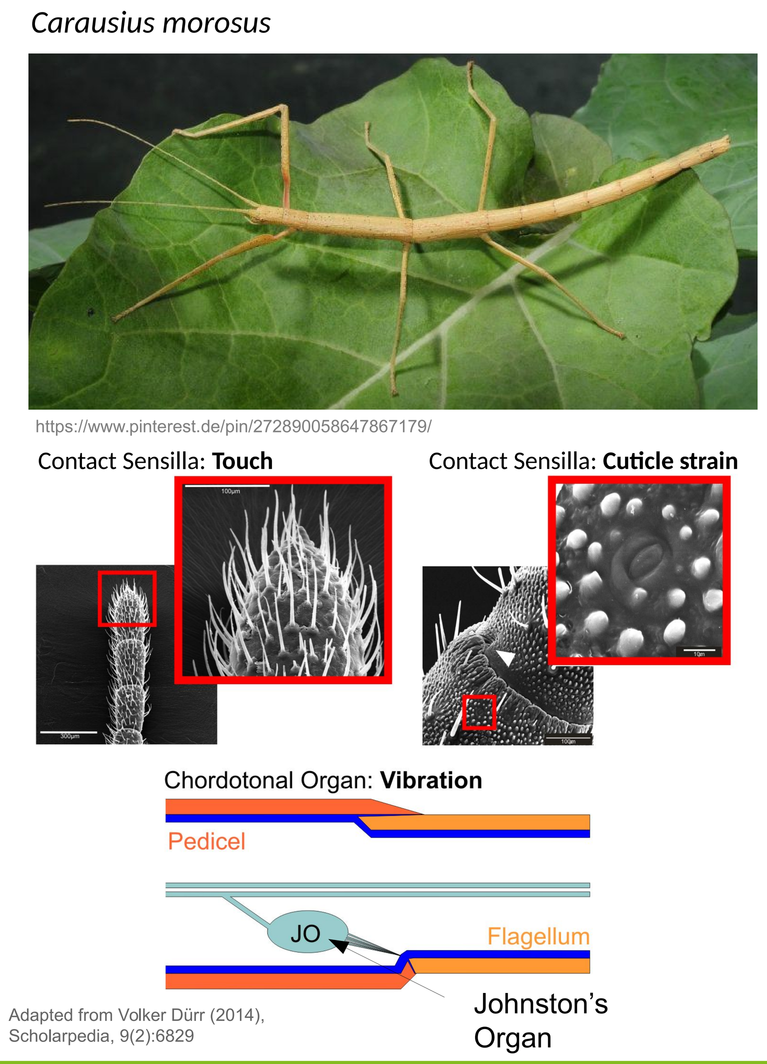
Universität Bielefeld
Department of Biological Cybernetics
CITEC

Toward a biomimetic Johnston's organ for touch localization

Luca Hermes, Volker Dürr and Thierry Hoinville
thierry.hoinville@uni-bielefeld.de

Introduction

Most insects use a pair of antennae to sense their near-range environment. For example, blindfolded stick insects climb obstacles by finding footholds for their front legs using their antennae [1]. Different types of mechano-receptors present on each antenna may contribute to contact localization. One of these receptors – Johnston's organ – might respond to contact-induced vibrations [2]. Prior approaches to construct biomimetic antennae have shown that vibration characteristics can be exploited to estimate the position of a contact along the antenna, the material and texture properties of the obstacle [3,4,5]. For distance estimation, only low-frequency high-amplitude components have been exploited. Besides increasing latency due to the lasting data segments required [4], maintaining extended contact phases in realistic robot scenarios appear not practical [5]. Here, we systematically evaluate which frequency bands result in best distance estimation.



