ISEF 2009 - XIV International Symposium on Electromagnetic Fields
in Mechatronics, Electrical and Electronic Engineering
Arras, France, September 10-12, 2009

Elastomer-based tactile sensor array for the artificial rat Psikharpax

Steve N'Guyen[1,2], Patrick Pirim[2], Jean-Arcady Meyer[1]

[1]ISIR - UPMC, Pyramide ISIR, 4 Place Jussieu 75005 Paris, France, {steve.nguyen,jean-arcady.meyer}@isir.fr

[2]BVS, 32 Rue du Javelot 75013, France, patrick.pirim@bvs-tech.com

Abstract ***– This article describes the elastomer-based whisker system that has been implemented in the artificial rat Psikharpax. The corresponding system calls upon two arrays of 33 whiskers each, which mimic as closely as possible the organization of a rat's vibrissae. The capacity of each whisker to perform texture discrimination is demonstrated. However, it is suggested that such task - and others like object recognition - should be performed in a much more efficient and robust manner should the whole whisker array be called on.***

Introduction

Touch is a very useful sensory modality that is implemented through a wide variety of mechanoreceptors - ranging from arthropod sensilla to primate skin. Rats, for instance, use their whiskers, or vibrissae, to finely discriminate textures ([3]; [7]), to recognize objects [1], and even to precisely determine an aperture width [10]. One can compare rat whiskers to human fingertips in terms of tactile capacity and this sensory modality is based on a very simple transduction mechanism when compared to vision for example.

To implement a variety of functions, many robots have been equipped in the past with whiskers that proved to be cheap, robust and powerful sensors [8]. Brooks [2], for instance, used a simple metal shaft fixed on a push button as a robust security sensor for a walking robot. Likewise, Russell [13] used probe whiskers made of a stem glued to a potentiometer to evaluate the contour of an object. Even wind sensitive sensors made of small springs surrounded by electric contacts allowed a robot to navigate through a labyrinth [4].

More recently, artificial whisker systems have proven their capability to discriminate textures. Whisker hairs of real rats, glued to capacitive sensors (electret microphone), have been used ([11]; [5]) to make an accurate vibrissa sensor, exploiting unidimensional dynamic signals only. With an active whisker array of such sensors mounted on a mobile robot, Fend et al. [5] successfully discriminated between a set of 11 textures. The corresponding data processing was based on power spectrum density. Kim and Möller [9] combined piezo and Hall-effect sensors, mounted in orthogonal pairs, to provide a bidimensional measure of vibrissa deflection that made it possible to discriminate a set of 7 sandpapers. Seth et al. [14] also performed texture discrimination using arrays of Flex sensors that provided an unidimensional measure of curvature. Here, temporal differences between pairs of vibrissae were fed into a spiking neuron-based barreloid system. Fox et al. [6] used two active whiskers with strain gage-based sensors mounted on a mobile robot. They explored different bioinspired feature extraction methods and the implication of unconstrained whisker-texture contact on classification performance.

The work reported here is a contribution to the Psikharpax project [12] which aims at designing a biomimetic artificial rat. None of the above-mentioned sensors and implementations was found to be suitable for this objective since we wanted to implement two highly integrated whisker arrays, with a minimum of 25 vibrissae each, that would mimic the natural rat's whisker pads in terms of morphology. So miniaturization was an important constraint for the conception of the system. The whole robot being approximately four times the size of a rat, the whisker pad had to fit an area of roughly 6*6 cm^2 in order to fit the head proportion. Moreover, each sensor had to provide 2D deflection information with DC component. Flex sensor were inappropriate because they provide unidimensional curvature information only, and because real whiskers themselves are not sensitive: only the follicles at their base detect deflections. Likewise, miniature electret microphones have been tested. Although they are quite small, they provide unidimensional AC measure only, and prove to be not robust enough due to the need of gluing stems to the diaphragms. Finally, although systems based on Hall effects and strain gages are very precise and can provide 2D measures, they were dismissed because of the supposed difficulty to arrange them in large scale arrays.

