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Toward a biomimetic Johnston’s organ for touch localization

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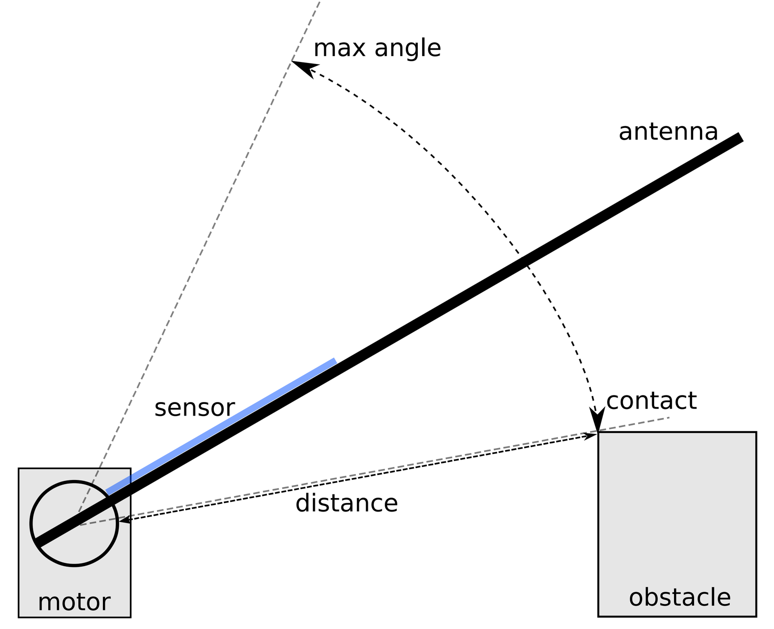
Introduction

Most insects utilize a pair of antennae to sense their near-range environment. When blindfolded these insects are still capable of climbing obstacles and finding footholds for their front legs using their antennae [Dürr01]. Different types of mechanoreceptors present in each antenna, are involved to perform this kind of orientation. One of these receptors - the Johnston's organ - is correlated to the sensing of antennal vibrations [JC96]. As vibrations are characterized by their amplitude, frequency and phase, all further information about the origin of the vibration is encoded in these properties. This includes forces applied to the antenna on movement or on a contact with another object. Prior approaches to construct a biomimetic antenna have proven, that vibration characteristics can be exploited to estimate a position of a contact on the antenna or material properties and texture of any touched object [KM04]. Depending on the sensor, a broad range of frequencies can be used but in order to minimise latency, higher frequency bands are preferable. Hereinafter we present our artificial biomimetic antenna that mimics the function of the Johnston’s organ for touch localization.

Experimental setup



Experimental Setup

- Polyacrylic tube as the antenna
- Piezoelectric sensor to pickup vibrations
- Servo-motor *Dynamixel XL-320* to drive the antenna up and down
- Metal socket as the obstacle
- Unit gain voltage buffer circuit for high impedance to low impedance conversion
- Signal gets recorded (at 44kHz) and stored

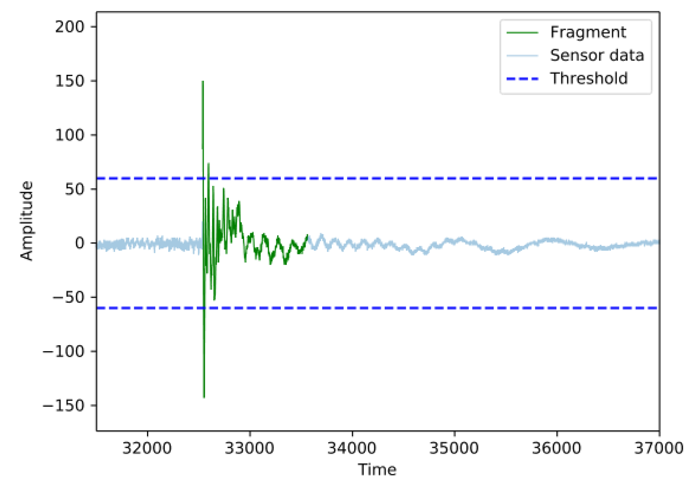
Antenna operation

Two-Phase-Oscillator:

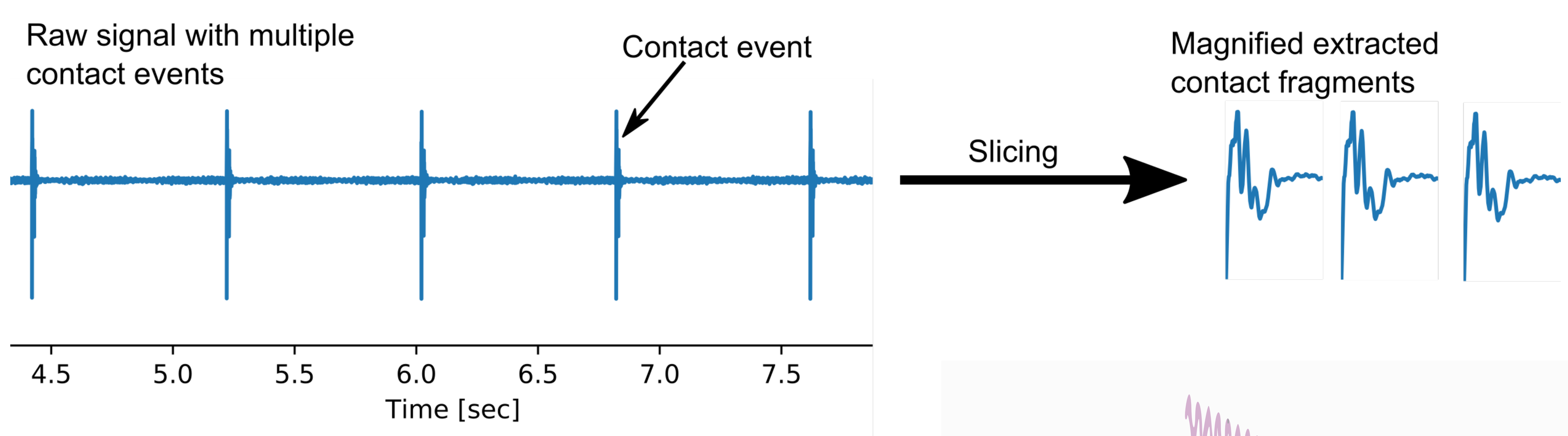
I. Antenna is going down to induce a contact
II. On contact occurrence, the phase is changed to upward movement
III. When the motor reaches a maximum angle the phase is inverted and the steps are repeated
IV. When a predefined number of contacts got detected the oscillator stops

Contact detection

- The incoming signal gets monitored
- On transgression of a static threshold value, a contact is detected.
- Contact recognition is deactivated for a short time after each detection to avoid counting rebounces