Data acquisition

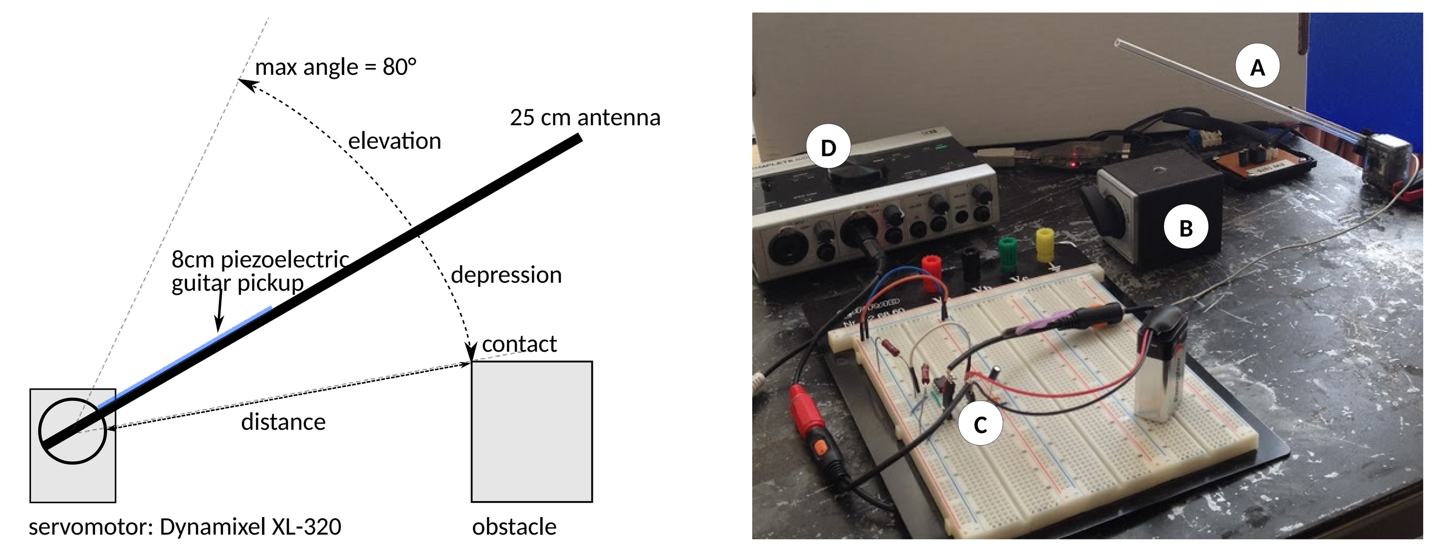
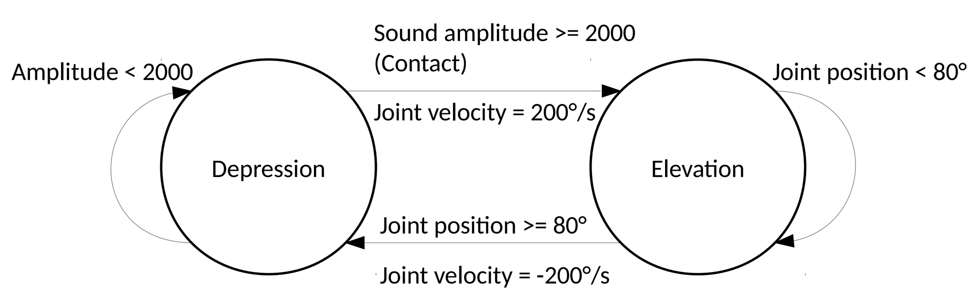


Figure 1: Experimental setup. **A.** Antenna **B.** Obstacle **C.** Voltage buffer (11 MΩ input impedance) **D.** Audio Interface (Native Instruments Komplete Audio 6)

