Works in Progress

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Ubiquitous System Software

THE MOST SENSED CAMPUS

Michael W. Bigrigg and H. Scott Matthews, *Carnegie Mellon University*

The Pervasive Infrastructure Sensor Networks project at Carnegie Mellon University (see www.ices.cmu.edu/sensornets) is looking to match CMU's strength as having been called one of the "most wired" and later "most wireless" campuses. The goal is to be the "most sensed" campus.

We're physically deploying a network of thousands of sensor nodes across the campus. Our approach to building such a large pervasive sensor network relies heavily on the existing computer infrastructure. We'll be able to economically create such a large network using the CMU Critter Sensor, which leverages computer resources by attaching a sensor to a host desktop computer to use its processing, disk, and networking resources. It also leverages existing system administration support.

We're developing the system in conjunction with applications researchers who are interested in physical infrastructures such as building management and energy monitoring. We've collected several gigabytes of sensor data since June 2003 from sensors pervasively deployed throughout one building. We're targeting an additional building this summer, and we plan to have thousands of sensors deployed by summer 2005. For more information or to obtain data, contact Michael Bigrigg at bigrigg@cmu.edu.

MONITORING EARTHQUAKE-INDUCED LOADING WITH CAMERA NETWORKS

Tara C. Hutchinson and Falko Kuester, *University of California, Irvine*

The Visualization and Interactive Systems group (vis.eng.uci.edu) at the University of California, Irvine is developing a specialized network of high-speed cameras for monitoring and tracking nonstructural elements within building structures. Teamed with the University of California, Los Angeles (nees.ucla.edu), the group is planning a full-scale vibration experiment on a vacant structure damaged during the 1994 Northridge earthquake. The building of interest is a four-story office building in Sherman Oaks, California. The investigation has two primary objectives:

- Characterize the seismic response of an important class of equipment and building contents
- Study the applicability of tracking this response using arrays of image-based monitoring systems

Of interest to the pervasive computing community—particularly in its construction of ubiquitous software layers—is how we apply, integrate, and control different monitoring devices throughout the structure. We control the entire hardware-monitoring system remotely from the building exterior to ensure the testing crew's safety (dynamic loading is input into the structure using large linear and eccentric-mass shakers). In total, we plan to deploy and independently control 12 high-speed charged-couple-device cameras (four cameras in each of three rooms) acquiring images at 80 frames per second, three USB-based Web cameras, one GPS system for time stamping, a gigabit Ethernet, and a dedicated data-acquisition system for capturing analog sensing measurements. Remote system control is invoked across an 802.11g wireless network. Analog (wired) sensors include approximately 15–20 piezometric accelerometers and 10–15 string potentiometers. We use the Network Time Protocol to synchronize all computational platforms via the dedicated high-speed gigabit Ethernet network. The designed system will acquire nearly 15 Gbytes of data per minute.

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Testing this system in the field under realistic loading conditions will strengthen the viability of using such network types in real buildings in the future. Our work exploits several issues in designing networked sensing systems for field applications:

- Viability of high-speed networks of sensors under adverse conditions (in this case, earthquake loads)

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- Communication with a variety of different sensor types
- Interpretation capacity of the sensed information (by a remote user)
- Network latency and failure tolerance under high-demand conditions (high rates of acquisition, through adverse conditions)

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MIN: MIDDLEWARE FOR NETWORK-CENTRIC UBIQUITOUS SYSTEMS

Lu Yan, *Turku Centre for Computer Science and Åbo Akademi University*

Historically, ubiquitous systems have been highly engineered for a particular task, with no spontaneous interactions among devices. Recent advances in wireless communication and sensor and actuator technologies have given rise to a new genre of ubiquitous systems. This new genre is characterized as self-organizing, critically resource constrained, and network-centric. The fundamental change is communication: numerous small devices operating collectively, rather than as stand-alone devices, form a dynamic, multihop routing network that connects each device to more powerful networks and processing resources.

At the Turku Centre for Computer Science, we're working on middleware support for these kinds of network-centric ubiquitous systems based on an overlay network framework. The framework, called MIN (Formal *M*ethods *in* Peer-to-Peer *N*etworking),[1] is an integrated architecture that lets us define a unified networking environment, exploiting advantages of both peer-to-peer and mobile ad hoc networks (MANET).

We're exploring how to solve communication problems in network-centric ubiquitous systems. Such systems require

- A self-organizing infrastructure
- Dynamic topology
- A hop connection
- Decentralized service
- Integrated routing
- Context awareness

So, we're designing middleware that can provide network connectivity in a decentralized fashion and use a self-organizing infrastructure to improve the availability of today's ubiquitous networks. We built MIN on top of an application-level P2P overlay over a link-level MANET, but the architecture isn't specific to the implementation environment. The design strategy is to reduce the dependence of networking on wired and wireless infrastructures, thus extending the reachability of current ubiquitous networks and increasing their resilience to failures and attacks.

