Automated tracking of head and vibrissae movements in freely-moving and anesthetized rats using videographic methods

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Rat vibrissal movements, together with rapid head and body movements, allow for efficient tactile sampling of the environment. Though behavioural electro-physiology has advanced much in recent years with the miniaturization of head-mounted amplifiers and wireless transmitters, efficient methods for describing whisker kinematics in freely-moving rats are still lacking.

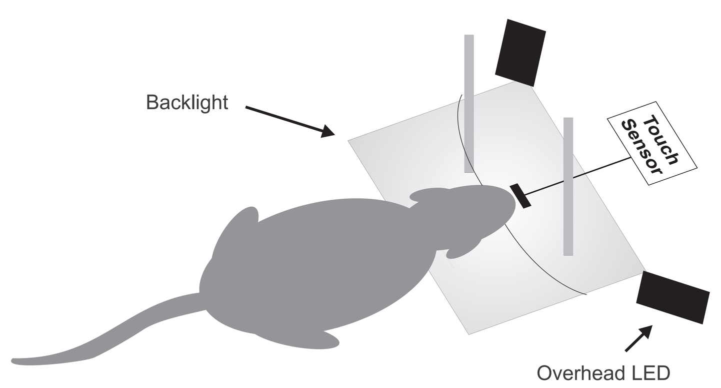
We describe a method whereby head and whisker movements in freely-moving rats are tracked using high-speed video and simple image processing techniques*

* See also (3) for a similar method

2 Instruments

Imaging system:
Redlake MotionScope PCI.

Resolutions:
Freely-moving: 320x280 pixels, 500 frames/sec
Anesthetized: 320x156 pixels, 1000 frames/sec



Whisker contrast against background was maximised by selecting short shutter opening-duration (10-100%), using a very bright lens (Navitar, USA), and strong backlight (LED array or fiberoptic).

Two overhead LED spotlights were used to produce a corneal reflection in freely-moving rats.

3 Methods: Overview

A. Track movements of the head — Box 4
   i) Localize eyes in individual frames
   ii) Low-pass filter head-traces

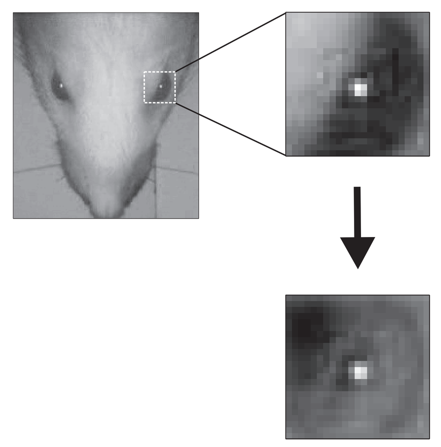
B. Track movements of the whiskers — Box 5
   i) Remove static features
   ii) Extract region of interest
   iii) Extrapolate new whisker location
   iv) Convolve with local angle filters
   v) Evaluate new, possible whisker locations

C. Post-processing

D. Kinematic analysis — Box 7

4 Methods: Head movements

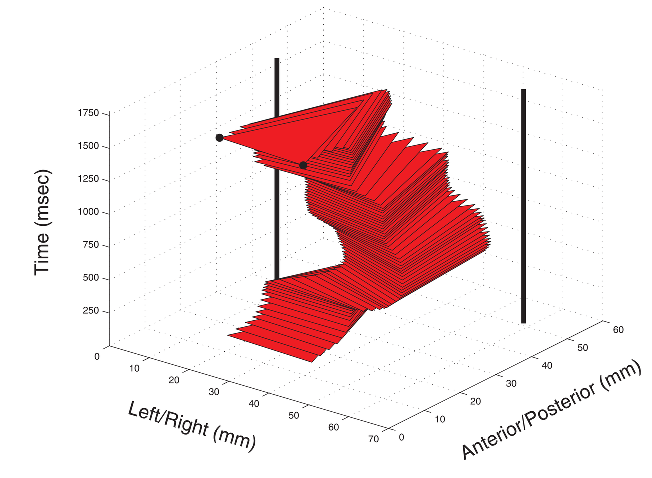
The corneal reflection was manually located in the 1st frame, then determined in subsequent frames by the following method:



Extract X-by-Y pixel region centered on eye's location in the previous frame.

