Intelligence Technology for Ubiquitous Robots

Jong-Hwan Kim, Sheir Afgen Zaheer, and Si-Jung Ryu

Department of Electrical Engineering, KAIST,
Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea
johkim@rit.kaist.ac.kr
http://rit.kaist.ac.kr/home

The evolution of computer technology, in terms of technology and its interrelationship with humans, inspired the dawn of ubiquitous computing [1]-[2]. This revolutionary concept of ubiquity inspired a new generation of robotics, i.e. ubiquitous robotics. In the second generation of robots, the service robots were characterized by standalone robotic platforms. As such, the capabilities of these service robots were limited to their current location. Even with advancements in the internet network that led to the development of innovative architectures, the interface provided by these robots was spatially restricted to their physical existence. On the other hand, ubiquitous robotics spawn the idea of an omnipresent robot platform. Both the service and interface provided by ubiquitous robots are not spatially limited.

The primary advantage of the ubiquitous robotics, the third generation of robotics, is that it permits the abstraction of intelligence from the real world by decoupling it from perception and action capabilities. In other words, ubiquitous robots can be considered as networked cooperative robot systems that can provide calm and seamless services.

During the past five decades, robots have come a long way from being high precision tools of the modern industrial development to our personal assistants, such as our pet companions and even as artificial body parts. All these applications vary considerably on the scales of precision and cognitive ability. To equip ubiquitous robots with these advancements, we present "intelligence technology (InT) for ubiquitous robots." InT is the application of machines and agents to perceive and process data and information for knowledge-based reasoning and to utilize their own reasoning to execute an appropriate action [3]. InT not only aims for intelligent behavior execution but also for equipping robots with thought mechanisms that lead them to actually manipulate intelligence via different components of ubiquitous robots.

1 Ubiquitous Robotics

Robotics has been defined as the 'intelligent connection of perception to action' [4]. Ubiquitous robotics justifies that definition by allowing us to redefine the interconnection between the three components: intelligence, perception and action. These are manifested individually as the intelligent software robot: Sobot,

S. Mohammed et al. (eds.), *Intelligent Assistive Robots*,
Springer Tracts in Advanced Robotics 106, DOI: 10.1007/978-3-319-12922-8_10

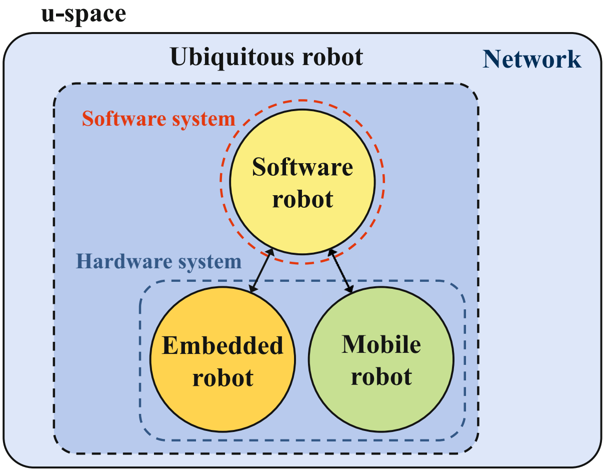


Fig. 1. Ubiquitous robot in ubiquitous space

the perceptive embedded robot: Embot and the physically active mobile robot: Mobot, respectively, as described in [5].

Ubiquitous robotics spawn the idea of an omnipresent robot platform. Both the service and interface provided by ubiquitous robots are not spatially limited. Ubiquitous robot systems enable the abstraction of intelligence from the real world by decoupling it from perception and action capabilities. Inspired from the attributes of ubiquitous computing, this abstraction allows ubiquitous robots to be calm, seamless and context aware.

The ubiquitous robot is created and exists within a u-space (Fig. 1) which consists of both physical and virtual environments. It can be conceptualized as a networked cooperative robot system. Software robots, or Sobots, constitute the core intelligence of the system, and are connected to the distributed Embot sensors in the physical space to ensure context awareness through perceived environmental information. The final outcomes of intelligent processing by Sobots in the virtual space are realized in the physical space by Mobots. Sensory information by Embots is standardized along with motor or action information of Mobots and this permits the abstract intelligence to proceed with the task of providing services in a calm and seamless manner.

Ubiquitous robots provide services through the network in a u-space through the distributed capabilities provided by their constituent Sobot, Embot and Mobot systems. Based on their application domain, each ubiquitous robot has its own specific intelligence and roles, and it can communicate information through networks. Some of the integrated services and solutions offered by the ubiquitous robot technology include ubiquitous home services for smart homes, location based services like GIS, health services in telemedicine, ubiquitous learning systems and ubiquitous commerce services.

The following subsections explain the aforementioned components of the ubiquitous robot system: Sobot, Embot and Mobot, along with Middleware for communications and implemented ubiquitous robot system, called the Ubibot system [6].

1.1 Software Robot: Sobot

Sobots are entirely confined to the virtual space of the network and are able to connect with other systems irrespective of temporal and geographical limitations. Sobots are capable of operating as intelligent entities without any help from other ubiquitous robots and are typically characterized as self-learning, context-aware, intelligent, calm and seamless. Sobots perceive the environmental context within the u-space and often make decisions and execute them without requiring direct supervision from the user. They are proactive and demonstrate rational behavior and show capabilities to learn new skills.

1.2 Embedded Robot: Embot

The embedded robots are implanted within the environment or upon Mobots. Embots sense and monitor the location of a user or a Mobot. They also integrate assorted sensory information to comprehend the current environmental situation in the physical space. Embots are also networked and equipped with processing capabilities. therefore, they may deliver information to the user directly or under the Sobot's instructions. The salient attributes of Embots are their calm sensing, information processing and information communication capabilities.

1.3 Mobile Robot: Mobot

Mobots are the application/service level component of the ubiquitous robot system in the physical 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 remains in continuous communication with the Sobot in order to provide practical services based on information given by the Embot. Moreover, Mobots also serve as a data gathering platform for Embots.