This article accordingly describes the design of a new artificial whisker system made of elastomer. This elastomer-based sensor was specially developed to make high density integration of whiskers possible. The capacity of this system to process significant enough information to discriminate textures is demonstrated. Finally, the effects of whisker characteristics on signal transduction are discussed, together with their potential benefits.

Sensor description

In order to fit our constraints we decided to design a totally new kind of tactile sensor. As a real follicle responds to deformation provoked by vibrissa deflection, we based our system on a material whose resistance varies when it is deformed. We therefore used a conductive elastomer roughly mimicking a very simplified artificial skin. A thin sheet (0.5mm) of conductive carbon-charged silicon elastomer (GETELEC BL 10000) is plated on a larger (5mm) insulating one (Esprit Composite Silicone RTV181). Figure 1 shows a longitudinal cut of such an elementary sensor unit.

Such conductive elastomer is typically used for electromagnetic shielding, conductive joints, LCD panels connectors. It has a very low impedance (< 6Ω.cm) producing low noise and requiring low amplification. Furthermore, it exhibits the interesting characteristic that its conductivity varies when it is deformed. Finally, this elastomer can be stretched up to 150% but, for our tactile sensor application, only a very small deformation is needed.

It thus appears that, by plugging a conductive vibrissa between two conductive probes, we can measure the variation of resistance when the vibrissa is moved. The corresponding sensor is resistive with low impedance. If we surround the vibrissa with 4 probes adequately disposed, we can measure the 2-axis deflection. Vibrissae are made of carbon fiber stems (ø 0.5 mm) glued by epoxy resin, which were chosen for their lightness, but any other material (with a conductive part at the base) can be used.

The sensor acts as a simple voltage divider, with a resting state value of half the voltage between A and C. Therefore, in order to measure 2D deflections in a whisker array, we used a Field Programmable Gate Array (FPGA) to sequentially measure the voltages in each -direction, and for each vibrissa. The measured voltage values may be amplified (but a gain of 1 is sufficient in practice) and digitally converted (Figure 2).

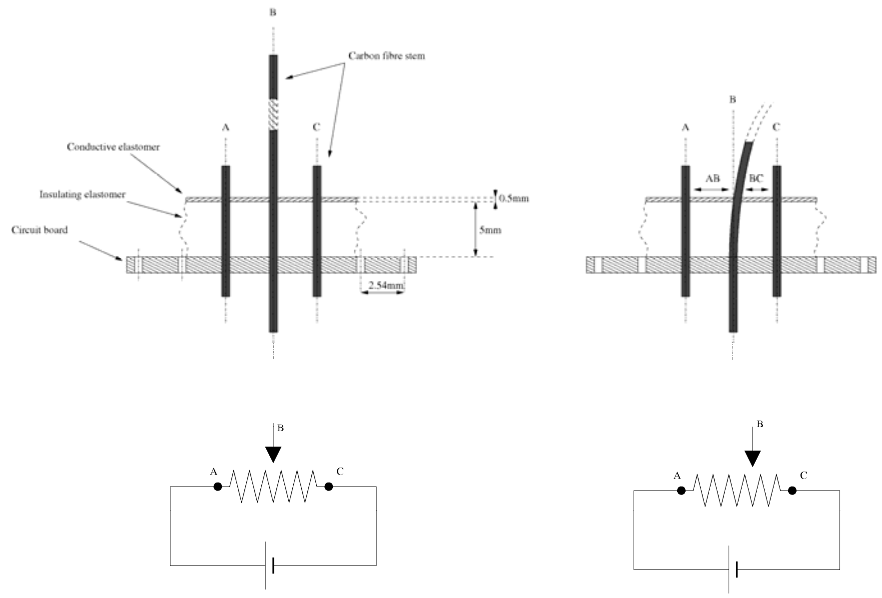

Fig. 1. Transversal view of a single sensor unit with its equivalent circuit. Left: initial position. Right: vibrissa bending. A and C are small immobile conductive probes. B is the measurement point.

