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14. ABSTRACT

“OrthopterNets” represent an ongoing R&D program which aims to apply insects as relays for chemical sensor and other types of messages over distances of a few meters to hundreds or thousands of meters. OrthopterNets establish ad hoc communications networks formed by insect nodes to pass information from sensors to one or more detection endpoints. The networks may be formed among calling insects (e.g., as with crickets and katydids) via acoustic modulation of their calls, or through RF transceivers attached to the insects. This paper summarizes ongoing work

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Report Title

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OrthopterNet Communications

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Abstract: *: "OrthopterNets" represent an ongoing R&D program which aims to apply insects as relays for chemical sensor detectors and other types of messages over distances of a few meters to hundreds or thousands of meters. OrthopterNets establish ad hoc communications networks formed by insect nodes to pass information from sensors to one or more detection endpoints. The networks may be formed among calling insects (e.g., as with crickets and katydids) via acoustic modulation of their calls, or through RF transceivers attached to the insects. This paper summarizes ongoing work towards the development of a viable OrthopterNet implementation.*

Keywords: OrthopterNet; insect communication; wireless mote.

Introduction

The OrthopterNet concept is named after the insect order *Orthoptera*, which includes common crickets, katydids, and related calling insects. One form of OrthopterNets currently under development makes use of calling insects whose calls are modulated via electro-mechanical means to carry a simple message. In the other network form, non-calling insects carry RF relay transceivers. Applications of OrthopterNets include chem-bio sensor message transmission for the warfighter, as well as sensor communications for search and rescue assistance (e.g., following natural disasters). In either case, swarms of specially equipped insects are released in the area of interest to aid in sensor message transmissions.

Figure 1 summarizes the OthopterNet concept. In the acoustic OrthopterNet approach, a sensor emits an acoustic signal corresponding to a parameter to be sensed in the environment. The sensor may be mounted on the insect, or remain separate. This signal is captured by a transceiver mounted on a calling insect. The transceiver has a microphone and signal detection circuit tuned to a specific sensor signal typically assigned to a narrow band frequency range and at a designated repetition rate. This sensor signal is stored in a local transceiver memory. When the insect starts to sing, the stored waveform is then translated into a voltage waveform that is applied to an electroactive polymer mounted on the insect's wing. As the polymer changes its shape and tension in response to the applied waveform, the insect's call is effectively modulated. This modulated insect call is subsequently detected by other transceivers and retransmitted in a similar fashion, thereby forming in effect a high latency, low bandwidth ad hoc network. Eventually, the signal will reach a delivery point. (e.g., a base station). The insect networking is intended to extend the propagation range of the sensor signal; depending on the type of insect, this range could reach hundreds or thousands of meters.

The RF implementation follows a parallel path, however in this case the sensor signals are emitted by the sensor to an RF transceiver mounted on the insect. The transceiver retransmits the sensor information for reception by a nearby insect equipped with a similar transceiver. This process continues until the signal reaches the delivery point. In the RF implementation, the insects essentially serve to provide mobile transport of the transceivers. It is for this reason that the insect does not have to sing, although if a singing insect is used a dual RF / acoustic OrthopterNet approach could be supported. In either case, the main challenge in supporting the OrthopterNet concept is management of the required circuitry's size, weight, and power (SWAP).

RF Implementation

Figure 2 shows a current prototype of an OrthopterNet mote configured as a transmitting sensor; in this case the sensor is a chip-scale microphone (for demonstration purposes). All RF functions and networking control are carried out within a TI CC2530 Zigbee chip which is clocked at 32 MHz and whose RF operating frequency is in the 2.4 GHz band. As can be seen in the figure, the entire transmitter and antenna are contained on a highly compact and thin PC board of approximate dimensions 14 mm x 14 mm with less than 1g total mass. This board is suitable for attachment to common, larger crawling insects including larger species of cockroaches, making the networking especially attractive for hard-to-reach areas where the insects tend to crawl (see Figure 3).

To better address SWAP requirements, the RF nodes will be replaced by custom chips (now under design) that draw less power, are smaller, and consequently will allow for extended mission life.