1.4 Middleware

To deliver the required services,ubiquitous robot systems require seamless communication. This calls for Middleware that 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

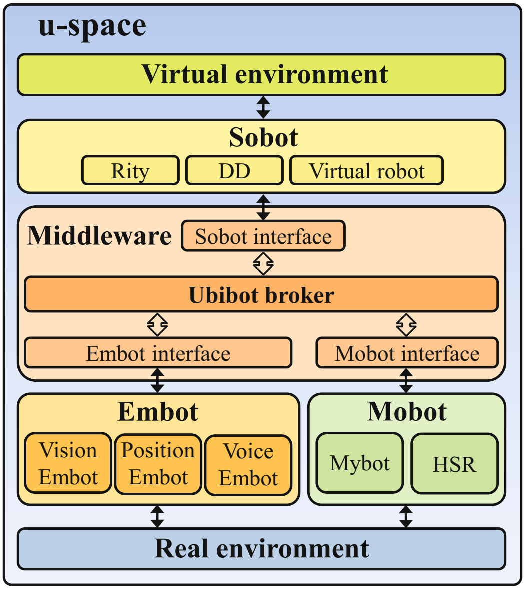


Fig. 2. The Ubibot System Architecture

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.

1.5 Ubibot: Implemented Ubiquitous Robot System

Ubibot was developed to demonstrate the functionality and effectiveness of a ubiquitous robot system. Ubibot consists of multiple Embots, two Mobots: Mybot and HSR, and a Sobot: Rity. The overall architecture of the Ubibot system is shown in Fig. 2. Various components of Ubibot are explained in the followings:

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

a. ***Vision Embot:*** The Vision Embot, implemented via a USB camera sensor, is used for object detection and facial recognition The face detection algorithm can detect faces within 120 cm of the camera, under various lighting conditions, with an operating time of 50∼100 ms, images being captured at a rate of 16 frame/sec.The face recognition module then acts on the detected

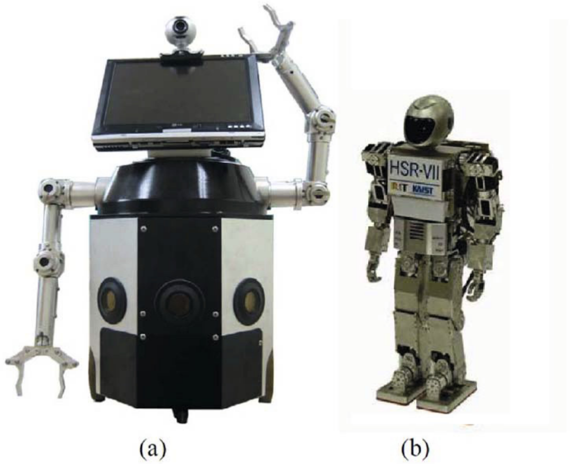


Fig. 3. Mobots: (a) Mybot–Wheeled mobile robot and (b) HSR–Humanoid robot type

face data and transmits the detected results asynchronously to Middleware at periodic intervals.

b. ***Sound Embot:*** The sound Embot employs a preprocessing algorithm to process background noise and categorize it into 5 levels: noisy, normal, calm, sudden loud, and sudden calm. It can also recognize 10 short sentences. The Sound Embot then transmits the detection results asynchronously to Middleware at periodic intervals of once in 4 seconds.
c. ***Position Embot:*** The Position Embot estimates the location of robots, objects, and humans in a 2D Cartesian coordinate system. The detected Cartesian coordinates are transmitted to Middleware at the rate of 10 hertz.

Mobots. The Ubibot system uses 2 Mobots, a wheeled mobile personal robot, Mybot and a small sized humanoid robot HSR.

a. ***MyBot:*** Mybot (Fig. 3(a)) uses a differential drive platform powered by DC motors. It is 31cm x 21cm x 42cm in size and weighs 12 Kg. It has an on-board Pentium III 850Mhz computer handling the drive, control and sensors. It is equipped with six Polaroid 6500 ultrasonic sensors covering 0.15m∼5 m in all directions on the horizontal plane. It has a mount for a Tablet PC which then communicates with the on-board 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 for the Vision Embot.
As it can be seen from Fig. 3(a), 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.

Fig. 4. The artificial creature Rity, Sobot of the Ubibot system, expressing different emotions

b. ***HSR:*** HSR (HanSaRam) is a small sized humanoid robot developed in the RIT Lab at KAIST. 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 on-board Pentium III compatible 666 MHz PC.

Sobot. An artificial creature, Rity, developed as an agent that behaves autonomously driven by its own motivation, homeostasis, and emotion operates as the software robot for the Ubibot system. Rity visually resembles a simulated 12 DOF dog with which users can interact in a number of ways as shown in Fig. 4. 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. 4 and can exhibit a total of 77 behaviors.

Rity 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. The internal architecture of Rity is depicted in Fig. 5.

The general architecture of Rity is composed of 5 primary modules: perception module to perceive the environment with virtual or real sensors, internal state module to defines motivation, homeostasis, and emotion, behavior selection module to select a proper behavior for the perceived information, learning module to learn from interaction with people, and motor module to execute behaviors and express emotions.

Middleware. Since all data communication is based on TCP/IP, the middleware is realized using TCP/IP related components provided by Visual C++

