An Algorithm for Automatic Tracking of Rat Whiskers

G. Gyory*, V. Rankov*, G. Gordon**, I. Perkon***, B. Mitchinson*, R. Grant*, T. Prescott*
**Department of Psychology, University of Sheffield, Sheffield, UK*
*** Department of Neurobiology, Weizmann Institute of Science, Rehovot 76100, Israel*
****Cognitive Neuroscience Sector, International School for Advanced Studies, Trieste, Italy*
****Italian Institute of Technology–SISSA Unit, Trieste, Italy*
ggyory@dsl.pipex.com; v.rankov@sheffield.ac.uk

Abstract

All mammals, apart from humans and primates, have facial 'whiskers'. Rodents are "whisker specialists" and have more than 30 whiskers on each side of their face, which they use to gather tactile sensory data on their near surroundings. Many rodents (including rats, discussed here) actively move their whiskers back and forth in a behaviour known as 'whisking'.

In attempting to understand this sensory system (and its neural underpinnings), there is a strong need for automatic tracking of these whisker movements.

Tracking all individual whiskers (more than 60) is a very difficult task (into which research is ongoing [1,2]). Here, we introduce an unsupervised algorithm for detection of the 'mean angular position' (MAP [3]) of the whiskers on each side of the face during active whisking from high speed greyscale video recordings of freely behaving animals. The core of the algorithm is a geometrical image transform which aids in finding the whiskers and calculating the whisker angles at their root. The only manual input required is to mark two points in the first video frame.

1. Introduction

Tracking the movement of whiskers in freely behaving rodents is not an easy task. This is due both to the high motion speed of the whiskers, and their small size (sub-millimetre), requiring cameras with both high temporal and spatial resolution. Other confounds, as in other applications, include motion blur, blurring due to limited depth of field, and illumination changes.

Some recently developed methods [1,2] have demonstrated the ability to obtain the location of a few whiskers in an animal with most of its whiskers removed, under specific conditions. In this paper, an image-processing based method is introduced that identifies bilateral MAP (on both sides of the face) in each video frame in an intact (all whiskers present), freely-behaving animal, and that is relatively robust.

Specific methods used include a classical geometrical inversion and a Hough transform. The only manual input required is the centre of the inversion and the tip of the animal's nose in the first video frame. In subsequent frames the algorithm finds the whiskers, their orientation, and tracks their movements, automatically.

2. Methodology

2.1. Experiment Set-up

Rats were filmed opportunistically (as they entered the field of view of the camera) whilst freely exploring a simple environment (a closed box). We use these simple environments and untrained animals in an attempt to elicit relatively natural behaviour. The box is under-lit with a high-power (1500W) high-frequency fluorescent light source. The camera, positioned overhead looking down, is a Photron Fastcam1024 (1024×1024 resolution, 500 frames/s and 0.5ms shutter). This set-up returns a spatial resolution of approximately 0.2mm/pixel at the level of the animal, and typically around 50% image saturation. The length of analysed video data is typically 0.4s or 200 frames.

2.2. Algorithm for image analysis

Treating each whisker as a curve, a large number of parameters must be estimated simultaneously to accurately track each whisker. A key feature of this algorithm is the observation that whisker images are approximately circle arcs with a common intersection, reducing the number of parameters per whisker to two - position of the root and direction (two additional parameters specify the common intersection centre [4]). Inverting the image ('turning inside out' with respect to a circle centred at this intersection) transforms these approximate circle arcs to approximate straight lines and, simultaneously, enlarges the image at the base of the whisker (with respect to the image of the outer parts of the whisker). Finding the whiskers using this approach does not require any image segmentation.

The proposed algorithm detects bilateral MAP from high-speed video images of freely-behaving animals. It is used off-line and is summarised below.

