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Towards Human-Centered Ubiquitous Computing
– Using a Paradigm Change as a Chance to Strengthen International Technological Competitiveness–

Masao Watari
Information and Communications Research Unit

1 Introduction

The word "ubiquitous" has come to be often heard these days. "Ubiquitous" is derived from the Latin word that means "existing everywhere." It is said that a ubiquitous information society in which computers and terminals can be connected to a network from anywhere will become a reality, bringing people convenient and enriched lives. The evolution of computers from large-scale models to smaller ones and eventually to personal computers has made it commonplace that a single person uses multiple computers. Networks have also made progress driven by mobile broadband technologies almost to the point where communications are enabled anywhere. Only constructing networks and installing computers everywhere, however, are not enough to provide users easy access to the necessary information whenever and wherever you need to get it. A mechanism and technology to exploit the potential of networks and computers are essential in order to let them make good use.

As the diffusion of PCs has reached a level of saturation, the industry, which has been enjoying rapid growth, is approaching a turning point. In addition, while networks have been growing in terms of speed and capacity, the demand for communications has not indicated an increase as great as expected. Information and communications technology (IT) is in a transition now. Even when people are surrounded by a variety of devices, these devices have not penetrated into their lives as technologies with true utility. IT must undergo a transition "from enable technologies for specialists to usable technologies for everyone" and "from computer-/network-centered to human-centered," and this is what is about to begin now. One of major technologies toward realization of this world is "Ubiquitous computing".

Ubiquitous computing is a technology that intends to provide information services "for individuals anytime anywhere, according to the situation" through computers and networks existing everywhere around people. This article describes the current status of ubiquitous computing technology and the challenges it faces. Since ubiquitous computing involves highly potential technological fields to Japan, such as mobile technology and home information appliances, and requires technologies that are not direct extensions of technologies in which European nations and the U.S. maintain strong positions, such as the Internet and techniques to enhance computer performance, it presents an excellent opportunity for Japan to improve its international technological competitiveness. To gain actual competitive strength through this opportunity, research and development in a spiral model in which basic research leads to experimental and applied studies, where next challenges are discovered to be addressed to the basic research stage, must be conducted with a fast pace. Hurdles involved in this process are described below.

2 The vision of ubiquitous computing

The word "ubiquitous computing" was first advocated by Mark Weiser at the Xerox Palo Alto

Research Center in 1991[1]. He did not intend for a superficial computing system in which "computers are everywhere" but "an environment where computing capability is embedded in various instruments and components of offices and homes to allow people to use it without even thinking about it." Ubiquitous computing is beyond carrying a notebook PC and having access to information via a wireless LAN. What he proposed was research on a human-centered computer system in which people can use computers without being aware of them, rather than a computing environment where individuals have to struggle to learn how to use computers.

In ubiquitous computing, numerous sensors and processors exist in everyday life environment so that sensed information and identified locations are used to track people's activities and assist them in whatever they are doing. In the future world, for example, computers will be able to sense your preferences to let you watch your favorite TV programs wherever you are, and you will be able to use a terminal, whether you are at home, in the office or any other place, just like your own PC, which can remind you about something you have forgotten. There will also be assistance systems readily available that support for everyone including the elderly and people with disabilities to access easily transport facilities or public institutions. The goal of