Convolve with difference of two gaussians.

Locate brightest pixel.

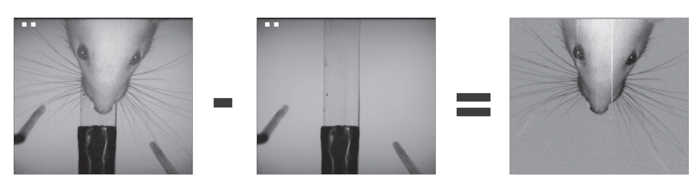


Tracked head-movementc obtained from eye locations. Rat entered frame at time zero, moved anterior and right, then centered its head and backed out of the frame. The X/Y coordinates of two objects are marked in black.

5 Methods: Whisker movements

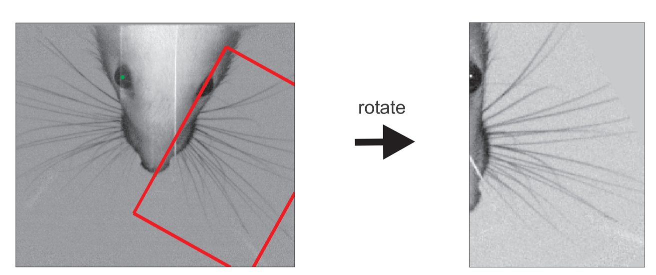
1. Remove background

A background image was obtained by averaging 50 to 200 frames where the rat was not in-frame. This background image was then subtracted from every individual frame.



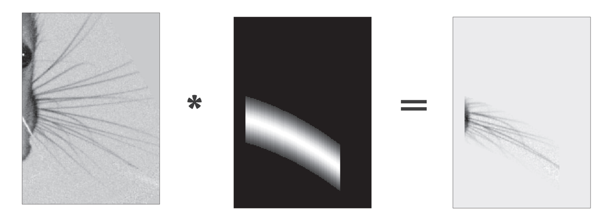
2. Extract region of interest

A region was extracted adjacent and parallel to the rat's head, using the eye and nose coordinates. The region of interest was then rotated and aligned with cut-outs from all other frames.



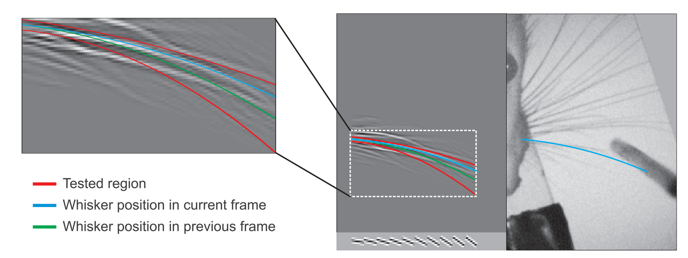
3. Extrapolate new location

Confusion with other whiskers was reduced by extrapolating the whisker's new location from it's velocity in preceeding frames and applying a smooth filter to the image.



