Tangible Agent Technologies for Tangible Space Initiative

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Abstract: In this paper, a novel concept of Tangible Agent is proposed together with Tangible Space that is a KIST vision of future digital society. Tangible Space is defined as a space in which people can feel a seamless integration between cyberspace and real space. For this, three key technologies such as Tangible Interface Technology, Responsive Cyberspace Technology and Tangible Agent Technology are newly defined and proposed. Tangible Agent enables users to explore and experience the unknown (data is not in the cyberspace) real world through autonomous navigation and various sensor data and to grasp and manipulate physical objects. Also, Tangible Agent makes environments intelligent using embedded sensing agents. The goal of Tangible Agent is to interface and bridge the gaps between responsive cyberspace and real world by providing reality sensing function and navigation with action capability. In order to implement the proposed concept of Tangible Agent, several key technologies are also defined and described to identify underlying research issues.

Keywords: Tangible agent, Tangible space, Bio-mimetic intelligent agent, Vision-based reality sensing, Active beacon, Intelligent robotics agent

1. INTRODUCTION

Internet and information technologies are changing the conventional sense of value, traditional culture, and life style. Also, those technologies make our imagination come true by proposing ways for experience on new and/or unknown worlds as shown in movies and cartoons. It is called as the information technology-based revolution comparable with the Industrial Revolution. It is expected that our home and office will be fronted with tremendous changes when a number of home appliances are combined with the Internet and ubiquitous computing environment. So, a number of international companies have proposed the concept of 'Networked Digital Home' or 'Smart Space (Home)' equipped with impressive multimedia devices for future society few years ago. It is expected that human-friendly robots will be a member of such a digital home or office. In order for the service robots to live with human beings, natural interface between the robots and human beings is essential and there have been proposed several research results on human-robot interaction and socially interactive robots [1][2][3]. Such human-friendly robots are a good motivation to open new markets for service robots considering that markets for conventional industrial robot manipulators are saturating. Also, it is a good chance to make intelligent robots be a product among intelligent home appliances such as televisions or refrigerators.

Also, due to rapid development of computer technologies and various skills for information processing, nowadays life paradigm is being shifted rapidly from analog style to digital life. Before the invention of cyberspace technologies, if people like to get information about the physical environments, they should be there from the viewpoint of time and space and get it by using their own sensing capabilities. But nowadays, people live between two realms: physical world and cyberspace. People could get information about the world where it is past or future, or it is long distance from them as if they were there at the time even for the never experienced world. In fact, these sort of cyberspace generated physically interactive environments are now commonly available not only in research laboratories but also in arcades and museums in many ways including interactive entertainment games. In order to enrich the feeling of "on-site in-time", many human computer interaction (HCI) technologies have been developed not only in the visual effect field but also in the haptic interactions. Although the ultimate goal is seamless interfaces between physical world and cyberspace, the interaction with the current HCI technologies are in fact separated to some extent from the ordinary physical environment within which we live and interact.

Here, our work is inspired by the vision of "Intelligent Robots", "Augmented Reality" and "Tangible Bits" especially. "Tangible Bits" is an attempt to bridge the gap between cyberspace and the physical environment by making digital information tangible [4]. They are developing ways to make information accessible through the physical environment. They also considered the background of human activities as well as the foreground activities. But current human computer interaction research including "Tangible Bits" is focusing primarily on how to enable users to feel real sensation (seamless interface) only for the information stored in computer in advance and/or generated by cyberspace while running. In other words, for the exploration work and/or unknown world, there is no way to give seamless interaction to users. The ultimate goal for digital life in the future, however, is seemed to give seamless integration between real worlds with not only experienced and hence data based cyberspace in advance but also unknown and hence newly augmented cyberspace.

