Pervasive Computing Approaches to Environmental Sustainability

**EDITOR’S INTRO**

In this issue’s Works in Progress department, we have eight projects with a focus on environmental sustainability. The first three projects explore sensing and pervasive computing techniques for monitoring environmental conditions in outdoor situations. The next four projects use pervasive computing in indoor environments to inform individuals about their energy and resource consumption with the goal of positively influencing their behaviors. The final project aims to develop an energy-generation infrastructure that combines multiple types of renewable energy sources.

—Anthony D. Joseph

**A DECISION SUPPORT SYSTEM FOR CROP MANAGEMENT**

Rolando A. Cardenas-Tamayo and J. Antonio Garcia-Macias, CICESE Research Center

The agricultural sector is one of the most important sources of income and production worldwide. Agriculture is directly related to sustainability issues such as water availability and soil conservation, so using these resources efficiently is important. Continuous monitoring systems can maximize their proper use. Such environments are highly dynamic, and systems that support the decision-making process are valuable tools. However, these systems need large amounts of information that must be provided continuously; additionally, they require constant attention by their users.

Therefore, we designed and implemented a decision-support system for monitoring crops using pervasive computing technologies such as wireless sensor and actuator networks. The prototype we implemented includes tools that provide real-time information about crop status and the surrounding environment, contributing to the use of techniques such as fertigation (the application of fertilizers, soil amendments, or other water-soluble products through an irrigation system).

We carried out an experimental evaluation of our prototype with a group of potential users based on the technology acceptance model (TAM), gathering the users’ perceptions about usefulness, ease of use, and intention. We believe that our proposal has the potential to reduce costs and, by using precise information, improve resource management for crop production. We’ve begun long-duration field tests that will enable a better assessment of our proposal.

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**ADAPT: AUDIENCE DESIGN OF PERSUASIVE TECHNOLOGY**

Timothy M. Miller, Patrick Rich, and Janet Davis, Grinnell College

Although many recent research efforts have used pervasive computing to persuade people to use less energy in the course of their everyday activities, stakeholders have rarely been involved in those design efforts. In response, we held a series of participatory design events at Grinnell College to involve potential users in designing an ambient persuasive display that targets an energy-consuming behavior. We used an exploratory game to help participants find places where they consume. We then introduced them to sensor and actuator technology through the Phidgets rapid prototyping framework (www.phidgets.com), engaged them in building mockups, and invited them to critique prototypes of several designs. Ultimately, we designed an interactive sculpture as part of a staircase in the science building, intended to attract people to the stairs from a nearby elevator. The system uses glowing LEDs embedded in hand-sized wire sculptures to evoke fireflies along the walls and stair railings. Participants can “catch” the fireflies, which are equipped with vibration sensors, by tapping them—thus triggering a celebratory animation. Users can race...
the fireflies up the stairs, showing that most people can walk faster than the nearby elevator. A smaller display near the elevator directs people to the sculpture in the stairway.

We’re currently gathering baseline data on stair and elevator use and preparing to install the system. We plan to evaluate the system with respect to frequency of stair and elevator use, frequency of interactions with the system itself, and self-reports regarding the system’s effectiveness in promoting behavior and attitude change.

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REALNET: AN ENVIRONMENTAL WIRELESS SENSOR NETWORK
Joan Albesa, Manel Gasulla, Jorge Higuera, Maria Teresa Penella, and José Garcia, Universitat Politècnica de Catalunya

Wireless sensor networks (WSNs) have recently emerged as a feasible technology in several fields, including environmental monitoring and control. We’re deploying an environmental WSN, called REALnet, at our campus to monitor physical parameters from the air, water, and soil and to act on the environment in a more sustainable way. We’re investigating several topics that can be critical barriers to developing WSNs:

- **Power consumption**: Implementing new low-power measuring methods; synchronizing nodes by compensating for the clock drifts to reduce duty cycle and power consumption.
- **Power supply of sensor nodes**: Energy harvesting as an alternative to primary batteries; using efficient energy and power management techniques.
- **Interoperability**: Implementing suitable wireless standards such as IEEE 802.15.4, Zigbee, and 6LoWPAN (IPv6-based low-power wireless personal area network); implementing IEEE 1451 on top of them to interoperate the diverse networks.

