

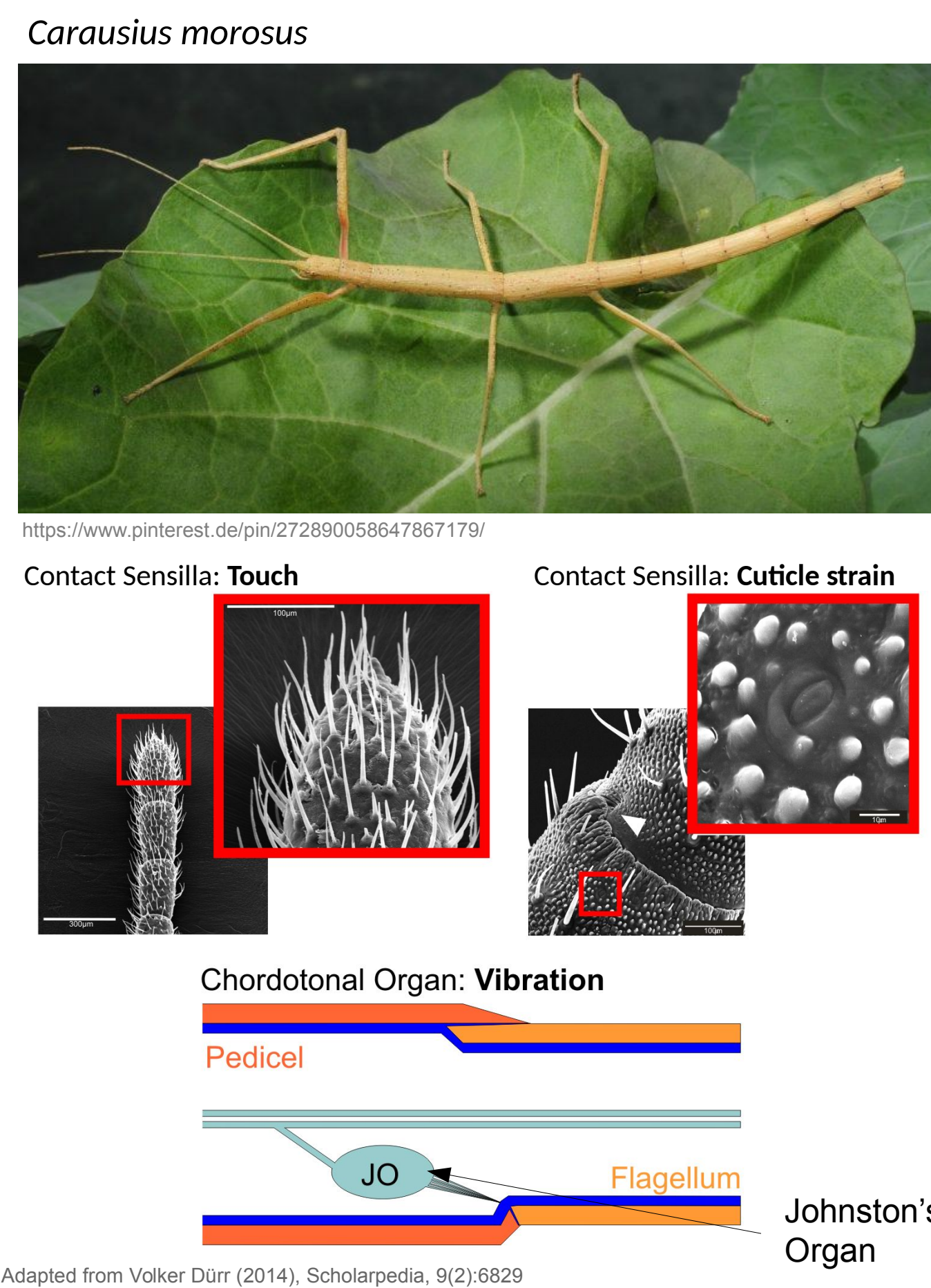
Toward a biomimetic Johnston's organ for touch localization

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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

