Smart Sensors for Small Rodent Observation

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***Abstract*— Working towards the observation of rats (and other small rodents) in the wild we have developed tools that will enable us to study their behavior using a wireless network of wearable sensor nodes. The space and weight constraints resulting from the size of the animals have led to simple but functional approaches for vocalization classification and position estimation. For the resulting data we have developed novel, delay-tolerant routing and collection strategies. These are expected to be used in a sparse, dynamic network resulting from various rats being tagged with our nodes and running around freely - an area that will eventually be too big to be covered solely by stationary data sinks. Furthermore, the system is designed to extract information on the social interactions between animals from the routing data. It currently works in an indoor environment and we are preparing it for tests in a controlled outdoor setup.**

I. Introduction

One core motivation in sensor networks research is the vision of deploying sensor networks in nature to observe natural phenomena. In this paper, we discuss our contribution to make this vision a reality. With the help of sensor networks, we plan to observe several aspects of rat behavior.

Rats have lived as commensals of humans, presumably since the latter began to settle down and, like humans, they are extremely successful in coping with a variety of environmental adversities. Although rats have served as one of the most widespread laboratory animals throughout the history of science, little is known about their behavior in the wild. This is mainly because essential parts of their habits remain inaccessible to human observation due to their subterranean lifestyle.

As observational methods in animal behavior research have always gone hand in hand with the development of new technologies we started to customize available sensor node technology to apply it in a network that collects and propagates data from burrow-living animals.

Currently, we are equipping rats with standard sensor nodes (mica2dot) and developing a custom sensor suite, adapted to their specific requirements. Each sensor is contained in a module (referred to as sensor board) that performs signal conditioning and basic feature extraction.

Sensor nodes (often called motes) are attached to laboratory rats using a leather harness, fitted with a pocket for the sensing equipment (see figure 1). The long term goal is to attach, or even implant, the sensor nodes to wild rats.

In a rat burrow radio communication is limited, and so sensor nodes can only communicate with each other when the

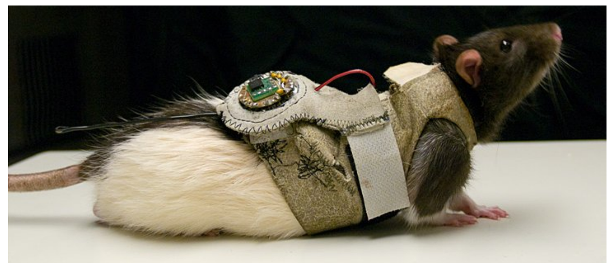

Fig. 1. A Norway rat carrying a sensor node

rats carrying them meet within a certain range. As a result, the sensor nodes are only sporadically connected and the network topology is highly dynamic, making our deployment scenario significantly different from the typically envisioned static networks.

II. Related Work

A number of relevant wildlife tracking projects already exist. Of these, there are two of particular interest for our project. The ZebraNet project [1] equipped zebras with customized sensor nodes. The animals' position and other relevant quantities were monitored via GPS. In addition, the sensor nodes recorded when and where zebras met. From these data, biologists evaluated the zebras' movement and social interactions. The DTAG project [2] works in a communication scenario similar to ours: whales spend most of their time (up to 95%) under water, making radio communication impossible. Their approach is to record relevant data and detach the recording tag from the whale once the memory is full. The tag then floats to the surface to be collected by the researchers. While this approach is very elegant for underwater animals, it is not feasible for research on burrowing animals.

