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# Sensor-Based Intelligent Appliances

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## Abstract

*The paper discusses features of a new generation of intelligent sensing agents and sensor-based appliances for distributed heterogeneous real-time pervasive computing applications.*

## 1. Introduction

Since its emergence, some forty years go, computing industry has passed through a rapid sequence of technological phases: central computing/mainframe (1950s-1980s), personal computer/PC (1980s-...), computer networks (1990s -...). A fourth era is emerging now, when computers become pervasive, i.e. a technology more noticeable by its absence than its presence, [1]-[9].

The first mass-produced pervasive computing devices are starting to appear. The Clarion AutoPC [4] provides an efficient, reliable and secure integrated communications, computing, navigation, car control and entertainment system. The NCR Microwave Oven/Home Banking Terminal [5] and the Electrolux Internet Connected Screen Fridge [6], allow effortless home management. A good example scenario is given in [2]. Opening the fridge to take out a soda, you may notice that there is only one left. The "smart" fridge recorded that and adds an action item on your shopping list. The next day, as you drive home from work, the GPS-enabled AutoPC in your car, previously informed by your fridge that purchases need to be made, signals that you are near a supermarket. As you cruise the isles of the supermarket, wearing your augmented-reality goggles and your wearable computer [7], a soda supply triggers an object recognition program and an alarm reminds you to buy soda. The same could be done by your pocket Personal Digital Assistant (PDA) when sensing the presence of the soda supply.

Another pervasive computing example is given in [8]:

> "Your *intelligent* car develops an engine problem, but instead of flashing you a warning light it sends a message directly to the manufacturer over a wireless connection to the network. The manufacturer's systems diagnose the problem and transmit a fix back to the electronics complex in your car. In fact, that corrective fix is transmitted to all models everywhere in the world, without ever having to notify the owners. .... Instant information on performance is captured and sent immediately into product development and manufacturing. "

Electric servo systems are a good example of pervasive technology, [1]. The average North American home contains two dozen or more electric motors. A multitude of sensors is gathering the information needed to control them. As all these are buried inside many appliances (vacuum cleaners, microwave ovens, refrigerators, VCRs, etc.) we have difficulty identifying them and we actually don't care where and how many they are as long as they are doing their job. In the future, the same will be true with computers, most of which will be hidden in *information appliances*. 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 kitchen toasters. Pervasive Computing envisions the "networked home" where domestic devices can interact seamlessly with each other and with in-home and external networks. Using the existing home infrastructure based on open industry standards, a person will be able to integrate the home network with external networks to easily manage home devices, both locally and remotely.

Recent progress in computer, integrated circuit, and communications technologies allow the use of complex algorithms from various domains (such as signal and image processing, system identification, modelling, control, and AI). It becomes also possible to implement user friendly virtual environments for the development of an ever growing diversity of real-time *intelligent sensing* applications ranging from Computer Integrated Manufacturing (CIM) to smart homes and offices, [10]-[13].

Early digital and computer-based instrumentation architectures and communications standards as *HP-IB* (*IEEE 488)* represented embryonic smart sensing solutions supporting the first generation of computer based industrial applications. Microprocessor controlled sensors and virtual instrumentation integration environments such as *LabView* together with wireless and internet communications allowed to develop a large variety of embedded industrial applications.

The advent of pervasive computing marks an urgent need for a new generation of intelligent sensing agents and sensor-based appliances as well as for related resource management environments to be used in a broader selection of applications involving loosely coupled, event-driven, heterogeneous *intelligent sensing agents and appliances*.

The aim of this paper is to discuss development scenarios for intelligent sensor environments able to support a new generation of *intelligent sensing agents and sensor-based appliances* for distributed heterogeneous real-time pervasive computing applications.

## 2. Sensor-based intelligent appliances

While the smart networked home is a very good showcase for *information appliances*, the development of *intelligent sensing agents and sensor-based appliances* will spread the pervasive technology ideas to other areas of human activity such as mining and manufacturing, security industry, transportation, training and health etc. It is not exaggerate to claim that this technology, when integrated with the emerging global information infrastructure, will have a profound impact on our personal and professional activities, and will open business opportunities, of a similar or even higher scale than what we are experiencing presently with the Internet.

As their perception ability grows, the *information appliances* are evolving into ***sensor-based intelligent appliances*** representing the next evolutionary stage for the pervasive computing paradigm. These appliances will provide a seamless intelligent connection of the perception to action, [14].

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 [14], [15]. The use of multiple sensors is beneficial in improving the accuracy, the cost and robustness of the perception process. World models, built and maintained from information gathered by a multitude of sensors, provide a common abstract representation of the state of the environment. At the perception level, the world model is analyzed 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 sensor-models and world-models will provide superior modularity, interchangeability ("plug and play") and transparence. All these will eventually allow for easier sensor fusion and knowledge extraction.