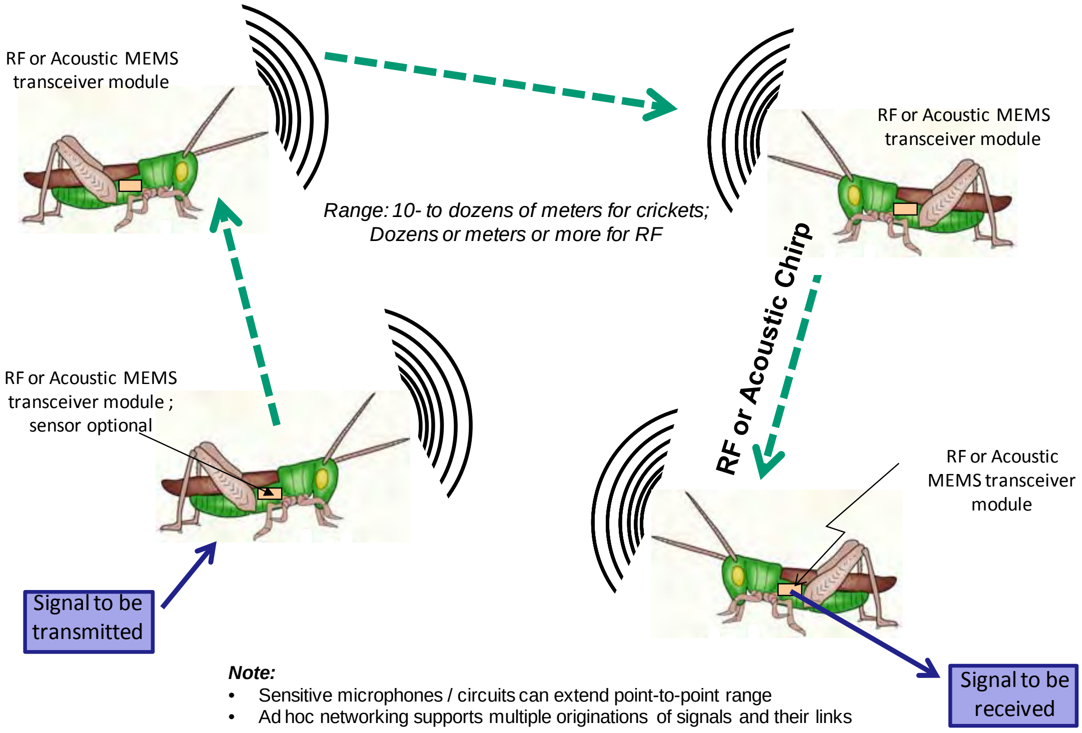

Figure 1. OrthopterNet Concept

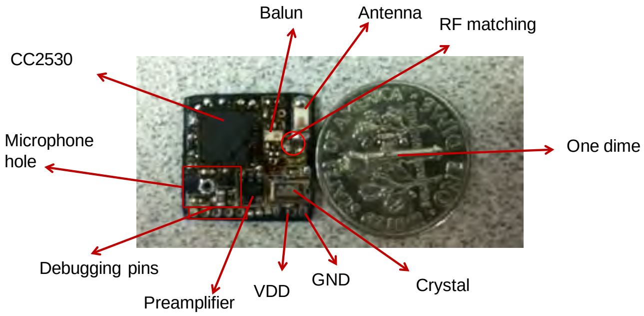

Figure 2. OrthopterNet RF mote configured as a transmitter.

Based on the use of our initial Zigbee board, we have begun development of a second generation board with the custom RF chip designed for supporting the OrthopterNet application. The chip's characteristics are as follows:

- Max power of 6mW for the RF front-end
- Bit error rate (BER) < 10^{-3} @ 10m
- Technology: 130nm IBM RF-CMOS
- IC area: 2mm x 2mm before packaging
- Time division duplexing (TDD)
- Operation frequency = 2 ~ 2.5GHz.
- Modulation: binary On/Off Keying (OOK).
- Baseband coding = Manchester coding.

Figure 3. Mounting of custom RF board on Madagascar "Hissing" Cockroach (*Gromphadorhina portentosa*).