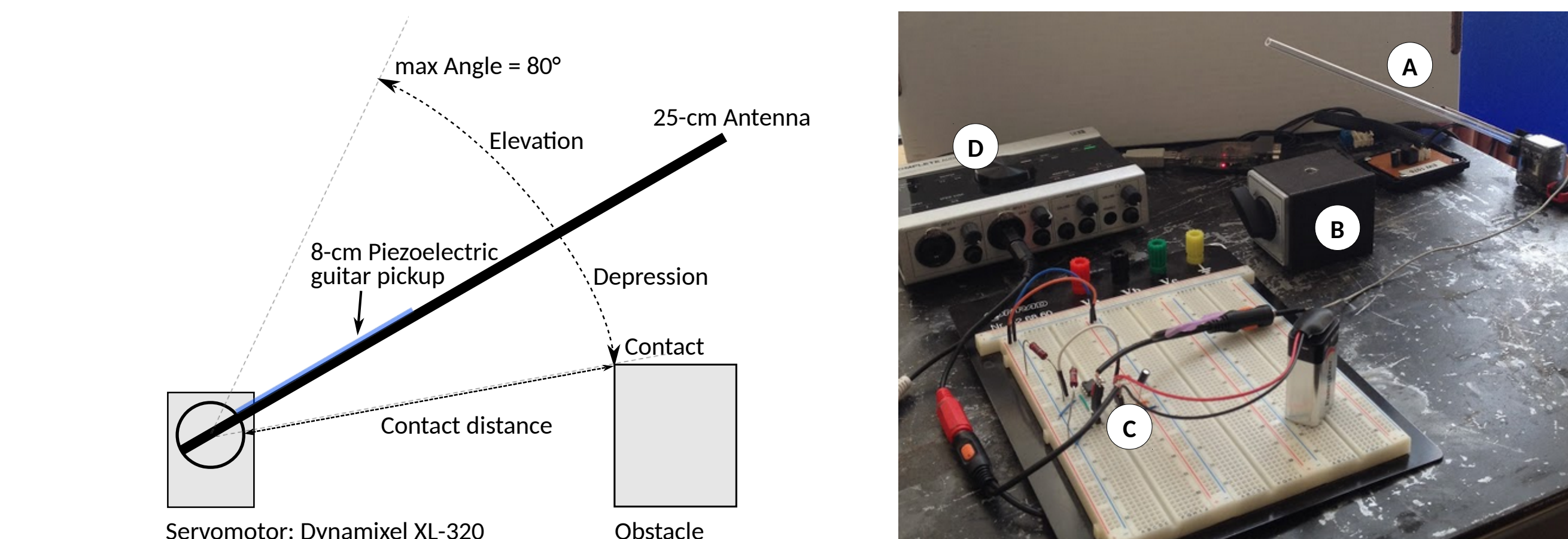
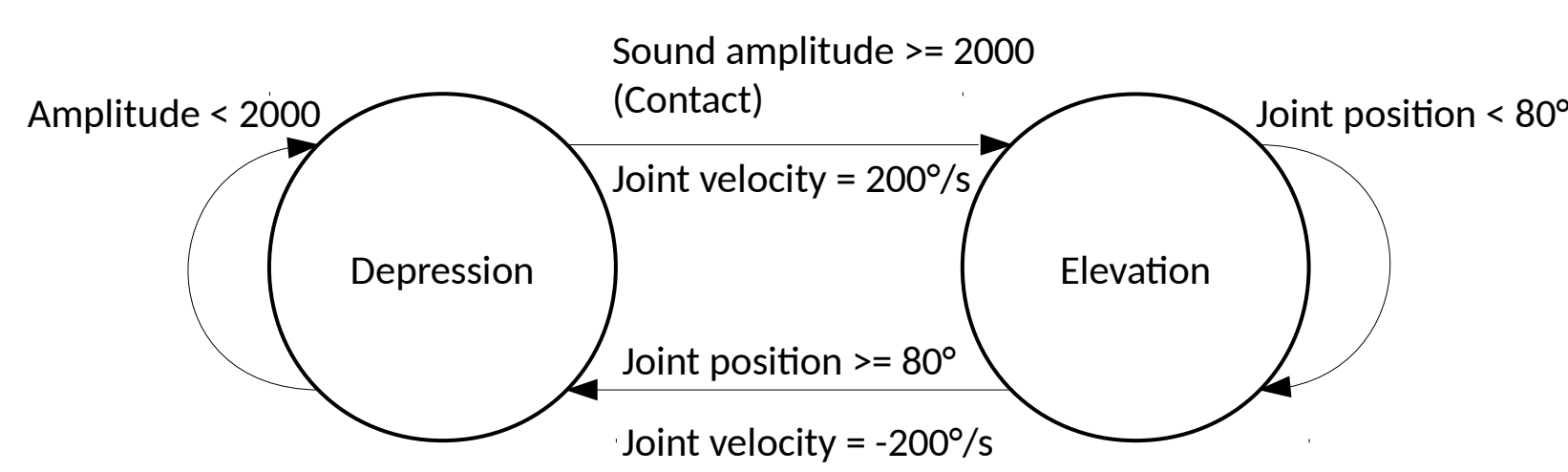


Figure 1: Experimental setup. (A) Antenna. (B) Obstacle. (C) Voltage buffer (11 MΩ input impedance). (D) Audio Interface (Native Instruments Komplete Audio 6).

