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Ubiquitous Robot: A New Paradigm for Integrated Services

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Abstract—**This paper presents the components and overall architecture of the ubiquitous robot (Ubibot) system developed to demonstrate ubiquitous robotics, a new paradigm for integrated services. The system has been developed on the basis of the definition of the ubiquitous robot as that of encompassing the Software robot Sobot, Embedded Robot Embot and the Mobile Robot Mobot. This tripartite partition, which independently manifests Intelligence, Perception and Action, enables the abstraction of intelligence through the standardization of sensory data and motor or action commands. The Ubibot system itself is introduced along with its component subsystems of Embots, the Position Embot, Vision Embot and Sound Embot, the Mobots of Mybot and HSR, the Sobot, Rity, a virtual pet modeled as an artificial creature, and finally the Middleware which seamlessly enables interconnection between other components. Three kinds of experiments are devised to demonstrate the fundamental features, of calm sensing, context awareness and seamless service transcending the spatial limitations in the abilities of earlier generation personal robots. The experiments demonstrate the proof of concept of this powerful new paradigm which shows great promise.**

I. Introduction

We are upon the threshold of the ubiquitous era. Developments in computer and network technology have hastened this era, which is characterized by objects and devices that are fully networked. Such an environment shall ideally and fully be utilized by highly advanced robots to provide us with a variety of services, at any place, by any device, and whenever needed.

Ubiquitous computing (UC) coined by Mark Weiser [15], motivated a paradigm shift in computer technology, in terms of relationship between technology and human beings. This shift has hastened the ubiquitous revolution which has further manifested itself in the new multidisciplinary research area, ubiquitous robotics, initiating the third generation of robotics following the industrial robot first generation and the second generation of the personal robot.

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The second generation of robotics was characterized by stand-alone type robotic platforms serving as personal robots providing a wide variety of services. This generation however was characterized by the spatially localized entity - the personal robot itself, thereby leading to limitations, which could prevent it from serving humans better. Later advancements in internetworking lead to innovative architectures being researched [5]. Yet the nub of the problem was the limited ability to sense the user’s requirements, since all sensory capabilities were located onto the robot platform, thus introducing spatial limitations in the ability to sense and thus serve.

The ubiquitous robotic systems negate the necessity for personal robotics to utilize this conventional notion of a stand-alone robot platform. This notion forms the crux of the current generation of robotics, that of the personal robot. In this regard, Brady defined robotics as the ‘Intelligent connection of perception to action’ [2]. Ubiquitous robotics lends itself to that description, by allowing us to redefine the interconnection between the three components, intelligence, perception and action, by manifesting them individually as the intelligent software robot - Sobot, the perceptive embedded robot - Embot and the physically active mobile robot – Mobot, respectively, as described in [7]. The interconnection is therefore created through the network and the integration is carried out using the middleware in the ubiquitous space (u-space). Ubiquitous robotic systems are emerging and it is not difficult to imagine their widespread prevalence in the UC era.

The ubiquitous robot system, the Ubibot has been under development at the Robot Intelligence Technology Lab, KAIST since 2000. Following the general concepts of ubiquitous computing it is designed to be seamless, calm, and context aware. This paper describes the architecture and functioning of the Ubibot system including its component subsystems.

Section 2 of this paper defines and describes the ubiquitous robot system along with its constituent components, the Embot, the Sobot, and the Mobot. Section 3 describes in detail the implementation of the Ubibot system including the Embots, the Mobots *Mybot,* and HSR, and the Sobot *Rity.* Section 4 presents some experimental results as a proof of concept. The conclusions are finally presented in Section 5.

II. Ubiquitous Robot System

The ubiquitous robot system as defined earlier comprises of Sobots, Embots and Mobots in their various forms. The ubiquitous robot is created and exists within a u-space which provides both its physical and virtual environment. It is anticipated that in the years to come the world will consist of many such u-spaces, each being based on the IPv6 protocol or a similar system and be interconnected through wired or wireless broadband network in real time.

This can be conceptualized as a networked cooperative robot system. The core intelligence of this system is constituted by software robots. Distributed Embot sensors ensure that the Sobots possess context aware perceptive capabilities. Lastly, Mobots act upon the service requests in the physical domain. Ubiquitous robots will thus be able to understand what the user needs, even without the issuance of a direct command, and be able to supply continuous and seamless service.