Table 1:Examples of ubiquitous computing research projects

Project	Research body	Time period	Description
TRON Intelligent House	Sakamura &, Intelligent house research group	1988–1990	Home automation experiments. Systems for air conditioning, security alarming, lighting and AV equipment are interconnected and operate in a coordinated fashion.
Position Detection System by Personal Card	Oki Electric Industry, Takenaka Corp.	1988	Studied as part of a research project on an intelligent building but stopped short of commercialization.
Easy Living	Microsoft	1999–	Tracks user activities and controls/manages devices in the room.
Aware Home	GIT (Georgia Institute of Technology)	1999	Keeps logs of users' daily activities and displays the degree of activity (for activity assistance to the elderly).
Oxygen	MIT Laboratory for Computer Science	1999–	A handheld device (Handy 21), An invisible computer (Enviro 21), and An environment-aware network architecture (Network 21).
Smart Dust	Univ. of California, Berkeley, and Intel	1999–	Built a prototype sensor device of a 5mm square (30¢) consisting of a computer, a sensor and communications capability, based on MEMS technology. Demonstrated 800 sensors using multi-hop routing.
Smart Space	Keio Univ.	1999–	Built an experimental system for Smart Space. Prototype systems for location/situation recognition, roaming service, personal message boards, automatic library access control, etc.
STONE ROOM	Univ. of Tokyo	1999–	Built a 150m^2 experimental system. Prototyped a location sensor (Dolphin), a mobile terminal with a laser pointer (Smart Tact), and a pilot communications device of a 10cm cube (U-cube).
CoBIT	National Institute of Advanced Industrial Science and Technology	2001–	Prototyped a compact battery-less information terminal (CoBIT) consisting of a solar cell, an earphone and a reflective sheet.
Smart-its Tag	Univ. of Karlsrule	2001–	Situation recognition with sensors attached to objects in living environments. Capability of actions such as generation of an audible alarm when the distance between two tags exceeds 3m.
Sentient Computing	AT&T Laboratories Cambridge (UK)	2001–	A large-scale experimental system to provide location-based services to individuals in the office with handheld devices (Bats).

ubiquitous computing technology is to provide "services to individuals anytime anywhere, according to the situation." Information and communications technology, which has been making remarkable progress, is now reaching a point where technology-oriented perspectives will be replaced by the pursuit of technologies that are friendly to users and can support user activities in the background.

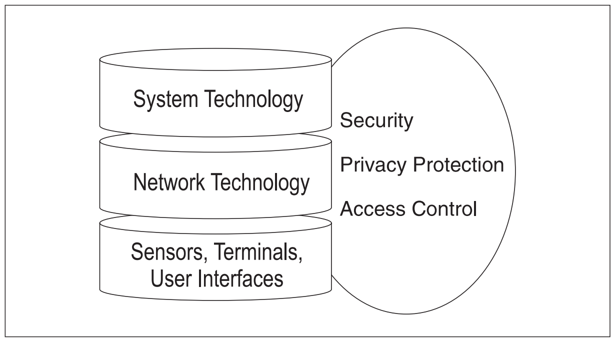
So far studies on office automation, home automation, user interfaces and so forth have been underway in order to support human activities as described above. However, in the early days, such a system requires large-scale computers and a heavily wired network, rendering a huge unrealistic system. Recently, the emergence of smaller computers and network equipment has made human support technologies easier to employ and such technological advance has allowed attention to be paid again to studies on ubiquitous computing as a research field directed toward an ideal system to support human activities. As Table 1, in particular many studies were launched in around 1999 funded by the Defense Advanced Research Projects Agency (DARPA), stimulated from the challenge papers[2] proposing ubiquitous computing in the U.S. scientific societies in around 1998, stemming from researches on the next-generation Internet and the next-generation mobile technologies.

The concept of human-centered computing described above is referred to as ubiquitous computing in Japan, while in Europe and the U.S. the same concept is sometimes known as "pervasive computing" or "invisible computing" from the perspective of computers operating in the background, and also as "proactive computing" or "sentient computing" in terms of empowering users' ability.

3 The current status and challenges of ubiquitous computing technology

To implement ubiquitous computing, technologies in different categories, namely, the terminal/device layer, the network layer, the application layer, and the security layer as shown in Figure 1, are needed. The current status and challenges of the technologies in each layer are discussed below. A report published in June 2002 by the study group on the future outlook for ubiquitous network technology in the Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT) outlines the future of ubiquitous computing as follows. By 2005, information adapted for the user situation such as the time and place will be accessed or transmitted through specific network services. The services will be made accessible to people with disabilities and the elderly via customized terminals. By 2010, information selected for each user based on the user's activity log will become available and transmissible via a personalized terminal over any network. The present state of these technologies and the future challenges in researches on them are described below.

Figure 1:Technologies of Ubiquitous Computing



3.1 Sensors, terminals, and user interfaces

For ubiquitous computing, which starts with gathering information in the real world, different types of sensors and terminals are being studied. User interfaces to exchange information with users also need to be devised to accommodate diverse practical situations.

(1) Sensors

The device that sensors real-world situations must have three functions in compact form: sensing (sensing the situation), computing (information processing), and communications (communications with the network).

In the Smart Dust project[3] of the University of California at Berkeley (UCB), MEMS (Micro Electrical Mechanical Systems) technology has been employed to create a sensor device of a 5mm square that contains the sensing, computing, and communications functions.

