Towards Indoor Navigation of a Flapping Wing Robot via Optical Flow

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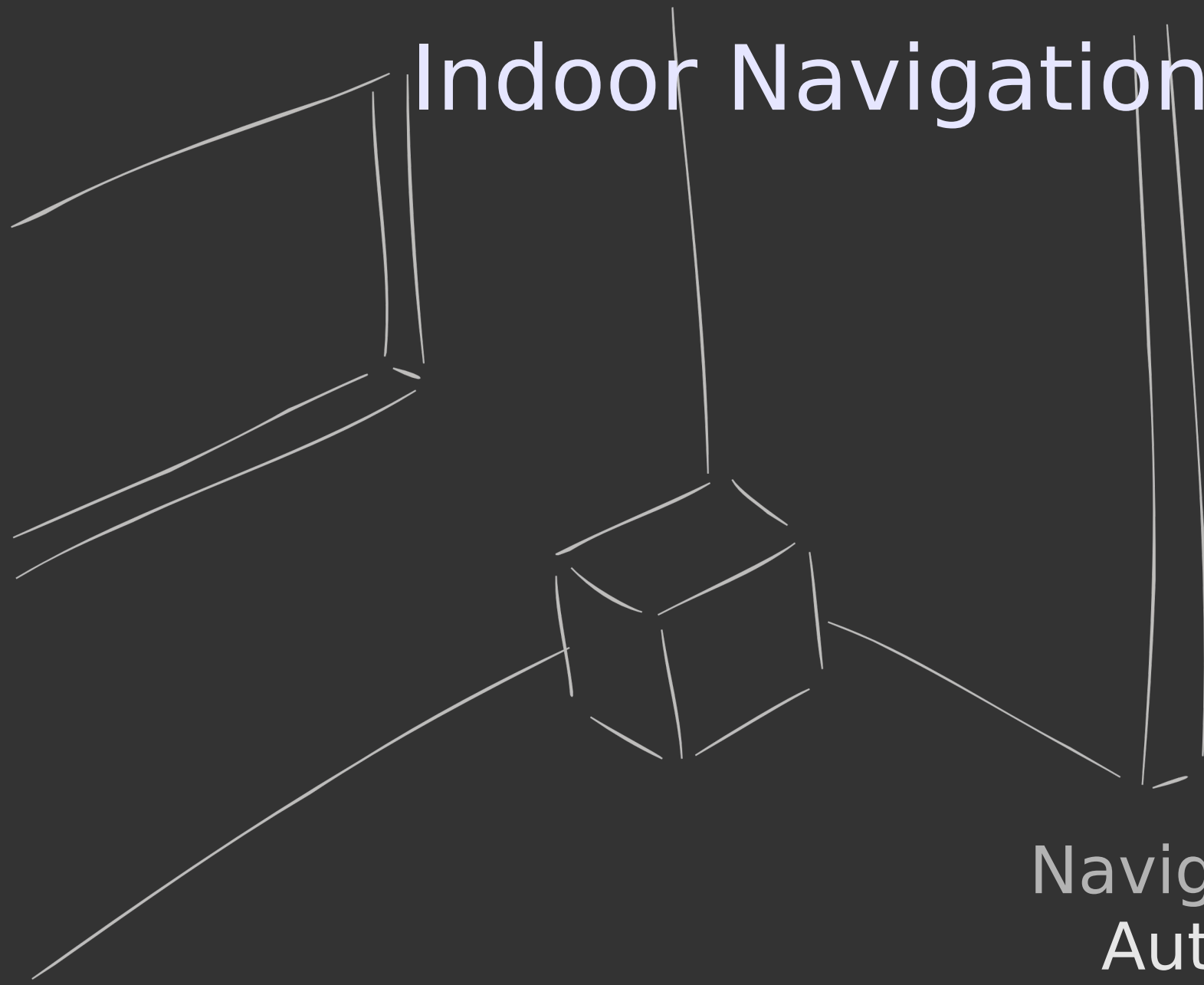
CIfAR Neural Computation & Adaptive Perception
Summer School 2010

Indoor Navigation



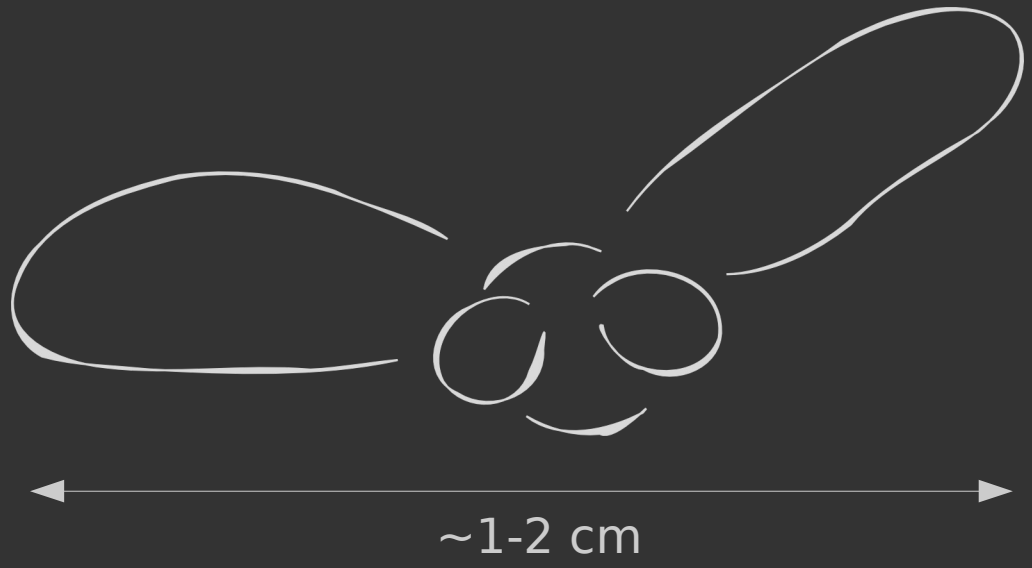
Navigation Goals

Autonomous

Versatile

Agile

Biological Solution

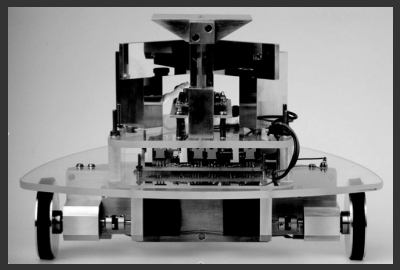


Sensing

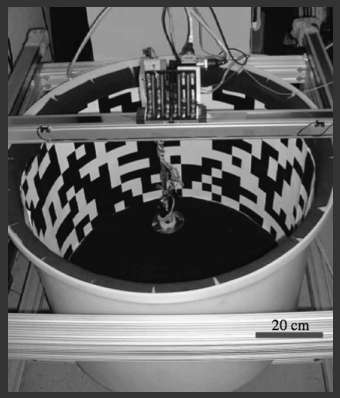
Halteres	gyroscopes
Ocelli	horizon
Hair	airspeed
Compound Eyes	motion

