Editor: Mary Baker ■ HP Labs ■ mary.baker@hp.com

Real-World Challenges of Pervasive Computing

Albrecht Schmidt, Sarah Spiekermann, Anatole Gershman, and Florian Michahelles

The idea of pervasive computing has been around for more than a decade, and we're seeing more and more real-world deployments of the technologies. At the Pervasive Technologies Applied workshop on 7 May (as part of Pervasive 2006), about 30 people met to discuss the challenges of deploying RFID technologies, sensor networks, and their related applications. The participants were mainly researchers from US, European, and Asian academic institutions and industrial research labs.

The presentations and discussions made plain that many issues easily solved from a technical perspective in laboratory settings might turn out to be major obstacles when you try to solve them in the real world. In particular, requirements engineering seems to be a challenge if you want usage across partners in a supply chain. Furthermore, privacy and acceptance issues could become major impediments to deployment.

FINDING A "ONE FITS ALL" SOLUTION

Several presentations showed that defining appropriate technological standards for the myriad supply chain partners is crucial for deployment success. Leena Ukkonen and her colleagues (Tampere Univ. of Technology) reported on requirements for identifying industrial paper reels. Here, to build the application platform, the researchers had to resolve different industry partners' competing requirements in terms of reading distance, preferred frequency, and tag location. Christian Flörkemeier and his colleagues (ETH Zürich) described item-level tagging in the ski industry, where similar issues arise regarding conflicting requirements.

Defining appropriate technological standards for the myriad supply chain partners is crucial for deployment success.

In the ensuing discussion, participants suggested that disparate requirements might trigger demand for the inclusion of multiple tags in each product. Both presentations also raised the question of the economics of tag integration. The participants generally acknowledged that tag integration is financially beneficial if benefits accrue across the supply chain.

Christian Decker and his colleagues (Univ. of Karlsruhe and SAP Research) looked at how tags and sensor nodes with enhanced capabilities can benefit business processes, particularly in the case of hazardous-materials handling. Attaching computation power and sensing capabilities to objects lets you monitor processes more precisely and allows early intervention in the case of process difficulties.

The participants concluded that, owing to the lack of a predominant killer app for RFID technology, one approach is to identify several applications across the supply chain that generate enough return on investment to justify RFID funding. The overall challenge, accordingly, is to define the proper sequence of implementing those applications to

- gain experience and improve the technology, and
- generate sufficient ROI to continue with the stepwise introduction until, finally, the entire supply chain benefits from RFID.

Furthermore, the discussion made it clear that in many cases the manufacturer might be the best suited to drive the development. Incorporating RFID into products before customers demand such integration will allow the manufacturer more choices of how to do it.

TOWARD IMPLICIT INTERACTION

The workshop included several examples of how to realize implicit interaction. José Bravo and his colleagues (Castilla-La Mancha Univ.) reported on a system that supports hospital work processes. In the discussion that followed, participants commented that when you use information to improve accountability, the users themselves must gain a large-enough advantage from the technology to accept it.

Michael Crawford and his colleagues (IBM Software Group and University

Published by the IEEE CS and IEEE ComSoc ■ 1536-1268/06/$20.00 © 2006 IEEE

CONFERENCES

College Dublin) described their experience using wearable RFID tags to support meetings and room bookings. While deploying the technology, they encountered various problems, particularly with read accuracy. So, they had to build a customized reader to accommodate the application requirements.

Their experience reflected a recurring theme at the workshop: people had to build their own readers or tags to cope with requirements.

NEW TOOLS WILL EMERGE

Mareike Kritzler and her colleagues (Univ. of Münster) gave us a glance at the future science that pervasive technologies will enable. They used RFID to track laboratory mice in a seminatural environment. This technique provided continuous, complete tracking instead of traditional manual observation, which is sporadic and error prone. In the following discussion, the participants commented that sensor networks show similar potential for sensing and visualizing phenomena that couldn't be tracked before. Pervasive technologies can let you acquire a huge amount of data that's spatially and temporally referenced.

The participants' general opinion was that the development of these tagging and tracking technologies might have an effect on science similar to that of the invention of the microscope: making things visible that weren't so before. The researchers' experience, however, showed that it's vital for the scientific community (biologists, in this case) to adopt these new technologies and be open to new research processes.

SURVEILLANCE: THE KILLER APP FOR SENSOR NETWORKS?

Various presentations involved research on surveillance using sensor networks or tag tracking. Christopher Wren and Yuri Ivanov (Mitsubishi Electronic Research Labs) described a network of distributed cameras and motion sensors. Using additional sensors to add meta-information to accumulated video material seems an important and promising step forward. The amount of data being stored is already too huge for current technologies. Having the means to meaningfully access and query the collected data is essential. Here, in particular, spatial queries are of interest.