In this paper, a new concept of 'Tangible Agent' for 'Tangible Space' is proposed for future digital life. Especially, the paper is focused on bio-mimetic intelligent agent technologies, visual sensing technologies, and location awareness technologies for 'Tangible Agent'. 'Tangible Space' is defined as a space in which people can feel seamless integration between real world and cyberspace. 'Tangible Space' allows users to feel immersive impression as if they are on-site even for the newly exploring real world and enables users to touch and manipulate the objects generated by cyberspace and the newly faced objects in another real world. Major key technologies for the 'Tangible Space' are divided into three groups composed of Tangible Interface Technology, Responsive Cyberspace Technology, and Tangible Agent Technology. 'Tangible Agent' is an interface between Responsive Cyberspace and real world. Tangible agent technologies are robotic agent technologies in future digital life for reality sensing and intelligent action navigation.

The paper is composed of five sections. Section 2 introduces the concept of 'Tangible Space' for future digital life and the concept of 'Tangible Agent' will be proposed in section 3. Core technologies for 'Tangible Agent' are introduced in section 4 while the paper is concluded in section 5.

2. TANGIBLE SPACE

'Tangible Space' is our vision for implementation of the future digital life. Tangible Space is defined as a space in which people can feel seamless integration between real world and cyberspace. Tangible Space allows users to feel immersive impression as if they are on-site even for the newly exploring real world and enables users to touch and manipulate the objects generated by cyberspace and the newly faced objects in another real world. The main difference between 'Tangible Space' and 'Tangible Bits' including augmented reality research is that we continuously augment the newly exploring another remote real world.

'Tangible Space' treats the barrier between the physical interface environment and the virtual environment as a malleable structure that can be reshaped and colored according to the necessary realism required by the inhabitant, the user. The user may exist partially in the physical environment as well as in the virtual environment depending on the interfaces required by the required task. Basic components of 'Tangible Space' are users, 'Tangible Interface' for interaction, 'Responsive Cyber Space' for intelligent services, 'Tangible Agent' for real world interface, and real physical world as shown in Fig. 1. Fig. 1 introduces relationships between the basic components for seamless integration of users, cyber space, and real world. Here, core technologies for 'Tangible Space' are divided into Tangible Interface Technology, Responsive Cyberspace Technology, and Tangible Agent Technology. 'Tangible Interface' includes haptic interface between users and responsive cyber space for interaction and realistic display for information in responsive cyber space. 'Responsive Cyber Space' is an intelligent virtual space equipped with context-awareness and intelligent agents for seamless services.

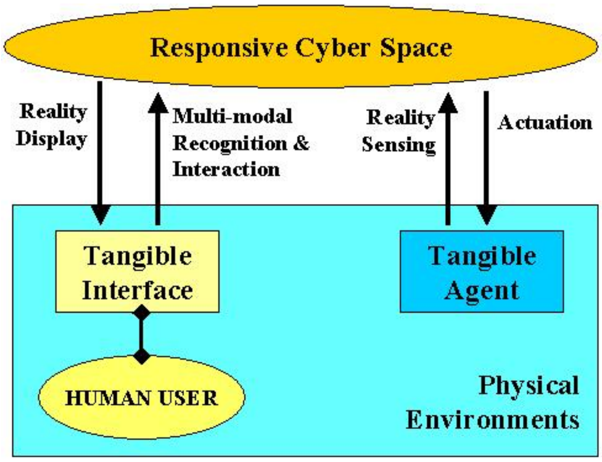


Fig. 1. Tangible Space Concept Diagram

3. TANGIBLE AGENT

'Tangible Agent' is an interface between 'Responsive Cyberspace' and real world. 'Tangible Agent' is defined as an agent of which functions are (1) to sense the real world and augment the sensed environments to the predefined cyberspace and/or give information to generate a new cyberspace, and (2) to navigate the real world to sense it and/or interact with real world to execute the user specified job or to gather tactile or invisible information. The definition of 'Tangible Agent' is similar to that of 'Autonomous Agent', which is defined as a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future [5]. Typical characteristics of 'Autonomous Agent' are (1) to perceive and interpret sensor data, (2) reflect events in their environment, and (3) to take actions to achieve given goals. From this, the reactive properties, that is, sensing and acting capability could be considered as the same characteristics between two agents. The difference is, however, that since 'Tangible Agent' is one of component technology for 'Tangible Space' of which goal is seamless integration between cyber space and real world, 'Tangible Agent' should provide its own reactive function while satisfying for users with seamless integration. That is, the most important functions for the Tangible Agent are how to enable users to feel seamless sensation for the cyber space that is augmented and interacted with the real world by the agent.

