Institute for Digital Communications

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Bachelor/Master Thesis, Research Project

Investigation of Insect Antennae as Receivers for Molecular Communication Systems

Background and Motivation: The insect antenna represents one of the most compelling natural sensing units for molecules, offering a unique experimental platform for the study of molecular communications (MC). MC describes the transmission of information via chemical molecules rather than electromagnetic waves and is considered to be one of the most promising paradigms for communication at the nano- and microscale and for interfacing with biological entities, with applications in biomedicine, nanorobotics, and synthetic biology [1].

Insects rely on volatile organic compounds (VOCs) for intra- and interspecies communication, where their antennae acts as a highly sensitive, selective biological receiver: Molecules in the environment (e.g., released by plants or other insects) bind to olfactory receptors in sensory neurons and elicit measurable electrical potentials [2, 3]. Moreover, insect antennae show strong analogies to conventional communication systems: phenomena such as inter-symbol interference (ISI) caused by residual molecules from previous signal pulses, habituation as a biological form of dynamic gain control, and cross-talk through competing molecules with similar structures in the environment [4, 5, 6]. Particularly interesting is the phenomenon of cross-habituation: adaptation to a background compound increases the relative selectivity of the antenna toward the target signal – a biological analogue to interference suppression in multi-user communication systems.

All these phenomena can be studied, e.g., by gas chromatography coupled with electroantennographic detection (GC-EAD), in which the receptor potential of a mounted insect antenna can be measured in response to individual compounds. This enables quantitative characterization of insect antennae and their analysis as biological receivers of MC systems [3, 7].

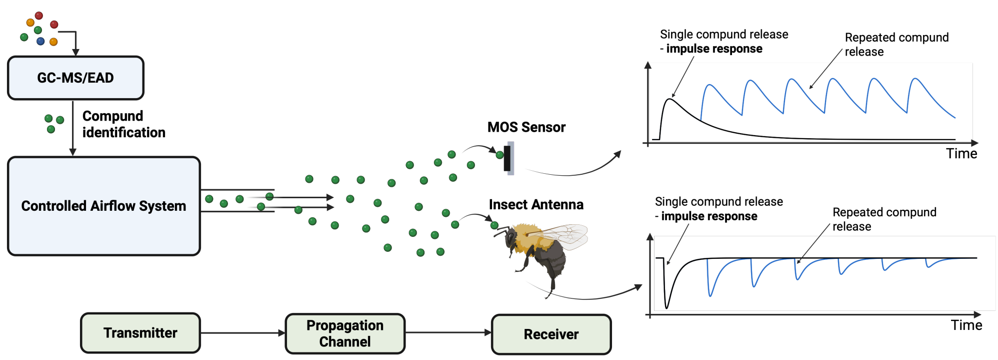

Figure 1: Experimental framework and measurement concept. Volatile compounds identified via GC-MS/EAD are released through a controlled airflow system toward two parallel receivers – a metal oxide semiconductor (MOS) sensor (as baseline) and an insect antenna. For each receiver, the channel impulse response (black) and the response to repeated compound release (blue) are shown, illustrating inter-symbol interference and, in the case of the insect antenna, habituation. The system can be mapped directly onto a conventional transmitter–channel–receiver communication system (bottom).

Project Overview: This project is carried out in close collaboration between the Chair of Plant-Insect Communication at the Technical University of Munich and the Institute for Digital Communications at FAU Erlangen-Nürnberg, combining experimental methods from chemical ecology with concepts from communications engineering.

In particular, the response of the antenna to defined doses of a single compound shall be measured and analyzed systematically under a controlled airflow system. Thus, the antenna is treated formally as an MC receiver whose response is obtained from the measurements and shall be compared to a first mathematical model. Building on this, sequences of concentration pulses shall be transmitted and analyzed to quantify how ISI degrades the received signal. The habituation kinetics (adaptation and recovery) of the antenna shall be characterized systematically. Optionally, the influence of a second interfering compound on the reception shall be investigated.

The overarching goal is to establish the insect antenna as a quantitatively describable MC system, to develop a simple physically motivated system model, and to demonstrate how biological adaptation mechanisms such as habituation can be interpreted as a natural form of signal processing and interference suppression.

Guidelines for the Project:

- **Measurement of the Channel Impulse Response**: Exposure of the mounted antenna to defined single-compound doses delivered via a controlled airflow system (flow-switching rather than puffs; a reference flow condition must be included). Recording of the receptor potential as a function of time. Derivation of the channel impulse response $h(t)$, characterizing the antenna as a linear (or nonlinear) MC receiver. Concentration and pulse duration are varied systematically. Moreover, if possible, a suitable MOS-sensor will be placed next to the insect antenna for an additional baseline measurement.
- **ISI Analysis**: Transmission of binary sequences (compound-loaded flow = 1, clean carrier flow = 0) at varying symbol rates. Measurement of the received signal and quantification of ISI as a function of symbol rate.
- **Characterization of Habituation and Recovery:** Stimulation of the antenna with a continuous flow of the target compound; recording of the time-dependent decay of the antennal response (habituation). Subsequent measurement of recovery kinetics following removal of the stimulus. The goal is to determine the habituation and recovery time constants as quantitative system parameters.
- **Mathematical Channel and Receiver Modeling**: Based on the measurements from the previous tasks: derivation of a first, physically motivated model of the antennal response (e.g. based on receptor binding kinetics and adaptation rate, as in [8]). Fitting of model parameters to the experimental data. Optional comparison with a purely data-driven model. The model should reproduce the impulse response, ISI behavior, and habituation kinetics.
- ***Optional:*** **Two-Compound Interference Experiment:** Introduction of an interfering compound next to the desired one as a continuous background flow (interference/noise source). Measurement of the antennal response to the target compound in the presence of the interferer at different time points. It is expected that the antenna initially shows elevated cross-talk, but subsequently habituates to the interferer, leading to improved relative selectivity toward the target signal (cross-habituation as biological interference suppression). In a second experiment, the interfering compound is the same as the desired compound to assess possible self-interference.

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End date: t.b.d

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