III. Rat Behavior

It is known that rats have a complex behavioral repertoire [3],[4]. As a starting point, our efforts are focused on two main aspects of rat behavior: vocalizations and movement. We proceed in a bottom-up fashion, working on low-level descriptions of locomotion and vocalizations that will combine to form more abstract descriptions and interpretations. The most basic aspect to describe a rat's motion is its gait. Previous studies on rat gaits have described them kinematically [5],

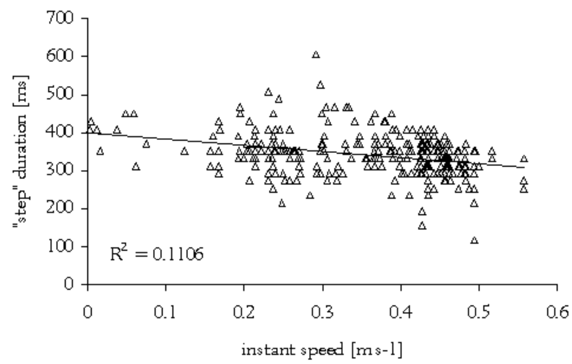

Fig. 2. Relation between step duration and walking speed

while our interest is focused on monitoring the instant speed at which they displace. If the movement of a rat is known in 2-D, foraging habits can be analyzed, while 3-D monitoring would allow the reconstruction of a map of the burrow.

Vocalizations play an essential role in communication among rats [3]. Since they serve as a standard signal to interpret behavioral responses of rats in laboratory environments, a number of studies have already characterized rat vocalizations under laboratory conditions [6]. We used these results to develop a system to help us describe the context in which these vocalizations are generated when rats are left to themselves. Being able to study rat vocalizations in the wild could shed new light on many unknown aspects of their social habits.

IV. Hardware

We use commercial, off-the-shelf motes that provide some storage (500kB), basic processing (8-bit,7MHz) and radio communication (900MHz) [7].

Motes are attached to the rats using a leather harness, onto which a bag (containing the mote) is fastened with Velcro. The initial version, seen on figure 1, restricts bending of the rat's spine, thus hindering its overall freedom of movement. To minimize this inconvenience the newer version consists of a leather band, wrapped around the rib cage, and a stiff wire loop around the neck to keep it from sagging off to the side.

In order to reduce processing and memory complexity we have developed "smart" sensing modules to perform - in hardware - as much of the signal conditioning and feature extraction as possible. At present, we have two functioning sensor boards: one for motion analysis and one for vocalization analysis.

A. Motion Sensor Board

In order to acquire information on a rat's movement we implemented a scheme somewhat similar to [8]. We have observed that the time between peaks in a filtered accelerometer signal roughly correlates with a rat's velocity (figure 2). In our setup, noise originates from two sources. For one the process itself is "noisy", as there are various influences other than walking on a rat's spine movements. For another the measurements are noisy because our speed estimation derives from light barriers spaced apart 25 cm, which means that a rat can interrupt multiple barriers at the same time. We are confident that upon improving the velocity measurements, the correlation between the estimated and the measured velocity will improve. We refer to these peaks as *pseudo-steps*, as they do originate from the stepping motion of the rat but are measured on the spine, rather than the feet. The electric signal is collected from an accelerometer (MMA7260QT, Freescale Semiconductor) and band-pass filtered between 4Hz and 12Hz. The filtered signal is passed to a comparator and the compared signal is read by the mote. The mote's firmware performs the calculation of the rat's speed based on the patterns of the edges in the compared signal. When no stepping is detected, the analog 3-D accelerometer signal is analyzed to obtain the elevation of the rat's longitudinal axis relative to gravity. This is a behavioral element that appears in territorial exploration.