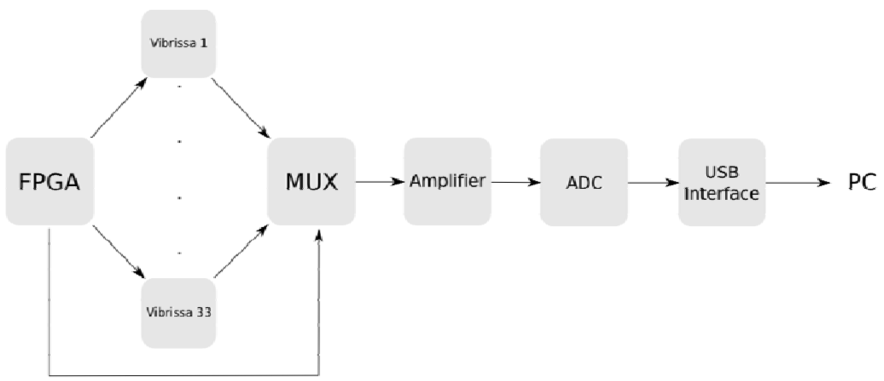

Fig. 2. Diagram of the whole system. A FPGA sequentially drives the X and Y measurement of each vibrissa into a multiplexer. The measured voltage is then fed into an amplifier and converted to 8-bit digital values sent to a PC by USB interface.

We also tried to mimic the precise organization of a rat's whisker pad, notably its arc/row disposition (cf. Figure 3) and its whisker lengths (cf. Table 1). Accordingly, Psikharpax's artificial whisker system is made of two arrays of 33 vibrissae each, implemented on each side of its nose. The sensory part consists on a single elastomer-based artificial skin sheet, covering a flexible electronic circuit containing voltage and measure wires. One of the appreciable properties of this system is that we can mold it with great freedom as long as we maintain A-B-C equidistant for clean measuring. So the whole sensor part is shaped as a conic rat nose. The electronic part is composed of a FPGA that switches the horizontal and vertical measures for each vibrissa, an amplification circuit (here the gain is fixed to 1), and an analog to digital converter. Data are then transferred to a PC by a custom USB interface. Each vibrissa is sampled sequentially at 1157Hz and provides 8-bit measures for both horizontal and vertical deflections.

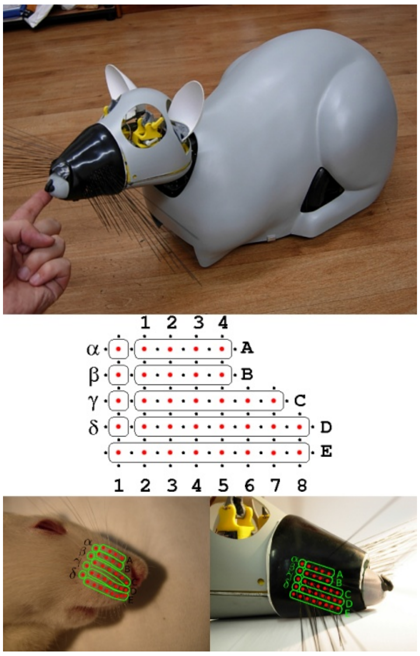

Fig. 3. Picture of Psikharpax (top). Arc/row implementation of the sensor array. Black dots are voltage probes and red dots are whiskers (middle). Comparison of the whisker implementations in a real rat and in Psikharpax (bottom).

