CENS: New Directions in Wireless Embedded Networked Sensing of Natural and Agricultural Ecosystems

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CENS, a US National Science Foundation Science & Technology Center, is developing Embedded Networked Sensing (ENS) Systems and applying this revolutionary technology to critical scientific and social applications. Like the Internet, these large-scale, distributed, systems, composed of smart sensors and actuators embedded in the physical world, will eventually infuse the entire world, but at a physical level instead of virtual. The CENS focus for ENS Technology Research draw on a diverse set of researchers within engineering, from distributed system design, to distributed robotics, to wireless communications, signal processing and low-power multi-modal sensor-technology design. In addition, the physically-embedded nature of this technology calls for significant experimentation and exploration within the context of the target application domains in order to identify the true challenges and opportunities. CENS technology research is currently focused in the following eight areas:

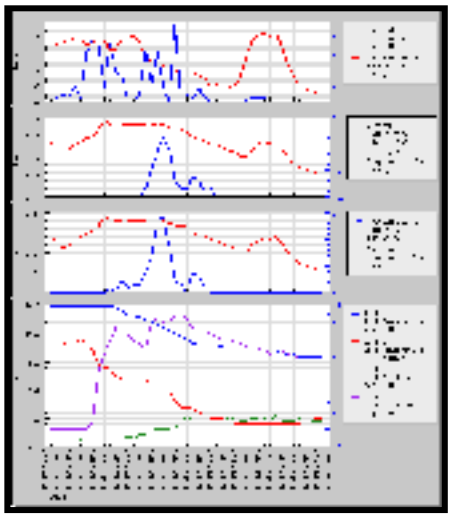
(1) Network Autonomy; (2) Programming and Storage; (3) Tools, Platforms, & Testbeds; (4) Actuation; (5) Collaborative Signal Processing; (6) Micro/Nano Sensor Technology; (7) Ethic, Legal & Social Implications; and (8) NIMS Network Infomechanical Systems.

The CENS focus for ENS Application Research is currently on four experimental application drivers: ecology and habitat sensing, seismic sensing and structure response, monitoring and modeling contaminant flows, and detection and identification of marine microorganisms. To support this scope, CENS combines the expertise of faculty from diverse engineering disciplines with the expertise of biological, environmental and earth scientists. During the lifetime of the Center, our is to plan to pursue additional opportunities for applying the technology to other natural and engineered systems. A multifaceted education, outreach and training program ensures that CENS research products, software, and technology/application research optimally benefit the target communities.

Three of the four CENS Applications Research areas focus **on Ecological and Habitat Sensing** to monitor the dynamics of biological complexity: environmental, organismal, and cultural conditions, and the interactions between them in natural and managed landscapes. Our overall goal continues to be in improving the design and deployment of embedded network systems for practical ecological, terrestrial, marine, and agricultural uses that can operate remotely, and in uncontrolled natural and settings, capturing chemical, physiological and environmental data across a wide range of ecological conditions, temporal and spatial scales. Significant work has begun in the effort to provide an infrastructure to field test Embedded Networked Sensing (ENS) and techniques within a range of habitats and ecosystems (including in the tropics), and to deploy experimental model systems suitable for addressing specialized and general ecological information needs. During this second period we have operated a 10 node, 100 sensor wireless microclimate array continuously at the James Reserve for 15 months, and are near the completion of new software that will enable us to increase this array to more than 100 nodes and thousands of sensors. A robust, 10 channel video network was completed to observe avian behavioral activities related to climate, nesting and reproduction. Soil mini-rhizotrons have been installed and below ground sensors and cameras are being designed for measuring soil moisture, nitrate, CO2, temperature, and root/fungi activities in response to weather. And finally, the first permanent networked info-mechanical system (NIMS) node was installed within the forest canopy and spanning a riparian ecosystem.

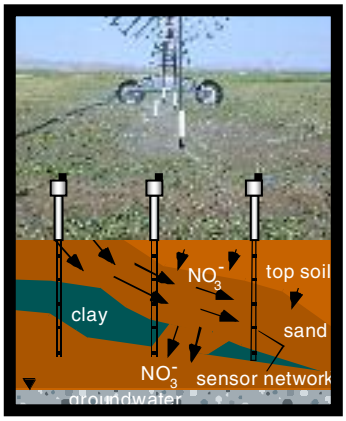
Research highlights

1. **Microclimate Sensor and Video Enabled Networks:**



- The Continuous Measurement System project is intended to investigate the requirements for a long-term data collection by deploying a system with simple, well-tested communication software and a limited number of nodes.
- The ESS is designed to be the test bed for sensors, interface hardware, RF communication hardware, communication protocols, databases and user interfaces to be used in CENS Habitat sensing.
- The system will support characterization of microclimatic influences on nesting activity and nest success
- The data gathered will be used to test systems for automatically classifying nest box images in real time at remote nest sites.

2. **Embedded network sensing within soils**



- A networked robotic mini-rhizotron array is being developed for obtaining real-time, simultaneous field data on root/mycorrhizal dynamics in conjuction with soil respiration (CO2), nutrient flux (N, P, etc.), and moisture. Current minirhizotron cameras are cumbersome to operate and are very time-consuming during data collection, management, and interpretation. However, they provide valuable in situ observations impossible through other means
- The soil array will be used to investigate the effect that diurnal temperature changes have on water movement through soil and how that water movement is affected by the presence of rocks on the soil surface.
- A second ESS-based micro-climate and soils monitoring system to be deployed in a French Polynesian-based botanical garden will support study of the micro-climate and soil preferences of traditional and contemporary Tahitian crops of cultural, medicinal, and economic significance.
- Conducted a successful Soil Sensing Workshop to bring together experts in the field, the culmination being a proposal submitted to the NSF as well as a paper written for the journal BIOSCIENCE.

3. **Other related projects**

- Ecophysiological studies utilizing Mobile Sensor Platforms
- Sensor Arrays for Avian Acoustic pattern recognition
- Video Imager and Mote Development for Agricultural and Habitat Applications