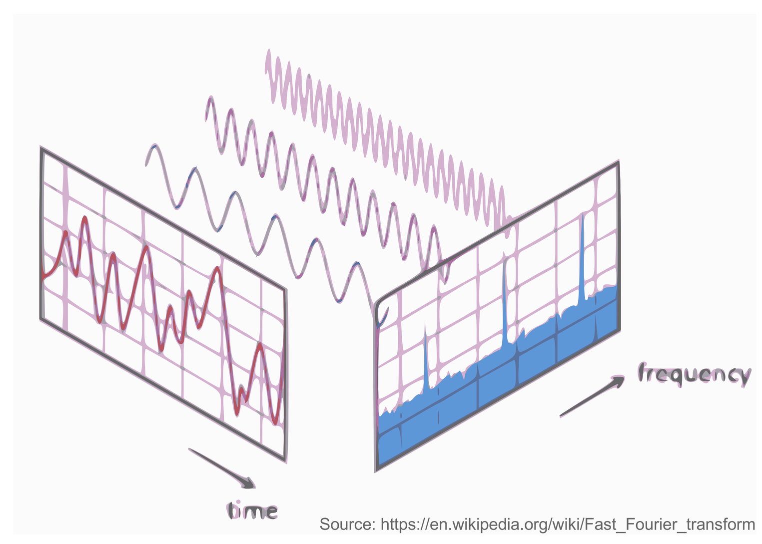


Analytical methods



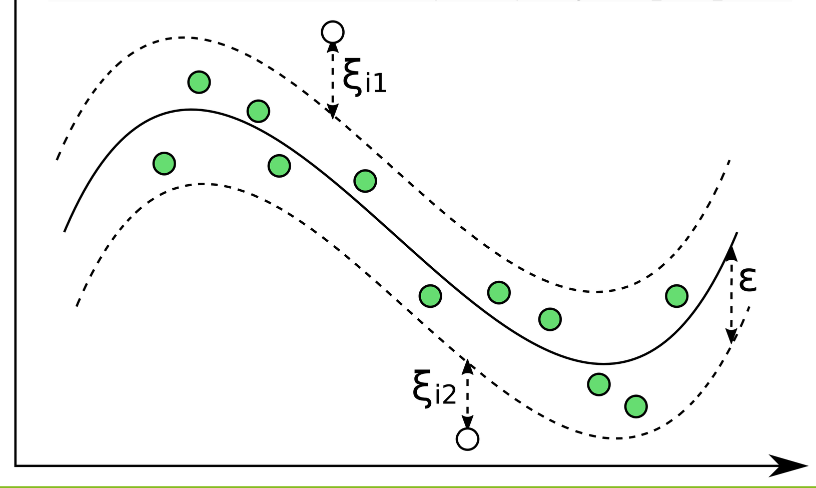
Power spectral density calculation (Welch's method)

- Applied on every extracted region
- Returns spectrum of frequency powers
- Resolution depends on sampling rate of the input signal