Table 1. Lengths (millimeters) of the vibrissae in the 3 first arcs of a whisker pad, as measured on a natural rat and on Psikharpax (scale 4)

Vibrissa	Natural rat	Psikharpax
α	39	156
β	29	116
γ	58	232
δ	42	168
A1	47	188
B1	34	136
C1	26	104
D1	35	140
E1	36	144
A2	34	136
B2	24	96
C2	37	148
D2	35	140
E2	38	152
A3	24	96
B3	26	104
C3	28	112
D3	28	112
E3	28	112

Experimental setup

To demonstrate the capacity of the whisker system just described to discriminate textures, we used a test bench made of a PVC cylinder on which different textures where glued (cf. Figure 4). A voltage-controlled DC motor drove the cylinder and a Hall effect sensor with a small magnet allowed to control the cylinder's speed. Four different textures - i.e., grit 100 sandpaper, grit 60 sandpaper, 7mm metal square mesh and 2cm cardboard strip - were intentionally chosen to belong to 2 very different groups of 2 quite similar textures. A set of whiskers was maintained in contact with a given texture while it turned, and the corresponding induced vibrations were logged and post processed.

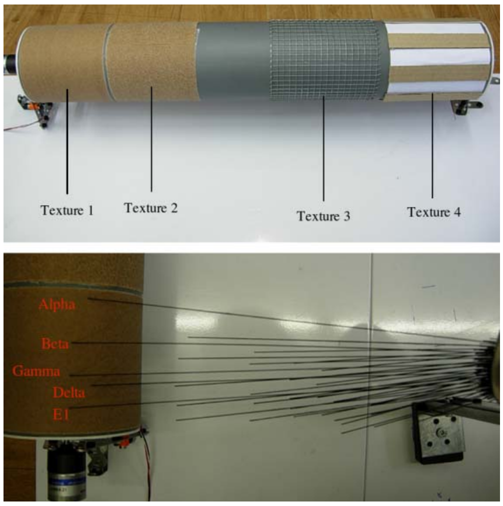

Fig. 4. Texture test bench. Texture 1 is P100 sandpaper, texture 2 is P60 sandpaper, texture 3 is 7 mm metal square mesh and texture 4 is 2 cm cardboard strip (top). 5 vibrissae in contact with the test bench (bottom).

Only the 5 first vibrissae of arc 1 were used, i.e., α, β, γ, δ and E1 (cf. Figure 4). The rotation speed of the cylinder was maintained constant, allowing the point of contact of a vibrissa with the texture to move at 0.12 m/s. 100 measures of 3s were logged for each vibrissa on each texture.

Data analysis

Because this experiment didn't exploit any information on whisker orientation, x and y measures were normed ($\sqrt{x^2 + y^2}$) in order to consider the absolute deflection only. Data analysis was performed in the frequency domain because such approach already proved to be efficient for texture discrimination [5]. More specifically, considering phase information as negligible, we computed the power spectral density (PSD) of each measured signal - which describes its power distribution among frequencies - according to the Welch average periodogram method [15].

We then performed a principal component analysis (PCA) on the input matrix of dimensions M x N, N being the number of data and M the number of frequencies: N=100 (measures) x 5 (vibrissae) x 4 (textures); M = 129 (frequencies).

