Measuring activity in ant colonies

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Ants, as paradigm of social insects, have become a recurrent example of efficient problem solvers via self-organization. In spite of the simple behavior of each individual, the colony as a whole displays "swarm intelligence:" the organization of ant trails for foraging is a typical output of it. But conventional techniques of observation can hardly record the amount of data needed to get a detailed understanding of self-organization of ant swarms in the wild. Here we are presenting a measurement system intended to monitor ant activity in the field comprising massive data acquisition and high sensitivity. A central role is played by an infrared sensor devised specifically to monitor relevant parameters to the activity of ants through the exits of the nest, although other sensors detecting temperature and luminosity are added to the system. We study the characteristics of the activity sensor and its performance in the field. Finally, we present massive data measured at one exit of a nest of *Atta insularis*, an ant endemic to Cuba, to illustrate the potential of our system. © *2006 American Institute of Physics.* [DOI: 10.1063/1.2400215]

Social insects have become a paradigm to describe a number of properties of complex systems, such as self-organization:[1] in spite of the extremely simple behavior of each individual, an ant colony as a whole exhibits amazing properties ranging from activity oscillations[2] to optimization in foraging trails.[3,4] Moreover, such "swarm intelligence" is being seriously considered by engineers as a model to design "herds of robots."[5] However, conventional biological techniques—mainly direct visual observation—still dominate the measurement of insect activity in the wild. In the last decades, other approaches such as quantitative image analysis have been applied only in controlled laboratory conditions.[6] In this article, we report the design, construction, and test of a data collecting system, including an infrared sensor to quantify the activity of ant nests at their entries/exits, during prolonged periods of time.

Our system, sketched in Fig. 1 and based on the SNAP,[7] is intended to collect data in the field in an uninterrupted fashion. It collects a data stream from the sensors, wired across the field, processes it, and later transfers it to the servers in the laboratory using the wireless fidelity (Wi-Fi) infrastructure or general packet radio service (GPRS) over the cellular network. The small power requirements of the system permit to operate it, for over 20 h, off a 6 V–4 A h lead-acid cell. In the experiments we reported here, it is powered from the grid and the battery remained as a backup.

Our in-field system collects, filters, and aggregates a data stream from the ant nest sensors and then uploads it to the server. The output file contains information about local temperature distribution, daylight intensity, and activity at the nests exits, along with a time stamp for every sample taken. *Activity* in this case is defined as the number of counts the sensor generates when ants enter or leave the nest during a given time interval. For the experiments made so far, the time resolution was set to 2 samples/min. Over ten sensor nodes could be easily deployed in the field.

In order to measure the ant activity at nest entries—our fundamental parameter—we have devised an *ad hoc* infrared sensor. The principle of the activity sensor is very simple yet effective. A light beam is reflected in the inner surface of a cylindrical mirror build from a thin metallic band. The reflective band is open at one point where a tiny IR light-emitting diode (LED) and phototransistor are stacked back to back and positioned close to the mirror surface. Thus the light beam experiences multiple reflections confined within a radial distance of 1–2 mm above the inner surface of the mirror, only interrupted by trespassing ants. Special care is required during the installation to maximize the fraction of light that reaches the phototransistor. Figures 2(a) and 2(b) show diagrams that illustrate the functioning of the sensor. The diameters of the mirrors were chosen so that the assembly can fit conveniently, given different sizes of nest entries in the range of 10–25 mm.

Very low power and low noise analog electronics has been used for conditioning the signal and detecting the changes of intensity in the reflected beam arriving at the phototransistor due to the ants interrupting the infrared light ring. In order to isolate the signal level shifts produced by the trespassing ants, from those created by the environment light changes, a filter has been implemented. We exploit the temporal differences of these events and compare a voltage, proportional to the intensity of the reflected beam, to a low pass filtered sample of the same signal. The last one accounts mostly for the dynamic threshold imposed by the infrared component of the daylight biasing the phototransistor. The filter was tuned resulting in a time constant of about 10 s. The output of the comparator is used to drive the input of a 32 bit counter from Maxim, the DS2423.[8] The inset in Fig. 1 shows details of the node.

When ants enter the nest, they step through the 4 mm wide metal band and the thin light curtain over this mirror is interrupted, which leads the comparator to trigger the counter. Figures 2(c) and 2(d) show pictures of the sensor in the laboratory and installed on a nest exit, respectively.