Dataset parameters

Contact distances	5, 7, 9, ..., 23 cm (N = 10)
Contacts per distance	n = 50
Sample rate	44100 Hz
Sample resolution	16 bits

Finite-state machine controller



Results

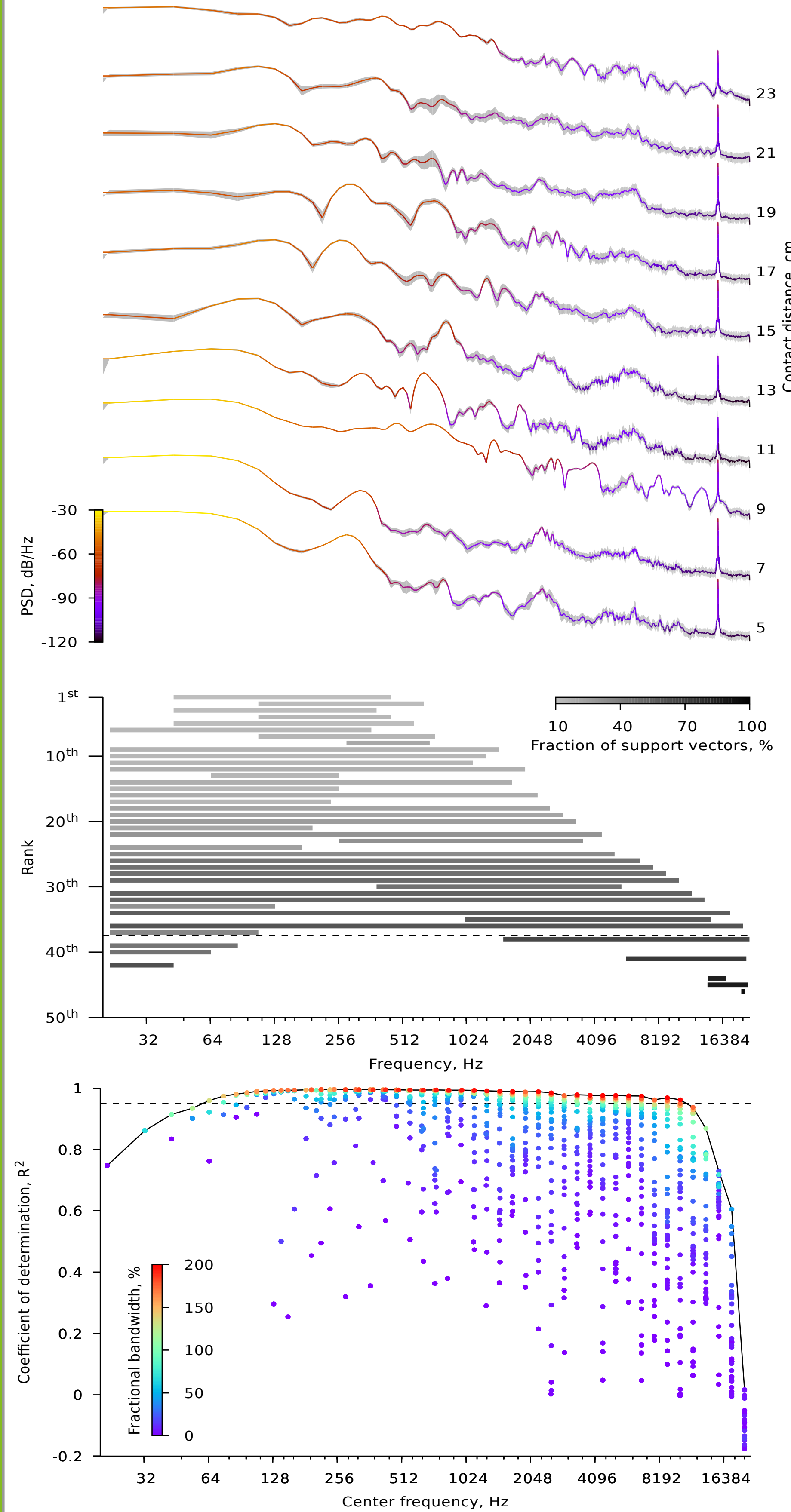


Figure 2: (Top) Mean contact periodogram for each contact distance (n = 50). Shaded area, standard deviation; PSD, power spectral density. (Middle) Best-prediction frequency bands (sorted in descending R²-order). Bands above the dashed line correspond to R² > 0.95. (Bottom) Prediction performance of support vector regression for periodograms of systematically varied frequency bands. Solid line, best-prediction frequency bands (see middle) over varying center frequency; dashed line, R² = 0.95.

