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Sensor-Based Information Appliances

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The computing industry has passed through a rapid sequence of technological phases: central computing with mainframes (1950s through the 1980s), personal computers (1980s to present), and computer networks (1990s to present). A fourth era is now emerging—as computers become ubiquitous, technology more noticeable by its absence than its presence [1], [5], [10], [17], [20]. This article discusses intelligent sensor environments and pervasive computer architectures that may be able to support a new generation of *information appliances*.

Mass-produced computing devices are starting to appear. The Clarion AutoPC provides integrated communications, computing, navigation, car control, and an entertainment system [7]. The NCR Microwave Oven/Home Banking Terminal and the Electrolux Internet Connected Screen Fridge hint at home management [16].

Electric servo appliances are also examples of pervasive technology [3], [6]. The average North American home contains two dozen or more electric motors. A multitude of sensors gather the information needed to control them. Because they are all buried inside many appliances (vacuum cleaners, microwave ovens, refrigerators, VCRs, etc.), we have difficulty identifying them, and we actually don't care where or how many there are as long as they do their jobs. In the future, the same will be true with computers, most of which will be hidden in information appliances [17]. These new appliances are "smart devices" embedded with microprocessors that allow users to plug into intelligent networks and gain direct, simple, and secure access to both relevant information and services. These devices are as simple to use as calculators, telephones, or toasters. Pervasive computing envisions the "net-

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worked home," where domestic devices can interact seamlessly with each other and with both local, in-home, and external networks. Using the existing home infrastructure based on open industry standards, we will be able to integrate the home network with external networks to easily manage home devices, both locally and remotely.

The advent of pervasive computing marks an urgent need for a new generation of intelligent sensing agents and information appliances. It will also demand environments for resource management of broad applications involving loosely coupled, event-driven, diverse information appliances.

Intelligent Sensing Agents

The development of *intelligent sensing agents* and sensor-based information appliances will spread pervasive technology to a multitude of human activities such as mining and manufacturing, security, transportation, sports, and health care. This technology, when integrated with the emerging infrastructure for global information, will have a profound impact on all of our activities. It will open business opportunities of a similar or even bigger scale than what we currently experience with the Internet.

User-centered technology integrates computers, sensors, and actuators into task-specific appliances—all the power of information without the hassle.

As their perception, intelligence, and networking abilities grow, electric appliances evolve into information appliances representing the next information-intensive, evolutionary stage for the pervasive computing paradigm. Donald Norman makes a compelling argument for the information appliance as being, "the natural successor to today's [computer] complexity...through the user-centered, human-centered, humane technology of appliances where the technology of the computer disappears behind the scenes into task-specific devices that maintain all the power without the difficulties" [17]. The business model for this disruptive technology shifts from the technology-driven computer industry to the consumer-driven model of the consumer appliance industry.

The nature of pervasive information appliances requires distributed rather than centralized architectures to provide a seamless, intelligent connection between perception and action [6]. These new developments point to a new type of intelligent control based on a *multisensory perception* of the state of the controlled process and its environment [6], [9]. The use of multiple sensors improves the accuracy, cost-effectiveness, and robustness of the perception process. Global models, built and maintained from information gathered by a multitude of sensors, provide a common abstract representation of the state of the environment. Perception analyzes the global model to infer relationships between different objects.

Sensor architectures integrating both *proprioceptors* (sensors monitoring the internal state of information appliances) and *exteroceptors* (sensors monitoring the state of the environment outside the information appliance), using both sensor and global models, will provide superior modularity, interchangeability ("plug and play"), and transparency. All of these will eventually allow for easier fusion of data derived from sensors and, ultimately, the extraction of knowledge.

Intelligent, task-directed, information-gathering features will allow for a more elastic and efficient use of the inherently limited sensing and processing capabilities of each sensor. Each task that a sensor performs determines the nature and level of the information that is actually needed. Sensors should be capable of *selective environment perception* that focuses on parameters important for the specific task at hand and avoids wasting effort to process irrelevant data. A task-specific, decision-making process will guide the incremental refinement of the model of the environment.

Information appliances should be able to learn and adapt their behavior to changes in their working environment, which includes other appliances and human users. The smart habitat controls of some cars, which offer automatic seat and mirror adjustment and "tilt wheel" to accommodate every driver's preference, already provide such adaptability. These appliances should also be able to deal with multiple redundant communication carriers (intranet, Internet, power lines, wireless, infrared, etc.).

Some of the objectives for the development of sensor-based information appliances are:

- The design of hybrid deliberative / reactive architectures integrating reasoning and behavior-based control functions [4];
- The design of model-based multisensor systems able to integrate a variety of sensors that cover all four phases in the environment perception process: far away, near to, touching, and manipulation;
- The study of new, task-directed, sensor-fusion and learning methods for an active perception, which will allow the information appliance to gather information by interaction with the environment; and
- The design of redundant multicarrier communication systems.