Background on OF Navigation

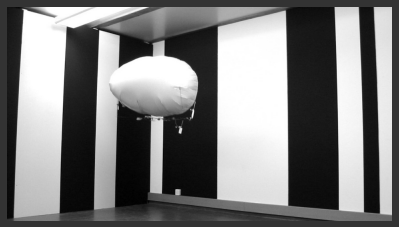
Simplified Textures



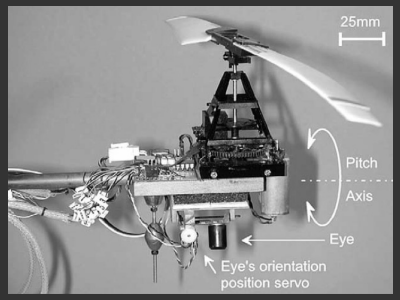
Srinivasan et al, 1997



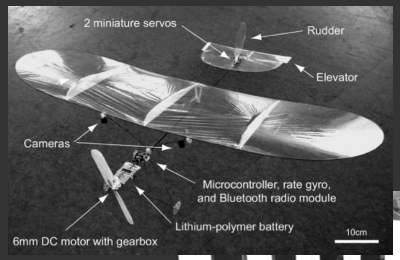
Reiser & Dickinson, 2003

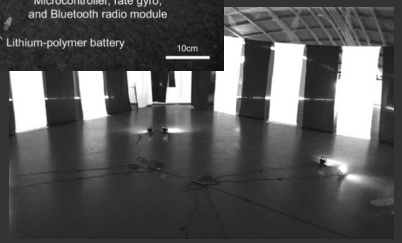


Zufferey et al, 2006

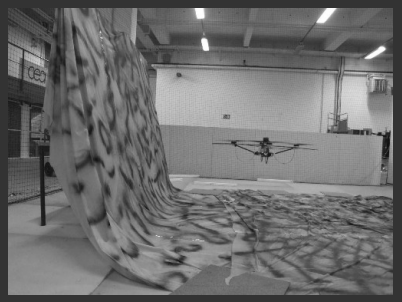


Ruffier & Franceschini, 2005





Zufferey & Floreano, 2006



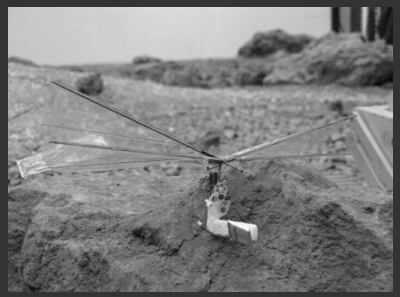
Herisse et al, 2010

Realistic Textures

Iida, 2003

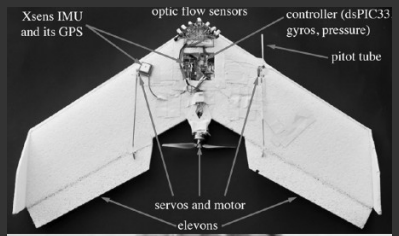
Barrows et al, 2003 (Chahl)

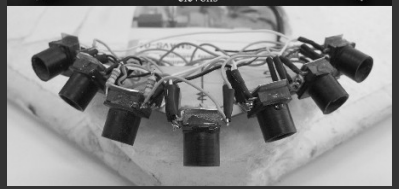
Barrows et al, 2003



Wagter et al, 2007

Zingg et al, 2010





Zufferey et al, 2010

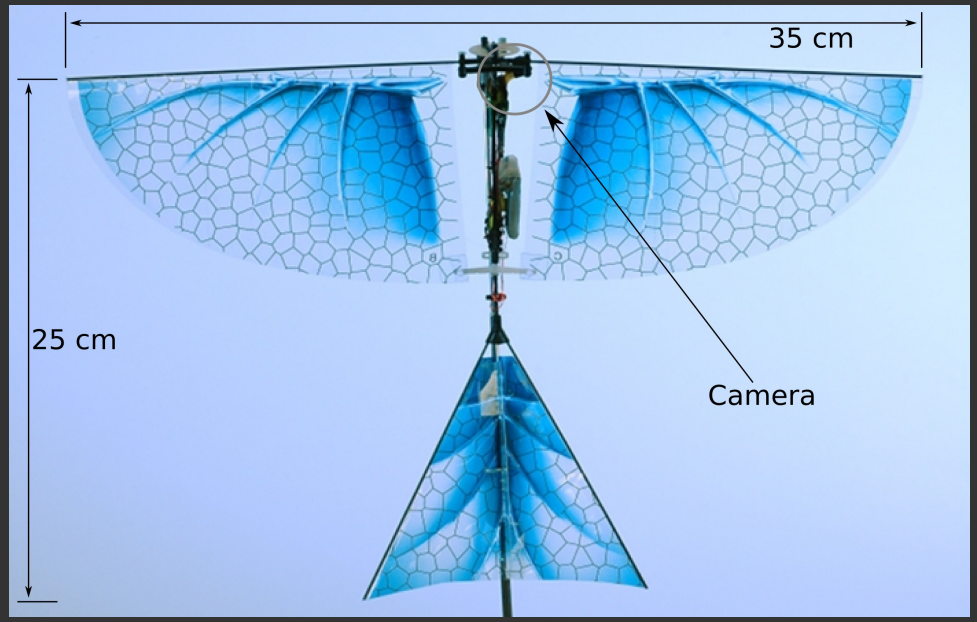
Background on OF Navigation

Type	Group	Env.	Texture	Other Sensors	Behaviors
Airship	Iida, 2003	In	Natural	-	Odometry, Height Reg., Centering (~10m)
	Zufferey et al., 2006	In	Stripes	Gyro, Altitude, Anemometer	Evolved Controller, Obstacle Avoidance (~95m)
Fixed Wing	Zufferey & Floreano, 2006	In	Stripes	Rate gyro	Obstacle Avoidance (~300m, 50 saccades)
	Zufferey et al., 2010	Out	Natural	IMU, GPS	Waypoint nav., height reg., obs. Avoidance (~32km)
	Barrows et al., 2003	Out	Natural	-	Terrain following, some obstacle avoidance (~30m)
Helicopter	Ruffier & Franceschini, 2005	In	Stripes	-	Tethered terrain following, wing gusts (~24m)
	Chahl's group, ~2000	Out	Natural	IMU	Altitude control, hover under wind gusts
Quad-rotor	Herisse et al., 2010	In	Random stripes	IMU, barometer	Obstacle avoidance, terrain follorwing (~5m)
	Zingg et al., 2010	In	Natural	IMU	Depth estimation for corridor centering (~70m)
Flapper	Wagter et al., 2007	Sim	Natural	-	Horizon detection, terrain following
	Our group	In	Natural		