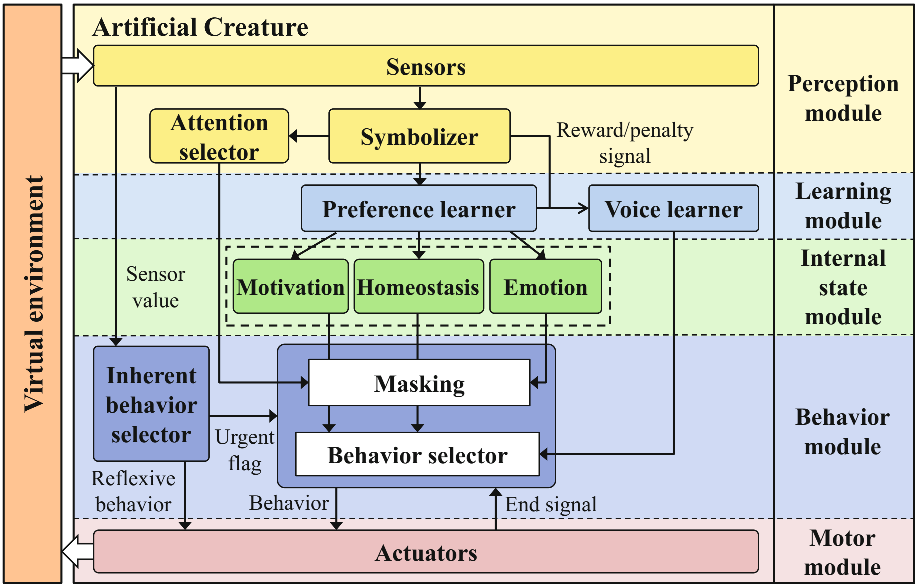


Fig. 5. Internal architecture of Rity

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.

2 Intelligence Technology (InT)

Since Capek's first depiction in 1921 [7], robots have been fantasized as intelligent machines that are subservient to humans. The core issue in realizing this fantasy is to equip robots with human-like intelligence for natural interaction with humans. However, unlike humans, robots do not posses a sophisticated and highly evolved medium to manipulate intelligence. Therefore, to replicate biological intelligence, robots need to be equipped with appropriate technology for intelligent operation. To address this issue, we proposed InT [8]. InT is the application of machines and agents to perceive and process data and information for knowledge- based reasoning and to utilize their own reasoning to execute an appropriate action. InT covers all aspects of intelligence from perception at sensor level to reasoning at cognitive level to behavior planning at execution level for each low level segment of the machine.

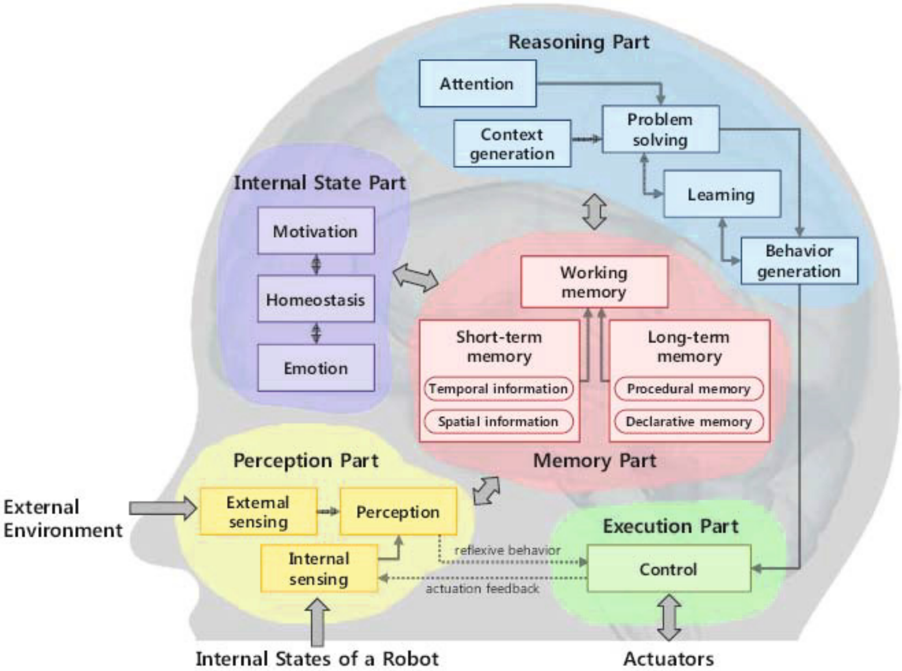


Fig. 6. Intelligence operating architecture (iOA)

2.1 Intelligence Operating Architecture for InT

To realize all aspects of InT, we proposed a modular architecture inspired by human brain functions and capable of implementing all aspects of InT. We named it as intelligence operating architecture (iOA) and it is graphically depicted in Fig. 6. The details about the five parts and 15 modules are described as follows [8].

In perception part, external and internal sensing modules gather sensory data respectively from external environment and internal states of the robot. The perception module converts the sensory data from the two sensing modules to context data and transmits it to other modules such as attention, memory, internal state modules, etc. If the context data requires an urgent response from the robot, it is directly forwarded to the control module in execution part to generate a reflexive behavior. In internal state part, each of the three modules for motivation, homeostasis and emotion controls the corresponding internal state value of the robot based on the context data through memory part. Moreover, all data including the internal state values and the context are shared with other modules through memory part.

There are three kinds of memory modules in memory part. The short-term memory module stores spatial and temporal information from the environment for a short period of time. On the contrary, the long-term memory module deals with information stored for a long period of time. There are two types of long-term memory: procedural memory and declarative memory. The procedural memory holds information needed to use objects and to execute movements. The declarative memory refers to memories which can be consciously recalled such as facts and knowledge; it can be divided into two categories: episodic memory and semantic memory. The episodic memory stores specific events that happened in the past. The semantic memory contains factual information that is not associated with time and place. Moreover, the long-term memory module enables the robot to improve its behaviors in the future through a learning module in reasoning part. Lastly, the working memory module holds the information needed to perform tasks such as reasoning, memorizing numbers, objects, making a decision, etc., at the working moment.

In reasoning part, the attention module decides which percept has to be focused on by referring to memory part and it allows the robot to gather more useful sensory data in the environment through the gaze control. The context generation module generates a high level and/or complex contexts from the information provided by the perception module through memory part. The problem solving module is responsible for making sense of the context, analyzing all available options and selecting a plausible behavior or a course of behaviors by planning, scheduling, etc. However, the behaviors selected by this module are in a high level or abstract form, e.g. "going to a particular waypoint." To execute the selected behavior through the actuators of a particular robot, such behaviors need to be translated into basic low level tasks, e.g. "going to a particular waypoint" requires a footstep generation algorithm for a humanoid robot but in the case of wheeled robots, a steering algorithm is required. The behavior generation module deals with conversion of the high level behavior, selected by the problem solving module, into low level behaviors by utilizing algorithm(s) to handle actuator level generation of such behaviors. The learning module works in conjunction with the behavior generation module and the problem solving module. It helps both modules to learn from previous experiences stored in the long-term memory by updating the memory contents. The control module in execution part actualizes the selected behaviors through the actuators of the robot. It also sends actuation feedback to the internal sensing module in perception part.

