A SURVEY OF UBIQUITOUS SPACE WHERE UBIQUITOUS ROBOTS WILL EXIST

Kang-Hee Lee and Jong-Hwan Kim

Dept. of Electrical Engineering and Computer Science, Korea Advanced Institute of Science and Technology (KAIST), Guseong-dong, Yuseong-gu, Daejeon-shi, 305-701, Republic of Korea.
{khlee, johkim}@rit.kaist.ac.kr

ABSTRACT
This paper surveys the birth, the history, and the characteristics of the ubiquitous space. The changes of life which result from the appearance of the ubiquitous space are considered through the scenarios in political, the economic, and the social aspects. Based on the concept of this ubiquitous space, the definition of the ubiquitous robot is proposed and its characteristics and related components such as ubiquitous space, Sobot, Embot, and Mobot are presented.

1. INTRODUCTION
Since the beginning of the world, human beings have developed going through a great number of revolutions and paradigm shifts. Among them, there are representative examples such as the civilization revolution, the industrial revolution, and the information revolution. The main spaces of men’s activity have changed from the primitive space to the electronic space via the physical space by these revolutions. Nowadays the electronic space and the physical space coexist and are continuously co-evolving for the ultimate fusion called the ubiquitous space. The information revolution created the electronic space and succeeded in the unification of a global village by extending men’s activities beyond spatiotemporal limitations. But humans still share the physical activity such as production, transportation, and management as well as there are some limitations in the internet-connectivity environment and the portability of the computer. To overcome these limitations, it is inevitable to construct and put to practical use a new space which can integrate the streams of matter and information anywhere. This is the very ubiquitous revolution, of which the goal is the ubiquitous access without restriction to a time and a situation in this space.

The ubiquitous revolution or the ubiquitous computing was advocated by Mark Weiser who was a researcher of the PARC research center in Xerox. He proposed the following four characteristics of the ubiquitous computing [1]. First, a computer which is not connected with the network is not the ubiquitous computer, second, its human-like interface is invisible, third, it is always possible to use a computer in a real world, not a virtual world, and finally its service changes according to an user’s context at any place, any device, any ID, any time, any temperature, or any weather.

As shown in Figure 1, Mark Weiser classified the evolutionary process of the computer into three phases according to relationship between technologies and humans [2][3]. The first phase is the mainframe era in which many people share an expensive computer, the second phase is the personal computer era in which a man uses his own computer, and finally the third phase is the ubiquitous computing era or the age of calm technology, in which diverse humans use diverse built-in computers unconsciously through networks. To realize the ubiquitous revolution like this he insisted that the researches for five issues such as visibility, complexity, abstraction, connectivity, and invisibility be necessary. Visibility means that we should give shape to the computers in the ubiquitous computing era after ten years based on present published papers and theories. Complexity means that network-based applications suitable for the ubiquitous computing era should be proposed. Abstraction means that the ubiquitous computers based on nanotechnologies or parallel systems should have lower cost, higher tech, and higher integration. Connectivity means that the ubiquitous network should provide clients with largescale computing space through high-speed, security, and effectiveness of internet and other communications under the guarantee of broadband channels. Finally, invisibility means that the user interface should develop from the present computer-centered interface such as a keyboard or a mouse to the human-friendly interface such as wearables. Thus the ubiquitous revolution started to be systemized based on Mark Weiser’s thoughts and its meaning has been growing definite along with the progress of diverse technologies.

In this paper the birth, the history, and the characteristics of the ubiquitous space are presented. The changes of life which result from the appearance of the ubiquitous space are considered through the scenarios in political, the economic, and the social aspects and the recent research trends
of the whole world for the ubiquitous computing and various technologies are presented.

Based on the basic ideologies of the ubiquitous revolution in this way, this paper is organized as follows. In Section 2, the birth and the characteristics of the ubiquitous space are presented. Section 3 describes the scenarios for the ubiquitous space in the political, the economical, and the social aspects. Based on the concept of this ubiquitous space, Section 4 introduces the definition and the characteristics of a ubiquitous robot and its related components such as ubiquitous space, Sobot, Embot, and Mobot and finally concluding remarks follow in Section 5.