The primary advantage of the ubiquitous robot system is that they permit abstraction of intelligence from the real-world by decoupling it from perception and action capabilities. Sensory information is standardized along with motor or action information and this permits, the abstract intelligence to proceed with the task of providing services in a calm and context aware manner.

Ubiquitous robots provide us with services through the network at anytime and anywhere in a u-space through its distributed capabilities provided by the component Sobot, Embot and Mobot systems. Each ubiquitous robot however has specific individual intelligence and roles, and can communicate information through networks.

Some of the integrated services and solutions offered by the ubiquitous robot technology include ubiquitous home services for security and safety, location based services like GIS, health services in telemedicine, ubiquitous learning systems and ubiquitous commerce services.

As mentioned earlier, the ubiquitous robot system incorporates three kinds of robot systems: Sobots, Embots and Mobots under the ambit of its broader definition provided earlier.

A. Software Robot: Sobot

Sobots are the intelligent component of the Ubibot system whose domain lies wholly within the software realm of the network. It can easily traverse through the network to connect with other systems irrespective of temporal and geographical limitations. Sobots are capable of operating as intelligent entities without help from other ubiquitous robots and have and are typically characterized by self-learning, context-aware intelligence and, calm and seamless interaction abilities. Within the u-space, Sobots try and recognize the prevalent situation and often make decisions on the course of action and implement them without directly consulting the user each time. They are proactive and demonstrate rational behavior and show capabilities to learn new skills. It is also totally pervasive in its scope and thus is able to provide seamless services throughout the network.

B. Embedded Robot: Embot

The embedded robots as the name implies are implanted within the environment or upon Mobots. Utilizing a wide variety of sensors in a sensor network, Embots detect and monitor the location of a user or a Mobot, authenticating them and also integrate assorted sensory information thus comprehending the current environmental situation. Embots are also networked and equipped with processing capabilities and thus may deliver information directly or under the Sobot's instructions to the user.

Embots are characterized by their calm sensing, information processing and information communication capabilities. Embots offer great functionality by being able to sense features such as human behavior, status, relationships and also environmental conditions impacting human behavior.

C. Mobile Robot: Mobot

Mobots offer a broad range of services for general users specifically within the physical domain of the u-space. Mobility is a key property of Mobots, as well as the general capacity to provide services in conjunction with Embots and Sobots. The Mobot is usually in continuous communication with the Sobot in order to provide practical services based on information given by the Embot. Alternately Mobots, serve Embots as a platform for data gathering.

D. Middleware

Middleware allows communication within and among ubiquitous robots using a variety of network interfaces and protocols. Middleware usually varies from one vendor to the next depending upon a variety of factors. The selected middleware allows conversion of the constituent entities of the ubiquitous robot system into specific components with respect to the developer, thereby making it convenient to update functions, maintain resources and perform power management. The Middleware structure for a ubiquitous robot system must contain at least one interface and one broker. The interfaces refer to the hardware level interfaces of the communication protocols such as Bluetooth and Ethernet and the software level interfaces like HTTP and FTP. The broker enables the system to make an offer of service irrespective of the operating structure, position and type of interface. This thus enables Sobots to receive information from a wide variety of Embots and to communicate with the Mobots.

III. The Ubibot System

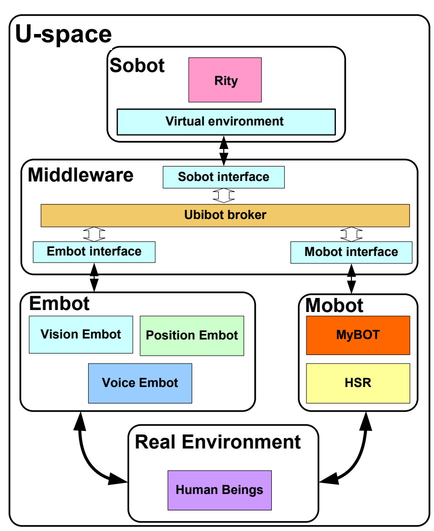


Fig. 1. The Ubibot System Architecture

The ubiquitous robot system, Ubibot, was developed to demonstrate the ubiquitous robot paradigm. It consists of multiple Embots, the Mobots Mybot and HSR and the Sobot Rity. The architecture of the Ubibot system can be seen in Figure 1. The technical aspects of the various component systems are described in this Section.

A. Embots

The Ubibot system uses 3 kinds of Embots. They are the Vision Embot, Sound Embot, and Position Embot.