The frequency parameter is determined from the antenna dimensions. The proliferation of the services in ~2.4GHz band has accelerated antenna miniaturization, which is crucial for the OrthopterNet transceivers. A wide frequency range is chosen in order to provide flexibility in selecting carrier frequency without collision.

Binary On/Off Keying (OOK) has lower power consumption compared to other high-order modulation techniques. Given our rather slow data rates, OOK should be fully adequate for the information flow. Manchester coding scheme allows further decreases in power consumption of the receiver by simplifying the DC offset cancellation circuitry at the expense of doubling the bandwidth.

The RF networking implements a simple flooding protocol now under development for this purpose.

Acoustic Implementation

The acoustic implementation of OrthopterNets, which is likewise under development, makes use of the insect *Gampsocleis gratiosa*, which is very a large singing kaydid found in parts of Eastern Asia. This insect was selected because of its loud and frequent call, and large size to help overcome the SWAP challenges.

A key component in the acoustic OrthopterNet implementation is the electroactive polymer that modulates the wing during the insect's singing. In our present implementation, this is accomplished with a ribbon of Ionic Polymer Metallic Composition (IPMC), which was procured from Environmental Robots of Bangor, Maine. A typical ribbon is about 1 cm in length and about .25 cm in width. Figure 4 shows such a ribbon mounted on the large katydid (which can grow to about 6 cm in length). When 1V DC is applied to the faces of the ribbon at one end, the other end of the ribbon moves about 1 mm. Reversing the polarity causes the ribbon to move about 1 mm in the opposite direction. Removal of the voltage causes the ribbon to return to its starting state. Note the movement of the ribbon is not instantaneous, and requires about a half to one second to reach its 1 mm traverse. By sustaining the 1V input in either polarity, the ribbon will rest in its place. As the ribbon moves, current draw peaks at about 3 mA, then returns to zero as the ribbon reaches its final position. Applying 2V causes the ribbon to move about 4 mm. Our preliminary experiments show that the IPMC offers good potential as a means of altering the katydid wing position through electroactivation, with low voltage and relatively low current draw (below 3 mA). In addition, the material's flexible sheet-like form factor allows the sheets to be cut to the needed size and shape. This compares to the very high voltages required for piezoelectric type materials, which can require hundreds or thousands of volts to achieve comparable motion. One drawback of IPMC is its cost, due to the sheet's high platinum content.

The circuitry at present is a variation of the Zigbee RF board described earlier in this paper, but with an Analog Devices chip-scale microphone and audio amplifier attached, which drive the Zigbee module's built-in A/D converter. Electroactivation of the IPMC ribbon is achieved by a tap off of one of the Zigbee module's digital output pins, effectively applying patterns of 0V / +Vdd to the ribbon. Note the use of the Zigbee board also should allow support of a hybrid acoustic / RF system, as described earlier.

Figure 4. A photo showing the attachment of an IPMC strip to katydid's back using Whiteout as the adhesive.

Preliminary waveform measurements are shown in Figure 5 for a singing insect with and without the IPMC mounted on its wing. When a voltage is applied to the IPMC ribbon, the insect's regular call is disrupted in a manner that changes the repetition rate of the chirp and the chirp's frequency components. It is this change that forms the basis of the signal modulation, thereby conveying the message for later detection. Further efforts are now underway to assure a repeatable effect of the IPMC activation.

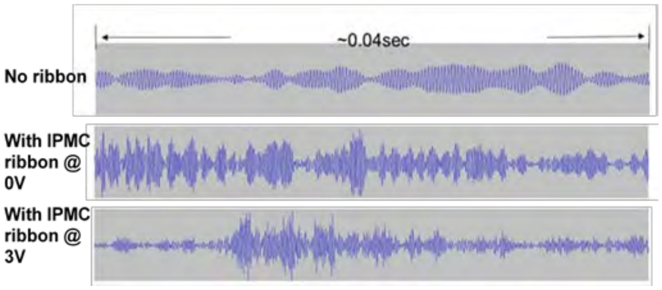

Figure 5. Acoustic chip waveforms from a singing katydid.

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