A lot of these devices have been placed in a target space in order to gather environmental information. To conduct an ecological survey on birds' habitats on the Great Duck Island, the Smart Dust sensors were left in nests of storm petrels to remotely monitor nest temperature, humidity, etc., in real time.

Keio University, the National Institute of Advanced Industrial Science and Technology and others have been developing in the SELF (Sensorized Environment for LiFe) project[4] a system that consists of a number of sensors embedded in the living space to observe their physiological conditions and activities to provide assistance to them. If the sensors are connected to a network, they detect blood pressure, temperature, the pulse rate and so forth which can be recorded for management of fundamental health data. The researchers are seeking to apply this technology to remote assistance services for elderly people, specialized medical services and emergency medical services in areas such as medicine, nursing care and welfare. To give a feeling of security and confidence to the people who would receive such services, technology for the rigorous management of personal information is certainly essential. Moreover, if the sensors were installed in a wider range of public spaces and connected to the network, safety and security in public spaces could be improved through their applications for environment monitoring, traffic monitoring and control, and crime prevention. Further development in this research field is much awaited.

Studies on sensor devices have been actively conducted in Japan as well. Recently commercialization of a radio frequency identification (RFID) tag without a battery (see the article in the nineth issue for details), which is the simplest form of sensors, was demonstrated. The RFID tag contains an IC chip and an antenna and responds to external radio-wave signals. Its processing capacity, though not comparing to that of a computer, is enough to read and write simple information such as product identification codes. The captured information is transferred to the network through a reader/writer to help identify the location and the condition of the object it is attached to. The technology is quickly finding wide application in areas such as distribution management. In addition, when linked with a guidance system, RFID can assist individuals in their daily lives. For example, an RFID tag attached to an airline ticket could guide the ticket holder from the check-in counter to the gate in an airport equipped with navigation displays having built-in RFID readers. Similar user assistance systems that are friendly even to the elderly could be built into transport and other public facilities. In the future, we will see user-friendly systems based on RFID technology.

Meanwhile, sensor device researchers face challenges such as the development of long-life sensors with power control capability that operate only when requested, ultra-low power sensor devices, ultra-small computers, and super-micro chip technologies.

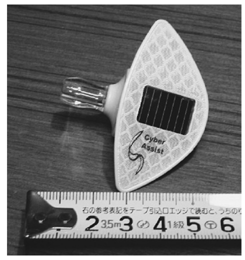
(2) Terminals and user interfaces

The major candidate for the terminal used for ubiquitous computing is the cellular phone, which has come into wide use. However, various forms of terminals may be used. One of them is the wearable terminal (the wearable computer). R&D for this type of terminal is ongoing aiming at a terminal "to wear" rather than "to carry." While products such as head-mounted, wristwatch, and pocketable models have been introduced, they have yet to find wide application besides some particular applications.

The terminals are expected to offer ease of use (usability) and a user interface fitted for the usage. A computer typically interfaces with users via the display and the keyboard. Even a terminal that does not have such user interfaces can be a user-friendly terminal as long as it is supported by an adequate information system (ubiquitous computing environment). For instance, the National Institute of Advanced Industrial Science and Technology has developed some prototype ultra-small mobile devices that combine simple user interface components including a button called a MyButton[5], audio input/output, and optical communications. The Institute is now working on the application of the devices for a guidance system for railway stations and airports. They have designed a pocketable model as well as an earphone type (Figure 2) that is intended primarily for audio communications. In another project, AT&T Laboratories Cambridge has built a prototype of a small mobile device called a Bat[6] (Figure 3), which has two buttons, two LEDs and a beeper for input and output. This project indicates that even a system with a simplified interface can be useful in supporting office operations such as schedule notification and call forwarding to personnel wherever they are. These researches suggest that, depending on the situation, terminals do not always need a display and a keyboard for the user interface. What Japan is waiting to see as a world-leading nation in mobile communications and home information appliances technology are advances in the research on user interfaces that are derived from innovative ideas generated by thinking outside of the traditional computer box.

So-called "smart furniture," a concept of embedding computers invisibly in furniture and building components, is another research subject in this field[7]. Researchers seek to allow computer functions, which are not in the traditional form of the computer, to be used as part of everyday life without making people aware of them. They have prototyped a lighting fixture that is on while someone is present and a chair that automatically turns on the TV when someone sits on it. Collaborative research efforts with designers are critical in this area.