1. Pre-processing: a) Automatic brightness adjustment using histogram analysis; b) background extraction based on the maximal brightness levels in every 40th frame; c) the image is eroded than expanded and the resulting image subtracted from the original, leaving only the whiskers; d) Sobel edge enhancement.
2. Head tracking: In the first frame the user marks the tip of the snout and the best common intersection of the whiskers. The distance between the two is computed. A component of a broader whisker image processing suite (the 'BIOTACT Whisker Tracking Tool' [5]), is used to track the contour of the snout in the vicinity of the whisker pad in subsequent frames. These data are used to maintain the location of the nose tip and the centre of intersection automatically for the remainder of the video.
3. Whisker tracking: Determination of the whisker angles is the contribution of the algorithm described here. It involves three main steps: a) Geometrical inversion; b) Polar to rectangular transformation; c) Hough transform for detecting straight lines.

After pre-processing the inverted image is computed and centred (Figure 1c). The grey area of this image corresponds to the points outside the original image and in the sequel it is treated as white. As the parts near the inversion centre are imaged much larger than parts distant from the inversion centre, two rodents meeting and whisking each other can be treated separately. With a well-chosen inversion centre the resulting whiskers have approximately radial orientation. Small user errors in locating the inversion centre do not seem to influence detection.

A polar-rectangular transformation and a horizontal circular shift (the latter equivalent to rotating the original image so that the snout points downwards) are applied next, putting the image of the snout at the left and right edges as in Figure (1d). As the whisker images were approximately radial after the inversion (1c), they are approximately vertical after the coordinate transform (1d).

The Hough transform for finding straight lines is the most computationally intensive part of the program. The limits of approximate verticality of the whisker images allow us to compute only the relevant part of the Hough accumulator (Figure 1e). Pre-processing reduces the number of (dark) image points used in the Hough transform, further reducing processing time and also increasing the legibility of the results. This process is summarised below.

1. The straight lines corresponding to the local maxima in the Hough accumulator represent arcs tangents to the whiskers at the root (irrespective of the whisker size), the two sides of Figure 1d corresponding to the two sides of the rat (the weak whisker images towards the centre correspond to the non-targeted whiskers towards the rear of the animal's head). The segments found, transformed back to the original image, give the whiskers' base positions and angles.
2. Finally, the mean angle across all whiskers detected on each side is computed to give an estimate of the bilateral MAP (variable whisker detection across frames is, thus, a source of noise in this signal; see Discussion).

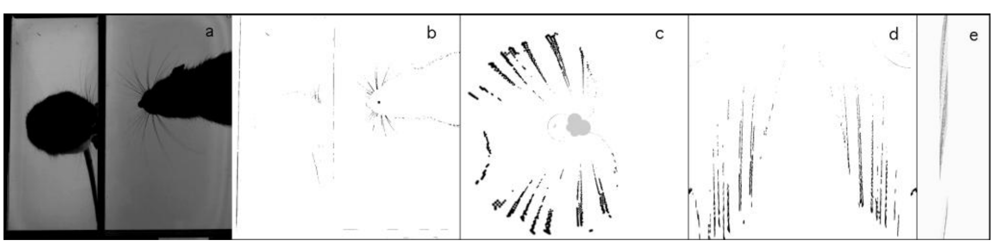

Figure 1 a. Input image of an exploring rat. b. The pre-processed image with the inversion centre marked. c. Inversion of b. d. Polar-rectangular transform of c. e. The relevant part of the Hough accumulator.

3. Results

Illustrative results from the proposed algorithm are presented in Figure 2 which shows an original video frame with automatically-determined whisker positions overlaid and calculated MAP emphasised.

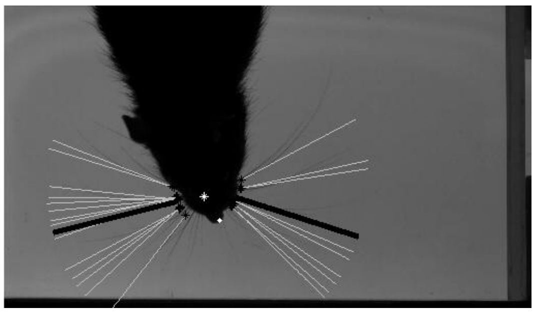

Figure 2 Original video frame with automatic tracking overlaid. Light grey shows determined whisker positions; thick black lines represent MAP on each side. Nose tip and inversion point are shown as a white dot and white star, respectively.