We’ve already deployed five nodes: one coordinator node, powered from the mains; one sensor node, powered by primary batteries, that monitors the campus pond’s water level and temperature; and three router nodes, powered by solar cells, that route data from the sensor node to the central node. Router nodes also transmit data about the level of solar irradiation, temperature, and battery level. We’ll soon add nodes to monitor a tiny weather station and low-power sensors to measure the soil temperature and moisture. We’re implementing the IEEE 1451 standard and will save data on a database server for access through the Internet.

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AUTOMATING SMART-ENVIRONMENT SYSTEMS
Alejandro Fernández-Montes, Universidad de Sevilla

This work focuses on learning user preferences about lighting and air conditioning to plan actions that an automated smart-environment system should perform to satisfy these preferences. However, the system must also detect inhabitants’ wasteful behaviors such as turning on lights when natural light is available or abusing the air conditioning system when it’s not necessary. The system must then teach the inhabitants to save energy by avoiding those behaviors.

My research group proposes a general software architecture that can guide developers in building smart-environment solutions with sustainability features. I have empirically tested this architecture, using it to develop a smart-environment solution for learning users’ lighting preferences.

This proposal is based on the goals of ubiquitous computing as Mark Weiser proposed them in the late 1980s. Taking this as a starting point, we believe that automation in smart environments should be organized as continuous interaction between three main tasks: perception, reasoning, and acting.

The system perceives the environment’s state by means of the physical components distributed throughout the environment. It then reasons about the state and produces a list of possible actions to take. Finally, it carries out these actions, each of which is made up of several processes. A policy manager can guide developers to deploy green policies in order to save energy.

To test this general software architecture, we’re developing a smart solution that covers tasks of perception, reasoning, and acting. This is a Java solution built on top of the Sentilla Development Kit. It has been very useful in polishing this architecture proposal.

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WIRELESS SENSOR NETWORKS FOR EMERGENCY APPLICATIONS
Maria-Angeles Grado-Caffaro, Sapienza Studies

The European Union’s Sixth Framework Programme is funding the WINSOC project (wireless sensor networks with self-organization capabilities for critical and emergency applications). This research started in September 2006 and is due to finish in February 2009. The project aims to radically improve sensor networks’ performance using a biologically inspired design.

The system can self-assemble into organized structures in which the sensor nodes behave as biological entities that are able to make decisions on the basis of their local environments and their own individual states. These nodes are small calculating machines (much simpler than the current ones) in the network that need to carry out only very simple rules, thus eliminating the need for the inefficient, complex
protocol interactions used for end-to-end communications. This approach lets us build distributed detection and estimation capabilities that are crucial for understanding a WSN scenario and eliminates the need for sending all the data to a fusion center.

This technology is attractive for a wide range of environmental purposes; so far, the WINSOC team has analyzed landslide and wildfire applications. In India, our Amrita University partner has deployed sensors to monitor humidity and porosity in the terrain as well as the forces involved in terrain displacements. The system sends this information to a satellite, which then conveys it to a control center. Also, our Czech Center for Science and Society partner has introduced sensors in a forest to detect and locate heat and smoke sources. A simulation of a spreading fire, developed by the WINSOC team, provides monitoring and alerts.

Selex Communications (Italy) coordinates the WINSOC project. Other partners include the University of Rome “La Sapienza” (Italy), the Ecole Polytechnique Fédérale de Lausanne (Switzerland), Intracom Telecom (Greece), the Commissariat per l’Energie Atomique-LETI (France), the Czech Center for Science and Society (Czech Republic), Dune (Italy), Universitat Politècnica de Catalunya (Spain), the Indian Space Organization (India), Amrita University (India), and the science and technology consultancy firm Sapienza Studies (Spain).