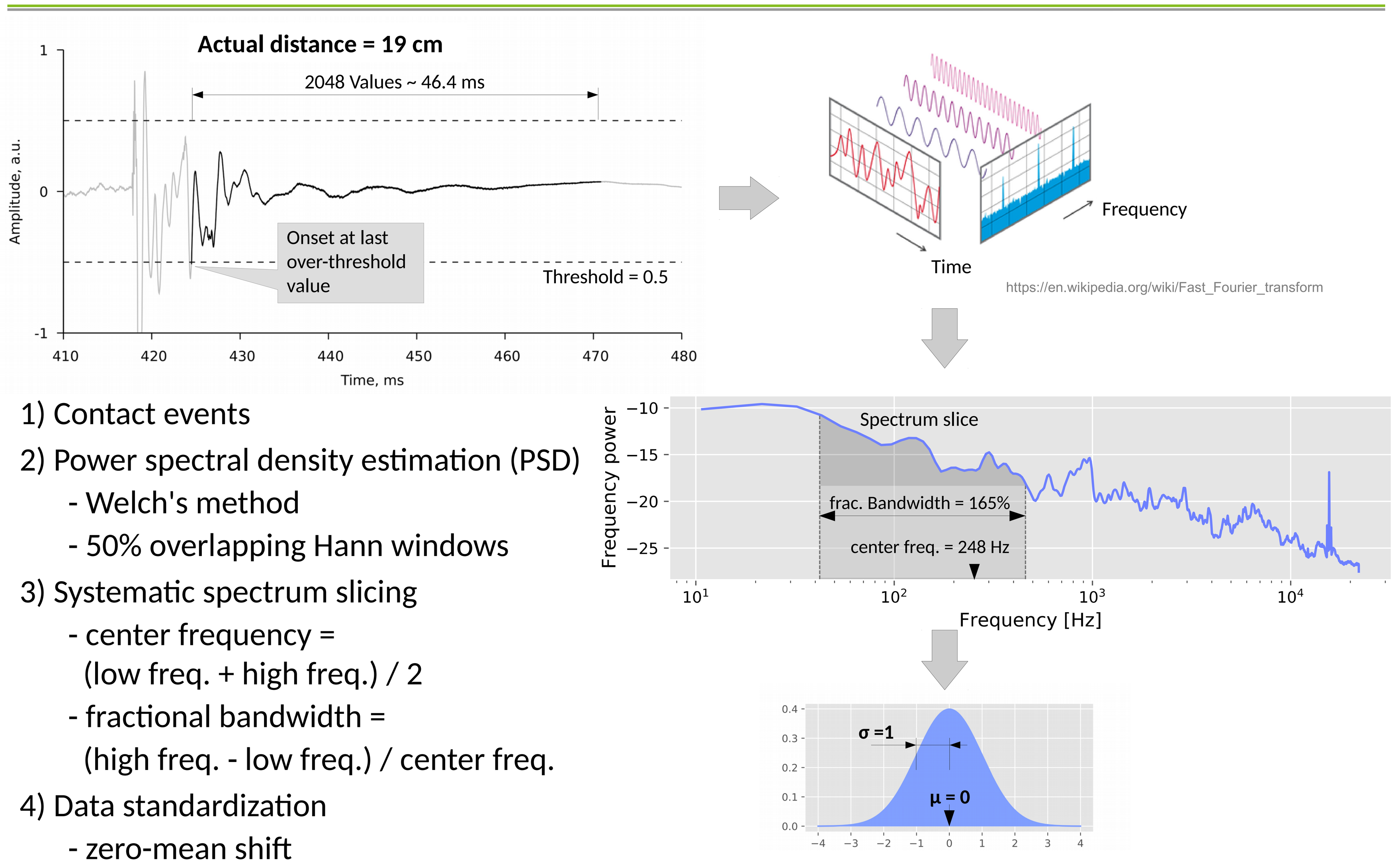
Dataset parameters

Contact distances	5, 7, 9, .., 23 cm
Contacts per distance	50
Sample rate	44100 Hz
Sample format	16 bit integer