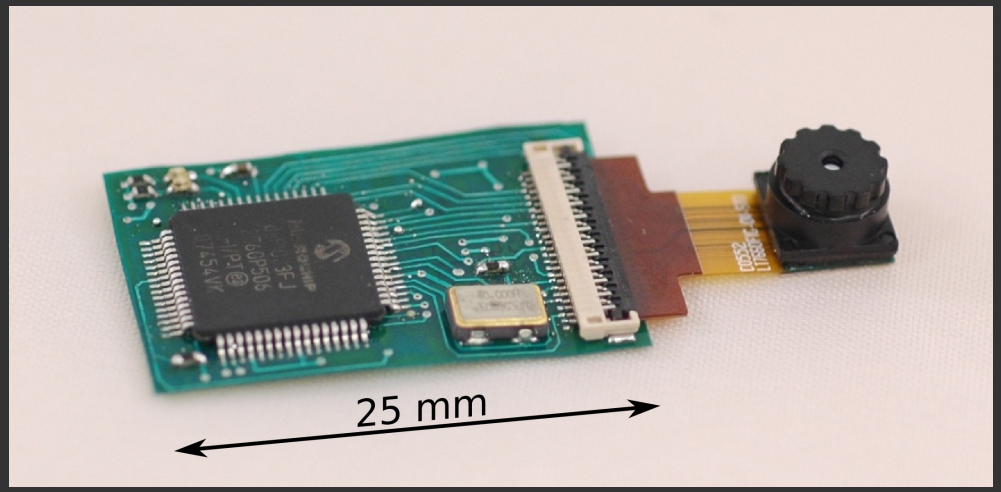
Robot Specifics

Interactive Toy's VAMP RC Ornithopter

Weight	13.6 g
Flapping Frequency	12-17Hz
Power Consumption	~150 mA @ 3.7V



Implementation Specifics



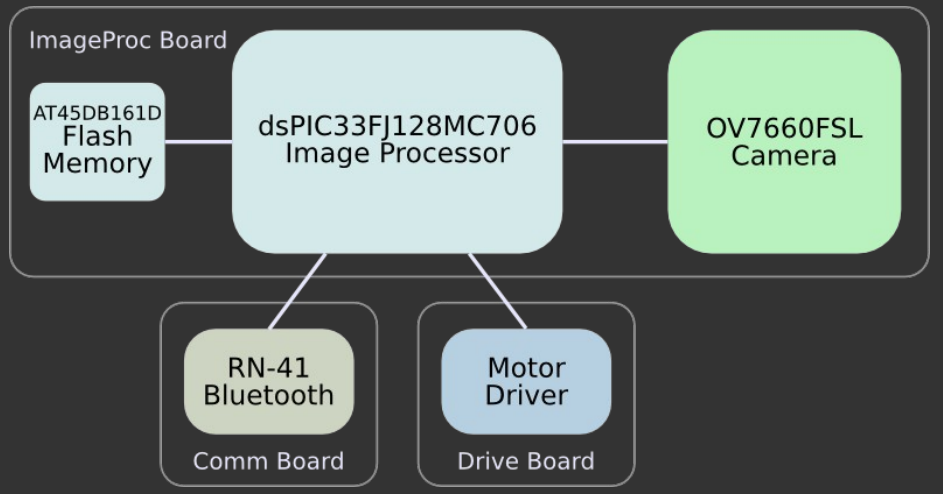


Image Processing Board	1.1 g – 15x35 mm
dsPIC Processor Speed	40 MHz
Video Capture	160x120px @ 25fps
Motor Driver Board	70mg – 10x10 mm
RN-41 Bluetooth Board	1.3 g – 13x25 mm
Power Consumption	70-150 mA @ 3.3V
LiPoly Battery	90mAh @ up to 15C – 2.6 g

Indoor Environment

HMMB Lobby

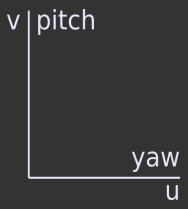
Optical Flow Algorithm: EMD

$$u_{i,j}(k) = I_{i,j}(k+1) \cdot I_{i+1,j}(k) - I_{i+1,j}(k+1) \cdot I_{i,j}(k),$$
$$v_{i,j}(k) = I_{i,j}(k+1) \cdot I_{i,j+1}(k) - I_{i,j+1}(k+1) \cdot I_{i,j}(k).$$

Hassenstein and Reichardt, 1956

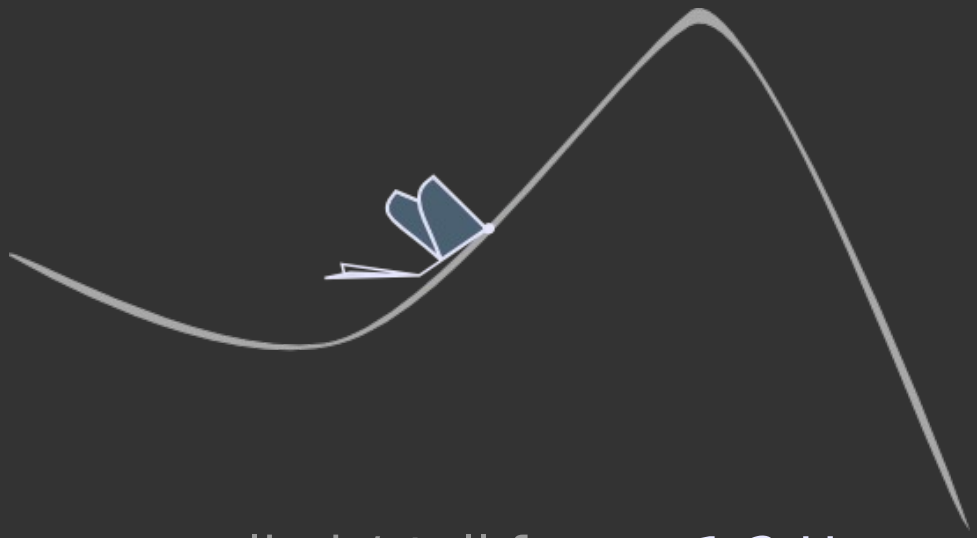
$$U(k) = \frac{\sum_i \sum_j u_{i,j}(k)}{\sqrt{\sum_i \sum_j |u_{i,j}(k)|^2}},$$
$$V(k) = \frac{\sum_i \sum_j v_{i,j}(k)}{\sqrt{\sum_i \sum_j |v_{i,j}(k)|^2}}.$$