2.2 Taxonomy of Intelligence Technology

InT is used to realize six types of intelligences: cognitive intelligence, social intelligence, behavioral intelligence, ambient intelligence, collective intelligence, and genetic intelligence.

Cognitive Intelligence. Usually, robots utilize a rigid decision process to instantly react upon the perceived information, which is generated from sensory data. However, users often expect robots to act more intelligently, such as being able to adapt to the situation by memorizing and learning. This is where cognitive intelligence steps in to reason complex or unknown context from perceived information. Cognitive intelligence is closely related to technologies like decision making, task scheduling and memory management.

Related Application: Gaze Control
When a humanoid robot navigates in a complex dynamic environment, it needs to determine the most appropriate gaze direction after gathering useful information in the surrounding environment. It should consider the user's preference for objectives in navigation along with various types of information, such as the distance and velocity of dynamic obstacles, the localization errors of surrounding obstacles and the robot itself, its walking state, etc. For this purpose, the fuzzy integral-based gaze control algorithm was proposed [9]. After receiving the context and user's preference information, the functionality of the gaze control algorithm is mainly distributed among three modules of reasoning part. The attention module chooses the most important object to focus on, the problem solving module computes the corresponding gaze direction for the robot, and finally, the behavior generation module generate the necessary actuator level behaviors to achieve that gaze direction. The proposed algorithm considers a stand-alone robot, with a local vision system based on four criteria (or objectives) and the corresponding partial evaluation functions. The details about this proposed gaze control can be found in [9].

To perform simulations, an OpenInventor-based navigation simulator was developed by using the model of HSR (Fig. 7). The simulations were performed in a dynamic environment with moving obstacles. The robot was able to effectively deal with moving obstacles through the gaze control-based navigation in a dynamic environment.

Social Intelligence. Social intelligence deals with the sociability of robots. While interacting with humans, the robot should be able to empathize towards the interacting humans in order to understand the nature of the interaction. Social intelligence includes both proactive and reactive aspects of sociability. The robot is socially proactive when it seeks the attention of interacting humans, and it is socially reactive when it responds to human attention or commands.

Related Application: Robotic Doll, Gomdoll
A robotic doll, Gomdoll, is a specially designed to manipulate social intelligence through emotional behaviors as shown in Fig. 8 [10]. Gomdoll has emotions and motivations, which are implemented in internal state part, to reflect its internal state. Moreover, to provide natural interaction, it utilizes reasoning part to express its internal state by selecting the most appropriate behavior.

The Big Five framework [11] of personality traits is employed in this research. The framework consists of five basic dimensions of personality, referred to as the Big Five personality dimensions. They are classified as follows: extroverted (as opposed to introverted), agreeable (as opposed to antagonistic), conscientious (as opposed to negligent), openness (as opposed to closedness), and neuroticism (as opposed to emotional stability). Gomdoll evolved in a virtual world by customizing the genetic code satisfying the propensity desired by the user. In this

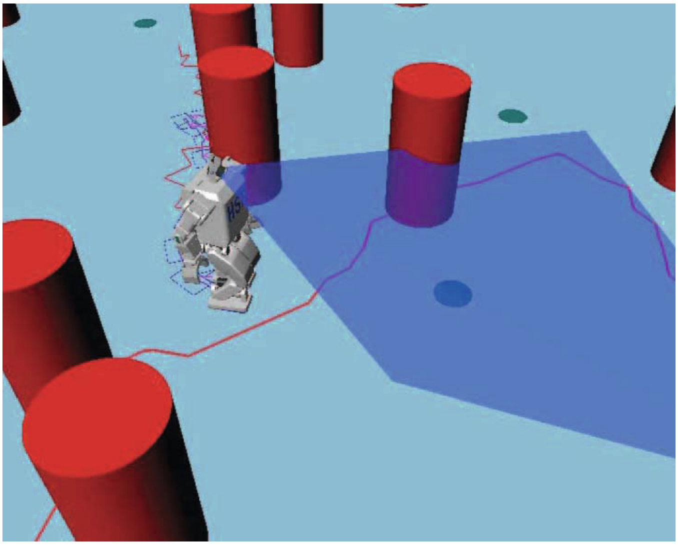


Fig. 7. Humanoid robot simulator for gaze control

(a) Happiness. (b) Sadness. (c) Anger. (d) Fear.

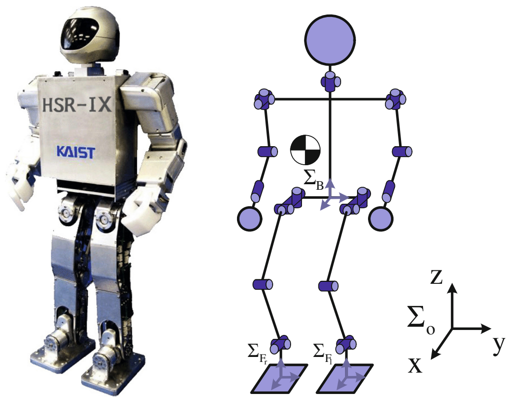
Fig. 8. Emotional behaviors of Gomdoll

way, robots possessing the user desired propensity could be developed for more social interaction with the user.

Behavioral Intelligence. Behavioral intelligence enables the robot to execute behaviors in an appropriate manner. It allows the robot to plan its behavior execution at the actuator level and to alter its discourse if the robot encounters an unwanted object or an obstacle.

Related Application: Walking Pattern Generator for Humanoids

The behavioral intelligence in humanoid robots is manipulated through walking pattern generation algorithms. Walking pattern generator in the behavior generation module and control algorithm in the control module play a significant role in the walking behavior. In order to handle complex navigational commands from the problem solving module in real time, a modifiable walking



(a) HanSaRam-IX. (b) Configuration.