4. Filter according to angle

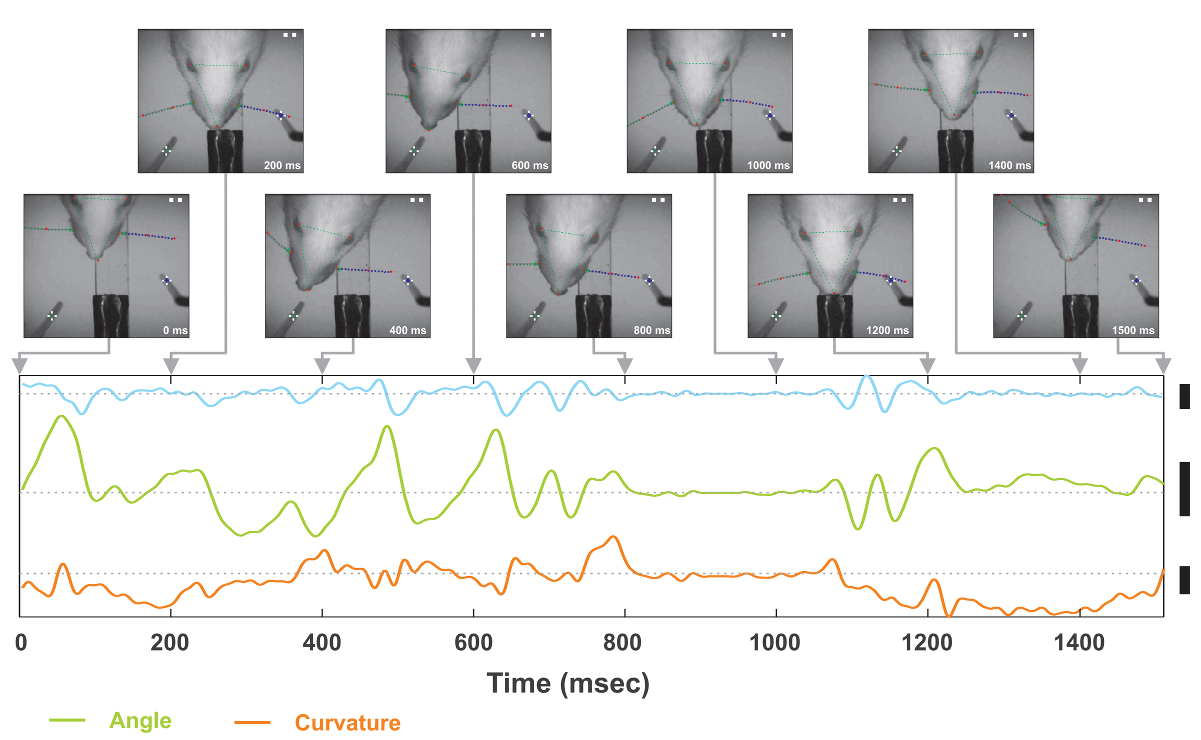
The image was convolved across columns according to local angle of the whisker in the preceeding frame. The whisker's shape was approximated by a cubic spline. A population of splines were produced that fell within a pre-defined distance from the whisker's location in the preceeding frame. The sum of pixel-values falling on individual splines were computed, and the spline with the largest sum selected as the whisker's new position.



6 Results: Freely moving

One whisker was left on each side of the face (marked in green and blue). One frame for every 200 msec are shown. Eye locations and approximated nose position are indicated by red dots. Touched locations on the two objects are indicated by crosses.

Traces of angle, curvature and velocity of the blue whisker are shown in the bottom panel. Curvature is positive when the inner side of the whisker faces posteriorly. Curvature was naturally negative, but increased and became positive upon touch with the object.



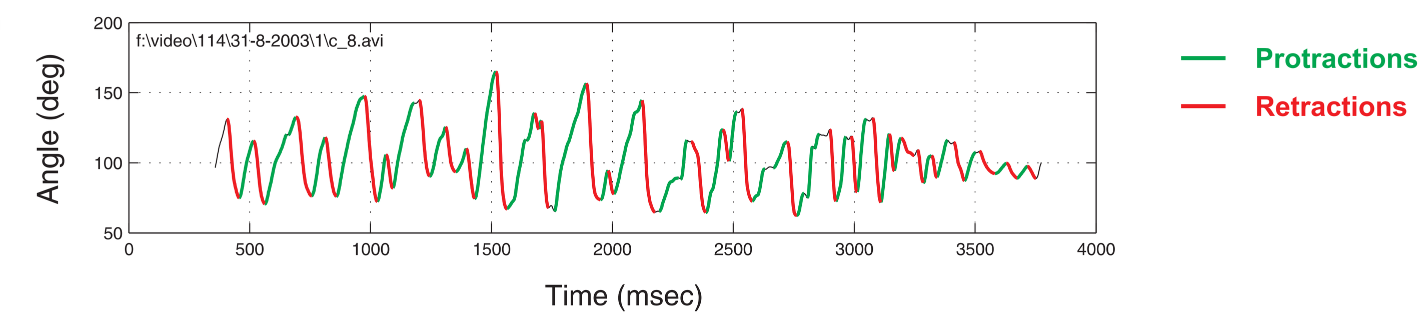
7 Results: Freely-moving

Identification of protractions and retractions

We obtained whisker traces from rats trained in an object localization task

Protractions and retractions were identified from the amplitude envelope of the low-pass filtered angle trace.