The detail specifications and technologies for the Tangible Agent are still under discussion. At first, key technologies for the Tangible Agent are divided into two groups of 'Intelligent Action Navigator' and 'Reality Sensing'. 'Intelligent Action Navigator' technologies are divided again into bio-mimetic intelligence for navigation and manipulation, and key component technologies such as smart actuator technology. 'Reality Sensing' technologies are composed of visual sensing technology, tactile sensing technology, and information augmentation technology.

Until now, we do not believe the classified technologies are sufficient to implement our new concept of 'Tangible Space' and 'Tangible Agent'. Rather, we like to raise a set of new research questions such as "What is the difference between 'Tangible Agent' and software agent, or robotic agent?", "What is the detail specifications to satisfy the seamless integration?", and so on.

4. TANGIBLE AGENT TECHNOLOGIES

4.1 Internet-based Human-Robotic agent-Environment Interaction Framework

Nowadays, human-robot interface (HRI) for intelligent robotic agents becomes important since the robotic agents provide human-friendly useful services to human beings living together. Concurrently, many people use wireless equipments accessible via Internet such as PDA and notebook computer. Therefore, Internet-based HRI that explores Internet to communicate with other service clients has become important comparing with direct HRI. In this work, a new framework for Internet-based HRI using agent technology is proposed to deal with two problems. The first problem is how to provide Internet-based HRI in offline situation and the second problem is how to coordinate robots and distributed sensors in environments without complex configuration.

To overcome the offline situation of a robotic agent, a systematic framework for Internet-based HRI is required. In [6], an agent-based framework, in that users communicate with a robot via a video camera located outside of the robot was introduced. It provides a ubiquitous access method that explores the agent as a means to establish communication between users and robots via distributed sensors. Although this framework is designed for HRI using agent technology, it does not solve the offline problem. The offline problem is caused by impermanent presence of a robotic agent. Sometimes, the robotic agent is not available because of battery charging, instable connection, system failures, etc. Therefore, a systematic framework is needed in order to discover services, to assign tasks, and to provide interaction with service interfaces when robotic agents are offline. So, a new framework for Internet-based HRI is proposed in this paper to help users and robotic agents to discover and explore services of each partner even in offline situation based on the concept that a world is considered as a set of workspaces controlled by multi-agent systems. The multi-agent system is used for fusing distributed sensors to monitor environments and it coordinates robotic agents and users in the environment.

Next, the systematic framework has to be able to coordinate various robotic agents, distributed sensors and users for Internet-based HRI. Especially, robotic agents have to be coordinated with distributed sensors to get information on environments. In [7], a framework for coordinating distributed video cameras to track human movement is proposed. Using the framework, information about one environment can be obtained by any partner. However, this framework does not provide the coordination method. So, a new framework for the coordination of robotic agents together with distributed sensors without complex configuration is proposed using the concept of *coordinator agent*. This agent receives requests from users, does path planning and checks sensors to adapt its plan to the changes in the environment by discovering robotic agents that require coordination services. Using the coordinator agent, the environment becomes responsive because it can provide information about itself to other partners.

The key issue to solve previous two problems in our framework is service discovery in offline situation. Service discovery methods are categorized into non agent-based approach and agent-based approach. Non-agent based approach is used in many distributed and peer-to-peer applications. JINI [8] is a representative non-agent based approach. Jini uses a centralized scheme where all types of services are registered to a lookup service. Users can interact with the services by obtaining the interface for the services. The service implementation part still needs to be online at the time the service is called. In the agent-based approach like FIPA [9], service discovery in an agent platform (AP) is provided by a special agent named Directory Facilitator (DF). DF provides a service management mechanism to design an Internet-based HRI interface system but DF cannot solve the offline situation. Finally, an approach for offline service discovery is proposed in this paper by migrating slave agents for services to the main container of an AP when robots connect to Internet while a virtual directory facilitator (VFD) is proposed to control the slave agents and synchronize data passing among the agents.