Power spectra

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

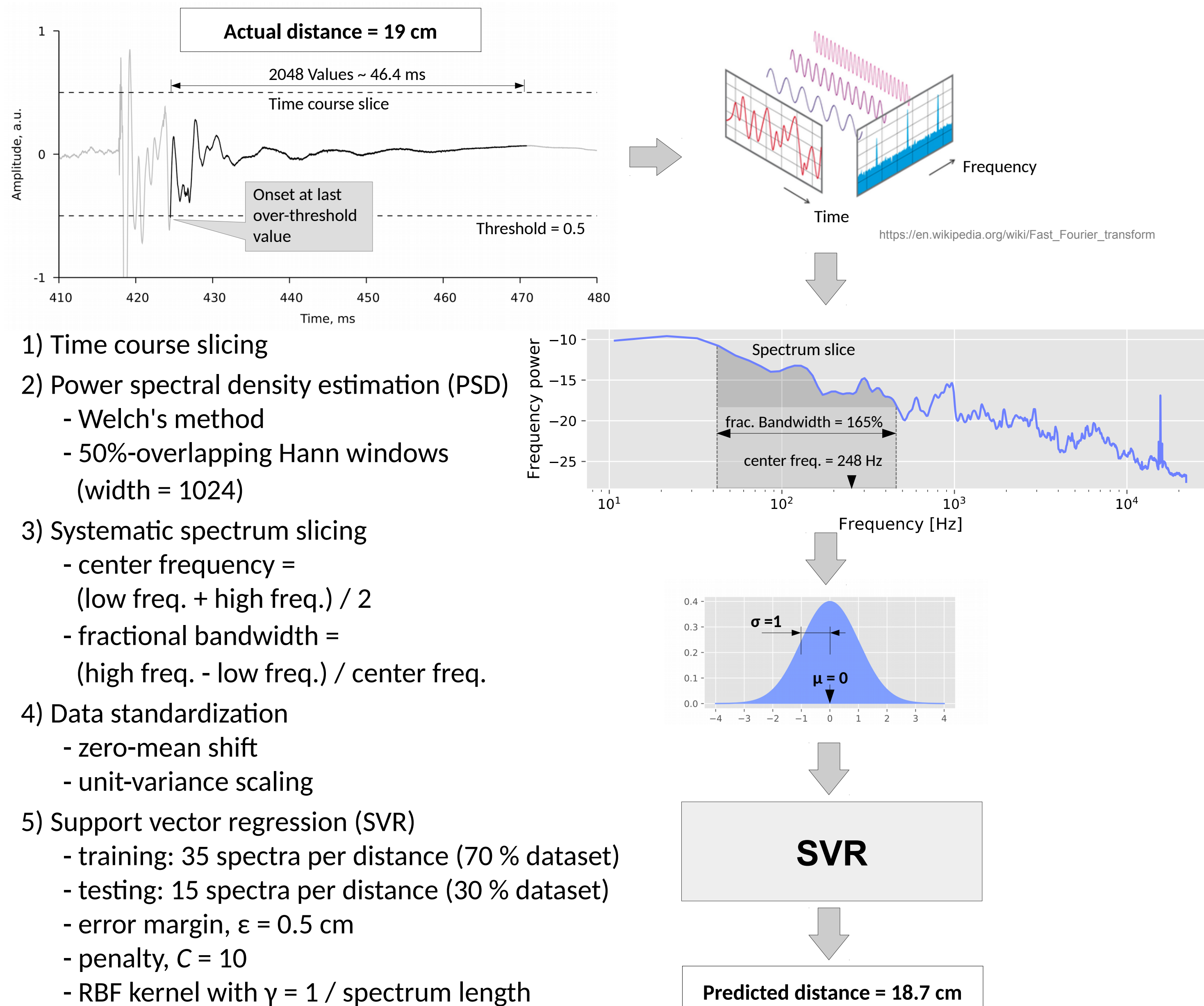
Best frequency bands for prediction

- Best of all: 43 – 452 Hz (R² = 0.996)
- 8 best bands below 640 Hz
- Only 4 out of 9 bands > 200 Hz with R² > 0.95
- Few wide bands, all starting at 20 Hz