Figure 2: An earphone-type CoBIT, a compact battery-less information terminal



Source: National Institute of Advanced Industrial Science and Technology

Figure 3: A Bat, a compact handheld terminal consisting of 2 buttons, 2 LEDs and a beeper

Source: IEEE Computer, Aug. 2001

3.2 Network technology

Important and necessary technologies in the Network field for ubiquitous computing are communications method for sensor information (sensor networking), information services that can follow changes in the user situation (seamless services), and the optimal network structure including the internet and new sensor networks (network architectures). Researches in these fields are ongoing as described below.

(1) Sensor networking

Communications in ubiquitous computing involve not only person-to-person communications through PCs and mobile terminals but also interactions with devices (objects) that contain embedded sensors. In other words, person-to-object and object-to-object communications are to be performed in addition to traditional person-to-person communications. The number of such objects may far exceed the number of persons. A compatible technology with the Internet that can provide communications between a person and many objects is IPv6, which allows for a large address space. However, communications protocols designed for the Internet require relatively large processing power, which would be an overload for a miniature device like a sensor. Therefore, lighter communications processing methods need to be developed for networks to connect sensors. Where no communication beyond the local range is needed, which is often the case, a sensor network does not have to be a global network such as the Internet. Smaller and lighter operating systems to run on sensor devices are also demanded.

In an environment where a multitude of sensors with wireless communication capability exist, an ad hoc network is often deployed to link them. In an ad hoc network, information to be communicated is relayed from device to device until it reaches the destination, forming a network at this session only. This technique has the advantage of being adjustable to variations in the location and the number of sensors. A challenge for the ad hoc network, a technology that has been developed for military purposes in the U.S., is to reduce the communications processing requirements to enable applications to smaller sensors. Other popular research themes in this field are communications routing control and high-efficiency communications systems.

(2) Seamless services and roaming service

In ubiquitous computing, it is desirable that the same service be provided over dissimilar networks. A video conferencing system, for example, should be available on your desktop PC and also on your cellular phone without interruption of service while you are switching from one terminal to another. The goal here is to implement the video conferencing system on any terminal, whether through a fixed line or wireless communications, which is a concept being studied under the name of roaming service (enabling services to move across heterogeneous networks) or seamless services (services without interruption). In the STONE Room project[8] at the University of Tokyo in collaboration with the Smart Space Lab project[9] of Keio University, the research on roaming service has been conducted as field testing to transfer moving picture services from a cellular phone to projection equipment in the room. For seamless services, whose commercialization is anticipated by users, there are a number of difficult hurdles that must be crossed before they become practical, partly because of the technologies of network architectures and the business models of network services. The first step forward would be the development of technically-efficient systems such as systems to detect available services and to transfer services across heterogeneous networks.

(3) Network architectures

To implement ubiquitous computing over networks, the current network architecture needs to be redesigned. The Internet, the mainstream network of today, has been designed based on a system to enable "equal communications between end user sites," a design principle dating back to the 1970s. In ubiquitous computing, on the other hand, the focus is on facilitating smooth communications around user spaces, where there is no need for the sensors around user spaces to be given equal access to anywhere in the world as would be given on the Internet. Moreover, from the viewpoint of personal information management, a network is required to hold personal information within the local network and to prevent such information from being released to the global network.

Networks have been developed in order to access to every kind of content throughout the world. They, however, can access only to computers and mobile terminals connected to the Internet. The architecture of overall networks poses a major challenge in terms of what kind of network should be used to access information close to us, or information within the so-called "first 10m," and how to connect the local network to the global network.

As the Internet has begun to handle more diverse content and networks have been given greater functionality such as video streams that must be transmitted in real time and content management to protect security and privacy, a fear that may become a reality is that requirements for the Internet, could go beyond the current capacity of Internet technology. In the U.S., research on new network architectures has begun with an eye beyond the Internet limitations. In these activities, however, few researchers have paid attention to ubiquitous computing. In Japan, network architectures have been studied in relation to mobile communications and home networking of information appliances. These activities should broaden their horizons and address the architecture of overall networks including those for ubiquitous computing.