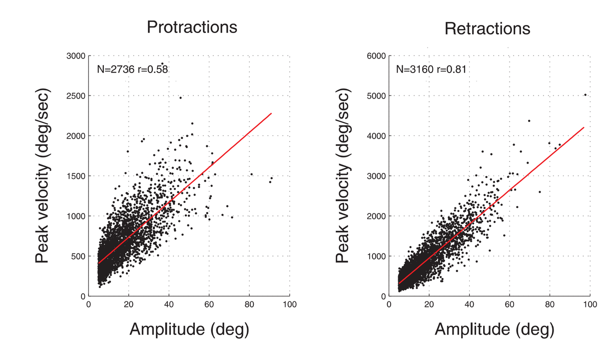
Protractions followed by a retraction were defined as 'whisks'. We observed, however, that many movements occurred in isolation.



Protraction and retraction kinematics

We compared kinematics of 5896 protractions and retractions obtained from one rat across 5 sessions.

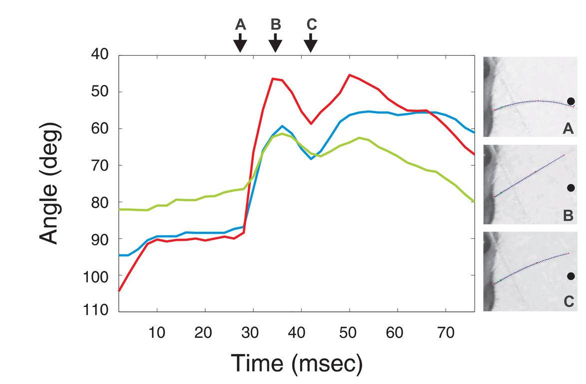
Retraction amplitude and velocity was strongly correlated, consistent with previous observations (1).



Whisker resonance

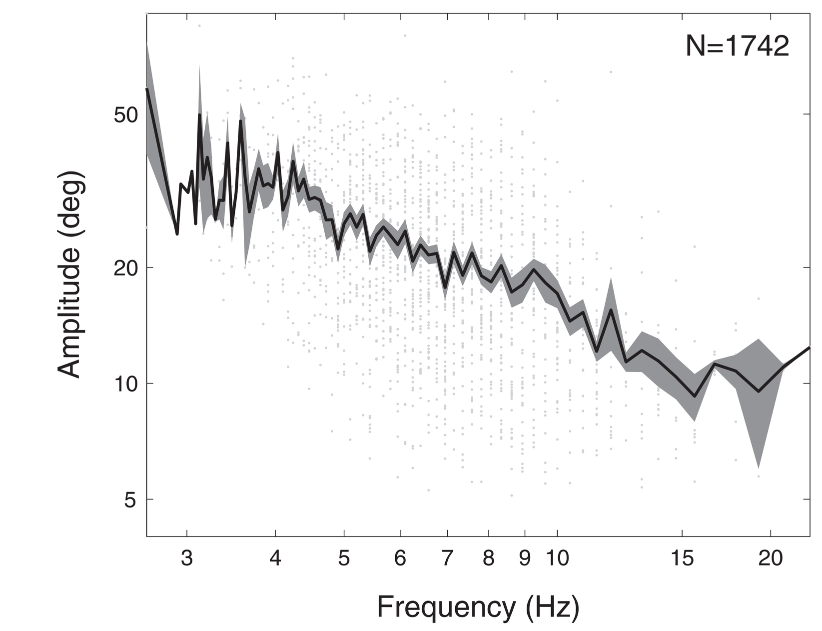
Whisker resonance (3) was observed when a whisker pushed against an object and drove beyond it.

Three events are shown to the right when the same whisker, in different trials, moved past the object during retraction. Though velocities were different as the whisker passed the object, the resonant frequency for this whisker (~66Hz) remained nearly constant.