4.2 Visual Sensing Technologies

'Tangible Agent' is an information server to supply real-time information for real environments, a virtual agent as a replica of a human being and an agent for online or offline contents authoring. In order to perform the roles, the Tangible Agent is equipped with a number of sensors such as video cameras, global positioning system (GPS), ultrasonic sensors, laser range finders, temperature sensors, humidity sensors, contact sensors, force sensors, wind sensors, and so on. Using the sensors, the Tangible Agent is able to supply environmental information enough for a user of Tangible Space to feel the reality as the user is where the Tangible Agent is.

Most of all, visual information is very effective for the user to feel the reality considering that 80% of the information that human beings is getting for a day depends on visual information through eyes. So, a number of visual sensing technologies can be considered for reality sensing. Now, the research is concentrated on three-dimensional contents authoring technology, visual navigation technology, and multiple objects tracking technology location awareness.

For contents authoring, the Tangible Agent has to know self-location as well as three-dimensional information for environments. So, the Tangible Agent is equipped with technologies for localization, map building, navigation and real-time three-dimensional reconstruction. It is expected that an automobile will be used as the Tangible Agent in outdoors while an autonomous mobile robot will be adopted in indoors. We hope a three-dimensional model, which is useful for virtual spaces, for environments are reconstructed autonomously without the intervention by human beings through the integration of three-dimensional reconstruction technology with autonomous navigation technology for 'Tangible Agent'. By using the reconstructed three-dimensional information, the Responsive Cyber Space will make a graphic model to be used in Tangible Space or other virtual space. It is expected that technologies for vision-based localization and navigation are very important in indoors since it is difficult and tedious to attach artificial signs in real environments for localization and map building. Also, the localization technology by using DGPS (Digital Global Positioning System) whose measurement error is small compared with other localization sensors will be used for outdoors. Finally, three-dimensional mapping (or map building) technologies will be developed for contents authoring by combining the localization technology with three-dimensional reconstruction technology using multiple sensors. Now, a mobile robot platform equipped with a three-dimensional laser range finder for 3-D reconstruction and a two-dimensional laser range finder for localization of the mobile robot is used as 'Tangible Agent' for reality sensing as shown in Fig. 2.

Fig. 2. Autonomous Contents Authoring System

Fig. 3 shows an image example obtained by the upper 3-D laser range finder for 180 degree scan while Fig. 4 shows an experimental result to combine two range data autonomously. In order to combine the two range data at different location based on the three-dimensional range data and the location information of the mobile robot, an image-based matching technology are under development by using image features of points and line segments. Also, a fast Markov localization scheme is under development to shorten the sampling time for localization using angle histogram of laser range data. The idea is focused on the reduction of memory size for an environmental map and computational load by decrease the number of data to express the environmental map.