Finite-state machine controller



Data processing

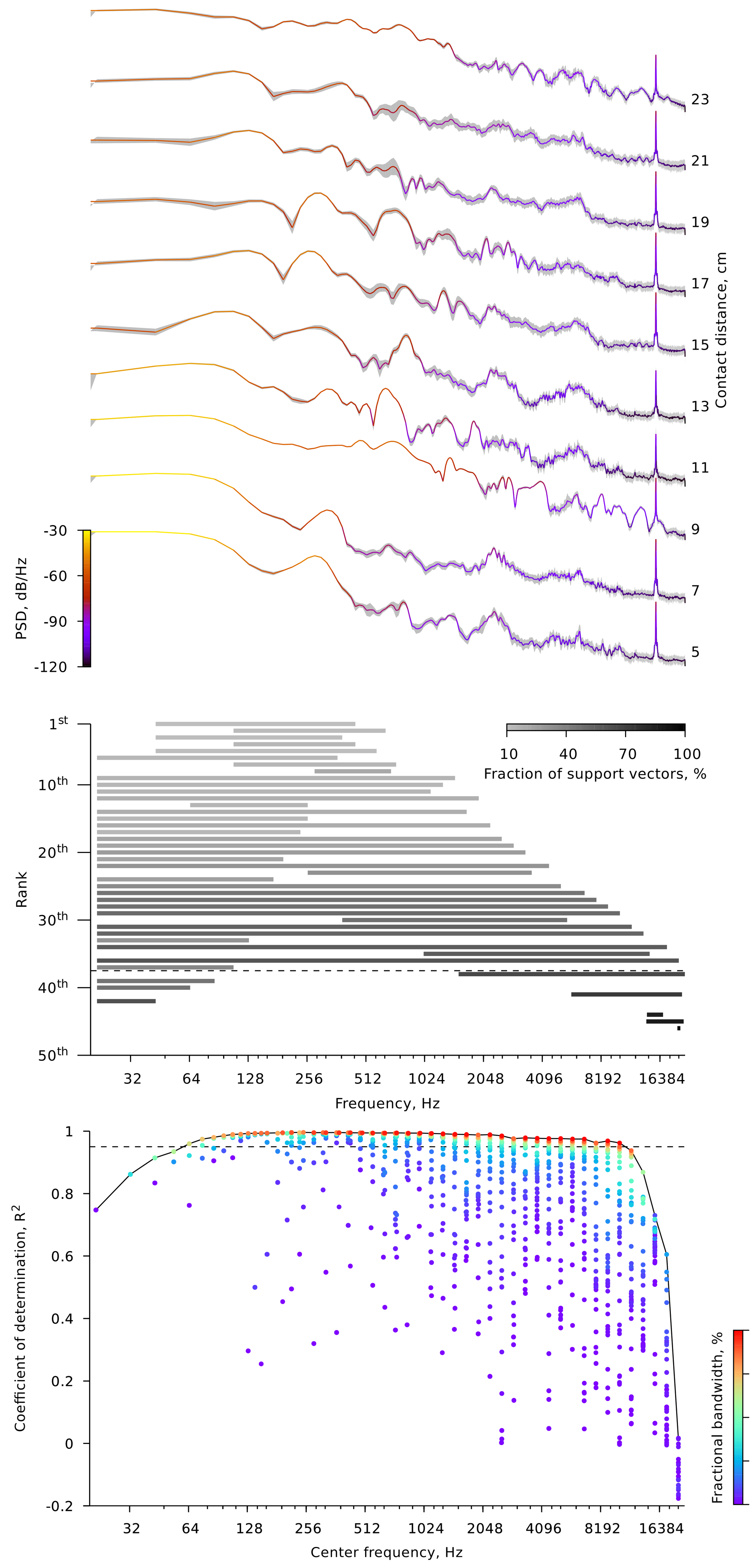


1) Contact events
2) Power spectral density estimation (PSD)
   - Welch's method
   - 50% overlapping Hann windows
3) Systematic spectrum slicing
   - center frequency = (low freq. + high freq.) / 2
   - fractional bandwidth = (high freq. - low freq.) / center freq.
4) Data standardization
   - zero-mean shift
   - unit-variance scaling
5) Support vector regression (SVR)
   - training: 35 spectra per distance (70 % dataset)
   - testing: 15 spectra per distance (30 % dataset)
   - error margin, ε = 0.5 cm
   - penalty, C = 10
   - RBF kernel with γ = 1 / spectrum length

SVR

Predicted distance = 18.7 cm

Results



Power spectra

- Consistent profile per distance
- Distance-dependent spectral changes:
  - < 640 Hz smooth transitions
  - 640 – 5000 Hz rough transitions
  - > 5000 Hz similar low-power plateaus
  - ~16 kHz peak at sensor's resonance frequency

Best frequency bands for prediction

- Best of all: 43 – 452 Hz (R^2 = 0.996)
- 8 best bands below 640 Hz
- Only 4 out of 9 bands > 200 Hz with R^2 > 0.95
- Few wide bands, all starting at 20 Hz

Performance of each frequency band

- High scores (R^2 > 0.95) mostly for fractional bandwidth > 100%, i.e. narrow bands within low frequencies to wide bands within higher frequencies
- Performance drops in the upper half of the frequency range (center frequency > 10 kHz)

Figure 2: *Top*: Mean contact periodogram for each contact distance (N = 50). Shaded area, standard deviation; PSD, power spectral density. *Middle*: Best-prediction frequency bands (sorted in descending R^2-order). Bands above the dashed line correspond to R^2 > 0.95. *Bottom*: Prediction performance of support vector regression for periodograms of systematically varied frequency bands. Solid line, best-prediction frequency bands (cf. Middle panel) over varying center frequency; dashed line, R^2 = 0.95.