Performance of each frequency band

- High scores (R² > 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)

Data processing



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

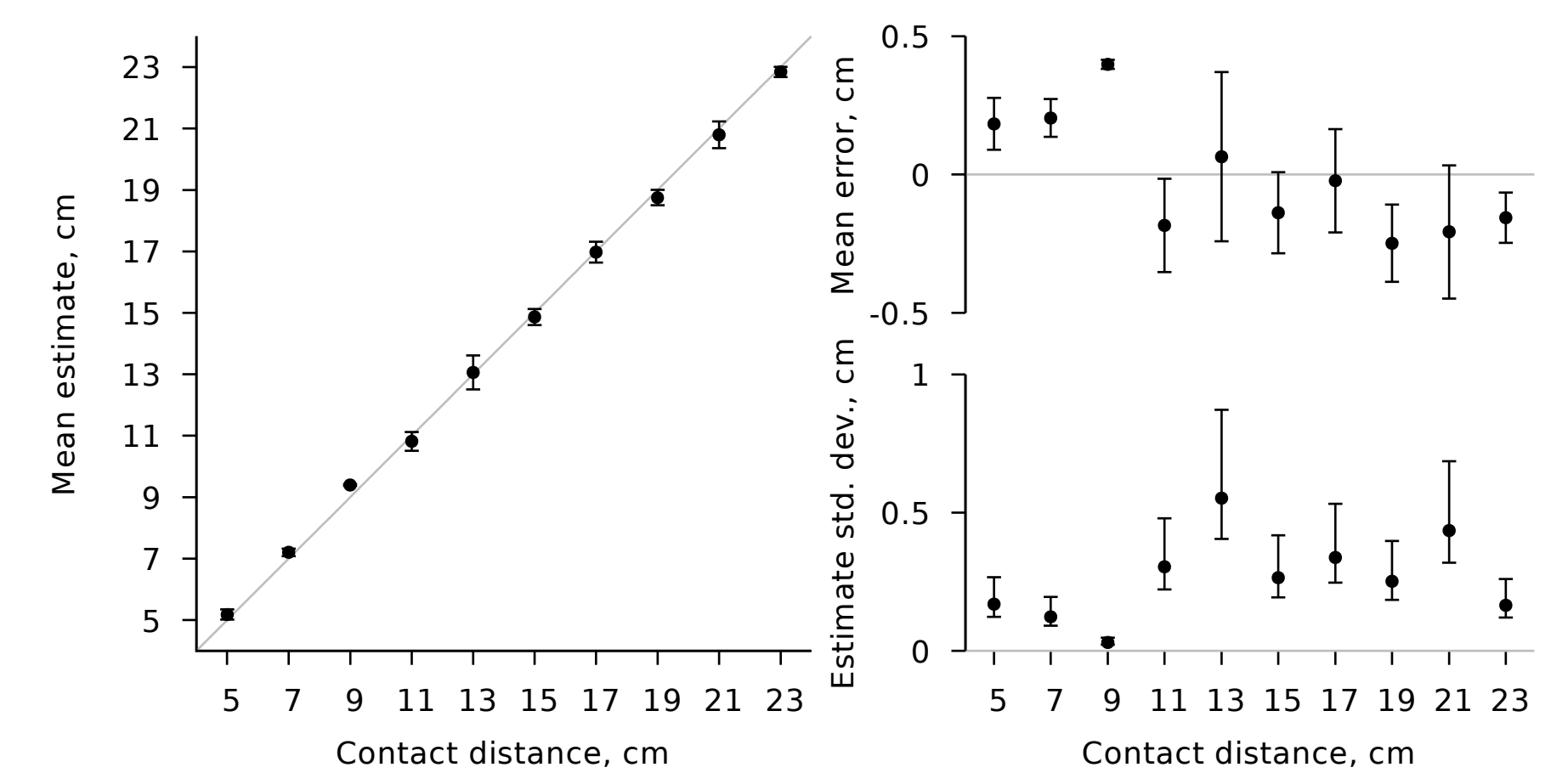


Figure 3: Prediction (left), accuracy (upper right), and precision (lower right) versus contact distance for the highest-score frequency band, 43-452 Hz (R² = 0.996). Error bars, estimate standard deviation (left) and 95% confidence intervals (right); grey lines, ideal values.

Conclusion and Discussion

- Contact distance can be estimated from various frequency bands, including relatively high 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.
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- [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.