Single and Borst, 1998

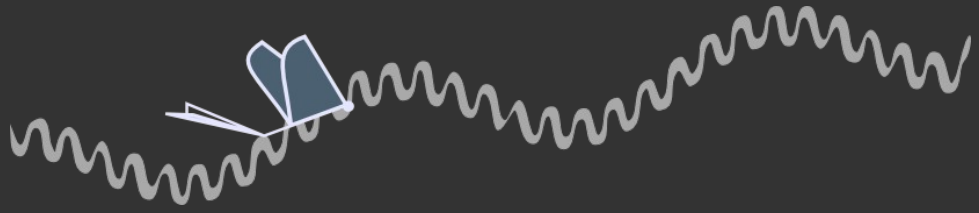


Gliding vs. Flapping

IROS 2009



climb/stall freq ~ 1-2 Hz

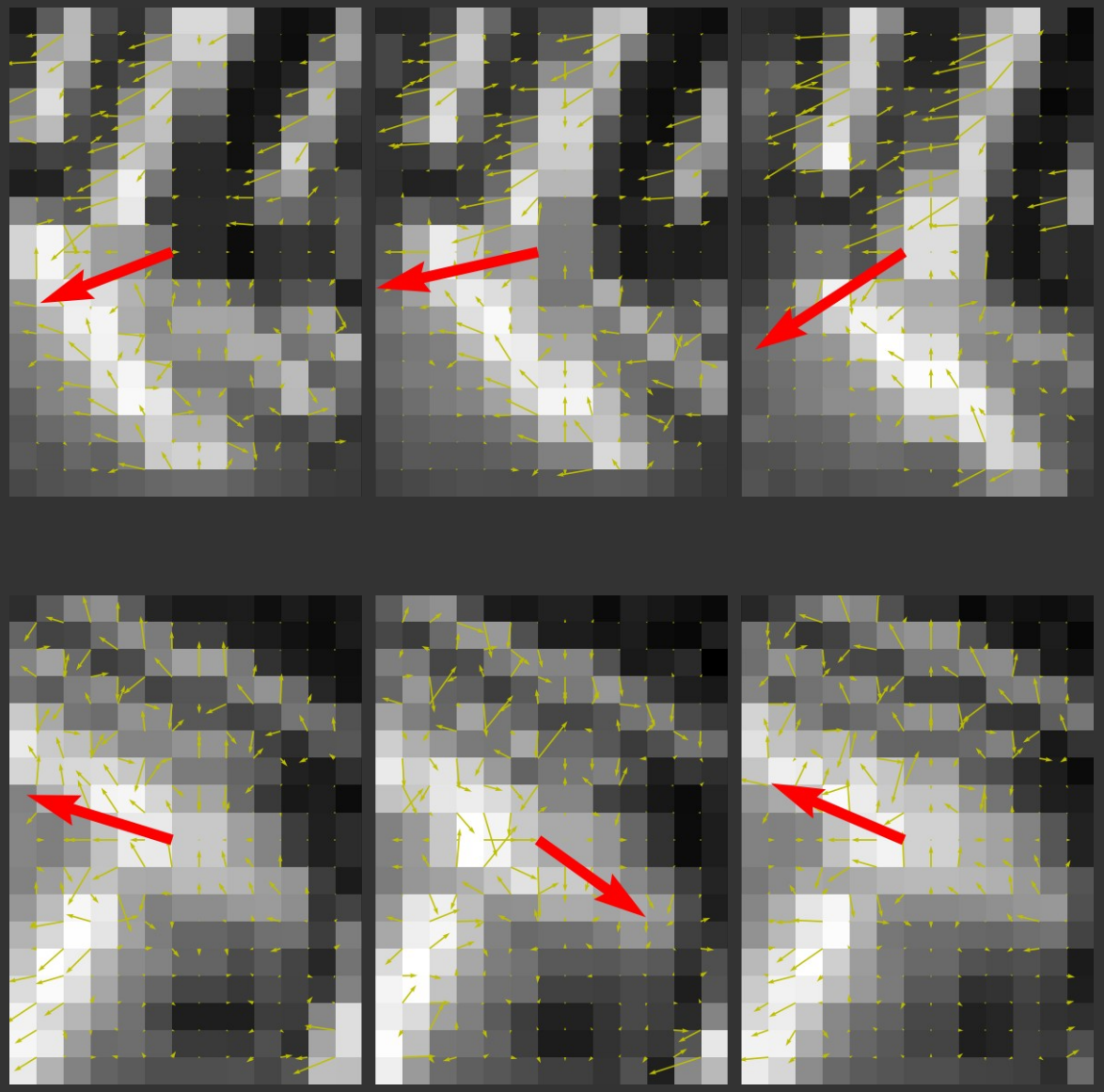


flapping freq ~ 12-17 Hz
climb/stall freq ~ 1-2 Hz

Comparison

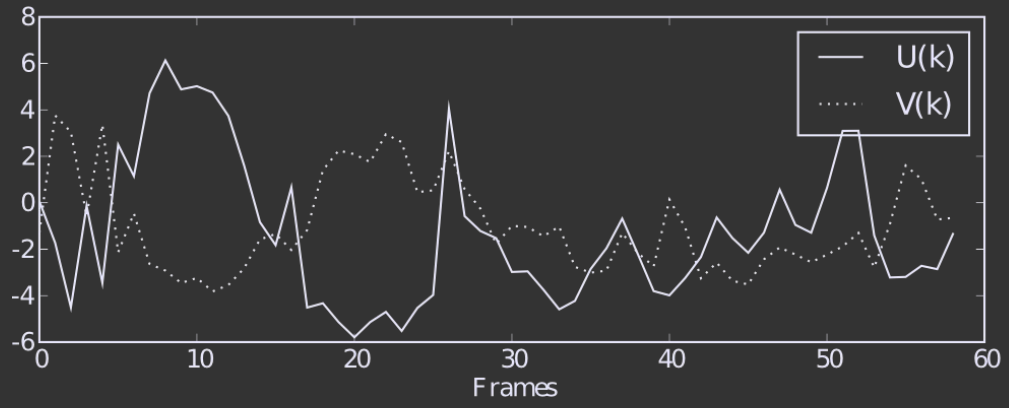
Gliding

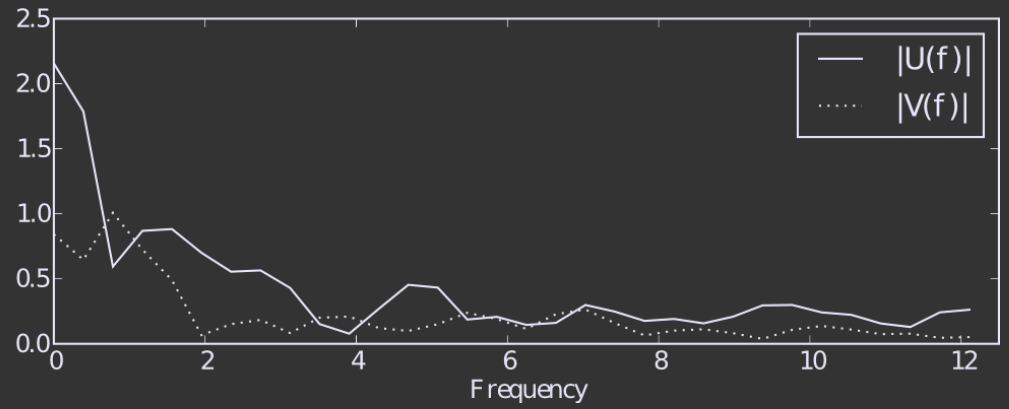
Flapping