Performance of the best band (43-452 Hz)

- Average errors < 0.5 cm
- Estimate spread < 0.5 cm (except at 13 cm)
- Distances < 10 cm higher precision, lower accuracy
- Distances > 10 cm lower precision, higher accuracy

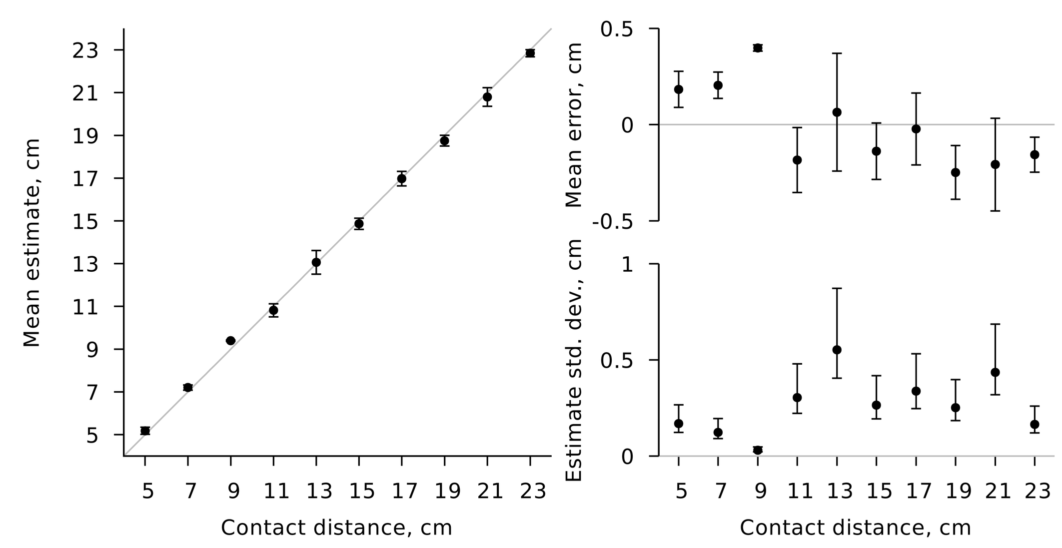


Figure 3: Prediction (left), accuracy (upper right), and precision (lower right) versus contact distance for the highest-score frequency band, 43–452 Hz (R^2 = 0.996). Error bars, estimate standard deviation (left) and 95% confidence intervals (right); grey lines, ideal values.

Conclusion and Discussion

- Contact distance can be estimated from various frequency bands, including relatively high-frequency ones.
- Power level also varies with contact distance, this would be exploited by any regression method
- In realistic scenarios, power level may vary with other unpredictable factors like antennal and/or obstacle speed
- How does our method generalize when antennal speed is varied?

[1] Schütz, C., Dürr, V. (2011). Active tactile exploration for adaptive locomotion in the stick insect. Proc. R. Soc. Lond. B 366 (1581):2996-3005.
[2] Staudacher, E; Gebhardt, M J and Dürr, V (2005). Antennal movements and mechanoreception: Neurobiology of active tactile sensors. Advances in Insect Physiology 32: 49-205.
[3] Kim DE, Möller R (2004) A biomimetic whisker for texture discrimination and distance estimation. From animals to animats, 8, 140-149.
[4] Hoinville, Harischandra, Krause & Dürr (2014). Insect-inspired tactile contour sampling using vibration-based robotic antennae. Living Machines 2014, 118-129.
[5] Ueno, Svinin & Kaneko (1998). Dynamic contact sensing by flexible beam. IEEE/ASME Transactions on Mechatronics, 3(4), 254-264.