In such research activities on network architectures, for which proposals of new architectures in the basic research phase and the construction of pilot networks in the experimental phase are essential, efforts in both the basic and the application stages are equally important for progress.

3.3 System technology

In the application of ubiquitous computing, technologies for position detection, situation recognition, personalization and dynamically adaptable software are used to construct systems.

(1) Position detection and situation recognition technologies

By capturing the location and the status of users, a variety of services could be provided in accordance with the situation. A number of position detection techniques have been under investigation, including GPS-based systems, locating with sensors that can detect RFID tags carried by users, and a system that identifies the location by analyzing images captured by cameras. In the Sentient Computing Project by AT&T Laboratories Cambridge[6], for example, each user carries a Bat, a compact handheld device that helps track the user through interactions with ultrasonic sensors installed across the building. The user's location information and schedule are used to determine what the person is doing (on the road, attending a meeting, on the phone, etc.) in real time. The system can automatically forward incoming calls to the person's extension number to the telephone nearest to his/her current location unless the person is in an important meeting. The office service system built for the project is now in pilot operation with 50 participants. There is another ongoing project, EasyLiving[10] by Microsoft, which seeks to predict the location and the situation of users through the analysis of images taken by cameras.

(2) Personalization technology

Personalization technology helps systems predict user preferences and customizes them to individual users. Institutes such as MIT (the Context-Aware Computing project), the NTT Software Research Laboratory and NEC have developed techniques to record and analyze users' Web access logs to generate their profiles, which are used to suggest the next page they would open while they are browsing the Web and to pick up the specific information they desire.

Research themes in the field of system technology were used to address part of the research on artificial intelligence and have led to commercialization of some systems to deal with simple situations. In practical applications, however, the user situation should be determined not only from straightforward information but also from interactions with multiple sensors and multiple users. As systems are expected to coordinate to multiple-user environments and make decisions with reference to ambiguous conditions, researchers need to tackle in the future would be techniques for interaction analysis, mediation/consensus building and cooperative problem solving.

For the objective of building up and disseminating ubiquitous computing software, the development of middleware for common use and application program interfaces (APIs) is crucial. Since standardization competition is highly likely in this domain, future movements toward this direction should be carefully monitored.

3.4 Other essential technologies

In ubiquitous computing, personal information is collected to provide assistance to users. To give the users a sense of security, protecting the collected information and preventing it from unauthorized use, or security and privacy protection technology, to be more specific, are essential. In managing personal information, administration rules (the privacy policy) that must be followed need to be set according to the nature of the target information. Elements that should be taken into account during the development of a privacy policy are said to be announcement of collecting personal data, choice and consent about the usage of data, anonymity, localization of the usage of data, and adequate security management for personal data[11]. In addition, as there may be cases where password protection is not applicable such as when services are provided for passers-by, how to conduct authentication and security management in such cases also poses a challenge.

Another possible requirement for ubiquitous computing systems is the capability of cutting off connections with global networks. Also returning individuals' medical information to the patients as soon as they recover completely and removing it from the medical facilities would be desired in order to prevent their sensitive data from being diverted for other purposes. In addition, needed is technology to ensure that the information temporarily released to a third party has been deleted. As mentioned above, enhancement of such privacy management techniques should be sought. Since management of security and privacy is a race against abusers, it is essential to be aware of the need to deploy up-to-date security/privacy protection techniques.

4 Status of the projects in Japan and other countries

In Japan, many of the national projects, led mainly by the Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT) and the Ministry of Economy, Trade and Industry (METI), have focused on building hardware-based infrastructures such as the construction of broadband and mobile networks. However, studying software and applications is indispensable for the research into ubiquitous computing. Although investments in research on software and applications have been gradually increasing since 2002 as shown in Table 3, they should achieve further growth in the future.