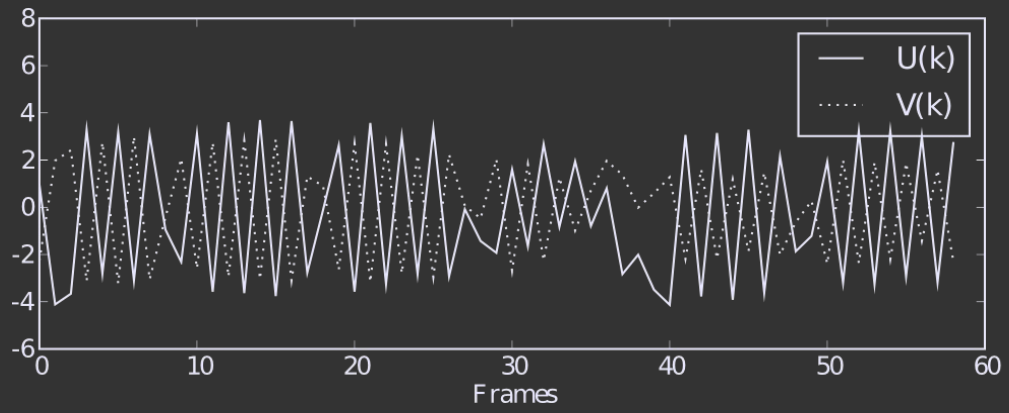
Analysis

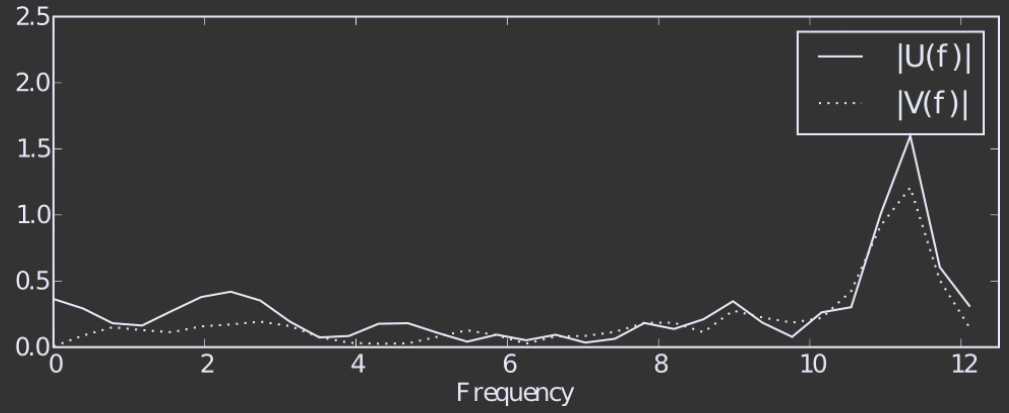
Gliding



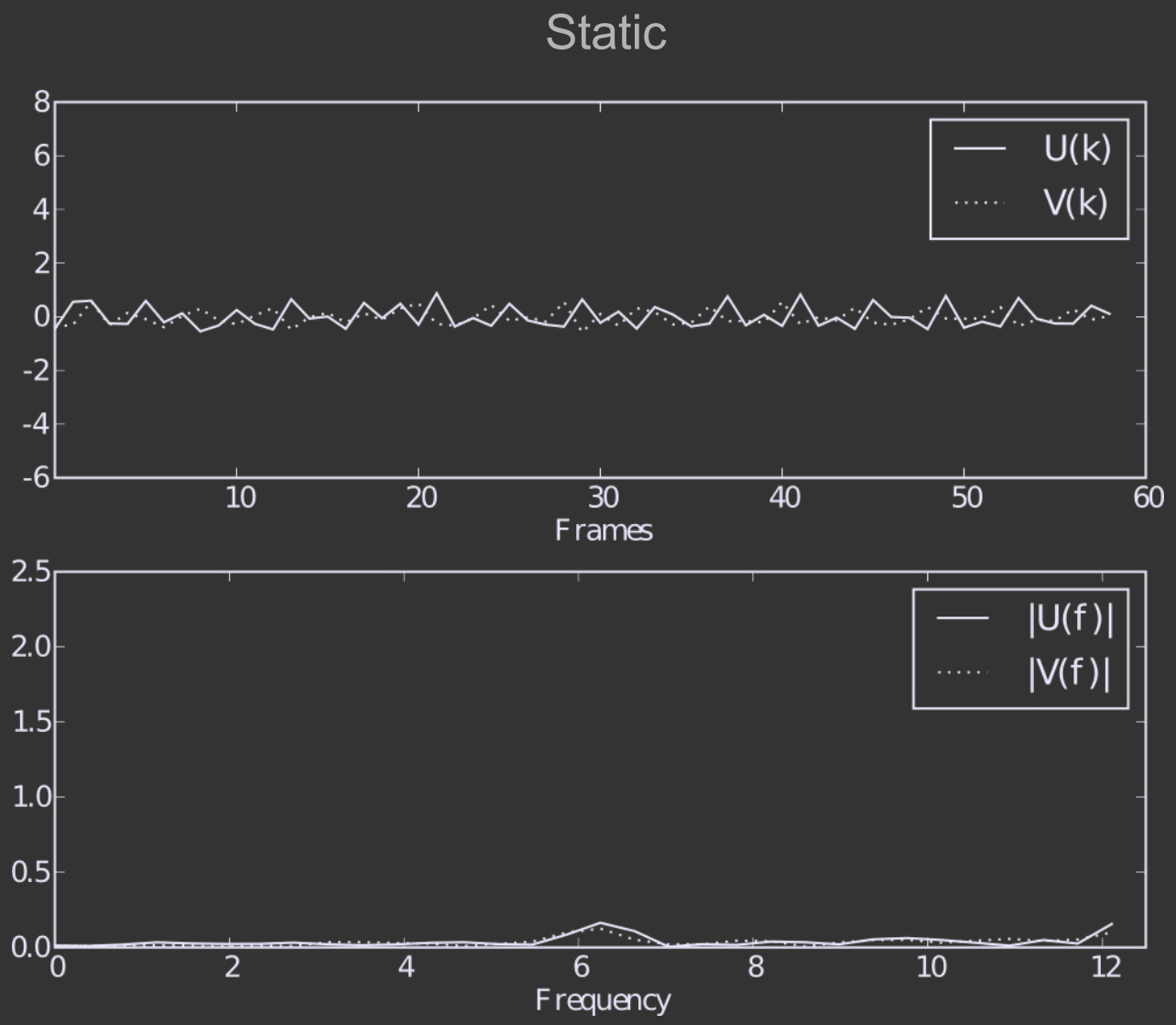


Flapping





Control



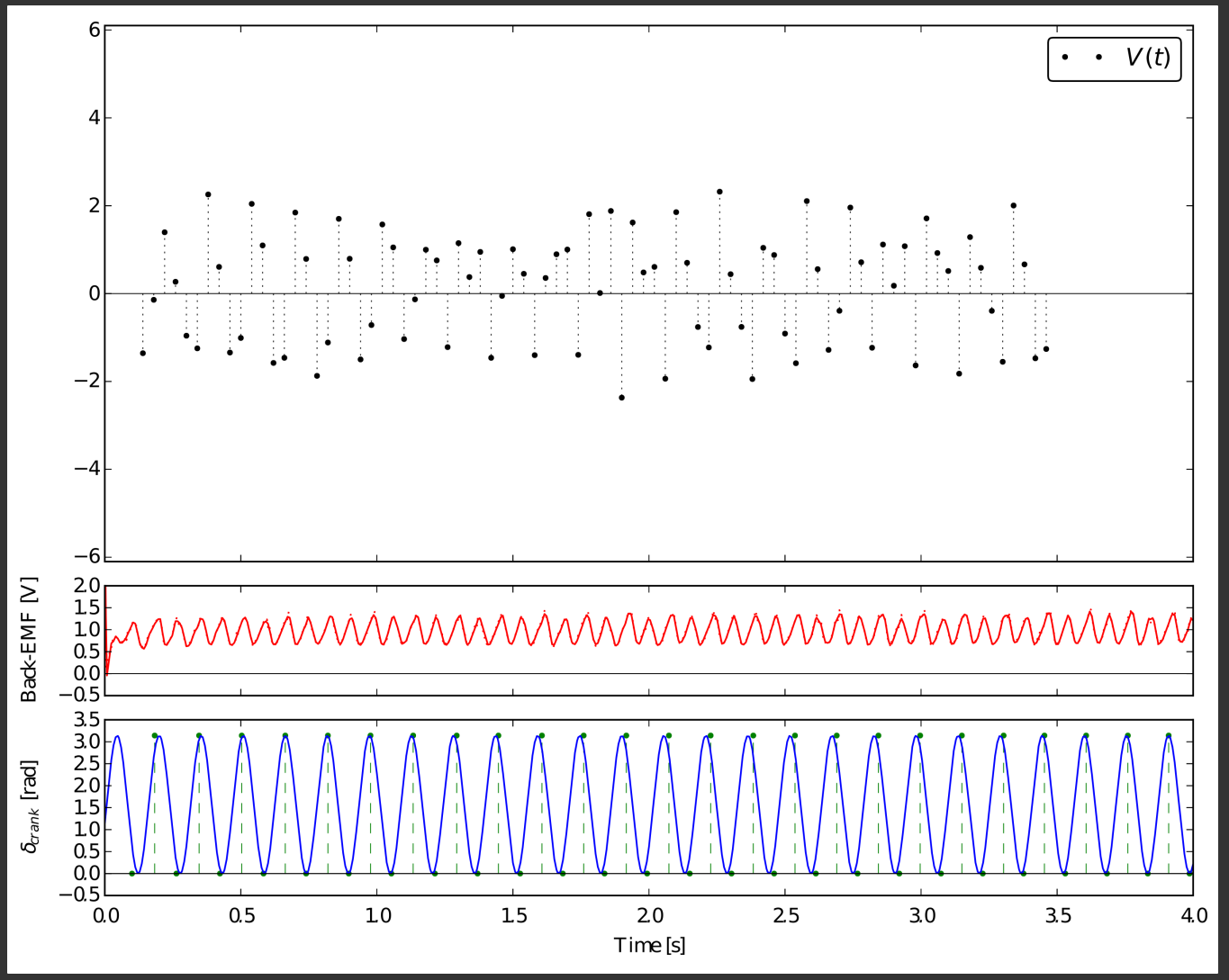
Follow-up questions

- Can we disambiguate the true OF from the noise caused by flapping, on-board?
- Is motor current or voltage correlated w/OF?