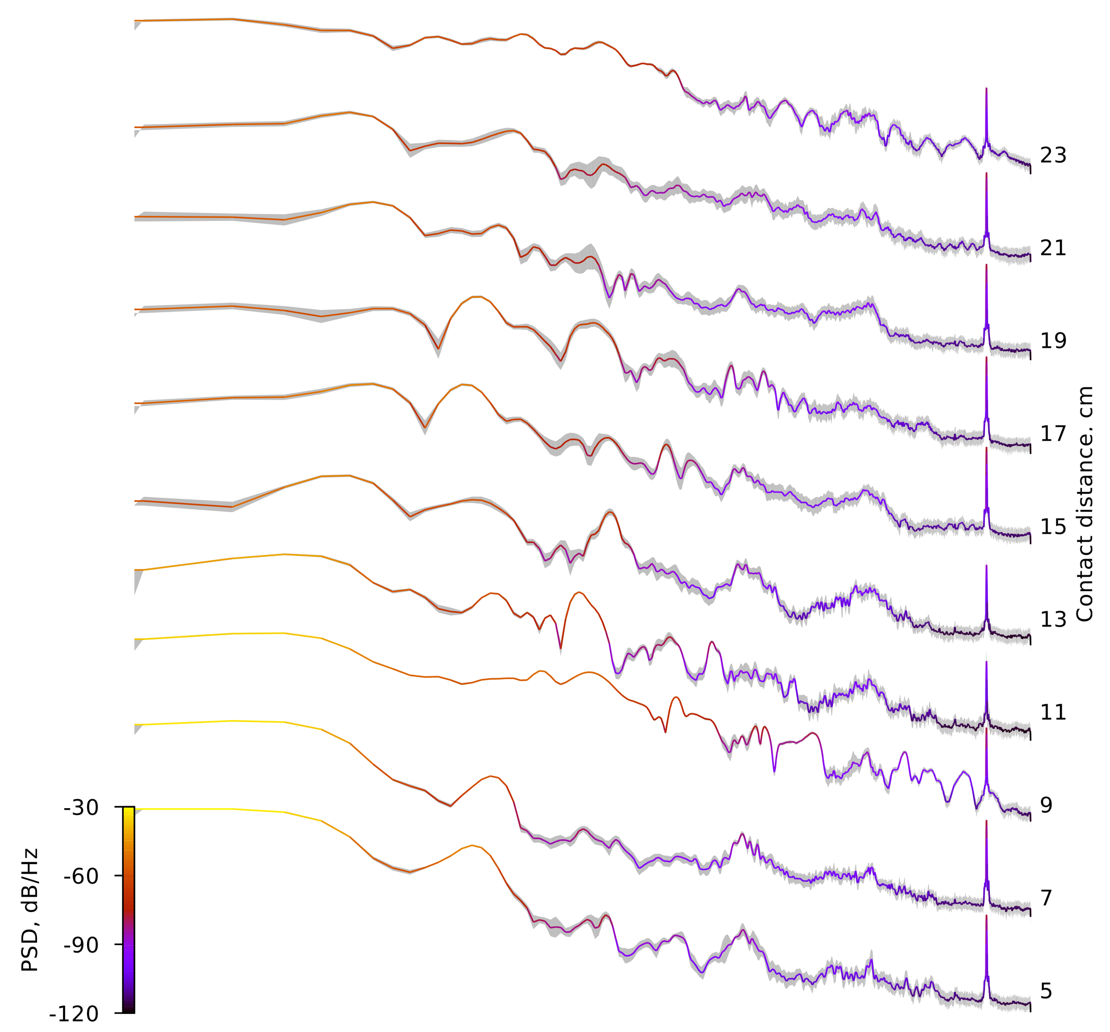


Support vector regression (SVR)

- machine learning approach for regression
- Input: Region of frequency spectrum
- Output: Distance in cm
- finds ε-hypertube minimizing the loss function
- Different regions were taken for training and testing the model