Fig. 9. Humanoid robot, HanSaRam-IX, and its configuration

pattern generator (MWPG) was proposed [12]. This is implemented in the behavior generation module. The MWPG receives navigational commands from the problem solving module and provides the desired joint angles to ensure the execution in the control module. The MWPG extended a conventional 3-D linear inverted pendulum model (3-D LIPM) in which the primary dynamics of the humanoid robot is modeled as the 3-D LIPM. Moreover, the MWPG enables modification of the walking period and the step length in both sagittal and lateral planes.

The small-sized humanoid robot, HanSaRam-IX, was used for experiments, as shown in Fig. 9. Fig. 10 shows the generated walking pattern on a flat plane using the proposed method. In addition, the robot is able to walk on inclined planes and uneven terrains by using the extended MWPG [13]-[16]. From the viewpoint of behavioral intelligence, the walking pattern generator is useful to generate proper locomotion that consists of repeated actions such as walking.

Ambient Intelligence. Sensory data is meaningful in itself but high level processes, including decision making, usually require high level context information. Therefore, sensory data can be more useful when it is translated into higher level context information. Ambient intelligence recognizes the context from sensory data collected in the environment. It is often realized through a sub-system such as vision-based face recognition system, gesture recognition system, RFID-based object recognition system [17].

Related Application: Interactive Robot-Based Tutoring System

In contrast to the established paradigm of researches focused on robot behaviors and learning under human supervision, the interactive robot-based tutoring system (IRTS) proposed a framework in which a robot was used to provide tutoring service to humans.

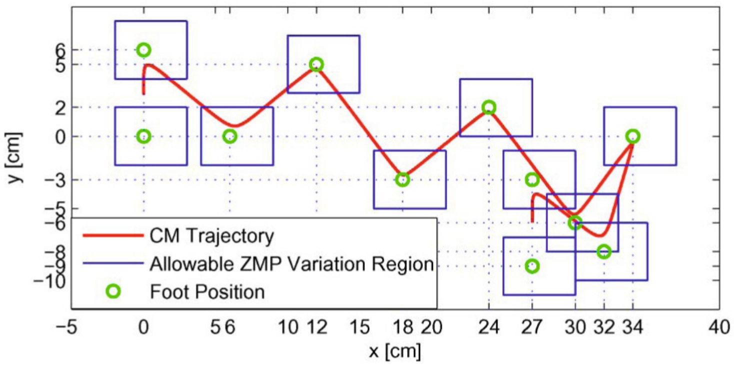


Fig. 10. Generated walking pattern using MWPG

This research proposed IRTS with intelligent tutoring system (ITS) based on the concept of ambient intelligence [20]. ITS is a computer-based expert system to provide customized instruction or feedback to users. The IRTS involves the robot interacting with a user, generating the user model, providing training tasks for guiding the user, and giving feedback on his/her performance. The proposed system is applied to ball-passing training as shown in Fig. 11, where a human trainee passes a ball to a robot tutor and receives feedback from the robot on how to improve kicking, based on the direction and velocity of the ball. The global vision system on the robot is used for ambient intelligence to gather the information about ball position and velocity.

Fig. 11. Snapshot of the ball-passing training

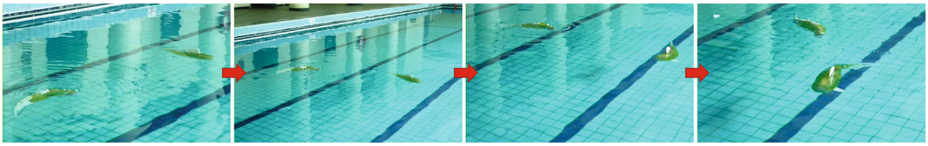


Fig. 12. Schooling behavior of two robotic fishes

Collective Intelligence. Collective intelligence is responsible for enabling cooperative behavior among multiple robots. The key issue to collective intelligence is information sharing; therefore, robots need to have the ability to communicate with each other. Utilizing collective intelligence, robots can carry out tasks that are difficult or impossible for a single robot to do [18]-[19].

Related Application: Schooling Behavior of Fibo

Schooling behavior is a large scale coordinated movement of fish. The schooling behavior consists of three movements: alignment, separation, and cohesion. Alignment is required to follow the same direction as the leading fish, whereas separation is required to avoid crowding and cohesion is required to move toward the leading fish while trying to minimize the distance between the two.

In this research, a camera was installed on the front of the robotic fish head. In this way, the robotic fish can calculate both the angle and distance between its head and the goal. Then, the robotic fish should determine its heading direction with respect to the goal location. To control the steering angle of the robotic fish towards the horizontal component of the heading direction, the line of sight method was used. The vertical component of heading direction was controlled by adjusting the center of the mass and using an artificial bladder.

Using vision and control algorithms, two robotic fishes could perform schooling behavior while swimming like real fishes do. Using color and shape of the robotic fish, the following robotic fish could distinguish the leading robotic fish (Fig. 12) [21]-[22].

Genetic Intelligence. Genetic intelligence relates to the personal traits and knowledge of a robot that it inherited from its parents. These inherited personal aspects define the personality of the robot. The behaviors generated by the robot are dictated by the personality of the robot. The representation of such personal parameters, similar to genes in biological species, constitutes the genetic code in robots and artificial species. Robots and artificial species with diverse personalities can be generated by the genetic code, which represents a specific personality desired by user for more natural HRI.