Valery Petrushin and his colleagues (Accenture Technology Labs, Chicago) and Michele Bezzi and Robin Groenevelt (Accenture Technology Park, Sophia Antipolis) commented on issues related to applying reasoning to indoor surveillance. A central consideration is that when modeling individuals' location and behavior, you must make probabilities an inherent part of the model.

Generally, the audience was deeply divided about surveillance—not from a technical perspective, but regarding the business case, user acceptance, and ethics. An interesting discussion arose around using physical activity and proximity in the office (who is close to whom for what time) to analyze social networks. The question was whether people would opportunistically adjust their behavior to the technologies to mimic expected behavior patterns, while impairing their productivity and social interactions.

Providing users with an acceptable return for their privacy investment seems essential for gaining acceptance.

DEPLOYMENT AND ACCEPTANCE

Albrecht Schmidt (Univ. of Munich) led a panel discussion that assessed technical and business issues as well as security and privacy. Panel member Sarah Spiekermann (Humboldt-Univ. Berlin) reported on a large technology-acceptance study of RFID use in the retail sector. She highlighted the importance of trust in the technology supplier and stressed the necessity of providing benefits for users to gain their acceptance. Michael Beigl, a cofounder of Particle Computer, discussed bringing a research prototype of a sensor network into the market. His experience showed that in many cases requiring full support for the supply chain, RFID might not be sufficient. Sensor networks can provide the required additional benefits; however, price still seems to be the main obstacle for introducing the technologies.

Anatole Gershman, head of Accenture Technology Labs, presented a recent project that introduced RFID in passport documents to enhance and speed up border checks. Accenture discovered that you need to start with applications that provide some immediate benefit, even if the results aren't perfect. In the border-check project, information used by the customs officer is prefetched on the basis of an RFID read.

The Vienna Marathon, which took place the same day as the workshop, provided an opposite example. More than 24,000 tags were distributed to the runners to measure their time. A requirement for this application was that all tags must be read; it would be unacceptable if a participant didn't get his or her time measured correctly.

The panel discussion was controversial at points; pervasive technology's acceptance is a central issue and can be achieved by various means. Providing users with an acceptable return for their privacy investment seems essential for gaining acceptance. However, one participant also stated that "privacy is sacred but cheap"—that is, people might believe that privacy is extremely important, but it's also easily dispensed with. This led to the questions of whether we as a society need to reach an agreement about these issues and whether we need ethical guidelines. Even from a purely business perspective, it might be important to have accepted guidelines or even laws to avoid backlash when people feel that they're being tricked.

Another hotly debated issue was how tracking, surveillance, and sensor network technologies make it easier to

acquire information about individuals and processes remotely. So, spying on someone or something becomes much easier. Before pervasive technologies, much information might have been available, but you could access it only at much higher cost (for example, hiring a private investigator). One suggestion was to introduce cost or friction into systems to still allow access to information but to make it harder to acquire large amounts.

TOWARD A ROADMAP FOR APPLIED PERVASIVE COMPUTING

The participants' general belief was that many pervasive computing technologies will make their way into the real world. In breakout sessions, they assessed research issues related to RFID and sensor networks.

RFID research issues

Participants discussed seven main issues.

Consumer applications. There might be many interesting consumer applications that you can build using RFID and sensors. However, before you implement any of them, you must consider the trade-off between privacy and benefits.

New business models. When you look at supply chain dynamics associated with the introduction of RFID and sensors, it becomes apparent that we need more research on cooperative strategies and suitable standards.

Health issues. So far, little research has been conducted on health issues related to RFID readers. We need to assess whether long-range readers affect the people who work near them. We also need to ensure that continuous exposure has no negative effects.

Data handling, distribution, and mining. Comprehensive models that support handling of data and data mining as well as correlation over space and time will improve the usefulness of data collected. Of particular interest are where to store data (on the tag, in the supplier's systems, in customer systems, or at a trusted third party) and how to organize sharing along the supply chain.

Benchmarking and usage contexts. Several projects showed that individual tags, even from the same manufacturer, behave differently. So, it would be very useful to have benchmarking tests that are accepted and that we can use to evaluate how different tags perform with different readers. Such tests would need to take into account the materials onto which tags are attached and reading environments. We need to understand what determines tags' suitability in different contexts and what the basis is for different quality standards.

Security. RFID involves many security aspects, from encrypted storage on the tag to secure radio protocols or password protection of tags. For many application scenarios, we need to provide practical and secure solutions before we can expect RFID use to increase.

Computation and sensors on RFID. Including sensors in passively powered tags seems a promising research area. Similarly, including more computational capabilities will improve the possibilities for deployments. This will require further research on all levels, from hardware development to applications.

Sensor network research issues

Few sensor networks are installed beyond the research community, and there's little experience with real-world applications that have larger deployments. The following are four essential research challenges whose solution might ease the path to deployment.

Albrecht Schmidt is the head of the embedded-interaction research group at the University of Munich. Contact him at albrecht.schmidt@ifi.lmu.de.