"Symbiont" Intelligent Appliances

Many applications, such as remote sensing, environment monitoring, and telerobotics for hazardous operating environments, require very complex monitoring and control processes and cannot be fully automated. Human operator expertise is still needed to carry out tasks requiring a higher level of intelligence. In such cases, human operators and intelligent sensing systems are called to work together as *symbionts*, each contributing the best of their specific abilities, as illustrated in Fig. 1. Proper control of these operations cannot

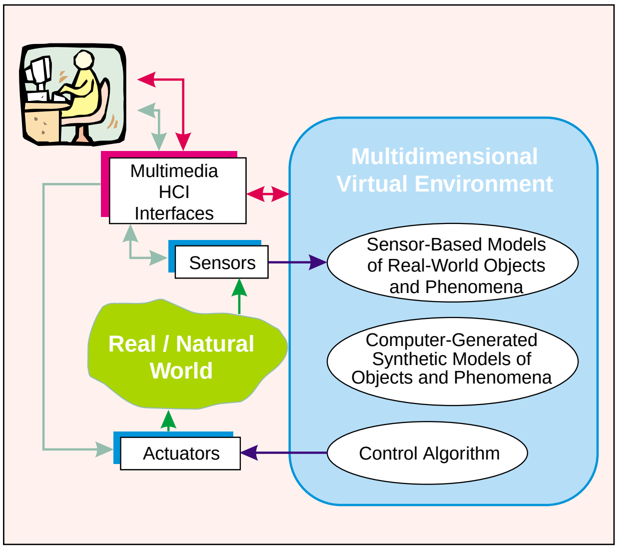

Fig. 1. Human operators and sensor-based appliances work together as *symbionts*, each contributing the best of their specific abilities. Human Computer Interaction (HCI) interfaces provide a telepresence capability, allowing the human operator to experience the feeling of virtual immersion in the working environment.

be accomplished without some telepresence capability allowing the human operator to feel and experience that virtual immersion in the working environment. Furthermore, visual and auditory HCI devices currently available will need augmentation from human-feedback devices that use geometry, force, and touch. Finally, these symbiont intelligent appliances must combine their intrinsic reactive behavior with higher-order, global representations of the immersive virtual reality systems to find efficient solutions to the complex perception tasks.

Management of Heterogeneous Functions

Pervasive computing environments involve interaction and cooperation paradigms for both human-machine and machine-machine interfaces. Machine-machine interaction and cooperation needs a framework similar to human communications and cooperation, which require a common language and an underlying system of shared knowledge and common values. The framework would manage heterogeneous functions and knowledge for diverse computing devices.

A framework for machine-machine interaction should address the communication needs of pervasive devices at a higher level than both the classical communication network protocols and distributed computing frameworks such as CORBA (Common Object Request Broker Architecture), which provide transparency in distribution. We should not realistically expect heterogeneous, pervasive computing devices to talk exactly the same language. However, these devices will share domain-specific knowledge, which may be expressed by each of them in different formats or dialects. Accordingly, the proposed management framework should define a domain-specific semantic for common knowledge and functions. This framework is expected to act as a universal translator between different dialects.

Information appliances and heterogeneous, pervasive computing devices need methods that allow different devices to exchange the grammars describing their own dialects and to learn to understand each other. This way, the devices will be able to advertise their own functions, search and discover providers of required services, and express their needs in a collaborative environment. Fig. 2 illustrates the main communication processes an information appliance is supposed to manage.

Extensible Markup Language (XML) could go beyond its original scope of interchanging structured documents conveniently over the Internet; it could provide high-level protocols for exchanging information between different information appliances [11], [21]. XML provides a syntax for building a formal model known as a Document Type Definition (DTD), which describes relationships between entities, elements, and attributes of each class of documents related to a certain application domain. Since a DTD gives a standard format for information related to a specific domain, it can be used to simplify the exchange of information between different sources that refer to the same domain regardless of the internal format used by each source. Many kinds of domains have standard DTDs, as integrated circuit manufacturers and chemical applications do, for example. XML could also be developed to facilitate the interoperability of information appliances.

Networking Technologies

Existing technologies for global network infrastructure, both wireless (infrared and radio) and wire-line, will be rendered inefficient for connecting a very large number of devices. Bandwidth and resource limitations of the wireless medium currently require that information content be "compressed" as much as possible. Unfortunately, compression leads to low

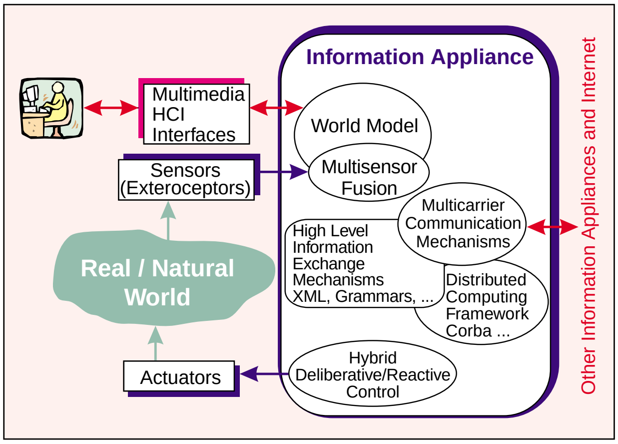

Fig. 2. Information appliances should interact in an unobtrusive way with humans, other appliances, and the rest of the world. A distributed computing framework, together with high-level, information-exchange mechanisms provide a flexible, extensible, open framework that allows for the information appliances' interoperability. Special communication mechanisms will allow the information appliance to handle a variety of redundant and complementary information channels.