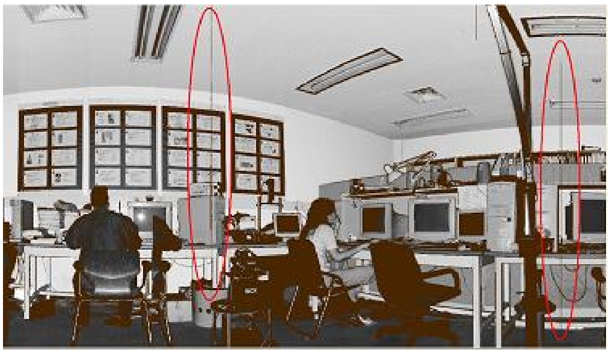
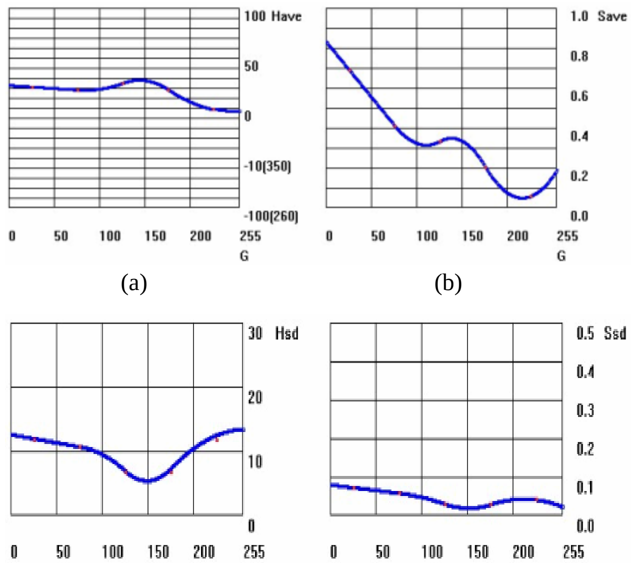


Fig. 3. Sample Image

Fig. 4. Integration of Two Range Data Sets

Multiple objects tracking algorithm is developed. The visual tracking algorithm is essential for vision-based location awareness and gesture recognition in human computer interaction. That is, if the properties – such as color, shape, and texture – are known, the visual tracking is possible. Visual tracking is, however, suffered from color/shape/texture variations induced from irregular illumination variations and the viewing geometry of a camera. The consistency of a single-colored object is maintained within a bounded volume in color spaces under a fixed illumination condition. And, it is known that hue is insensitive to surface orientation, illumination direction, intensity and highlights under a white illumination. It is not easy, however, to maintain the color consistency when the motion of the object is included since illumination conditions are changed abruptly and the brightness of the object is varying in irregular patterns. The phenomena can be observed when a human being walks through a corridor. The direction of a light with respect to the human being determines the brightness distribution on one's face. And, if a door or a window is opened, the brightness distribution on the human face is affected by lights emitted from another electrical lights or sunlight. So, the single-colored target object – for example, a human face - cannot be segmented correctly by using a color model ignoring brightness information since the color distribution is changed even in HS (Hue-Saturation) plane when the brightness is changed.

So, technologies for visual tracking and color clustering are developed considering the reliability under variable illumination conditions in HSI (Hue-Saturation-Intensity) color space. The algorithm is based on the fact that color distribution of a single-colored object even in HS plane is not invariant with respect to brightness variations in practical cameras and illuminations. That is, a color has different statistical characteristics at different intensities. So, color modeling is converted into statistical characteristics modeling of a color with respect to intensity. The statistical characteristics include the means and standard deviations of hue and saturation with respect to intensity. The following Fig. 5 shows a modeling result for color characteristics of skin (face) area by using B-spline curve. Fig. 5-(a) is the curve of mean of hue with respect to brightness variation while Fig. 5-(b) is the curve of standard deviation of hue with respect to brightness variation. Fig. 5-(c) is the curve of mean of saturation with respect to brightness variation while Fig. 5-(d) is the curve of standard deviation of saturation with respect to brightness variation. And, Fig. 6 in the beginning of the next page shows experimental results for skin color clustering under various illumination conditions as well as performance evaluation result comparing with other approaches. The first column is original images under different illumination conditions used for experiments. The second column is results by the developed approach while the third column shows results by [9]. The fourth column and fifth column show experimental results by [10] and [11], respectively. It is found that our skin color model is better than three other approaches in the aspect of skin color clustering. Especially, the proposed skin color model is more robust to brightness variations than three other approaches.



(a) (b)

(c) (d)

Fig. 5. Color Characteristics for Human Faces

Also, a new event-based approach for real-time tracking of multiple objects is developed using primary events for visual tracking. Here, initiation, continuation, termination, and overlapping constitute a primary event set and are fired by the change of number-of-measurements between previous frame and current frame. Overall visual tracking process is described by a Petri-net graph useful for description of discrete event-based systems. Also, discriminative focus of attention is adopted to detect new objects for tracking while reducing the computational load for scanning a whole image based on the face that the resolution of human eye decreases as going outside of the fovea. Finally, the proposed algorithm is applied for visual tracking of visual ID to determine the location of human beings using multiple video cameras and for visual tracking of multiple parts of a human body including a face and hands successfully.