Figure 3 compares examples of the automatically-determined MAP as it changes over time with an estimate of MAP computed from manual tracking of the same data. The automatically-determined MAP displays very similar dynamics to that obtained from manual tracking, with the most substantial error being the presence of a slowly-changing angular offset. This error, as well as the possible absence of data in some regions of the plots (not the case in the shown video), is due to the changing performance in detecting whiskers (i.e. motion blur). Nonetheless, behavioural researchers are often most interested in higher-level measures, such as amplitude and frequency of whisking [6], rather than accurate whisker positional information. These metrics can be obtained effectively despite the (generally small) offset error and they are included in Table 1. Corresponding sinusoidal signals for manual and automatic case are also included in graphs in Figure 3.

a) b)

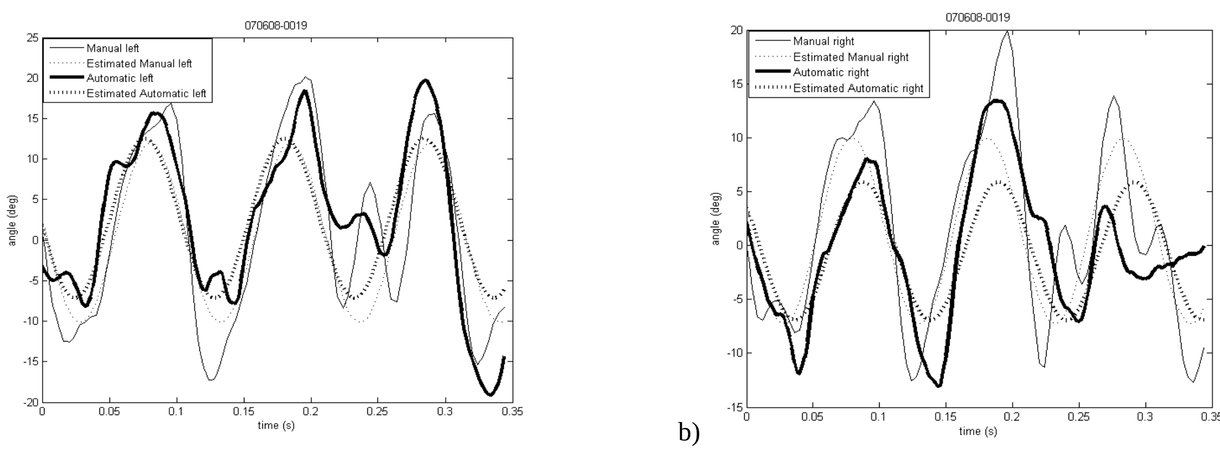

Figure 3 Comparison of automatically-determined MAP with that determined from manual tracking (two solid lines) shown in figures a) and b) representing left and right tracking respectively from the same video clip. Estimated sinusoidal signals representing the amplitude and frequency of whisking for manual and automatic case (two dashed lines) are included in these plots too.

		Left side	**Right side**
manual est	frequency [Hz]	9.6154	9.8039
	peak to peak amplitude [deg]	22.0694	17.1978
automatic est	frequency [Hz]	9.6154	9.8039
	peak to peak amplitude [deg]	19.6678	12.8214

Table 1 Estimated amplitude and frequency of whisking for the video clip/ cases as in Figure 3.

4. Implementation

The bulk of the algorithm described is implemented in C++, as a mex file running in Matlab. Gain adjustment, computation of the mean, and visualisation of results is performed directly in Matlab. In addition, maintenance of nose and snout location are performed by the 'BIOTACT Whisker Tracking Tool' [5] in Matlab. Overall, the system performs at around 2 frames/s on a single 2.4GHz x86 core.