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**AN AMBIENT WATER CONSUMPTION DISPLAY**

Karin Kappel and Thomas Grechenig, Vienna University of Technology

Water is becoming a scarce resource worldwide. Nevertheless, according to the United Nations, water usage has grown at twice the rate of population growth during the past century. There is an urgent need for people to change their water usage behavior. Ambient displays can help people by giving immediate and direct feedback regarding their consumption while at the same time blending in with the environment.

Water consumption for one shower varies heavily depending on the user’s shower habits, so the potential for water conservation is great. We built a prototype of an ambient water consumption display system for the shower, which gives the user feedback and an impression of the amount of water going down the drain (see Figure 1). This impression is achieved by using the metaphor of the drain being closed and the water level increasing within the shower. The imaginary water level is visualized in the form of LEDs that are vertically assembled on a stick. One additional LED lights up for every five liters, thus delivering direct feedback.

Two initial tests in two-person households show promising results. A couple used to argue over who used more water. After we installed the display, they learned that the woman used only half as much water even though she spent more time in the shower. This discovery stimulated the man to use even less water. Overall, each subject, depending on the individual goal, made different efforts to act more sustainably after having installed the ambient water consumption display.

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**HYBRID ENERGY PRODUCTION AND DELIVERY USING MULTIPLE RENEWABLE SOURCES**

İhan Umut, Kırklareli University

Erdem Uçar, Trakya University

This study investigates energy production from renewable energy sources such as solar, wind, and water and storage of the produced energy in batteries before consumption. The processes take place simultaneously. The hybrid system shown in Figure 2 will be able to supply energy uninterrupted. When one or more of the resources ceases functioning, the other sources will...
be able to feed the system. The main advantage of this type of system is the energy production’s independence from the electricity network. Therefore, we will be able to supply energy for environmental lighting and security systems, even in rural areas.

The system’s solar module is already in use (see Figure 3). We designed this module in such a way that the system follows the sun automatically. The studies for the other modules are continuing. We’ll conduct tests for the other modules once we can find a convenient location where we can produce energy from all three sources.

It will also be able to instantly measure the quantity of produced energy and send that data to a computer through a cable or wireless connection. The software will be able to express the amount of produced energy from each source as daily, monthly, and yearly totals. The system will record the data, monitor system status, and control the system.

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**OPTIMAL DISTRIBUTED CONTROL FOR SUSTAINABLE BUILDINGS**

**Josh Wall and John Ward, CSIRO**

With the building sector contributing 30 to 40 percent of global CO$_2$ emissions, sustainable building technologies have been identified as one of the most cost-effective approaches for reducing carbon emissions. Australia’s Commonwealth Scientific and Industrial Research Organization (CSIRO) believes that advances in optimal, distributed building controls will help realize significant savings while maintaining or even improving indoor climates.

CSIRO focuses on four key areas in intelligent building controls: optimizing the trade-off between user comfort, operating cost, and carbon emissions; forecasting building conditions; applying localized control responses; and identifying anomalous conditions that might represent faults or inefficiencies. The application of pervasive computing technologies is enabling these developments. Specifically, by using high-spatial-resolution mesh networks, we can obtain detailed condition, operation, and energy mappings for use both at a local sensing and control level and when aggregated for whole-building optimization.

CSIRO is extending its optimal building control technology to wireless sensor networks to facilitate low-cost, ubiquitous controls. With low energy consumption and robust ad hoc communications, such controls are ideal for retrofits to existing building stock—which is crucial for maximizing carbon reductions. Using distributed, embedded hardware, intelligence can be immersed into building sensor and control networks using localized data as input to optimized adaptive control routines with fast response and low network and computational overhead. This input can be combined with real-time comfort feedback from occupants via pervasive PC-based virtual comfort sensor software (see Figure 4). This technology has the potential to break through traditional comfort barriers by improving thermal satisfaction—not only from the direct physical effect of occupant adjustments on indoor climate but also from the empowerment of the occupants.

Supported by ever-evolving software architectures and embedded hardware platforms, possibilities for optimal, distributed control of sustainable buildings are growing dramatically, with significant potential energy savings and reduction of carbon emissions becoming reality.

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