4.3 Location Awareness using Active Beacons

We are under development a new active beacon system by adding a pan-tilt mechanism for location awareness of robotic agents and/or human beings as shown in Fig. 7. and Fig. 8. Two methods are proposed to solve the problems of the existent systems [12][13][14][15][16][17]. Since ultrasonic sensors have the limited beam-angle, we can rotate one beacon toward some mobile agent while the other beacon toward other agent according to the judgment of RF beacon (beacon with Radio-Frequency module installed) and can transmit the ultrasonic signals with no interference if we use the active mechanism in the multi-agents' localization. In this way, we can transmit the ultrasonic signals to the multiple mobile objects simultaneously. Therefore, wider area can be covered with the same number of beacons in the proposed localization. Second, RF beacon receives the data about each agent's velocity as well as position via RF communication from the agents. Also, the RF beacon gives a priority – how often to make localization – which is based on the velocity of the mobile agents: it gives higher priority to faster object. Hence, the sampling time is changed efficiently corresponding to the velocities of tangible agents.

Fig. 7. Receiver, RF beacon and Beacon

Fig. 8. Pan-Tilt Mechanism

Fig. 9 shows the usable area which is used the developed active beacon.

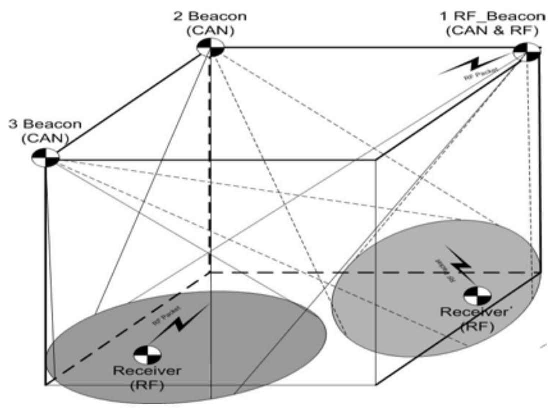


Fig. 9. Usable Area for the Active Beacon

Fig. 10 shows the active beacon system attached on the ceiling of our laboratory. It is composed of multiple active beacons equipped with pan-tilt mechanism and a rail system for linear motion of the active beacons.

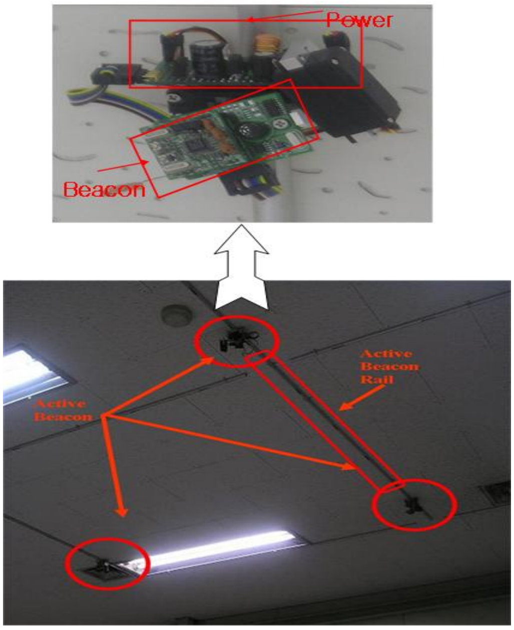


Fig. 10. Active Beacon System

The developed active beacon system is better than the existent beacon system in two factors – both the successful receiving rate and the accuracy of localization. Naturally, this system is not perfect up to now. Average error is over the 30 mm and maximal error over the 60 mm. It is noted, however, we confirm the possibility for efficient location awareness. And the accuracy and the successful receiving rates heavily depend on the electronic circuits and software's delay. The delay by software is factor of error in each distance between receivers and beacons.