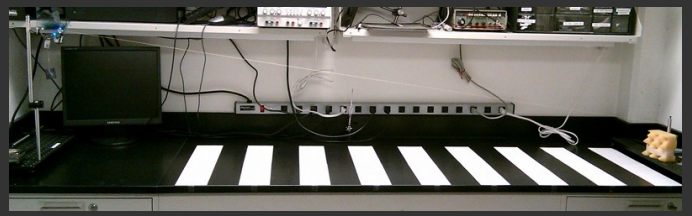
OF Correlation with Back-EMF

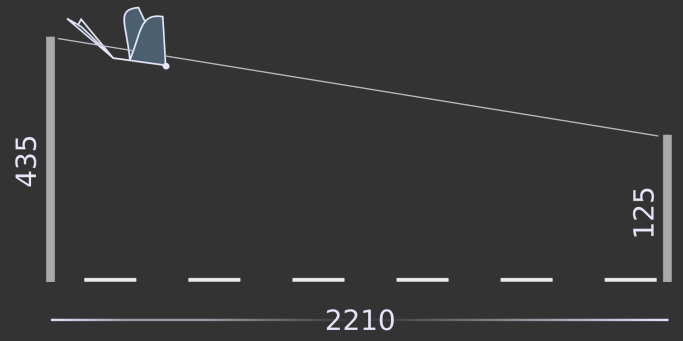
Experimental Setup

On-board Camera Viewpoint

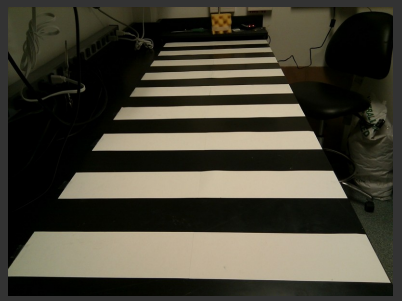


OF Disambiguation via Back-EMF





Experimental Setup
(not to scale, dimensions are in mm)



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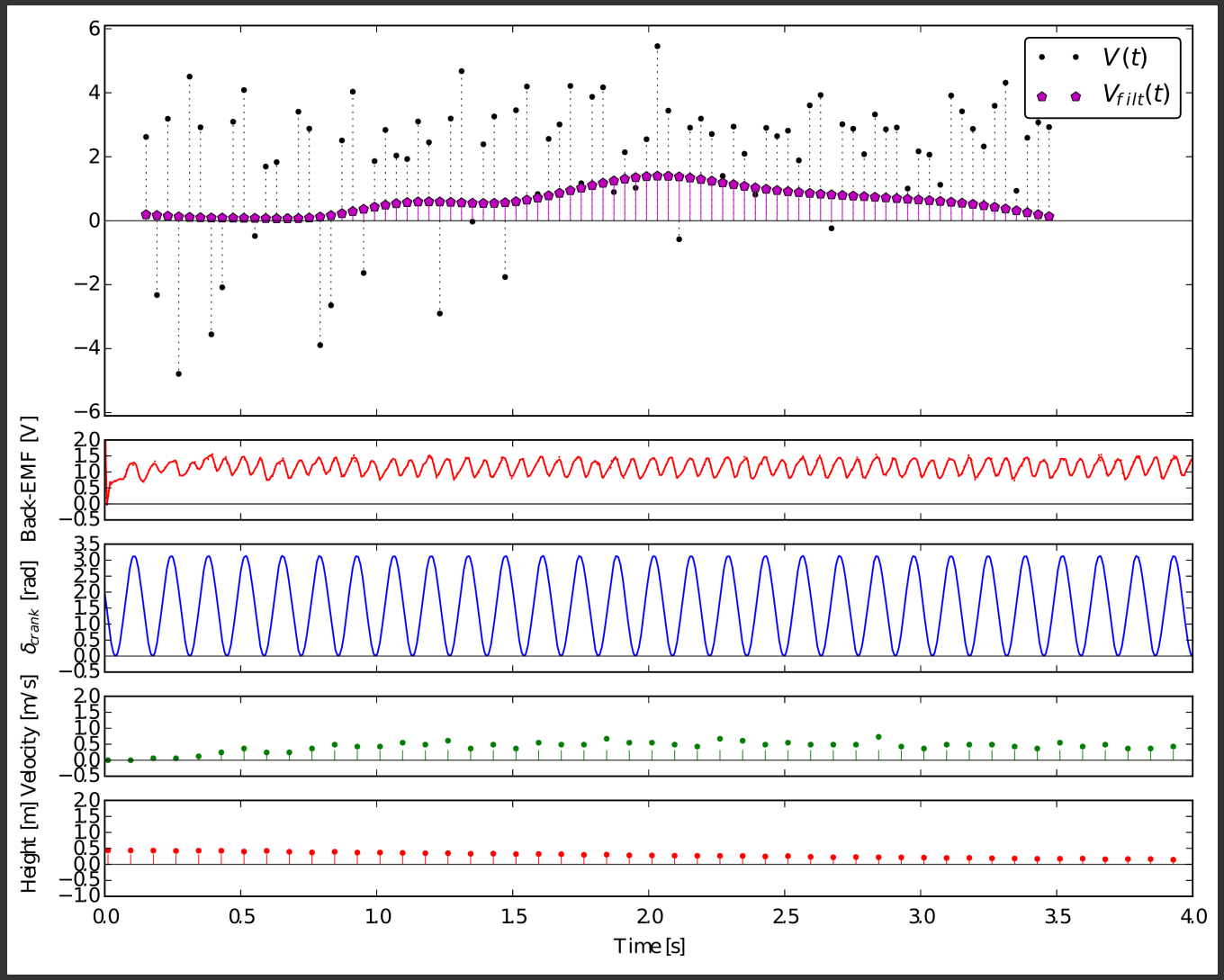
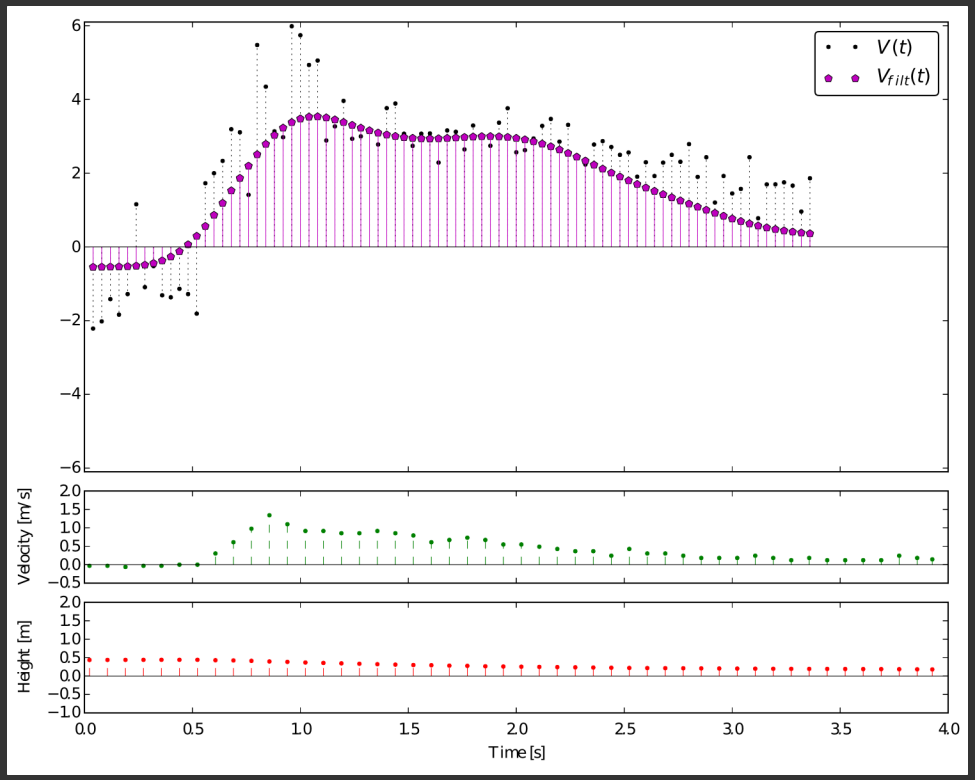
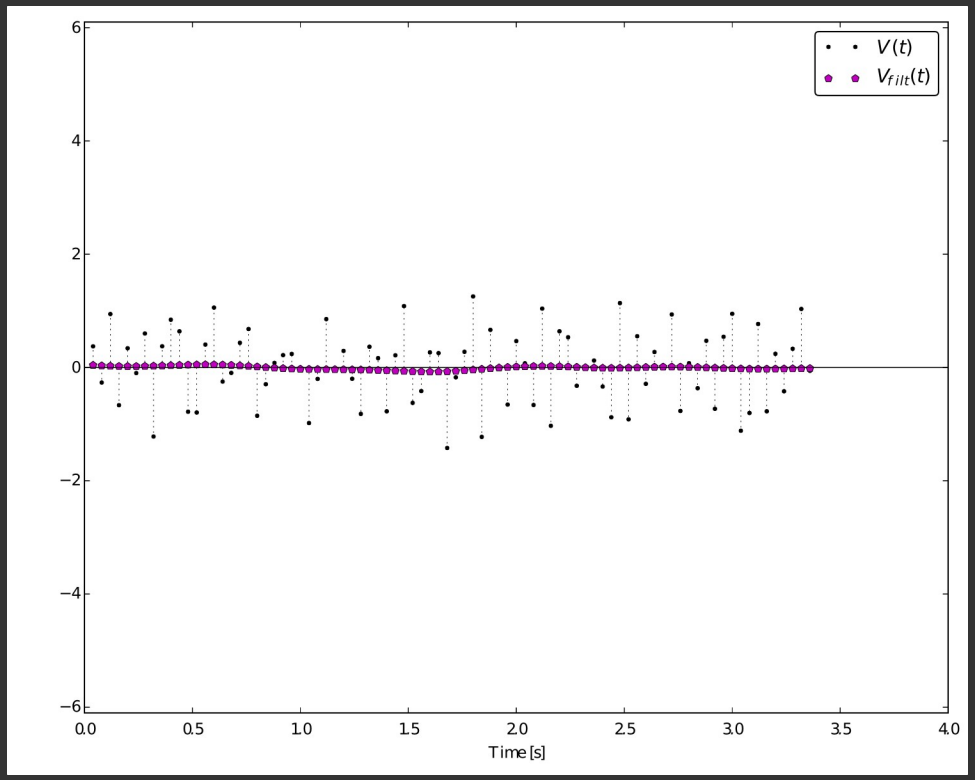