1) Vision Embot: The Vision Embot, shown in Fig. 2, can detect 10 objects for each color and can perform face-recognition for 10 faces, for a distance within 1m from the USB camera sensor. The face detection algorithm can detect faces within 120 cm of the camera, under various lighting conditions, with an operating time of 50~100ms, images being captured at a rate of 16 frame/sec. The input image is of resolution 320x240 and can have a plane rotation of -15~+15 deg under complex backgrounds of the interior. The face recognition module then acts on the detected face date with an operating time of ~1second, in an average of 2 fame/sec having a plane rotation lying between -10~+10 deg. It transmits the detected results asynchronously to the Middleware at periodic intervals.

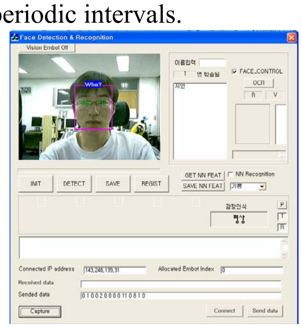


Fig. 2. Screenshot of the Vision Embot client performing Face Detection

2) Sound Embot: It uses a preprocessing algorithm which constantly discriminates against background noise in the process categorizing them into 5 levels (noisy, normal, calm, sudden loud, and sudden calm) and also can recognize 10 short sentences.

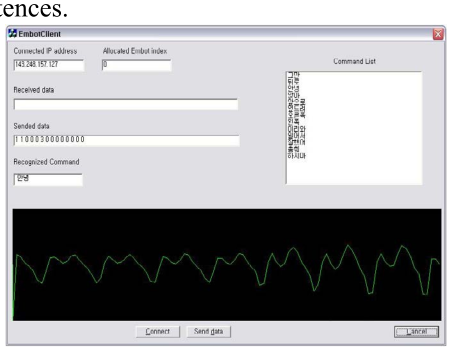
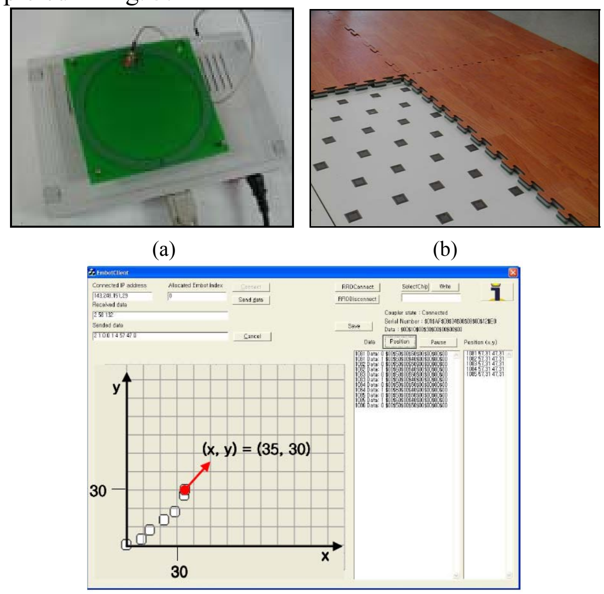


Fig. 3. Screenshot of the Sound Embot Client performing Speech recognition

The processor employed is the speaker-independent multi-voice recognizer which has strong noise endurance. It has a recognition rate of more than 99% in training and in noiseless environments. In more realistic conditions, it has a recognition rate of more than 90% in speech from a randomly chosen speaker approximately 80cms from the microphone sensor in an environment of noise level 60dB with a total running time being around 10ms per speech. The Sound Embot then transmits the detection results asynchronously to the Middleware at periodic intervals of once in 4 seconds. It is depicted in Fig. 3.



(a) (b)

(c)

Fig. 4. The Position Embot showing, (a) the PCB type Antenna, (b) the RFID Array, (c) Screenshot of the Position Embot client window

3) Position Embot: The Position Embot shown in Fig. 3, delivers location of robot, object, and human in 2D (x,y) coordinates with a static measured error of under 3 cm. It uses an array of RFID tags (ISO 15693 Standard Measure) each of which has a range of 18 cm and is spaced at 10cm from each other, with around 256 RFID tags covering a floor area of 1.5x1.5m. The receiver section is composed of a PCB type antenna module coupled with a 13.56 MHz Reader module. An anti-collision function is used to enable the antenna to read all of the tags. The position of the robot is calculated based on a weighted average within a fixed time frame using the collected data as in [4]. The detected cartesian coordinates are transmitted to middleware once every tenth of a second.