In this section, both advantages and disadvantages of the physical space and the electronic space are described. And also the birth and the necessity of the ubiquitous space, which results from the harmony between the two spaces, are described and its components and characteristics are considered.

2.1. The birth and the necessity of the ubiquitous space

Today the physical space which is our life space goes through all sorts of system-symptoms and diminishing marginal productivity. It fundamentally has the disadvantages of limits in the distance, the simultaneity, the storage, and the transportation. Wherever we travel, it costs in proportion to the distance. To negotiate an important business, however far it may be, it is necessary to meet at the same place simultaneously. The weight and the volume of products costs the storage and the transportation much expenses. In the same way, the electronic space has the disadvantages of the bubble space, the information smog, and the capricious consumers. Because there is fundamentally neither creation nor product, it is apt to be spoken ill and to generate the meaningless information smog due to its easy imitability. A great variety of information from hour to hour makes consumers’ fashion capricious. But the physical space has the advantages of the substantiality which means the firm stability while the electronic space has the advantages of the unlimitedness which can realize every conceivable thing. That is, the physical space is stable but resistive against all variations, while the electronic space is unstable but accommodates the creation and the renovation easily. Thus, as these two spaces make up for each disadvantage with their own advantages and coevolve repeating collisions and fusions, the ubiquitous space (u-space) is created [4]. As the government, the society, the economy, and the home are optimized to both the physical space and the electronic space and their activities are organically linked all together, it is also required to make sure of multidimensional mechanisms linking each space in order to maintain their coevolution. For example, there are ‘links between the electronic space and the physical space’ by giving physical objects electronic and intelligent functions, ‘links between the information technology and the ubiquitous ideology’ which always enables free connection with networks without restrictions to time and places, and ‘links among the ubiquitous services’ such that a driving man can check his son’s health while getting intelligent traffic services.

Consequently, it is anticipated that, in the future, the world will consist of numerous u-spaces, where each u-space will be based on the IPv6 or similar system and be connected to each other through wired or wireless broadband networks in real-time, Figure 3.
2.2. Components and characteristics of the ubiquitous space

In this section, the components and the characteristics of the ubiquitous space are described. The first component is the form of the ubiquitous space. It is determined by the following three requisites: i) whether the environments and the objects in the physical space mount chips, sensors, and agents with any function, ii) whether it is possible to recognize a user’s position and ID and to track them continuously, while IPv6 is applied, and iii) how wide the range of the network is to enable free connection and communication with it.

The second component is the function and the service of the ubiquitous space. It provides the space services and forms the spaces of the following functional communities: i) the implementation of the intelligence of objects and environments and the network among them, which coincides with users’ activity and demand and ii) the re-creation of the fundamental functional space such as u-government, u-industry, u-commerce, u-education, and u-home.

The third component is the foundational technology of the ubiquitous space. Based on the following technologies, users can always connect with the ubiquitous network and get the newest service calmly, seamlessly, and variously:

- **technology based on united broadband wire and wireless mobile network**: high capacity multimedia traffic, high speed wireless access, high level mobility management, seamlessly high speed wireless LAN, ultra broadband wireless technology

- **technology loading low price-oriented objects with chips or sensors**: MEMS and embedded computing technology

- **u-platform which affords convenience to users**: the technology for sensing, monitoring, and tracking such as GPS, GIS, Auto-ID, UFID (Unique Feature Identifier), and RFID (Radio Frequency Identification)[12][13] and the interface system such as HCI (Human Computer Interface), TCI (Thing Computer Interface), CCI (Computer Computer Interface), and Interspace

- **u-appliance with multiple functions**: the united multimedia service, the intelligent device suitable for users’ taste, and the device reliable with self-certification and security functions