By contrast, in the U.S., spurred by the 1999 proposal of the research strategy on Proactive Computing by the Defense Advanced Research Projects Agency (DARPA), ubiquitous computing has become a major research subject. To be more specific, studies on sensor devices and ubiquitous computing spaces (Smart Spaces)

Table 2:Technological challenges to Ubiquitous computing

Technology layer	Technological challenge
Sensors, Terminals, User interfaces	Low-power/long-life sensors Ultra-small computers, Super-micro chips Various kinds of mobile terminals, Smart building components User-adaptable interfaces
Network technology	Light processing for communications, Light operating systems Sensor networks, Ad-hoc networks Seamless services, Roaming service Technology to find the communications destination (naming technology) New network architecture
System technology	Position detection technology Situation recognition technology, Personalization technology Dynamically adaptable software technology
Essential technology	Security technology, Privacy protection technology Information access control technology Network disconnection technology Reliability technology, Fault-tolerant technology

Table 3:Major national projects concerning ubiquitous computing in Japan

Leading body	Time period	Program name	Project themes
Ministry of Public Management, Home Affairs, Posts and Telecommunications	2003–	R&D in the information and communications field	•Super-micro chip networking technologies •Control/management technologies for ubiquitous networks •Authentication/agent technologies for ubiquitous networks
Telecommunications Advancement Organization of Japan	2000–	Innovative Network Project	Part of the R&D on Super Internet Platform technologies s(construction of ubiquitous applications)
	2002–	R&D to extend research achievements	R&D on human-centric ubiquitous network infrastructures
Ministry of Economy, Trade and Industry	2002–	The Program for Upgrading the Telecommunications Foundation	Advanced network: service systems and platforms in ubiquitous environments
New Energy and Industrial Technology Development Organization	2002–	Industrial Technology Research Grant Program	Basic ad-hoc networking software for embedded devices to realize a safe ubiquitous society
Ministry of Education, Culture, Sports, Science and Technology	2000	Special coordination funds for promoting science and technology	Research on basic technologies for distributed real-time networks for human assistance

Table 4:Major national projects concerning ubiquitous computing in Europe and the U.S.

Region	Leading body	Time period	Project
U.S.	DARPA	1999– 2000–	SenseIT,MEMS Smart Spaces
	NSF	2001– 2002– 2003–	Scalable information infrastructure for pervasive computing and access Sensors and Sensor Networks Ubiquitous/Pervasive computing, Distributed sensor networks
Europe	EU Information Society Technology (IST) Research Program	2001–	Disappearing Computer Initiative • Global Smart Space • Designing Interactive, Intergenerational Interfaces for Living Together • Multiple Intimate Media Environments • Dynamic Information Controls in a Hybrid World • Smart Its • Situating Hybrid Assemblies in Public Environments ETC

have been launched. In January 2002, with a view to strengthening measures against terrorism, the Information Awareness Office (IAO) was established, which since then has been integrating and enhancing existing technological development programs concerning information detection and management. The IAO has been pressing ahead with the development of technologies for activity tracking, situation recognition and privacy protection. The National Science Foundation (NSF) has also been contributing by funding research projects on Pervasive Computing and Sensor Network in 2001.

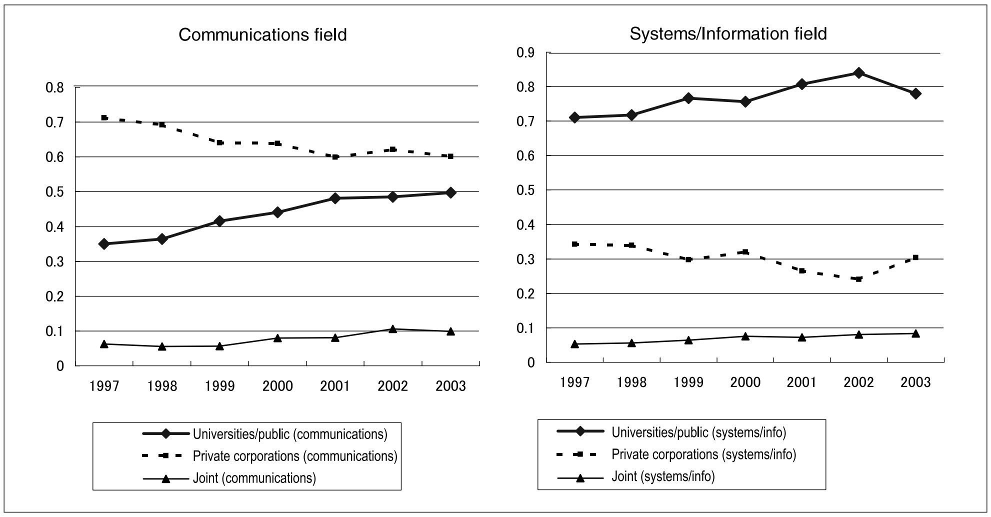
In Europe, the Disappearing Computer Initiative was launched in January 2001 to pursue ubiquitous computing studies through the Information Society Technologies (IST) Research Program, which is funded by the EU. Projects in this initiative will last for two to three years, with a total of 300 researchers annually participating from 37 research institutes across 13 countries. About 50% of the projects' funds will be provided by the EU.