B. Mobot: Mybot and HSR

The Ubibot at RIT Lab utilizes two kinds of mobile robots, the wheeled mobile personal robot type *Mybot* and the small sized humanoid robot HSR.

1) Mybot: The mobile robot type Mobot, *Mybot* using a differential drive platform powered by DC motors. It is 31cm x 21cm x 42cm in size and weighs 12 Kg. It has an onboard Pentium III 850Mhz computer handling the drive, control and sensors. It is equipped with six Polaroid 6500 ultrasonic sensors covering 15cm~5m in all directions on the horizontal plane. It has a mount for a Tablet PC which then communicates with the onboard PC to display the Sobot environment in real time apart from handling the wireless network access through a built-in WiFi card. A USB camera is provided to enable the operation of the Vision Embot. The platform can move with a top speed of 70 cm/s and a peak acceleration of 300cm/s^2

(a) (b)

Fig. 5. Mobots: (a) Mybot - Wheeled mobile robot and (b) HSR - Humanoid robot type

As it can be seen from Fig. 5a, it also has 2 arms with grippers at the end, enabling it to provide a wide variety of service. These arms also have additional purpose of serving as the means through which Mybot can emote. Mybot also has an interactive interface in the form of its tablet PC. Once the Sobot downloads itself onto the Mybot, it can be visually seen on the screen.

2) HSR: HSR (*HanSaRam*) is a small sized humanoid in continuous research and development at the RIT Lab since 2000. In its current version developed in 2006, HSR VII, seen in Fig. 5b, measures 52.8cms tall and weighs 4.5kgs. It consists of 13 DC motors in the lower body with 14 RC servomotors in the upper body giving it a total of 27 DOFs. It has a hand with fingers which can flex together. It thus has the ability for fully independent locomotion, sensing and processing, utilizing an onboard Pentium III compatible 666 MHz PC. Currently, stable walking has been achieved using the PO/PC technique [8], [11]. HSR has not as yet been integrated into the ubiquitous robot framework and the development of the behavior mapper needed to map the Sobot behaviors onto that of a humanoid shall be undertaken as a future work.

C. Sobot: Rity

The Ubibot system that was developed utilized the software robot, Rity, which was also designed to fulfill the requirements for an artificial creature. The artificial creature is defined as an agent that behaves autonomously driven by its own motivation, homeostasis, and emotion as in [16], [17], [1], [4].

Fig. 6. The Artificial Creature Rity, the Sobot of the Ubibot system, expressing different emotions

It must be able to interact with humans and its environment in real time. Rity visually resembles a simulated 12 DOF dog with which users can interact in a number of ways as shown in Fig. 6 and in Fig.8. Since the Sobot is the intelligent component of the Ubibot system, Rity has a complex internal architecture with 14 internal states. It has 47 perceptions, exhibits 5 facial expressions, some of which are shown in Fig. 6 and can exhibit a total of 77 behaviors. It has its own unique IP address with which it can be accessed.

Similar to humans, Rity holds several essential internal state components such as motivation, homeostasis, and emotion as in [6], [9], and [10]. It is an intelligent software robot that lives inside the virtual world of a computer network, but interfaces with the real world through the peripheral hardware attached to the network: cameras, input devices, screens, and audio systems. In this way, it is represented on the screen visually as a dog and may interact with humans based on stimuli that it receives from its peripheral sensors, in a manner based on studies in imitating dog ethology [3] and on the 5 factor personality model [13]. The internal architecture of Rity is depicted in Fig. 7.

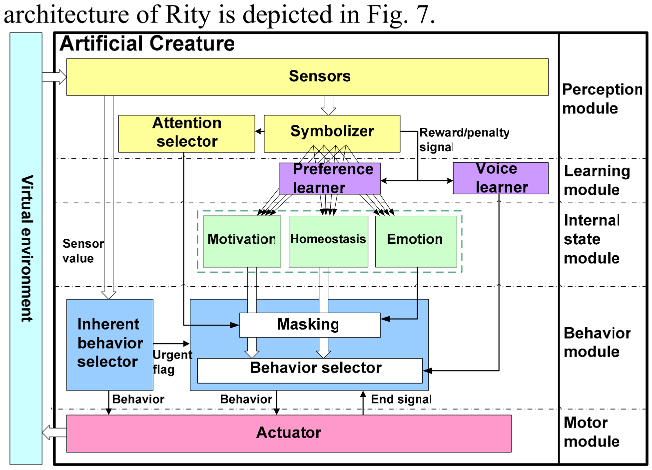


Fig. 7. Internal Architecture of Rity

The general architecture of Rity is composed of 5 primary modules.