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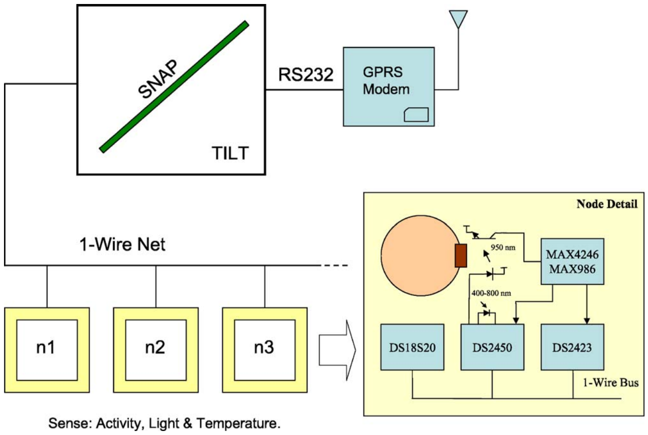

FIG. 1. (Color online) Block diagram of the data acquisition system.

To our surprise, ants consistently show undisturbed by the presence of the setup. However, due to the overlapping of ants trespassing the entry (which happens often beyond certain traffic density), one can expect missing ants in the counting and therefore a nonlinear performance of the activity sensor.

In order to characterize this effect, we have calibrated the sensor by videotaping it, carefully quantifying real activity from the resulting images, and then comparing it with the activity given by the sensor. The video was made with the sensor installed at several nest entries, with different traffic levels, while the system was performing a time-synchronized measurement. Then we watched the video with great care and counted ants entering the nest at regular time intervals, obtaining a variety of traffic density values that span from null (when the activity is very poor) to over 60 ants/min

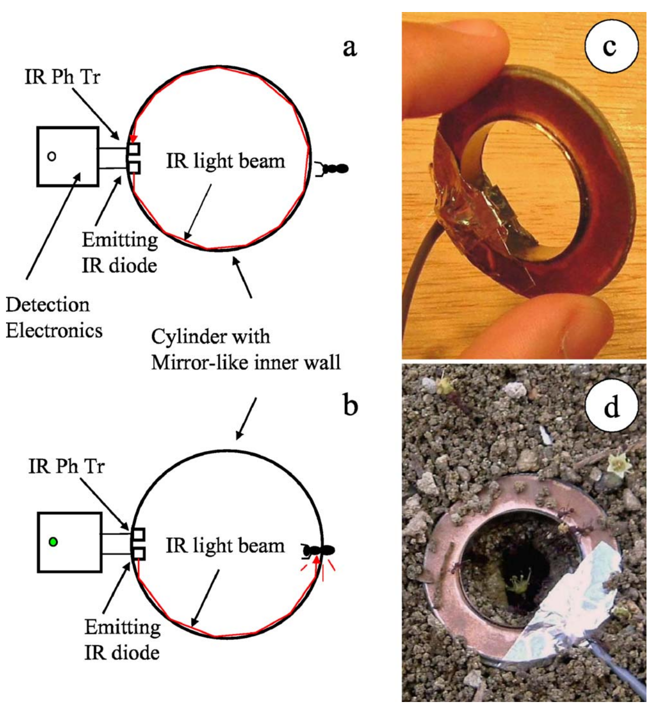

FIG. 2. (Color online) Description of the sensor that illustrates its functioning. (a) and (b) show a diagram to illustrate functioning. (c) and (d) show pictures of the ant activity sensor in the laboratory and set on a real nest exit, respectively.

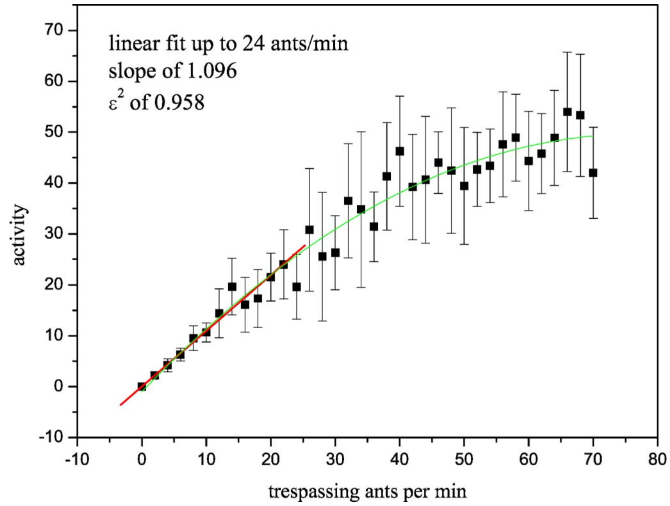

FIG. 3. (Color online) Calibration graph. The solid line is a linear fit from 0 to 24 ants/min, with a chi-squared of 0.958.

(when the activity is well organized and intense, typically very late at night).

Confronting this result with the simultaneous measurement carried out by the system, we analyze the nonlinearity of the sensor and its accuracy and establish the range of traffic densities for which it remains accurate. We have found that the sensor remains linear up to traffic levels of more than 20 ants/min. Ants' activity was plotted versus the number of trespassing ants as shown in Fig. 3. It is interesting to notice the larger the traffic, the greater the uncertainty of the measurement. This is indeed related to the increase of the probability that the sensor double counts a "struggling" ant at the entry point, carrying a piece of a leaf, or it might miss several ants entering or exiting simultaneously.