5 Future challenges

In a time when communications "anytime anywhere" are enabled thanks to the advances in broadband and mobile technologies, one may expect a ubiquitous information society is just around the corner. However, ubiquitous computing cannot be realized simply by placing a large number of computers around people's living environments and connecting them to a network. We have a long road to travel to implement ubiquitous computing that can provide adequate assistance as well as usability for users. The technological challenges in implementing ubiquitous computing mentioned in Chapter 3 include many technologies that would not be achieved through the conventional pursuit of higher speed and performance. While the U.S. assumes a dominant and leading position in the area of Internet and software technologies, Japan now has a chance to win the leadership in ubiquitous computing with its technological edge in mobile devices and intelligent home appliances.

The overwhelming presence of the U.S. in Internet technology can be attributed to a solid link between basic and applied researches enabled through business-academia collaboration. The Internet originates in the research network for universities created by DARPA, and then evolved as the ideas generated through basic researches were verified on pilot networks. Similarly, the use of Web browsers started within research communities before they came into widespread use. Although Japanese researchers tend to consider that field testing is synonymous with applied research and thus is the issue to be addressed by industry, such empirical studies allow them to discover future research challenges in each component technology and play a key role of feeding such issues back to the basic research stage. In some IT segments including ubiquitous computing, where concepts in basic researches must be tested on relatively large-scale systems without delay to keep up with fast-paced technological advances, close cooperation between industry and academia is indispensable.

Figure 4:The number of papers presented by Universities/Public institutes and Private corporations in the General Conference of IEICE



Note: "Universities/public" represents universities and public research institutes, and "Joint" represents joint presentations by universities/public bodies and private corporations.

In Japan, industry-academia cooperation is still a relatively new concept and immature. The recent IT slump has weakened IT businesses' research strength. On the other hand, universities have acquired greater amounts of research funds mainly as a result of the Science and Technology Basic Plan. To investigate the recent status of industry-academia joint research activities, the number of papers presented in the general conference of a major academic society in communications and systems/information, the fields that are the basis of ubiquitous computing technologies, was counted. As shown in Figure 4, since the latter half of the 1990s, the percentage of papers presented by authors from universities and public research institutes has been on the rise while the percentage of those by researchers of private corporations has been declining. The percentage of papers jointly presented by universities/public research institutes and private corporations has shown a slight increase but still remains low. While the business sector is withdrawing from the basic research domain affected by the IT slump, universities are still concentrating on basic research activities far away from the practical world. Despite the recent encouragement of industry-academia collaboration, remarkable joint research results have not been appeared. Government should take steps to facilitate more effective collaborative research activities between industry and academia.

6 Conclusion

Research on the realization of ubiquitous computing is aiming at shifting computers and networks from "machine-centered" to "human-centered." This translates into creating computers that are safe and easy to operate from the users' point of view. There are many technical hurdles that must be overcome before reaching this goal because it requires technologies for miniaturization, situation recognition and so forth, which will not be achieved through conventional approaches for advancing performance of computers and networks. While the U.S. assumes a dominant and leading position in the area of Internet and software technologies, Japan now has a chance to win the leadership in ubiquitous computing with its technological edge in mobile devices, intelligent home appliances and other areas, at a time when the IT sector is reaching a turning point.

Technological innovation in the IT sector is ongoing at a dizzy speed. Research and development in a spiral model in which basic research leads to experimental and applied studies, where next challenges are discovered to be addressed to the basic research stage, should be conducted in a short cycle. In recent years, IT businesses' research strength has weakened because of the IT slump, while universities, which are forming organizations to promote industry-academia collaboration, have been engaged primarily in basic research activities far away from the practical world. To move beyond the status quo, not only should both communities jointly work on more specific research themes, the focus of government research funds should also be shifted toward "basic researches that could be extended to future applications."

The goal for Japan is to lead the world in the development of ubiquitous computing technology by promoting and accelerating research and development in a spiral model through joint efforts of industry and academia.

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