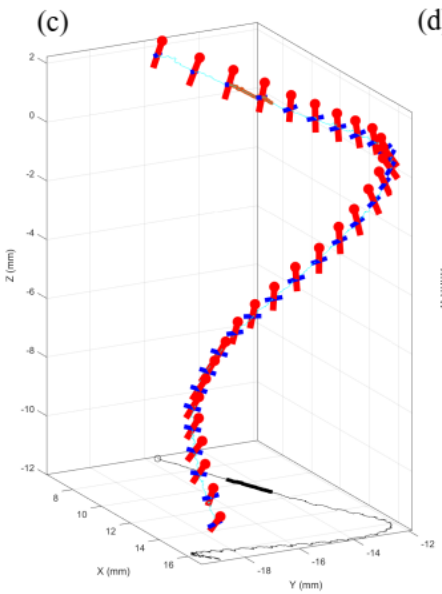
Results: Roll perturbation

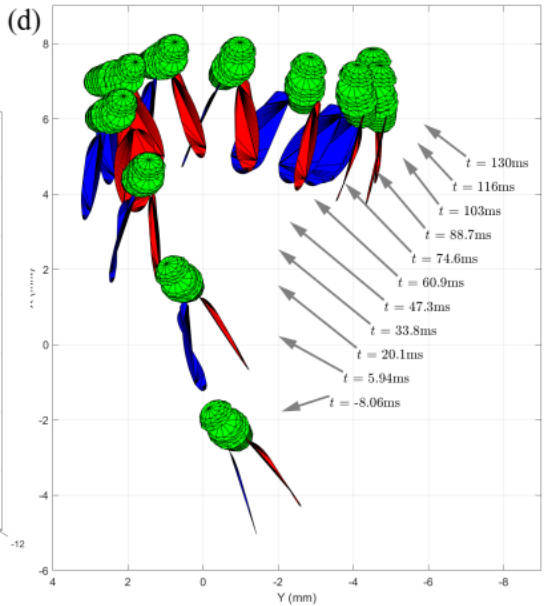




Results: Complex perturbation



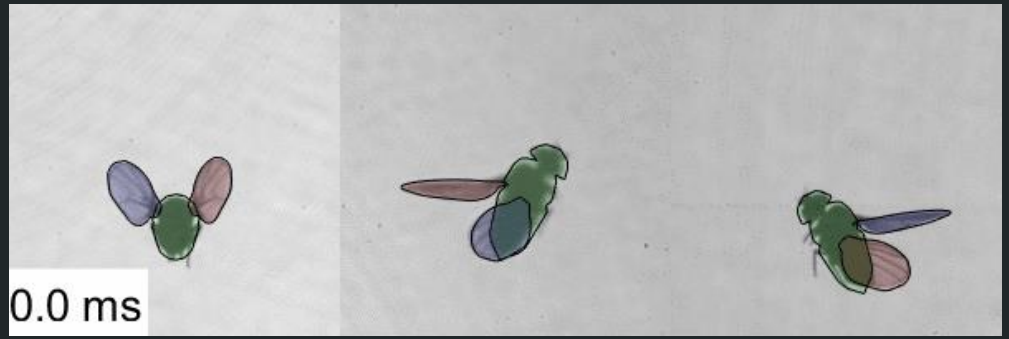




Results are noisy due to the fly's legs and model degeneracy

Summary: Work in progress

- New 17-DOF model with wing deformation and root position
- Identified ψ degeneracy (MRS/refitting)
- Simple to adapt to other insect models
- Problems identified:
  - Fly legs interfere with fitting (*e.g.* overlap with model wing)
  - Runtime: 2sec/frame, refitting and MRS increase to 20sec/frame on average
- Proposed solutions
  - Remove legs from raw images
  - A more realistic 3D model (grayscale)
  - Combine with other methods such as hull reconstruction / deep learning



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