5. CONCLUDING REMARKS

We have introduced the concept of 'Tangible Space' and 'Tangible Agent". 'Tangible Space' is composed of 'Tangible Interface', 'Responsive Cyber Space', and 'Tangible Agent'. 'Tangible Agent' is an interface between 'Responsive Cyberspace' and real world. Especially, there are proposed technologies for internet-based human-robotic agent-environments interaction framework, vision-based reality sensing, and location awareness using active beacons are proposed for tangible agents in future digital life.

REFERENCES

[1] T. Fong, I. Nourbakhsh, K. Dautenhahn, "A Survey on Socially Interactive Robots", International Journal of Robotics and Autonomous Systems, vol. 42, pp.143-166, 2003.

[2] C. Breazeal, "Toward Sociable Robots", International Journal of Robotics and Autonomous Systems, vol. 42, pp.167-175, 2003.

[3] R. C. Arkin, M. Fujita, T. Takagi, R. Hasegawa, "An Ethological and Emotional Basis for Human-Robot Interaction", International Journal of Robotics and Autonomous Systems, vol. 42, pp.191-201, 2003.

[4] H. Ishii, and B. Ullmer, "Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms," Proceedings of HCI'97, 1997.

[5] S. Franklin, and A. Graesser, "Is it an Agent, or just a Program?: A Taxonomy for Autonomous Agents," Proceedings of the 3rd Int'l Workshop on Agent Theories, Architectures, and Languages, Springer-Verlag, 1996.

[6] Hideaki Takeda, Nobuhide Kobayashi, Yoshiyuki Matsubara and Toyoaki Nishida, "Towards ubiquitous human-robot interaction", Working Notes for IJCAI-97 Workshop on Intelligent Multimodal Systems, pp. 1-8, 1997.

[7] K. Huang and M. M. Trivedi, "Video arrays for real-time tracking of person, head, and face in an intelligent room", Machine Vision and Applications, vol. 14, no. 2, pp. 103-111, 2003.

[8] Jini http://www.jini.org.

[9] FIPA – Foundation for Intelligent Physical Agents http://www.fipa.org.

[10] K. Sobottka and I. Pitas, "Segmentation and Tracking of Faces in Color Images", Proceedings of Automatic Face and Gesture Recognition, pp. 236-241, 1996.

[11] S. Feyrer and A. Zell, "Detection, Tracking, and Pursuit of Humans with an Autonomous Mobile Robot", Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 864-869, 1999.

[12] Y. Zhao, Vehicle Location and Navigation Systems, Artech House Publish, 1997.

[13] Pentland, "Machine Understanding of Human Action", *Proceeding of 7th International Forum on Frontier of Telecommunication Technology*, 1995.

[14] Soo-Yeong Yi and Jae-Ho Jin, "Self-localization of a Mobile Robot Using Global Ultrasonic Sensor System", *Journal of Control, Automation, and Systems Engineering*, Vol. 9 No.2, pp. 145-151, 2003.

[15] Y. G. Kim, J. S. Choi, J. O. Kim, and M. Kim, I. M., "A New Localization System for Mobile Robots Using Radio Frequency and Ultrasound", *2002 International conference on Control, Automation, and Systems*, pp. 148-152, 2002.

[16] Nissanka B. Priyantha, Anit Chakraborty, and Hari Balakrishnan, "The Cricket Location-Support System", *6th ACM International Conference on Mobile Computing and Networking (ACM MOBICOM)*, pp 32-43, 2000.

[17] Hari Balakrishnan, Roshan Baliga, Dorothy Curtis, Michel Goraczko, Allen Miu, Nissanka B. Priyantha, Adam Smith, Ken Steele, Seth Teller, Kevin Wang, "Lessons from Developing and Deploying the Cricket Indoor Location System", MIT Computer Science and Artificial Intelligence Laboratory (CSAIL), 2003.