Although the full activity range present in our measurements exceeds the linear zone of the sensor, the most relevant parts of it remain well below the nonlinear threshold. In normal conditions, the activity of a nest is typically periodic, with a very high, steady activity during night hours and nearly zero activity during daytime. The most interesting intervals are, however, those where this steady activity "builds up" and where it "slows down." These data subsets provide the valuable information on how the nest self-organizes and their global integrity and accuracy are not compromised by any of the above effects.

Atta insularis (common name *bibijaguas*), a leaf cutter endemic to Cuba, has been chosen for the preliminary study we are presenting as a field test of our system. Each individual measures from 3 to 9 mm in length. Experiments for the probe of concept took place at the park "Quinta de los Molinos" in Havana, where there is a sizable population of bibijaguas. A good nest entry with abundant flow was chosen to install the sensor. Figure 4 shows a typical run of the experiment at one exit of a nest. Temperature (upper panel) and accumulated activity (lower panel) are presented as a function of time, within a period of nearly two weeks.

The high resolution of the activity graph—which comprises more than 20 000 experimental points—becomes evident in the inset of the lower panel, which contains approximately half an hour of activity. Some global features of ants activity immediately become apparent. One is the correlation

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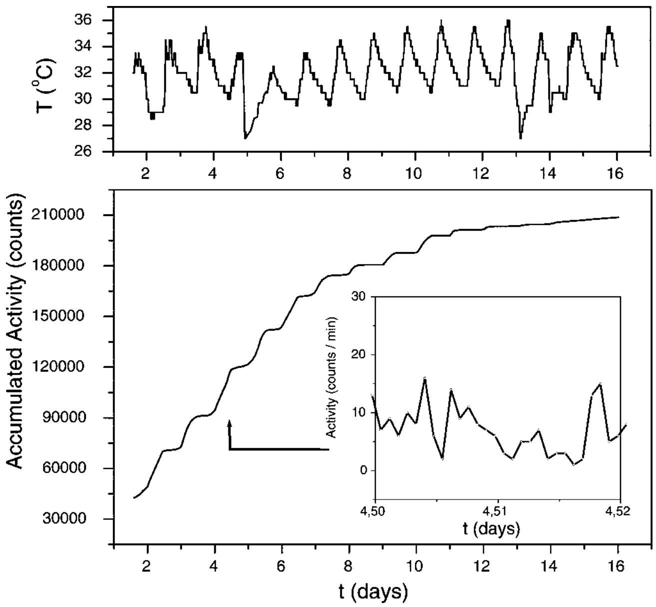

FIG. 4. Data from a typical run of the experiment. The upper panel shows temperature near the nest exit, and the lower panel reports cumulative activity.

between temperature and activity cycles, with a period of approximately 24 h: as the temperature starts to decrease each day, the activity starts to increase. A second observation is the net decrease in the use of the door under study as days pass by, due to "long-term" self-organization process probably modulated by availability of food. While the general features of this pattern are well known, our data probes them with an unprecedented level of detail, to our knowledge. It allows, for example, the calculation of the statistical distribution of activity variations, which will be discussed elsewhere. As a future prospect, we plan to deploy activity sensors at different exits of the same nest and, given the temporal series of activity, calculate correlation functions among them, in order to penetrate further in the details of the self organization mechanisms of the ant society.

At the core of our data acquisition system is the simple network application platform (SNAP™) from Imsys AB, an open JAVA reference platform based on the Cjip microprocessor for Networked, JAVA-based control, running at 66 MHz. The SNAP module includes several hardware input-output (I/O) options. We use the 1-Wire™ (Ref. 9) net as a convenient interface to our sensors. Also the Ethernet port could be used for connecting to the local network. The Cjip interprets native JAVA byte code directly, without a virtual machine, and full transmission control protocol/internet protocol (TCP/IP) stack is implemented along with a small footprint operating system (OS).

The sensor nodes and the SNAP™ talking over the 1-Wire™ bus allow the software to interrogate the nodes, widespread in the field, while using a minimum of wires. Typical required lengths to cover the entries of one nest extended up to a few tens of meters. Data are transferred serially via the 1-Wire™ protocol, which requires only a single data lead and a ground return. All in all, there are four wires in the bus: Vcc to power the nodes, Ground, 1-Wire Data, and a 1-Wire return. Each sensor node relies on several 1-Wire chips for the measurement process. A digital thermometer, the DS18S20,[10] provides 0.5 °C precision on temperature samples and the DS2450,[11] a quad analog-digital (AD) converter, will measure light intensity and control signaling LEDs. A photodiode is employed to detect daylight intensity at the nest entry. One channel of the AD converter directly measures the voltage across a resistor in series with the photodiode. A 64 bit registration number is factory lasered into each chip to provide a guaranteed unique identity which allows for absolute traceability and acts as node addresses for the multiple chips connected in parallel in the bus.

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