With the middleware, we can combine ad hoc wireless networks with infrastructure-based networks through ad hoc communication between them. After establishing basic connectivity, ubiquitous devices could self-organize and cooperatively provide network services that are normally provided by infrastructure servers, which are often absent in ubiquitous computing environments.

For more information, contact Lu Yan at lu.yan@ieee.org.

Reference

1. L. Yan et al., "Towards an Integrated Architecture for Peer-to-Peer and Ad Hoc Overlay Network Applications," *Proc. 10th IEEE Int'l Workshop Future Trends in Distributed Computing Systems* (FTDCS 04), IEEE CS Press, 2004, pp. 312–318.

DESIGNING UBIQUITOUS SYSTEMS THROUGH ARCHITECTURAL REFLECTION

Francesca Arcelli, Claudia Raibulet, Francesco Tisato, and Marzia Adorni, *Università degli Studi di Milano-Bicocca*

We're in the age of ubiquitous computing, where computers and information are everywhere and we have multiple ways of accessing and exploiting them. So, we must consider several relevant features when developing new systems, such as complex multimedia, multichannel, and mobile distributed systems. These features include context awareness, location awareness, self adaptation, service-orientation, quality-of-service support and awareness, and negotiation capability (to solve conflict resolution). In this scenario, software architectures play a central role.

We've designed a reflective architecture for *multichannel adaptive information systems* (the MAIS project). Architectural reflection is an emerging research topic that lets information systems observe and control their own structure and behavior through reflective knowledge. One of the principal difficulties raised by architectural reflection relates to understanding reflective knowledge and its proper design, implementation, and use. In our context, the reflective knowledge is QoS-oriented in that it captures the QoS features that the system components exhibit. We're interested in capturing the critical nonfunctional requirements that can drive architectural decisions and validate the architecture. We aim to explore how a system's architecture can express the expectation of QoS attributes and dynamically adapt itself in a changing environment to achieve such attributes. This will make it easier to develop QoS-demanding applications.

We'd also like to explore how our architecture could be used as a service-oriented architecture, where the interaction with the services follows a contract—that is, specifying the requests and responses from the services and letting the contract specify QoS levels.

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INTERACTION METAPHORS

Christoph Endres, *German Research Center for Artificial Intelligence*
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The FLUIDUM project (*Fl*exible *U*ser *I*nterfaces for *D*istributed *U*biquitous *M*achinery) of the German Research

Council (DFG) is investigating interaction metaphors for instrumented environments, taking them as example scenarios for ubiquitous computing. Researchers are questioning how people will interact with disappearing, ubiquitous computers in the near future. They're also researching how we'll develop a new interaction standard for these environments—one that provides a degree of standardization similar to the WIMP (windows, icons, menus, pointing devices) metaphor for desktop computers.

Investigating these questions implies first constructing such environments. Fluidum addresses instrumented environments at three different scales—the desk, room, and building levels. Like the window manager in WIMP GUIs, an environment manager provides basic functionalities. The setup of instrumented environments already poses interesting questions in itself, such as hardware access and management, API design, and device classification.

Our current prototype of a hardware and environment management API provides a flexible approach to classifying hardware. Instead of using a fixed taxonomy, we can use devices that provide and are described by a list of immediately and remotely accessible features. A central device manager provides a matchmaking mechanism between devices and their features on one side, and the applications wishing to access them on the other.

In addition to this centralized manager, which is an obvious bottleneck in otherwise highly distributed environments, we're investigating alternative decentralized approaches, such as a P2P architecture. See www.fluidum.org for more details.

APPLICATION MODELING FOR CONTEXT AWARENESS

Maja Vukovic and Peter Robinson, University of Cambridge

At the University of Cambridge, we're exploring computer application models that adapt to their context. Motivated by the complexity required to support context awareness, we propose constructing context-aware applications as dynamically composed sequences of calls to Web Services. Different service compositions of such sequences result from different contexts such as available resources, location, time constraints, and user requirements. Contextual changes might trigger further recomposition during services execution, causing the application to evolve dynamically.

To select Web Services and their execution sequence, the system architecture employs AI planning technology. Goal-oriented inferencing from the planning offers a solution to Web Service composition because it can make the possible operations explicit by employing expressive representation formalisms to specify the operations' preconditions and effects.

Using the proposed approach, we're dynamically synthesizing features of collaborative software to connect and coordinate users who might be working on a variety of platforms and environments. Initial experiments show that planning can be completed in real time.

Our current work involves investigating techniques for supporting nondeterminism, motivated by the dynamism and unpredictability of pervasive computing environments. Furthermore, as applications shift toward operating over a large physical space and serving a large, continuously changing user population, the architecture must be able to satisfy multiple service composition requests. It must also deal with an increasing amount of contextual data.

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ACKNOWLEDGMENTS

The IBM Zurich Research Laboratory supports this work.