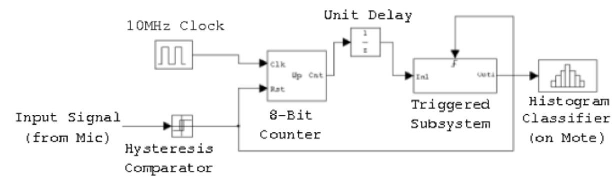

Fig. 3. Model of the vocalization analysis module

B. Vocalizations Sensor Board

We have developed a sensor board that allows us to classify rat vocalizations, burdening the processor on the mote significantly less than the calculation of a spectrogram would. The sensor board filters the ultrasound audio signal and detects zero-crossings in the filtered signal (see figure 3). The time between zero-crossings is measured using a digital counter, clocked at 10 MHz. A histogram over these times is computed on the microcontroller and serves as a feature vector for the call. In the stable, controlled environment of the laboratory, rats do not emit many vocalizations, making it difficult to obtain data for classification. Other studies have stimulated rats in different ways to obtain calls. We used data from [9] and [10] to show that our system allows a classification of known rat calls. In figure 4 the histograms of three different calls are shown. They belong to different frequency ranges and can be classified easily with our method. In order to be able to separate different types of calls within one frequency range, the duration of the call is an important classification feature. We have succeeded in separating calls within the aforementioned bands but, to verify this procedure thoroughly we require more training data.

V. Sensor Network

The described sensors are designed to function in a wireless network. As the nodes in this network are mounted on rats, and rats live in burrows, we can not assume to have constant radio communication throughout our system. In fact, we assume

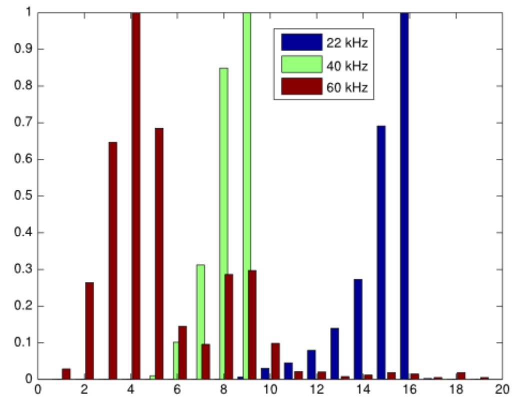

Fig. 4. Normalized histograms of zero-crossings of rat calls in three different frequency ranges

our network to be sparse and to have sporadic connectivity, which necessitates the use of delay tolerant networking (DTN) techniques. Our network is designed to incorporate the habits of rats into its routing protocols. From this interaction we expect to adjust the system to the specific needs of a rat colony, as well as possibly gain further insight into the colony's behavior.

A. Routing

Resources are limited (memory and processing), which is why we need to prioritize content. We consider two routing strategies: utility based and social network based.

For *utility based* routing, we assume data of different types to have varying relevance for behavioral studies. Different levels of priority are assigned to data packages of different types. During a meeting of two nodes, packets are then forwarded in the order of highest utility to the network.

Social network based routing considers the dynamic topology of our wireless network. Decisions on whether a data package is passed from one mote to another are made by minimizing the expected time it will take the package to be delivered to a base station. If no direct path is known, the packet is forwarded to the node with the highest number of neighbors in its meeting history, which then has a higher chance of finding a suitable route to the base station.

B. Data Reduction

In addition to the extraction of information from the raw sensor data, as performed by our sensor boards, our sensor network allows the reduction of data by context recognition and stream data mining. As soon as certain patterns of behavior become known, biological interest concentrates on the "outliers" (e.g.: rats are nocturnal animals, therefore a rat walking during the day is more relevant than one walking during the night). This approach allows us to reduce the amount of data transported over the wireless network.

VI. Conclusions

This paper presents the current status of a system, designed to monitor rat behavior in a non-invasive fashion. We present hardware modules adapted to the specific case of *Rattus norvegicus* that can easily be trimmed to suit many other animal species. In our design we trade measurement precision for processing simplicity, thus achieving faster measurements in a higher level of abstraction than raw sensor data. Our approach makes it possible to integrate different types of measurement data using low-end processing hardware.

Ongoing efforts are focused on estimating the heading of a mote, based on magnetometer and gyrometer readings. This feature, combined with our pseudo-step-counting, would enable us to estimate an animal's whereabouts in 2-D and study foraging habits or burrow layouts. In addition we are establishing a controlled outdoor setup, in an out-of-service aviary, to begin studying the rat burrowing habits.

Acknowledgments

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