1. Perception Module: perceives the environment with virtual or real sensors.
2. Internal State Module: defines motivation, homeostasis, and emotion.
3. Behavior Selection Module: selects a proper behavior for the perceived information.
4. Learning Module: learns from interaction with people.
5. Motor Module: executes a behavior and expresses emotion.

When accessed through a PC, the client window shown in fig.8 displays various parameters and settings for the user.

Rity has also been additionally used for the development of the radical concept of genetic robot wherein robotic genomes encode the artificial creature's personality as in [12]. Its personality is dictated by the artificial evolution process of robotic chromosomes, which is a set of computerized DNA (Deoxyribonucleic acid) code, for the creation of artificial creatures that can think, feel, express intention and desire, and could ultimately reproduce their kind and evolve their species.

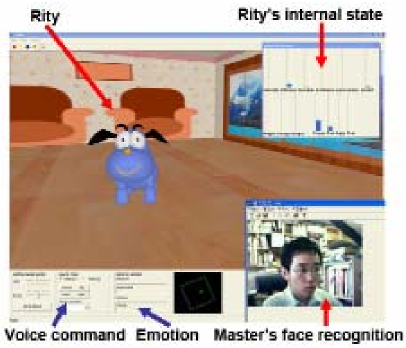


Fig. 8. A screenshot of the Sobot Client window showing its different components

D. Middleware

The Middleware arbitrates between different protocols between Sobot, Mobot and Embot in order to reliably send data. Since all data communication is based on TCP/IP, the middleware is realized using TCP/IP related components provided by Visual C++ 6.0 which is robust in a distributed environment. The Sobot transfer is accomplished through the File Transfer Protocol by using a buffer. The actual data is an abstract arrangement of its individual features encompassing data such as its internal state. The Ubibot broker program handles the transfers. Embot data transfer is done using Server/Client socket programming.

IV. Experiments

Three different kinds of experiments were conducted on the Ubibot system, as a proof of concept, indicating its wider applicability covering a multitude of integrated services as explained in Section 2. These experiments are meant to mimic different scenarios arising in real world service robot situations thus demonstrating the viability of ubiquitous robots.

A. Sobot Interaction and transfer

Fig. 9. Sobot Interaction and transfer: Sobot (yellow one) downloaded onto local site from remote site.

In this experiment, the ability of the Sobot to seamlessly, connect and transmit itself to any location was demonstrated. The aim was for one version of Rity to download itself to another location on the network where another Rity was in existence. As depicted in Fig. 11, the yellow *Rity* has just downloaded itself onto the environment and then proceeds to interact with the earlier one based on its internal states. This transfer was activated by the access to the remote Sobot's IP which then utilized the middleware to transfer itself.

This experiment demonstrated the seamless nature of the Sobot allowing it to move freely onto any environment in the network.

B. Sobot-User Interaction through Embots

The Sobot interacts with the user actively since it is designed as a synthetic pet. In a complex scenario such as a user moving about through a home environment, the Sobot needs to access and exchange information from a number of Embots and Mobots, the capabilities for which are tested in this experiment. In the image sequence shown in Fig.10, a demonstration is carried out which consists of user walking into the u-space simulated home environment, with a TV with attached computers, upon which the Ubibot becoming immediately aware through the position Embot and Vision Embot. The latter then performs face recognition to determine identity. Once the identity is established, Rity proceeds to react with joy and happiness and user may transmit commands through voice or using keyboard and mouse.