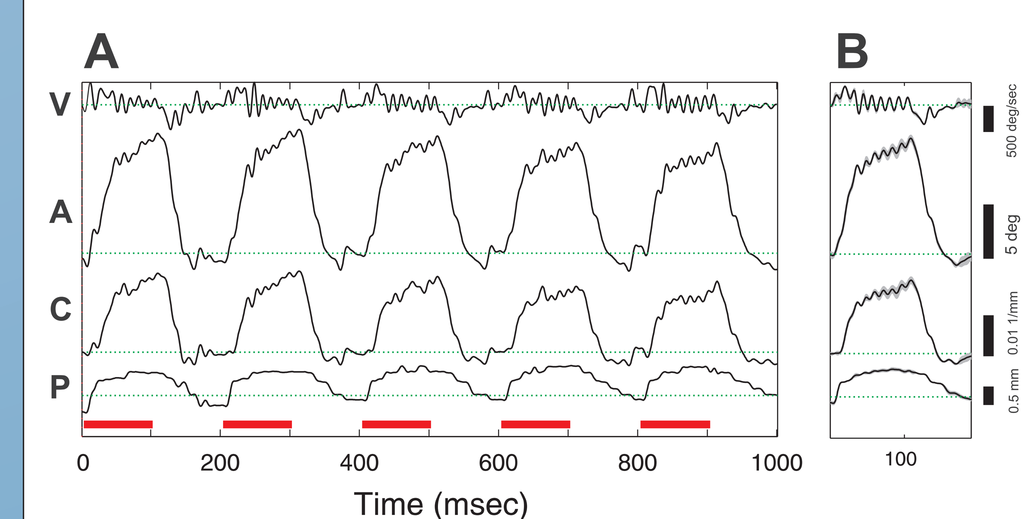
Whisk frequencies and amplitudes

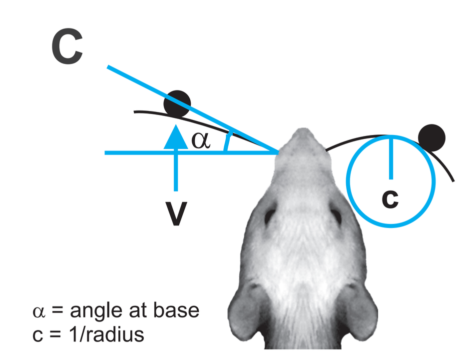
Frequencies of individual whisks are shown plotted against their amplitudes on a log-log scale (grey dots; black line shows mean). The absence of any salient clustering leads us to suggest that amplitude and frequency during whisking falls along a continuum, with amplitude decreasing roughly exponentially with increasing frequency.



8 Results: Anesthetized

Whisking induced in an anesthetized rat by stimulating the facial motor nerve. Traces of angle, velocity, curvature, stimulus trigger and distance of whisker from an object are shown (A), along with averages of all 5 cycles shown (B). See Derdikman et al (2003, this meeting) for more details.





A. **V**elocity, **A**ngle, Curvature and **P**osition from object of a tracked whisker. Touch moments were estimated from the position of object parameter. **B.** Cycle average of the trace in A

C. Illustration of the parameters obtained from the tracked data. Angle is measured close to where the whisker exits the follicle. Curvature calculated at the location along the whisker where 1/radius reaches maximum.

9 Summary

Our method manages to track whisker movements automatically in high frame-rate videos. The complete representation of the whisker's movements in 2D, captures its angle at tip and base, curvature and moments of object touch.

Freely-moving whisking data demonstrate that:

- **Amplitude of task-related whisking falls off with frequency.**
- **Peak-velocity is correlated with amplitude during retraction and (less) during protraction (1)**
- **Whisker oscillations were observed upon release from contact with on object, showing frequency constancy consistent with resonance oscillations (3).**

Acknowledgements: Maciej Pietr

Software download (from 1st quarter 2004): http://www.weizmann.ac.il/neurobiology/labs/ahissar/

References

1. Bermejo R., Houben D. and Zeigler H.P. Optoelectronic monitoring of individual whisker movements in rats, J. Neurosci Methods, 1998, 83:89-96.

2. Carvell, G.E. and Simons D.J., Biometric analysis of vibrissal tactile discrimination in the rat, J Neurosci, 1990, 10:2638-2648.

3. Hartmann, M.J., Johnson, N.J., Towal, R.B. and Assad, C. Mechanical characteristics of rat vibrissae: Resonant frequencies and damping in isolated whiskers and in the awake behaving animal. J Neurosci, 2003, 23:6510-6519.