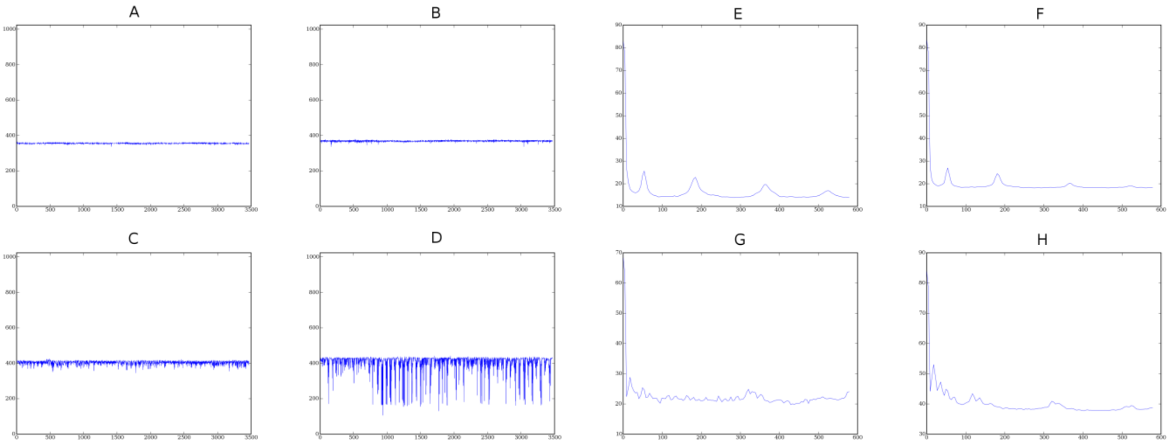

Fig. 5. Typical results obtained for each texture with vibrissa δ (left). A=texture 1, B=texture 2, C=texture 3, D=texture 4. Corresponding PSD (right) averaged over 100 measures. E=texture 1, F=texture 2, G=texture 3, H=texture 4.

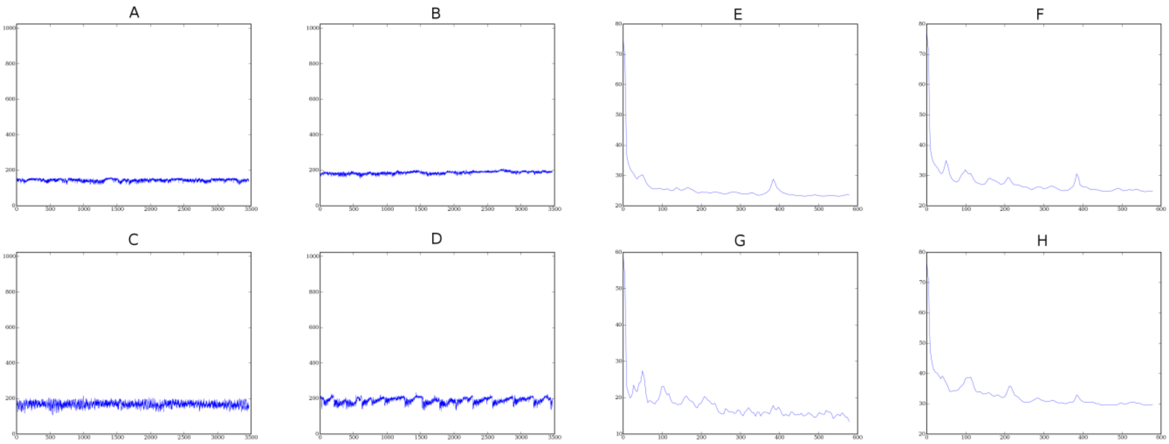

Fig. 6. Typical results obtained for each texture with vibrissa γ (left). A=texture 1, B=texture 2, C=texture 3, D=texture 4. Corresponding PSD (right) averaged over 100 measures. E=texture 1, F=texture 2, G=texture 3, H=texture 4.

Discussion

It may be deduced from the preceding results that a single whisker may successfully discriminate some textures. In particular, it has been shown that even the very low amplitude signals generated by textures 1 and 2 (P100 and P60 sandpapers) can be discriminated using the PSD representation.

However, the disparity of the results thus obtained strongly suggests that the strength and robustness of the whole system lie in the complementary nature of the information brought by each individual whisker. It may be noticed, for example, that δ and γ are adjacent whiskers whose orientation angles with respect to any texture they touch are very similar (this can be seen in Figure 4). In fact, the most evident difference between δ and γ is their size (cf. Table 1). Such difference in sizes implies a difference in self-resonant frequencies, which were measured to be 13Hz for δ and 18Hz for γ. Therefore, one explanation of the observed difference between the PSD of these two vibrissae may be that this mechanical characteristic produces a kind of filtering of the induced vibrations and somehow generates different PSD. This filtering behavior may amplify small differences between textures and using together a wide range of vibrissae sizes might enhance texture discrimination.