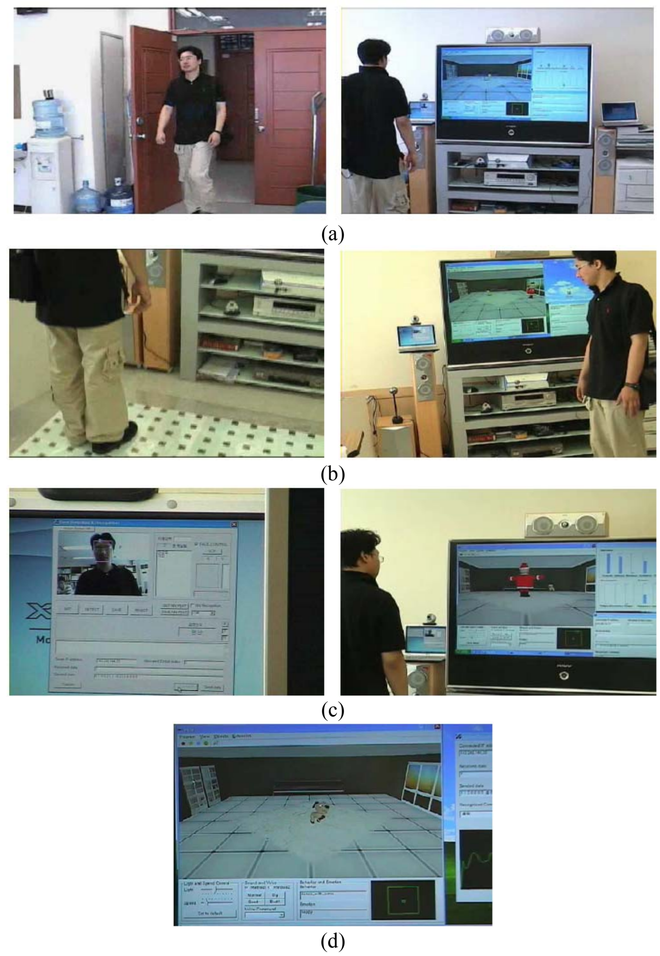


Fig. 11. Sobot-user interaction, (a) user enters the u-space, (b) position Embot senses user location and transmits information to Sobot, symbolically resembling the appearance of *Santa-Claus* figure in the world; (c) Vision Embot performs face recognition and Sobot exhibits happiness upon perceiving master, which (d) Sound Embot indicates that "Dance" command has been spoken, causing Sobot to comply and dance

This experiment demonstrated the calm-sensing and context aware capabilities of the Ubibot allowing it to monitor the user anytime and anyplace within the u-space.

C. Sobot-User Interaction through Mobot

In this experiment designed to test the seamless abilities, the aim is for the Sobot to actuate the Mobot to continually monitor and provide services to the human user. The user upon initiating the Sobot's attention as in Experiment B proceeds to move away. The Sobot perceiving this decides to follow the user. This scenario portrays a real world situation where user might dynamically engage and disengage various Embots, leading to the Sobot physically proceeding to follow, by moving onto the Mobot. This is depicted in Fig. 11, where the Sobot has downloaded itself via Middleware from the remote site, onto the Tablet PC of the *Mybot* Mobot thus enabling it to monitor the user in real time irrespective of his actual location.

Fig. 12. Sobot User Interaction through Mobot, the Sobot has downloaded itself onto *Mybot* to enable monitoring of the user and thus providing anyplace and anytime service.

This experiment once again verified the seamless integration of the Ubibot system transcending spatial limitations in its ability to provide services.

V. Conclusion

This work presented the Ubibot system, which is seamless, calm, context aware in its ability to provide integrated services. The component subsystems of three kinds of Embots, the Position Embot, Sound Embot, and Vision Embot, two kinds of Mobots, the mobile robot type Mybot, and humanoid type HSR and the artificial creature, Rity, the Sobot of the system were presented and their salient features were elucidated and their capabilities were discussed.

Three kinds of experiments were presented to depict a proof of concept of the integrated services possible, through the interaction of Sobot with the user and other Sobots, utilizing Embots, Mobots and the Middleware.

This technology has also been additionally used for the development of software robots running within PDA phones as a possible application and also as a test bed for genetic robot concepts. As a future work however, the Ubibot system shall be expanded to include multiple Embot, Sobot systems along with the humanoid robot HSR, as this would enable the demonstration of the full capabilities of the ubiquitous robot paradigm for providing integrated services.

The popular mythological tales, the Arabian Nights, spoke of a mythical creature, the *Genie*, emerging from within a magical lamp, which would satisfy all of our desires. Future systems, such as those based on the Ubibot, may very well realize this ancient dream through its immense capabilities of context-aware, calm, networked service available, at anytime, anyplace and whenever desired. Without a doubt, this technology is poised to completely transform our lives, permanently for the better in the years to come.

Acknowledgement

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