- **security-based technology**: password, security, and verification

- **fusion of the next generation computing technology such as IT, BT, NT, and RT**: wearable computing [5][6], nomadic computing [7], pervasive computing [8][9], silent computing, sentient computing [10], disposable computing, embedded computing, exotic computing, and implant computing

Thus, considering the characteristics of the ubiquitous space, the basic ideology appears as ‘5 Any of 5C.’ ‘5C’ denotes five components such as ‘Computing,’ ‘Communication,’ ‘Connectivity,’ ‘Contents,’ and ‘Calm’ and ‘5 Any’ denotes ‘Anytime,’ ‘Anywhere,’ ‘Anynetwork,’ ‘Anydevice,’ and ‘Any-service.’ It means that all the operations of ‘5C’ must be guaranteed transcending the limit of the time, the place, the network, the device, and the media. Here ‘Calm technology’ means the technology that users use unconsciously without a user’s intentional connection with the network and is the kernel of the ubiquitous space.

3. THE SCENARIO FOR THE UBIQUITOUS SPACE IN THE POLITICAL, ECONOMIC, AND SOCIAL ASPECTS

In this section, ideologies, services, and required technologies for the ubiquitous space are described in the political aspect, the economic aspect, and the social aspect.

3.1. The ubiquitous space in the political aspect

All over the world today, it can be said that one of the primary factors determining the administrative efficiency of the government is the effective management by the construction of the electronic government infra. But the future ubiquitous government (u-government) will get the maximum administrative efficiency compared to the present electronic government (e-government). For the maximization of the administrative efficiency, the e-government and the u-government are compared with each other, and the development phases of the future ubiquitous services are presented in the following.

First, there is the comparison between the e-government and the u-government as shown in Table 1. In u-government the character of information is changed to the context-aware
knowledge about links among environments, objects, and people in the ubiquitous space such as ID verification, position variation, movement, physical, chemical, and biological states and so on. Along with abundant context-aware information, the efficiency of the u-government is maximized. Because information targets are expanded from existing documents to objects and machines by many kinds of sensors and tags, so decision-makings and follow-up measures are possible in real time. For example, if a government organization buys some machines and equipments with embedded sensors and chips and configures their network, their practical uses and trouble states can be grasped in real time. Therefore the efficiency of the asset management increases by preventing needless overlapped purchase and saving a budget. And also if the traffic control center mounts traffic-flow sensors on some buildings inducing traffic congestion, it can manage them in real time and impose objective rates on them.

Second, the ubiquitous service will be continuously developed based on ubiquitous computing and information technologies as mentioned earlier. The development phases of the ubiquitous service in the u-government are as follows:

- **u-communication**: free communications and managements of business between the governmental organizations or between the government and the people are always possible by any device without restrictions to time and places

- **u-context-knowledge-offering service**: objects and computers track a user and offer the user context-knowledge which the user demands whenever he/she wants

- **u-context-knowledge-notifying service**: objects and computers grasp pre-demanded context-knowledge by themselves and offer users context-knowledge in real time

- **u-behavior-proposing service**: objects and computers guess the situation of the ubiquitous space by themselves and propose users optimal behaviors

- **u-space-intelligent-behavior service**: objects and computers grasp the situation of the ubiquitous space by themselves and take some actions to solve problems for users

The realization of the u-government based on ubiquitous computing, information technologies, and well-organized service development will bring us the administrative efficiency, the public stability, broader personal service, and the reliability and the transparency of the government.