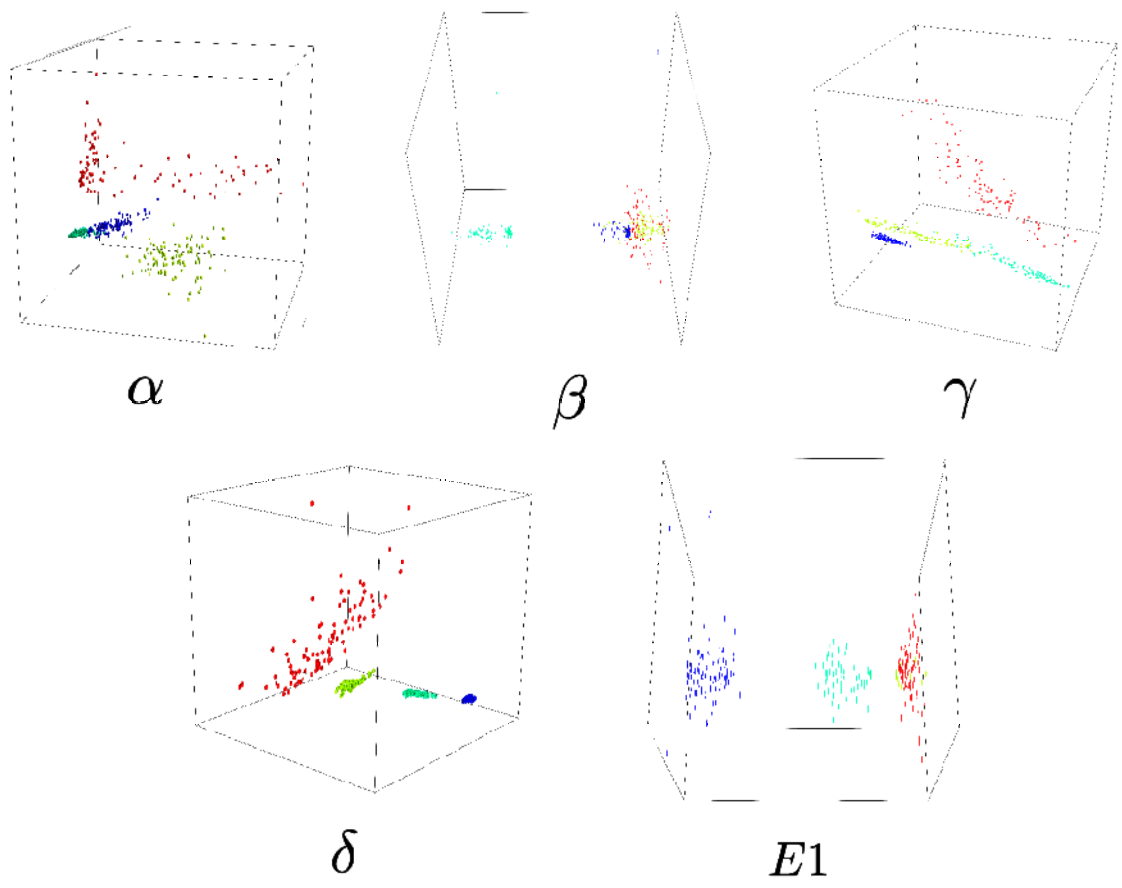

Fig. 7. PCA results projected in the 3 principal dimensions for each of the five vibrissae. Red: Texture 1, Yellow: Texture 2, Blue: Texture 3, Cyan: Texture 4.

Experiments aiming at demonstrating such complementary effects are currently underway.

Conclusion

An elastomer-based whisker system implemented in the artificial rat Psikharpax has been described. It has been shown that each individual whisker exhibits some capacities for texture discrimination and it has been suggested that these capacities complement each other, possibly exploiting differences in induced self resonant frequencies. Future experiment will call upon its whole whisker pad to assess Psikharpax's capacity to discriminate textures and recognize objects.