5. Discussion

We have presented a novel digital image-processing algorithm that enables a fully-automated determination of the mean angular position (MAP) of the whiskers of a freely behaving rodent (here, rat). This system can be used to calculate the statistics of whisker movements without any human supervision/intervention except for the determination of the inversion point and nose tip point in the first frame, and without trimming or marking of the animal's whiskers. Of particular interest to behavioural researchers [6] are metrics such as the amplitude and frequency of whisking, and the instantaneous speed of protraction/retraction. The main error made by the automatic system is in the absolute angular position, which has a limited effect on these metrics.

The algorithm presented does not run in real-time on typical desktop hardware, but it is fully automated and unsupervised (the initial human input in the first frame can be, of course, provided for many video clips in advance of processing). Here, we list the key features of the algorithm: a) It handles unrestrained (as well as restrained) animals; b) The reliability and quality of detection are reduced by blurring and by imaging the whiskers at too low a resolution, but are quite robust to changes in illumination conditions (brightness, contrast); c) Algorithm reliably tracks head movements and it is robust to the rats movement in horizontal plane; movements in a vertical plane can result in occlusion of some whiskers which can affect the algorithm result; d) The algorithm does not require the animal's whiskers to be trimmed, as for some other systems [1,2] (maximum number of whiskers tracked simultaneously during the experiments reported is 32 in one frame); e) Processing speed is around 2 frames/s using desktop hardware.

The automatic tracking system presented will be of use to researchers who study the way that rodents move their whiskers in order to optimise the quality of sensory information gathered whilst performing different tasks. This behavioural understanding is considered a pre-requisite to understanding how processing of sensory data proceeds in associated neural systems [7].

6. Future work

We now describe our plans for future work. First, we will optimise the algorithm for computational efficiency. Second, we plan to improve the derivation of MAP from the set of individual whisker angles, taking into account the occurrence of whisker detection failure. Failure to detect one or more whiskers in some frames introduces noise into a naive estimate of the MAP (this estimate is obtained by simple averaging across the angles of all detected whiskers). We expect to achieve considerable improvement in MAP estimation, thus, by modelling detection failure. Our approach will be to maintain correspondence between whiskers detected in all frames by using the positions of the bases of the whiskers as a key to their identification (whiskers may cross over along their length, but whisker base adjacency relationships are constrained by the anatomy of the animal).

References

[1] J. Voigts, B. Sakmann, T. Celikel. Unsupervised Whisker Tracking in Unrestrained Behaving Animals. *J Neurophysiol*, 100:504-515, 2008.

[2] P. M. Knutsen, D. Derdikman, E. Ahissar. Tracking Whisker and Head Movements in Unrestrained Behaving Rodents. *J Neurophysiol*, 93:2294-2301, 2005.

[3] R. A. Grant, B. Mitchinson, C. W. Fox, T. J. Prescott. Active Touch Sensing in the Rat: Anticipatory and Regulatory Control of Whisker Movements During Surface Exploration. *J Neurophysiol*, 101:862-874, 2009.

[4] C. S. Ogilvy. *Excursions in Geometry*. Dover Publ. Inc., 1991.

[5] G. Gordon, I. Perkon, V. Rankov. BIOTACT 'Whisker Tracking Tool' for whisking animals. *Under development*.

[6] R. Berg, D. Kleinfeld. Rhythmic Whisking by Rat: Retraction as Well as Protraction of the Vibrissae Is Under Active Muscular Control. *J Neurophysiol* 89:104-117, 2003.

[7] B. Mitchinson, C. J. Martin, R. A. Grant, T. J. Prescott. Feedback control in active sensing: rat exploratory whisking is modulated by environmental contact. *Proc. R. Soc. B* 274:1035–1041, 2007.

Acknowledgement

Preparation of this paper, and some of the work described, was supported financially by the European Union BIOTACT (ICT-215910) and ICEA (IST-027819) projects. The authors would like to thank Mathew Diamond and Ehud Ahissar for their assistance in developing the BIOTACT whisker tracking tool.