Two Controls



Sliding



Static

Where do we stand?

Type	Group	Env.	Texture	Other Sensors	Behaviors
Airship	Iida, 2003	In	Natural	-	Odometry, Height Reg., Centering (~10m)
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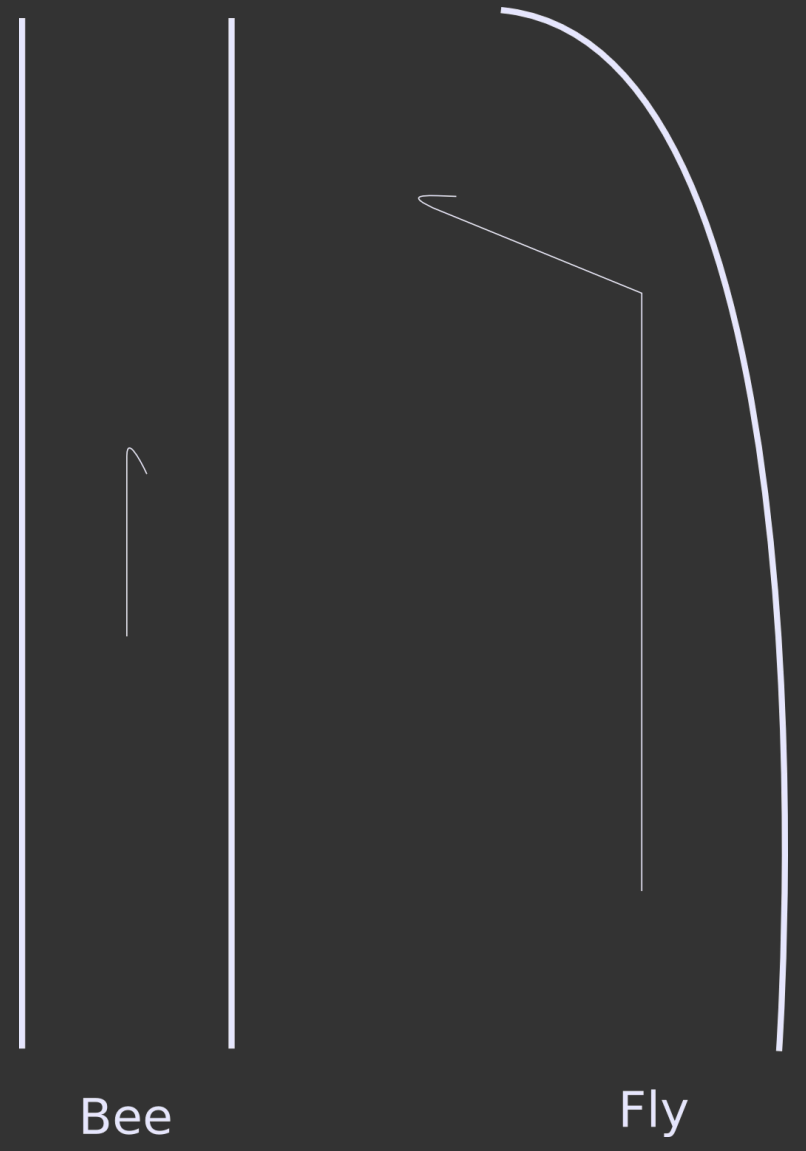
Flapper	Wagter et al., 2007	Sim	Natural	-	Horizon detection, terrain following
	Garcia Bermudez & Fearing, 2009+	In	Natural	Back-EMF	Flapping-oscillations disambiguation (~10m)