Related Application: Artificial Genome for Rity

An artificial creature has its own genome in which each chromosome consists of many genes that contribute to defining its personality. The large number of genes makes it a highly complex system. It becomes increasingly difficult and time consuming to ensure reliability, variability and consistency for the artificial creature's personality, if gene values are manually assigned for the individual genome. To solve

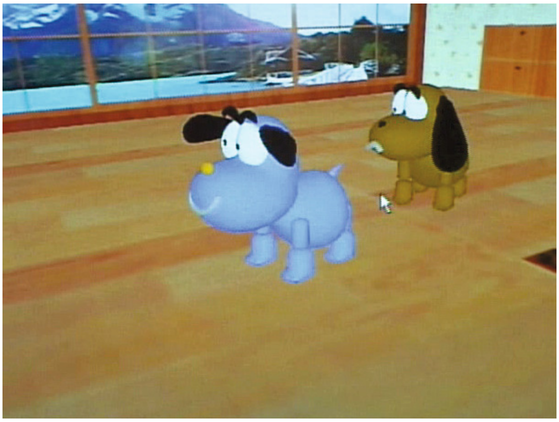


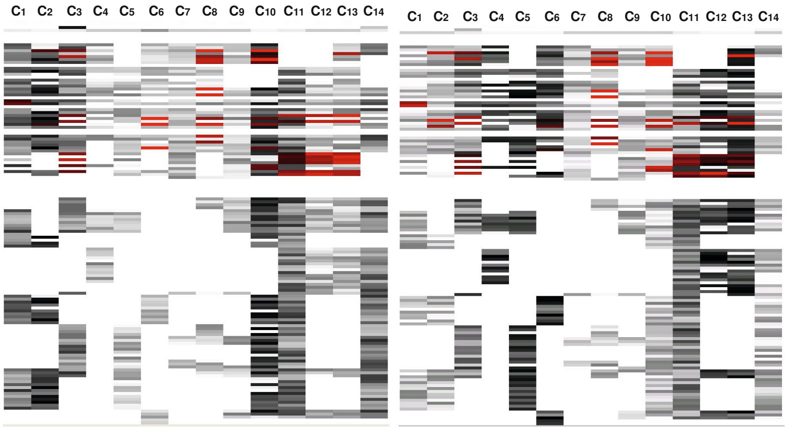
Fig. 13. Agreeable Rity (blue color) and antagonistic Rity (brown color) in a 3D virtual world

this problem, an evolutionary generation process (EGPP) for developing artificial creatures' genomes for specific personalities. Through EGPP, non-dominated genomes having specific personalities can be obtained and they are successfully tested by using an artificial creature, Rity, in the virtual 3D world created in a virtual space [23]. Rity is designed to be a believable interactive software agent for human-robot interaction as shown in Fig. 13.

The agreeable and antagonistic personality models were chosen to validate the proposed EGPP and the obtained fittest genome was implanted to Rity to verify the feasibility of EGPP [24]. The parameter settings of EGPP were applied equally in both the cases of agreeable and antagonistic personalities. The population size was 20 and the number of generations was 1,000. Crossover and mutation operate independently between two arbitrary parents at three different kinds of gene-dependent crossover and mutation rates. Fig. 14 shows generated genomes of an agreeable personality and antagonistic one in gray and red levels, where the grays denote positive values with darker shades representing higher values and the reds denote negative values with darker shades representing lower values. The key objective of this process is to generate an artificial creature with a personality that is both complex and feature rich, but still plausible by human standards for an intelligent life form.

3 Intelligence Technology Manipulation through Ubiquitous Robot System

Ubibot system was developed as a prototype to validate the effectiveness of ubiquitous robotics. Ubibot, through all its components is capable of manipulating all aspects of InT. The following subsections describe how different aspects of InT are manipulated by different components of Ubibot system.



(a) Agreeable genome (b) Antagonistic genome

Fig. 14. Generated genome by using EGPP

3.1 Sobot's Cognitive Intelligence

To make artificial creatures deliberately interact with their environment like living creatures, a cognitive architecture for mimicking living creatures thought mechanism is needed. To equip Sobot with cognitive intelligence, the degree of consideration-based mechanism of thought (DoC-MoT) for Rity was developed. Rity has a human-like thought process which is affected by personal biases and prejudices based on psychological, cognitive or environmental grounds, is used to model the mechanism of thought for artificial creatures. The creatures' degrees of consideration (DoCs) for their internal wills and environmental contexts constitute the basis of the thought mechanism. In the proposed model, the DoCs for input (i.e. wills and contexts) symbols are represented by the fuzzy measures and the fuzzy integral is used for the global evaluation of the target (i.e. behavior) symbol on the basis of the partial evaluations over input symbols and their DoCs [25].

Fig. 6, discussed in the previous section, shows the cognitive architecture for the Sobot. The context generation module identifies a current environmental context using perceptions from the perception module, and the internal state module identifies a current will of an artificial creature. The memory module stores all the necessary memory contents including symbols of wills, contexts and behaviors. It also has the information on the DoCs for input symbols and the knowledge links between input and behavior (target) symbols. The DoCs are represented by the fuzzy measures and the knowledge link strengths are given by the partial evaluation values of behavior symbols over each input symbol. Considering the identified will and context, the behavior selection algorithm in the problem solving module selects a proper deliberative behavior by the fuzzy integral aggregating the partial evaluation values and the DoCs for input symbols.

Fig. 15. 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

Reflexive behaviors are generated using sensor information from the perception module. The learning algorithm to change the characteristics of artificial creatures is executed in the learning module. The key modules for behavior selection, namely internal state, behavior selection, learning and memory modules, are described in [26].

3.2 Social Intelligence via Embots and Mobots

In the Ubibot system, the aim is for the Sobot to actuate the Mobot to continually monitor and provide services to the human user. After initiating the Sobot's attention, the user proceeds to move away. The Sobot perceives this and decides to follow the user. This setup portrays a real world situation where the user might dynamically engage and disengage various Embots, leading the Sobot to physically follow him/her by actually moving onto the Mobot. This is depicted in Fig. 15, where the Sobot has downloaded itself via Middleware from the remote site, onto the Tablet PC of the Mybot, thus enabling it to monitor the user in real time irrespective of his actual location. This verified the seamless integration of the Ubibot system transcending spatial limitations in its ability to provide services.