References

[1] Brecht, M., Preilowski, B., & Merzenich, M. (1997). Functional architecture of the mystacial vibrissae. Behavioural Brain Research, 84(1-2), 81-97.

[2] Brooks, R. A.(1989). A robot that walks: Emergent behaviors from a carefully evolved network (Tech. Rep. No. AI MEMO 1091). MIT.

[3] Carvell, G., & Simons, D. (1990). Biometric analyses of vibrissal tactile discimination in the rat. Journal of Neuroscience, 10(8), 2638-2648.

[4] Chapman, T., Hayes, A., & Tilden, T. (2000). Reactive maze solving with a biologically-inspired wind sensor. In J.A. Meyer, A. Berthoz, H. Roitblat, & S. Wilson (Eds.), From animals to animats 6. Proc. of the 6th int. conf. on simulation of adaptive behavior (p. 81-87). MA: MIT PRESS. A Bradford Book.

[5] Fend, M., Bovet, S., Yokoi, H., & Pfeifer, R. (2003). An active artificial whisker array for texture discrimination. In Proceedings of the IEEE/RSJ international conference on intelligent robots and systems (IROS) (Vol. II, p. 1044-1049).

[6] Fox, C. W., Mitchinson, B., Pearson, M. J., Pipe, A. G., & Prescott, T. J.(in press). Contact type dependency of texture classification in a whiskered mobile robot. Autonomous Robots.

[7] Guic-Robles, E., Valdivieso, C., & Guarjardo, G. (1989). Rats can learn a roughness discrimination using only their vibrissal system. Behavioural Brain Research, 31(3), 285-289.

[8] Hartmann, M. J. (2001). Active sensing capabilities of the rat whisker system. Autonomous Robots, 11, 249-254.

[9] Kim, R., D. and Moller. (2004). A biomimetic whisker for texture discrimination and distance estimation. In S. Schall, A. Ijspeert, A. Billard, S. Vijayakumar, J. Hallam, & J. A. Meyer (Eds.). From Animals to Animats 8. Proc. of the 8th int. conf. on simulation of adaptive behavior (p. 140-149). MA: MIT PRESS. A Bradford Book.

[10] Krupa, D. J., Matell, M. S., Brisben, A. J., Oliviera, L. M., & Nicolelis, M. A. L.(2001). Behavioural properties of the trigeminal somatosensory system in rats performing whisker-dependent tactile discrimination. J. Neurosci.(21), 5752-5763.

[11] Lungarella, M., Hafner, V., Pfeifer, R., & Yokoi, H. (2002). Artificial whisker sensors in robotics. Intelligent Robots and System, 2002. IEEE/RSJ International Conference on, 3, 2931- 2936.

[12] Meyer, J.-A., Guillot, A., Girard, B., Khamassi, M., Pirim, P., & Berthoz, A. (2005). The Psikharpax project: Towards building an artificial rat. Robotics and Autonomous Systems, 50(4), 211–223.

[13] Russell, R. A. (1985). Object recognition using articulated whisker probes. In Proc. 15th int. symp. industr. robots. (p. 605-612).

[14] Seth, A. K., McKinstry, J. L., Edelman, G. M., & Krichmar, J. L. (2004). Spatiotemporal processing of whisker input supports texture discrimination by a brain-based device. In S. Schall, A. Ijspeert, A. Billard, S. Vijayakumar, J. Hallam, & J. A. Meyer (Eds.), From animals to animats 8. Proc. of the 8th int. conf. on simulation of adaptive behavior (p. 130-139). MA: MIT PRESS. A Bradford Book.

[15] Welch, P. (1967). The use of Fast Fourier Transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms. Audio and Electroacoustics, IEEE Transactions on, 15(2), 70-73.