Reactive Behavior

- Height regulation
- Wall following
- Corridor Centering
- Obstacle avoidance



Srinivasan et al, 2004

Tammero and Dickinson, 2002

Elementary Motion Detector

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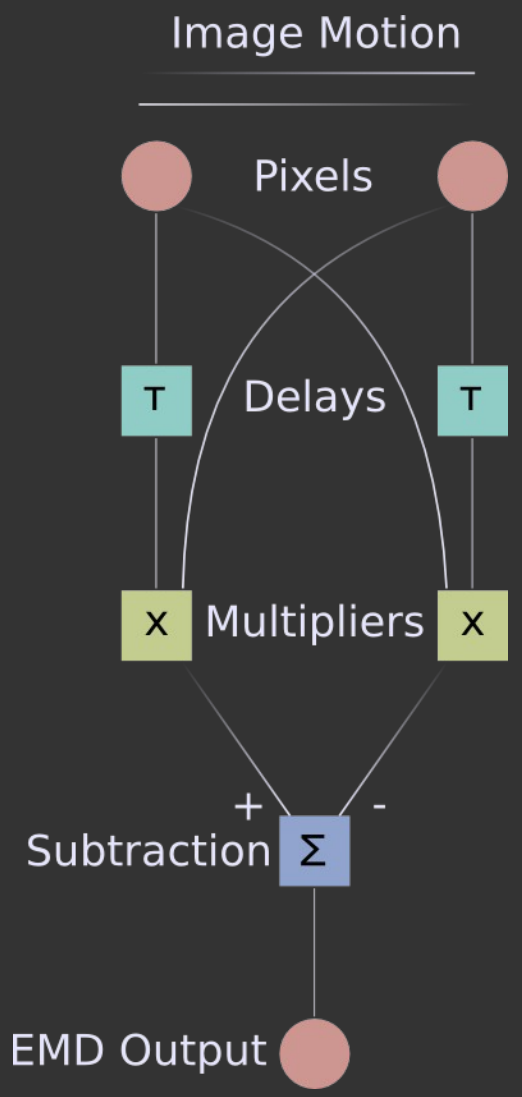
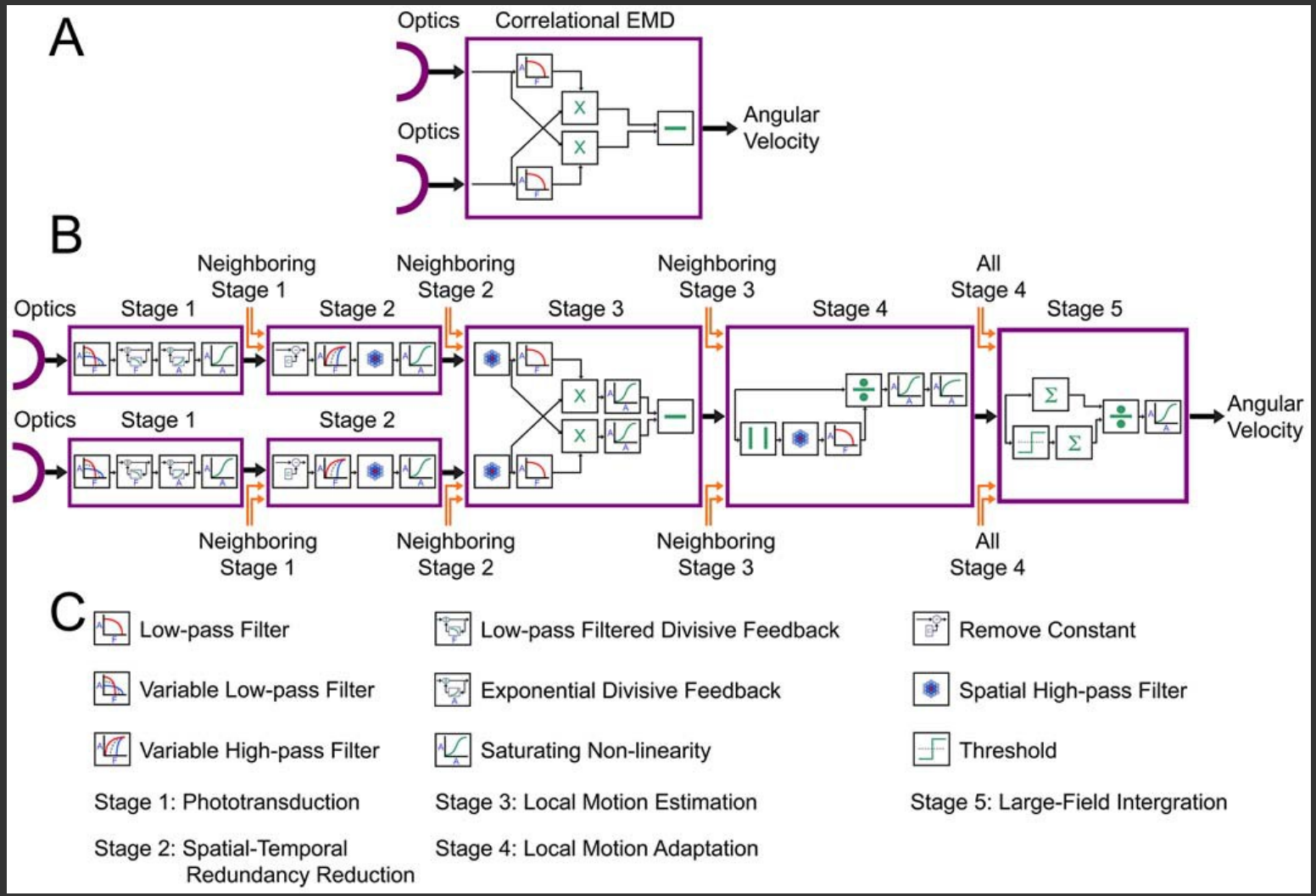
Hassenstein and Reichardt, 1956



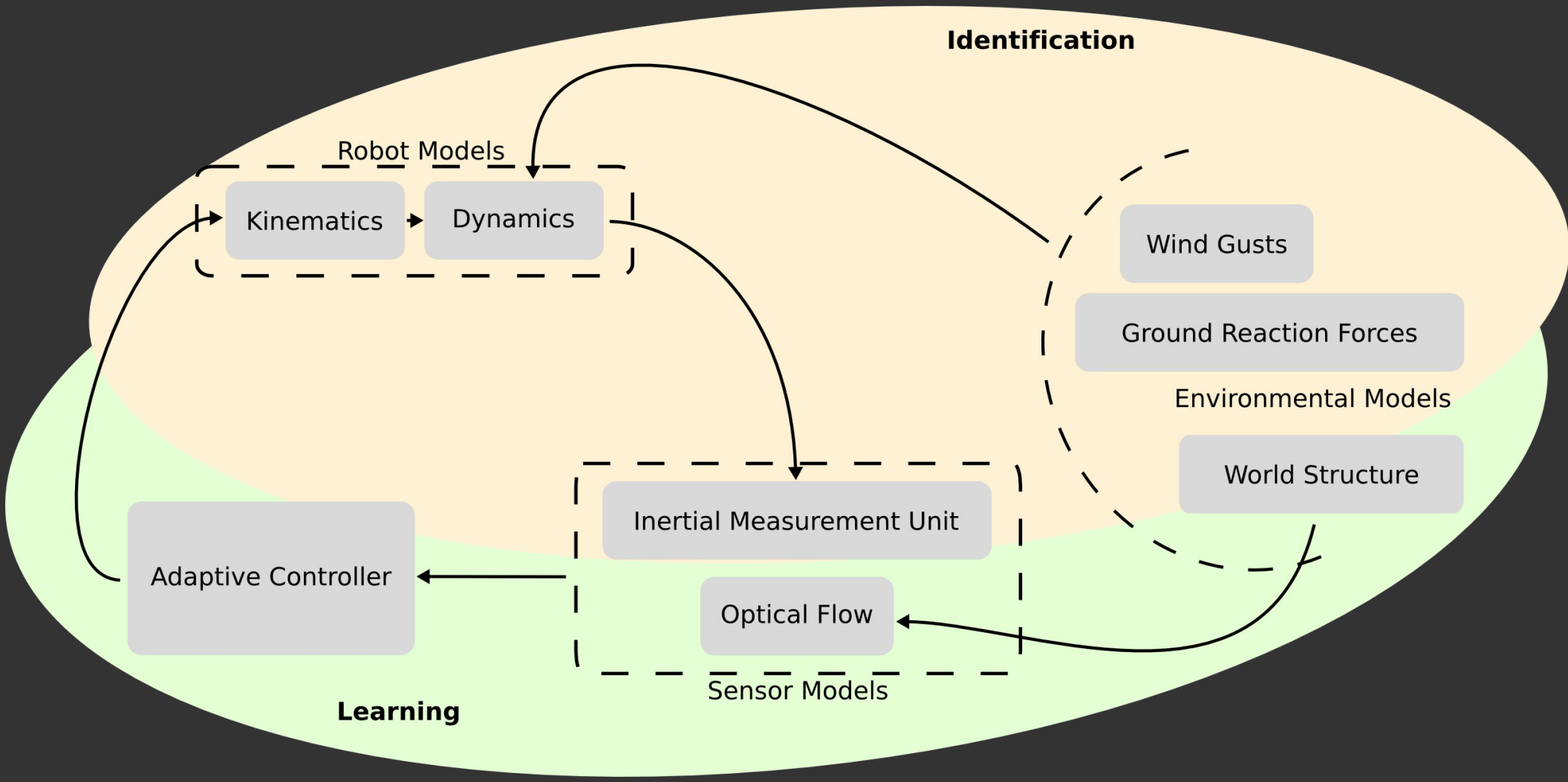
(adapted from Reichardt, 1987)

Extended EMD

Brinkworth and O'Carroll, 2009



Closing the loop



Thanks

www.eecs.berkeley.edu/~fgb

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EECS, UC Berkeley

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