### 3.2. The ubiquitous space in the economic aspect

The economic system of the ubiquitous space will go through two changes remarkably. First, the characteristics of the goods, which is the outcome of the economic life, are changed. The material goods in the physical space changes into the information goods in the electronic space, which finally changes into the space goods in the ubiquitous space. That is, the subject of possession changes into the subject of connection, which changes into the subject of residence. The space goods means main products and services that the ubiquitous space provides to a resident. The value inherent in the space goods is much stabler than that in information goods. Because it is difficult to copy, always accessible, and fixed in itself compared to the information goods based on the dangerous electronic space. On the other hand, the ubiquitous space is the basis of the stable value and the source of the wealth. Second, the space in which the economic activity takes place is changed. It changes from the market in the physical space to internet or networks in the electronic space. Also a community per network in a u-space are created. The mechanism of the price control, ‘invisible hand’ no longer dominates the market but instead the law of increasing returns and the externality of the network will do. For example, as the number of members increases, the attraction of the network increases and it means more increment in the number of members. The linear circulation
like this collapses the existing market logic. The ubiquitous space, the combination of the advantages of the physical space and the electronic space becomes a community where residents and objects are united and then the division between the provider and the consumer becomes ambiguous.

As shown in Table 2, the ubiquitous economy is developing as a concept of the u-commerce, which means the new business system which applies the advanced technology and skills such as the ubiquitous computing, the broadband wireless communication, the portable and the wearable terminal, and the next generation application software to various branches such as the management of shopping and departments, Supply Chain Management (SCM), Customer Relationship Management (CRM), the production control, the management of machines and parts, the transportation, the medical care, and the information service.

The main current of the marketing in the future will be the context-aware marketing which recognizes a consumer’s context and maximizes the efficiency by recommending his/her required products based on recency and freshness [11]. Also the business strategy of the on-off line combination such as ‘Click & Mortars’ will get into the spotlight. Organizations will recognize each member’s context automatically and distribute businesses among members without partiality. Also homes will become the silent self-organizing spaces as productive spaces. That is, the core of the ubiquitous space will be the combination of the inter-space and the hyper-space. The inter-space means a space of contact between spaces and the hyper-space means the organization composed of the electronic space, the physical space, and millions of hotspots where the wireless LAN can be operated. The future Critical Mass (CM) will change from the scale of the production and the distribution to the scale of the consuming space.

Services, convenience, and information productivity of these ubiquitous spaces will be the references of the space goods. While the main issue in the physical space was ‘maximization of the consumer’s possession’ and the main issue in the present electronic space is ‘maximization of the consumer’s connection,’ the main issue in the future u-space will be ‘the optimization of the consumer’s housing facility and the strategy for inter-space management.’

### 3.3. The ubiquitous space in the social aspect

Human beings are social creatures. In everyday life there are many physical spaces such as spaces of dwelling, playing, shopping, learning, working, traffic, and resting. The criteria used to classify these are the connection, the overlap, and the situational change among humans, objects, and places. The connection means the relationship between a housewife, a refrigerator, and a kitchen or between a shopping bag, a department store, and goods. The overlap means the overlap of objects and spaces which many people use commonly as their individual purposes. The situational change means that humans, objects, and places in daily life are not fixed but change continuously by various factors. But in the near future, the ubiquitous technologies will destroy the boundaries between these physical spaces because we will be able to use the resources of any space precisely and
quickly whenever we will need due to the broadband wire
and wireless networks and the mobile networks. At this
time, it is necessary to consider the next generation project
of MIT Media Lab. This project emphasizes the social roles
of the ubiquitous space and goes ahead with five research
consortia composed of Changing Places/House_n, Digital
Life, Digital Nations, Information: Organized, and Things
That Think. The goals of each project are as follows:

- **Changing Places/House_n**: explores how new tech-
nologies, materials, and strategies for design can make
possible dynamic, evolving places that respond to the
complexities of life and emphasizes links between the
home and places of healing, work, learning, and com-
unity [14].

- **Digital Life**: invents and explores new forms of com-
munities through research in structured media, learn-
ing, human expression, interfaces, and agents [15].

- **Digital Nations**: empowers people in all walks of life
to invent new opportunities for themselves and their
society, improving education, enhancing health care,
supporting community development through the in-
novative design and use of new technologies [16].