## 3. Intelligent sensing agents

*Intelligent sensing agents* will be developed as autonomous robot agents carrying out task-directed active investigation of specific environment parameters. Reliable communication modalities will allow them to cooperate in order to monitor the multi-parameter state of large systems.

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 agent. Each task a sensing agent has to carry out determines the nature and the level of the information that is actually needed. Sensing agents should be able of *selective environment perception* that focuses on parameters important for the specific task at hand and avoid wasting effort to process irrelevant data. A task-specific decision making process will guide the incremental refinement of the environment model.

Each intelligent sensing agent should be able to learn/adapt and be able to deal with multiple redundant communication carriers (intranet, internet, power lines, wireless, infrared, etc.).

Some of the specific objectives for the development of these intelligent sensing agents are:

(i) design of a model-based multi-sensor fusion system able to integrate a variety of sensors that cover all four phases in the environment perception process: far away, near to, touching, and manipulation,

(ii) study of new task-directed sensor fusion and learning methods for an active perception which will allow the robot to gather information by interaction with the environment

(iii) design of redundant multi-carrier communication systems for the sensing agents.

## 4. Human-computer "symbiont" sensing systems

Human-computer interaction (HCI) is a well-established field of computer science and engineering, [16]-[18]. The advent of the embedded computing systems led to a system integration approach to HCI design which is quite well summarized by the following quote from [18]:

> "Instead of workstations, computers may be in the form of embedded computational machines, such as parts of spacecraft cockpits or microwave ovens. Because the techniques for designing these interfaces bear so much relationship to the techniques for designing workstations interfaces, they can be profitably treated together."

As the era of pervasive computing commences, portable wireless PDAs or wearable computers will be widely used, [7] and [19].

There are applications such as remote sensing, environment monitoring, and telerobotics for hazardous operating environments requiring very complex investigation processes.

Many of these applications 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. A proper control of these operations cannot be accomplished without some telepresence capability allowing the human operator to experience the feeling that he/she is virtually immersed in the working environment.

Appropriate geometric-, force-, and touch-domain human-feedback devices will have to be developed in addition to the currently available visual and sound HCI devices.

In order to find efficient solutions to the complex perception tasks, these ***"symbiont" intelligent sensing agents*** will have to combine their intrinsic reactive-behavior with higher-order world model representations of the immersive virtual reality systems.

## 5. Management of heterogeneous functions for a large diversity of intelligent sensors and appliances

Pervasive computing environments involve both human-machine and machine-machine interaction and cooperation paradigms. The discussion will concentrate on machine-machine aspects.

We are all familiar with human-to-human communication and cooperation, which require a common language and an underlying system of shared knowledge and common values. In order to achieve a similar degree of machine-machine interaction and cooperation, a framework should be developed to allow for the management of heterogeneous functions and knowledge for a large diversity of pervasive computing devices.

Such a framework should address the communication needs of pervasive devices at a higher level than the classical communication network protocols and even distributed computing frameworks such as CORBA (Common Object Request Broker Architecture) which provide mainly distribution transparency. Heterogeneous pervasive computing devices cannot realistically be expected to talk exactly the same language. However, these devices will share domain-specific knowledge, which may be expressed by each of them in different format/dialect. 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.

In order to provide a flexible extensible open framework, methods should be developed to 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.

## 6. Networking technologies for pervasive intelligent sensing agents and appliances.

As a very large number of devices will be connected through the wireless and wire-line global networks infrastructure, existing technologies will be rendered inefficient; new solutions have to be invented.

Bandwidth and resource limitations of the wireless medium require that information content is “compressed” as much as possible, in order to “consume” the least amount of resource possible. However, such low redundancy makes the information vulnerable, especially in an error-prone environment such as wireless channels and networks.

The nature of pervasive computing and services devices require that the developed architectures should distributed rather than centralized.

*Personal Area Network* (IEEE 802.15) and existing *Local and Wide Area Network* (e.g. IEEE 802.11), *Internet Protocols* (Mobile IP, IPv6, RTP/RTCP, RSVP, XTP etc.) are already available. However, it is expected that the size and complexity of the problem would require the development of new technologies and standards when developing a new Distributed Networks Architectures

(DNA) suitable for the support of pervasive computing at a large scale.

The development should address wired and wireless networking issues looking for the development of cost-effective solutions for environments where deployment of advanced networking infrastructure could be unjustifiably costly. The following appear to be of an immediate interest:

- Service admission control and connection establishment policies, as well as resource allocation and resource adaptation algorithms for the support of pervasive devices.
- Quality of Service capable, error-resilient and resource allocation-efficient multiple-access protocols for the efficient transportation of sensor traffic.
- "Intelligent networking" infrastructure and definition of suitable architectures of distributed nature.
- Cost -effective network solutions for environments where there is no advanced networking infrastructure deployment.

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