3.3 Behavioral Intelligence in Mobots

The Ubibot system consists of various Mobots, both wheeled and humanoid. Therefore, Mobots require behavioral intelligence to execute motion and other behaviors in accordance with their hardware resources. the humanoid Mobot, HSR, has MWPG (discussed in the previous section) to walk from one point to another, while the wheeled Mobot is equipped with a navigation algorithm for differential wheeled robots. A non-singleton interval type-2 fuzzy logic controller for Xbot (a cleaning robot platform that can be used as a Mobot) was developed

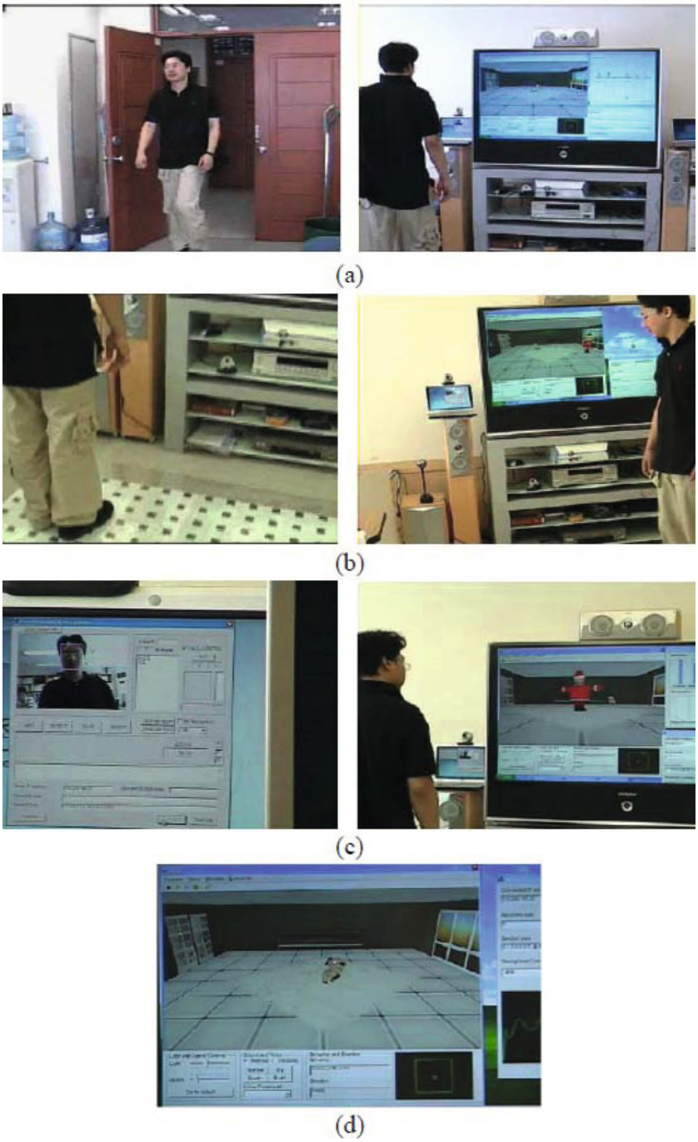


Fig. 16. Sobot-user interaction, (a) a subject enters the u-space, (b) position Embot senses the subject's location and transmits information to Sobot, symbolically resembling the appearance of Santa-Claus figure in the world; (c) Vision Embot performs face recognition and Sobot exhibits happiness upon perceiving its master, which (d) Sound Embot indicates that Dance command has been spoken, causing Sobot to comply and dance

to enable mobile robot to navigate in real world environments with measurement uncertainties. In [27], we demonstrated the effectiveness of such interval type-2 fuzzy logic controllers for systems with uncertainties. Such controllers enable the robot to autonomously take care of the navigation behavior in real environments with high uncertainties.

3.4 Ambient Intelligence via Embots

The Sobot interacts with a user actively since it is designed as a synthetic pet. In a complex scenario where a subject moves around in a home environment, the Sobot needs to access and exchange information from a number of Embots and Mobots. In the image sequence shown in Fig. 16, a demonstration was carried out, where the subject walked into the u-space simulated home environment with a TV with attached computers, upon which the Ubibot became immediately aware through the position Embot and Vision Embot. The latter then performed face recognition to identity the subject. Once the identification was established, Rity proceeded to react with joy and happiness and the user might transmit commands through voice or using keyboard and mouse.

This setup demonstrated the calm-sensing and context aware capabilities of the Ubibot allowing it to monitor its ambience, including the users and objects within the u-space.

3.5 Collective Intelligence

As the Ubibot system comprises of various components, some of which can function as standalone robots as well, collective intelligence is inevitable for the operation of ubiquitous robots. For seamless and calm operation of ubiquitous robots, all the Mobots, Embots and Sobot work in cohesion with each other. Sobot connects seamlessly and transmits itself to any location via Mobots. Moreover, different Sobots can co-operate with other Sobots (Ritys) by downloading themselves in the virtual spaces of each other and then proceed to interact with each other based on their internal states.

3.6 Sobot's Genetic Intelligence

Rity (Sobot) also has an artificial genome that was used for the realization of the concept of genetic robot wherein robotic genomes encode the artificial creature's personality, as in [23]. 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. The details about the artificial genome has been summarized in the previous section and Fig. 14.

4 Summary

In this chapter, the third generation of robotics, ubiquitous robotics, was introduced. Ubiquitous robots integrates three forms of robots: Sobot, Embot and Mobot. Sobots, which are software-based virtual robots in virtual environments, can traverse space through physical networks. Embots, the embedded robots, are implanted in the environment or embedded in Mobot, for sensing, detecting, recognizing, and verifying the objects or the situation. The processed information is to be transferred to Sobot or Mobot. Mobots provide integrated mobile services that Sobots and Embots cannot. Sobots and Embots can work individually or within Mobots. The Ubibot system is seamless, calm, context aware in its ability to provide integrated services. Rity, a 3D character and a Sobot, was introduced and implemented using two scenarios to demonstrate the possibility of realizing Ubibot.

We also presented InT for ubiquitous robots. The iOA was presented for intelligence technology to implement robot intelligence. Robot intelligence was classified into six categories: cognitive intelligence, social intelligence, behavioral intelligence, ambient intelligence, collective intelligence and genetic intelligence. Implementations, using software and hardware robots, demonstrated the significance of each category of robot intelligence.