Sarah Spiekermann is the director of the Berlin Research Centre on Internet Economics at Humboldt-University Berlin. Contact her at sspiek@wiwi.hu-berlin.de.

Anatole Gershman is the global director of research at Accenture Technology Labs USA. Contact him at anatole.v.gershman@accenture.com.

Florian Michahelles is the associate director of the Auto-ID Lab at ETH (the Swiss Federal Institute of Technology) Zurich/St. Gallen. Contact him at fmichahelles@ethz.ch.

Flexible system design. The design of flexible systems is essential from both the economic and rapid-development standpoints. System designers should allow flexibility in the placement and use of sensors, especially in regard to processing, memory, communication, and energy resources.

A single standard for high-level communication. Because we have a heterogeneous market and many different companies specializing in sensors, it's important that at least on a high communication layer, systems can interact. So, we need to specify higher-level communication with regard to semantics, syntax, and carrier.

Continued on inside of back cover

of standards at the device-interface level will reduce the development and maintenance costs of device adapters and their corresponding SODA services. However, standards at the services layer can provide the largest leverage for both the device and enterprise markets.

Rapid standardization of device services, device-services transport mechanisms, and tooling will let device manufacturers develop their interfaces and provide SODA services to the enterprise, shifting development responsibility for device adapters and services to the appropriate point in the supply chain rather than forcing enterprise developers to deal with thousands of APIs. For this adoption to take place, the SODA model must evolve with open and accessible standards, which must cover the specific services used within and across enterprises. Reducing the barriers to acceptance requires that the standards be open and part of a community and that samples, examples, frameworks, and tooling be made available through reference implementations. We can develop an open community of professionals by having government, corporate, and academic entities jointly sponsor such standards and activities that result in prototypes, pilots, and deployed solutions.

REFERENCES

1. T. Erl, *Service-Oriented Architecture: Concepts, Technology, and Design*, Prentice Hall, 2005.
2. D. Krafzig, K. Banke, and D. Slama, *Enterprise SOA: Service-Oriented Architecture Best Practices*, Prentice Hall, 2005.
3. T. Erl, *Service-Oriented Architecture: A Field Guide to Integrating XML and Web Services*, Prentice Hall, 2004.
4. H. Havenstein, "SOA App Quickly Boosts Storm Response," *Computer-World*, June 2006; www.computerworld.com/action/article.do?command=viewArticleBasic&articleId=112207.
5. C. Koch, "How SOA Really Works," *CIO*, Aug. 2005; www.cio.com/blog_view.html?CID=10591.
6. A. Stanford-Clark, "Coupled or Decoupled Plus Heavyweight and Lightweight Delivery Considerations in an Enterprise Service Bus Context," *Middlewarespectra*, Aug. 2004, pp. 26–33.

Randy Carroll is a senior software engineer at IBM. Contact him at rwcarroll@us.ibm.com.

Scott de Deugd is a senior engineer with IBM's Sensors and Actuators Solutions group. Contact him at dedeugd@us.ibm.com.

Kevin E. Kelly is an IBM senior technical staff member. He's also a member of HL7 and serves as the HL7 W3C Liason, and is chair of the W3C Compound Document Formats Working Group. Contact him at kevin.kelly@us.ibm.com.

Bill Millett is a senior software architect in IBM's Sensors and Actuators Solutions group. Contact him at bmillett@ca.ibm.com.

Jeffrey Ricker is the founder and CEO of Distributed Instruments, a company dedicated to providing tools and servers that solve the challenges of sensor fusion. He founded XMLSolutions, the first company dedicated to XML technology. Contact him at ricker@distributedinstruments.com.

Continued from page 93

Resource management and configuration. During deployment, system management and configuration often becomes a major concern and a significant cost factor. Consequently, we need to investigate dynamic resource management and minimal (or zero) configuration.

Business cases and applications. As sensor network technologies mature, research on potential application areas and business cases becomes more important. But this area has seen little research so far. We need to assess real-world applications and business. In addition, research from areas other than computer science, such as marketing, business, and electrical engineering, can provide important input.

As the workshop demonstrated, applied pervasive technologies have great potential. Many technologies will soon mature and provide great opportunities for enhancing processes in industry areas beyond logistics. However, we need to resolve many technical and cooperation issues. Pervasive technologies seem to generate the most benefit when they're tailored to specific contexts. It's also clear that, regardless of technologies and application scenarios, user acceptance is essential; we need to take it into account from the beginning to ensure successful deployment.

ACKNOWLEDGMENT

We thank all the workshop authors and participants for the fruitful discussion and valuable input for this article. All papers are part of the *Proceedings of the Pervasive 2006 Workshop Pervasive Technology Applied—Real-World Experiences with RFID and Sensor Networks*; most are available at www.hcilab.org/events/pta2006/proceedings.htm.