Results

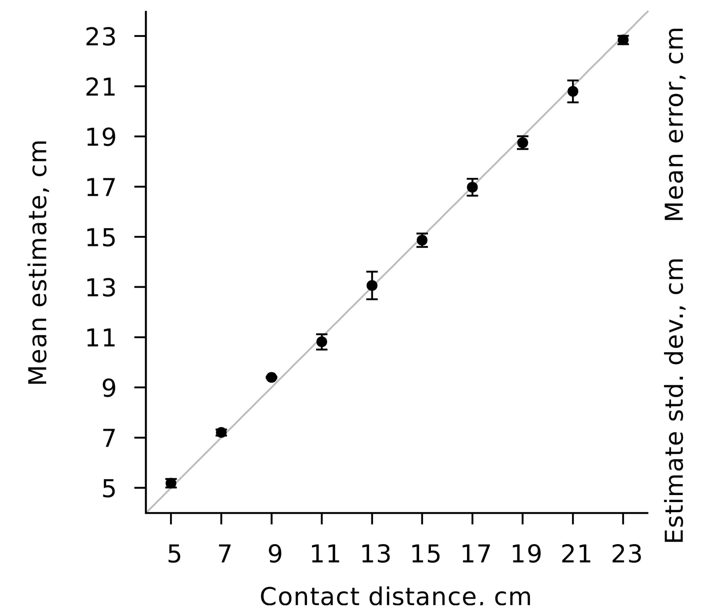


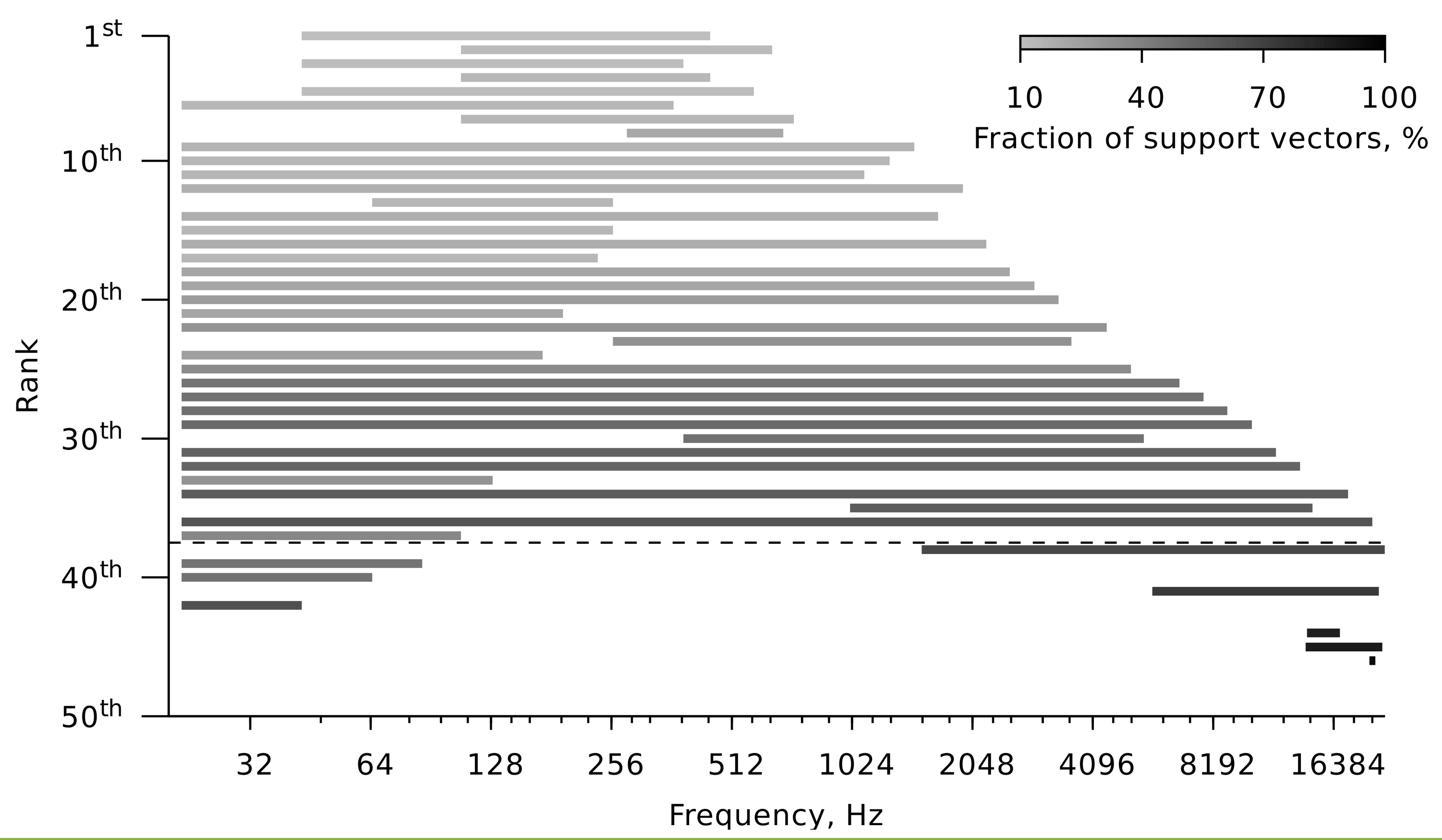
Power density spectra

- Mean spectra from 50 contacts per distance
- Consistent shape per distance
- Different in between distances
  → Distribution of frequency power depends on the contact position on the antenna
- Suitable input for the SVR
  → dependency alread visible

Support vector regression

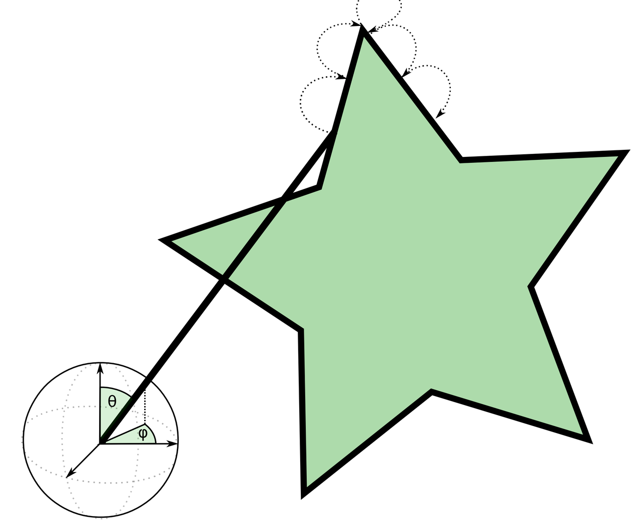
- Prediction error is below 0.5 cm
- precision ~ 98%
- Consistent predictions
- Different regions were taken for training and testing of the model
- Comparable results were obtained mainly in the frequency range of 40 – 10000 Hz





Conclusion

- Information about the position of contact on the antenna is encoded in the vibration frequencies
- A broad band of frequencies get influenced by a contact
- Mainly the lower part of the spectrum encodes exploitable distances information (up to ~ 10 kHz)
- Support vector regression results in precise predictions for the contact distance
- Even small frequency bands like 280 – 690 Hz are sufficient to get a score of > 99%
- More complex tasks are now possible i.e.
  - Contour sampling from antenna deflection angle + distance information
  - Material analysis
  - Orientation in complete darkness
- Much lower sampling rates are sufficient, so no professional interfaces and sensors are needed



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