References

1. Weiser, M.: The computer for the 21st century. Scientific American 265(3), 94–104 (1991)
2. Weiser, M.: Some computer science problems in ubiquitous computing. Communications of ACM 36(7), 75–84 (1993)
3. Kim, J.-H., Zaheer, S.A., Choi, S.-H.: The Next Technological Wave: Intelligence Technology for Intelligence Super Agent. IEEE Computational Intelligence Magazine 9(3), 54–64 (2014)
4. Brady, M.: Artificial Intelligence and Robotics. Artificial Intelligence 26, 79–121 (1985)
5. Kim, J.-H., Kim, Y.D., Lee, K.-H.: The 3rd Generation of Robotics: Ubiquitous Robot (Keynote Speech Paper). In: The Proceedings of International Conference on Autonomous Robots and Agents (2004)
6. Kim, J.-H., Lee, K.-H., Kim, Y.-D., Kuppuswamy, N.S., Jo, J.: Ubiquitous Robot: A New Paradigm for Integrated Services. In: The Proceedings of IEEE International Conference on Robotics and Automation, pp. 2853–2858 (2007)
7. Asimov, I.: The vocabulary of science fiction. Asimov's Science Fiction. Doubleday, New York (1979)
8. Kim, J.-H., Choi, S.-H., Park, I.-W., Zaheer, S.-A.: Intelligence Technology for Robots That Think. IEEE Computational Intelligence Magazine 8(3), 70–84 (2013)
9. Yoo, J.-K., Kim, J.-H.: Fuzzy integral-based gaze control architecture incorporated with modified-univector field navigation for humanoid robots. IEEE Transactions on Systems, Man, and Cybernetics C 42(1), 125–139 (2012)
10. Lee, D.-H., Kim, J.-H.: Evolutionary personalized robotic doll: GomDoll. In: The Proceedings of IEEE Congress on Evolutionary Computation, pp. 30254–33029 (2008)

11. McCrae, R.R., Costa, P.T.: Validation of a five-factor model of personality across instruments and observers. J. Pers. Social Psychol. 52, 81–90 (1987)
12. Lee, B.-J., Stonier, D., Kim, Y.-D., Yoo, J.-K., Kim, J.-H.: Modifiable walking pattern of a humanoid robot by using allowable ZMP variation. IEEE Transactions on Robotics 24(4), 917–923 (2008)
13. Hong, Y.-D., Kim, J.-H.: 3-D command state-based modifiable bipedal walking on uneven terrain. IEEE/ASME Transactions on Mechatronics 18(2), 657–663 (2013)
14. Hong, Y.-D., Lee, B.J., Kim, J.-H.: Command state-based modifiable walking pattern generation on an inclined plane in pitch and roll directions for humanoid robots. IEEE/ASME Transactions on Mechatronics 16(4), 783–789 (2011)
15. Hong, Y.-D., Park, C.-S., Kim, J.-H.: Human-like stable bipedal walking with a large stride by the height variation of the center of mass using an evolutionary optimized central pattern generator. In: Proceedings of Annual Conference on IEEE Industrial Electronics Society, pp. 136–141 (2011)
16. Hong, Y.-D., Kim, Y.-H., Han, J.-H., Yoo, J.-K., Kim, J.-H.: Evolutionary multi-objective footstep planning for humanoid robots. IEEE Transactions on Systems, Man, and Cybernetics C 41(4), 520–532 (2011)
17. Yan, R., Tee, K.P., Chua, Y., Li, H., Tang, H.: Gesture recognition based on localist attractor networks with application to robot control. IEEE Computational Intelligence Magazine 7(1), 64–74 (2012)
18. Lee, D.-H., Han, J.-H., Kim, J.-H.: A preference-based task allocation framework for multi-robot coordination. In: The Proceedings of IEEE International Conference on Robotics and Biomimetics, pp. 2925–2930 (2010)
19. Sayama, H.: Robust morphogenesis of robotic swarms. IEEE Computational Intelligence Magazine 5(3), 43–49 (2010)
20. Lee, D.-H., Kim, J.-H.: A framework for an interactive robot-based tutoring system and its application to ball-passing training. In: The Proceedings of IEEE International Conference on Robotics and Biomimetics, pp. 573–578 (2010)
21. Jeong, I.-B., Park, C.-S., Na, K.I., Han, S.-B., Kim, J.-H.: Particle swarm optimization-based central pattern generator for robotic fish locomotion. In: The Proceedings of IEEE Congress on Evolutionary Computation, pp. 152–157 (2011)
22. Na, K.I., Park, C.-S., Jeong, I.B., Han, S.-B., Kim, J.-H.: Locomotion generator for robotic fish using an evolutionary optimized central pattern generator. In: The Proceedings of IEEE International Conference on Robotics and Biomimetics, pp. 1069–1074 (2010)
23. Kim, J.-H., Lee, C.-H.: Multi-objective evolutionary generation process for specific personalities of artificial creature. IEEE Computational Intelligence Magazine 3, 43–53 (2008)
24. Kim, J.-H., Lee, C.H., Lee, K.-H.: Evolutionary generative process for an artificial creature's personality. IEEE Transactions on Systems, Man, and Cybernetics C 39(3), 331–342 (2009)
25. Kim, J.-H., Ko, W.-R., Han, J.-H., Zaheer, S.-A.: The degree of consideration-based mechanism of thought and its application to artificial creatures for behavior selection. IEEE Computational Intelligence Magazine 7(1), 49–63 (2012)
26. Kim, J.-H., Lee, K.-H., Kim, Y.-D.: The origin of artificial species: Genetic robot. Int. J. Control, Autom., Syst. 3(4), 564–570 (2005)
27. Zaheer, S.A., Kim, J.-H.: Type-2 Fuzzy Airplane Altitude Control: a Comparative Study. In: The Proceedings of IEEE International Conference on Fuzzy Systems, pp. 2170–2176 (2011)