- **Information: Organized**: makes the means of ex-
pression accessible without diminishing their quality
or complexity, understands how we are limited in our
decision-making capabilities, makes tools that can as-
sist us in decision-making tasks, has basic ‘common
sense’ understanding of our everyday world and the
ability to understand and react to the social and emo-
tional contexts of the user, and leverage the social
intelligence of communities of information creators
and consumers to further the exchange and critique
of ideas [17].

- **Things That Think**: invents the future of digitally
augmented objects and environments and embraces
things that utilize computational capability to serve
important human priorities like facilitating creativity
and productivity, taking control of individual health,
improving safety and well-being, and enhancing in-
teraction and learning [18].

The kernel of the social aspect of the ubiquitous space
is the improvement of the main common spaces. To do
so we should make the most of characteristics of spaces of
dwelling, playing, shopping, learning, working, traffic, and
resting and let these spaces share mutual functions freely,
referring systems, procedures, and spirit of these consortia.
Also, the most important factor for execution of the ubiq-
uitous society is the spontaneities of members in each com-

4. **UBIQUITOUS ROBOT: UBIBOT**

Ubibot is a general term for all types of robots incorporat-
ing software robot (Sobot), embedded robot (Embot), and
mobile robot (Mobot) which exist in the u-space. Ubibot
exists in a u-space which provides physical and virtual en-
vironments.

4.1. **U-space and Ubibot**

A robot working in a u-space is defined as a Ubibot and will
provide various services through any network by anyone at
anytime and anywhere in a u-space.

![Ubibot in ubiquitous space](image)

Ubibot in a u-space consists of both software and hard-
ware robots. Sobot is a type of a software system whereas
Embot and Mobot are hardware systems, Figure 4. Embots
are located within the environment, human or otherwise,
and are embedded in many devices. Their role is to sense,
analyze and convey information to other Ubibots. Mobots
are mobile robots. They can move both independently and
cooperatively, and provide practical services. Each Ubibot
has specific individual intelligence and roles, and commu-
nicates information through networks. Sobot is capable of
operating as an independent robot but it can also become
the master system, which controls other Sobots, Embots and
Mobots residing in other platforms as slave units.

4.2. **Software Robot: Sobot**

Because Sobot is software-based, it can easily move within
the network and connect to other systems without any time
or geographical limitations. It can be aware of situations
and interact with the user seamlessly. Sobot can be intro-
duced into any environment and also other robots as a core
system. It can control or, at an equal level, cooperate with
Mobots. It can operate as an individual entity, without any help from other Ubibots. Sobot has three main characteristics: self-learning, context-aware intelligence, and calm and seamless interaction.

4.3. Embedded Robot: Embot

EmBot is implanted in the environment or in Mobots. In cooperation with various sensors, Embot can detect the location of the user or a Mobot, authenticate them, integrate assorted sensor information and understand the environmental situation. An Embot may include all the objects which have both network and sensing functions, and be equipped with microprocessors. Embots generally have three major characteristics: calm sensing, information processing, and communication.

4.4. Mobile robot: Mobot

Mobot is able to offer both a broad range of services for general users and specific functions within a specific u-space. Operating in u-space, Mobots have mobility as well as the capacity to provide general services in cooperation with Sobots and neighboring Embots. Mobot has the characteristics where mobility can be implemented in various types such as wheel and biped. Mobot actions provide a broad range of services such as personal and public services, and in-house and field service.

5. CONCLUSIONS

This paper introduced the history and the basic ideologies of the ubiquitous revolution and surveyed the birth, the necessity, and the characteristics of the ubiquitous space. Also, the scenarios for the ubiquitous space in the political, economical, and social aspects were presented. Based on the concept of this ubiquitous space, the definition of the ubiquitous robot was proposed and its characteristics and related components such as ubiquitous space, Sobot, Embot, and Mobot were presented.

6. ACKNOWLEDGEMENT

This work was supported by the Ministry of information and Communications, Korea, under the Information Technology Research Center (ITRC) Support Program.

7. REFERENCES