redundancy in the information, which makes it vulnerable to errors. Standards such as Personal Area Network (IEEE 802.15), Local and Wide Area Network (e.g., IEEE 802.11), Internet Protocols (Mobile IP, IPv6, RTP/RTCP, RSVP, XTP, etc.), and Wireless Application Protocol (WAP) are already available. However, pervasive computing on a large scale would have problems in size and complexity that require new standards for distributed networks architectures (DNA). Clearly, network technology requires the invention of new solutions.

These new solutions must address both wired and wireless networking issues for advanced networking infrastructure in a cost-effective manner. The following appear to be of an immediate interest; the support of pervasive devices requires policies and protocols for:

- Service admission control and connection establishment, as well as resource allocation and resource adaptation algorithms;
- Efficient transportation of sensor traffic that is quality-of-service capable, error-resilient, and resource allocation-efficient with multiple-access;
- "Intelligent networking" infrastructure that has suitable, distributed architectures; and
- Cost-effective network solutions for environments with no advanced networking infrastructure.

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References

[1] B. Rhodes. A brief history of wearable computing. Available: http://wearables.www.media.mit.edu/projects/wearables/timeline.html.

[2] G. Perlman. Human-computer interaction bibliography. Available: http://www.hcibib.org/.

[3] "Special Issue on Information Appliances," *IEEE Computer Graphics and Applications Magazine*, May/Jun. 2000.

[4] R.C. Arkin, *Behavior-Based Robotics.* Cambridge, MA: MIT Press, 1998.

[5] J. Birnbaum, "Pervasive information systems," *Communications of the ACM*, vol. 40, no. 2, pp. 40-41, Feb. 1997.

[6] A. Brooks and L.A. Stein, "Building brains for bodies," *Autonomous Robots*, vol. 1, no. 1, pp. 7-25, Jan. 1994.

[7] Clarion Corp., Gardena, CA. Auto PC. Available: http://www.autopc.com/walkthrough/communication/.

[8] P. Dabke, "Enterprise integration via CORBA-based information agents," *IEEE Internet Computing*, vol. 3, no. 5, pp. 49-57, Sept.-Oct. 1999.

[9] B.V. Dasarathy, "Sensor fusion potential exploitation—innovative architectures and illustrative applications," *Proc. IEEE*, vol. 85, no. 1, pp. 24-38, Jan. 1997.

[10] M.L. Dertouzos, "The future of computing," *Scientific American*, vol. 52, pp. 52-55, Aug. 1999.

[11] L.M. Garshol. (1999 Aug.). Introduction to XML. Available: http://www.stud.ifi.uio.no/~lmariusg/download/xml/xml_eng.html.

[12] M. Hardwick, D.L. Spooner, T. Rando, and K.C. Morris, "Data protocols for the industrial virtual enterprise," *IEEE Internet Computing*, vol. 1, no. 1, pp. 20-29, Jan-Feb. 1997.

[13] R. Itschner, C. Pommerell, and M. Rutishausser, "Glass: remote monitoring of embedded systems in power engineering," *IEEE Internet Computing*, vol. 2, no. 3, pp. 46-52, May-Jun. 1998.

[14] S. Mann, "Wearable computing: a first step toward personal imaging," *IEEE Computer*, vol. 30, no. 2, Feb. 1997.

[15] S. Mann, "Humanistic computing: WearComp as a new framework and application for intelligent signal orocessing," *Proc. IEEE*, vol. 86, no. 11, pp. 2123-2151, Nov. 1998.

[16] (1998, Sept.) Microwave Madness. *Wired.com*. Available: http://www.wired.com/news/news/technology/story/14949.html.

[17] D.A. Norman. *The Invisible Computer: Why Good Products Can Fail, the Personal Computer Is so Complex, and Information Appliances Are the Solution.* Cambridge, MA: The MIT Press, 1999.

[18] C.M. Pancerella and N.M. Berry, "Adding intelligent agents to existing EI frameworks," *IEEE Internet Computing*, vol. 3, no. 5, pp. 60-61, Sept.-Oct. 1999.

[19] R.W. Picard, "Human-computer coupling," *Proc. IEEE*, vol. 86, no. 8, pp. 1803-1807, Aug. 1998.

[20] B. Rhodes. Context-aware computing (or, why context needs wearables and wearables need context). Available: http://wearables.www.media.mit.edu/projects/wearables/context.html.

[21] World Wide Web Consortium (W3C). (1998, Feb.). Extensible Markup Language (XML) 1.0. Available: http://www.w3.org/TR/REC-xml.

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