Designing Smart Skins for Adaptive Environments

A fuzzy logic approach to smart house design

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ABSTRACT

Recent developments in sensor, computing, information and communication technologies have inspired the creation of new smart devices and environments. This paper proposes "smart skins" that are capable of actively inferring and detecting various environmental conditions, making optimal decisions, and learning to use their functions to map environmental variations to occupants' needs. This paper explores the potential of smart skins and proposes three key elements for their integration: (1) intelligent agents, (2) context awareness, and (3) fuzzy logic and neuro-fuzzy system. This research discovers that correspondent relationships and experimental transmissions between occupants and environments make environmental agents' user experience-oriented, with context-awareness abilities based on the smart envelope prototype's construction, evaluation and analysis.

Keywords: intelligent agents, context awareness, fuzzy logic and neuro-fuzzy system

1. INTRODUCTION

Smart environments have recently become an important research subject. With the assistance of its adaptive components and materials, a "smart house" responds to both variations in the environment and the needs of its occupants. The recent development of smart houses has led in two directions: (1) A general emphasis on active and automatic intelligent control supporting environmental sustainability [15]; and (2) the adoption of a human-centered method of satisfying universal design principles with adaptive functions, and an endeavor to eliminate excessive and over-complex human-computer interfaces, making the home environment conducive to maximizing independence [2]. Chiu (2005a) [5] proposed that three key functions of a smart house include: (1) smart skin, (2) smart life, and (3) smart care.

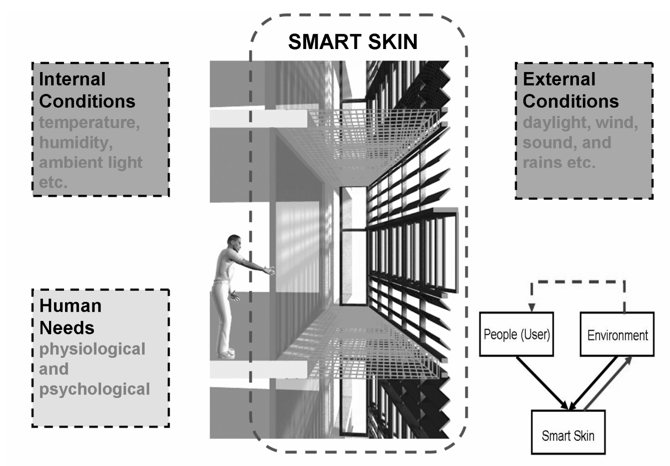


Fig. 1: Building skin in respond to external and internal conditions.

Context means situational information, and context-awareness means that one is able to use context information. A system is context-aware if it can extract, interpret and use context information and adapt its functionality to the current context of use [13], [7]. Building skins, including envelopes and partitions, have to respond to external and internal conditions (Fig. 1). Prior research [4] has verified that agent-based smart skins are able to implement simple context-aware functions via rule-based inferences, but cannot handle complex situations. However, agent-based interfaces can describe the state of the environment (indoor and outdoor) and prompt users.

(Fig. 2) shows a feasible computing device (Campbell CR510 data logger, [3]) receiving data from sensors and allowing simple rule-based program design. The start of measurements and control of functions are based on time or event. The data logger is able to drive external devices, such as pumps, starters, or control valves. The data logger's programming software is known as EDLOG. EDLOG contains computing units for input and output, processing, processing control, and output processing. In addition, VB program executable files are needed to activate interface agents. Database applications programs (Dream-weaver+ ASP+ Access) can be used to design a user interface and establish a database. The figure shows indoor and outdoor light sensors. The data logger can adjust the sunshade angle on the basis of its inferences. If, however, information from the two sensors causes a logical conflict (XOR), the user must communicate interactively with the interface agent.

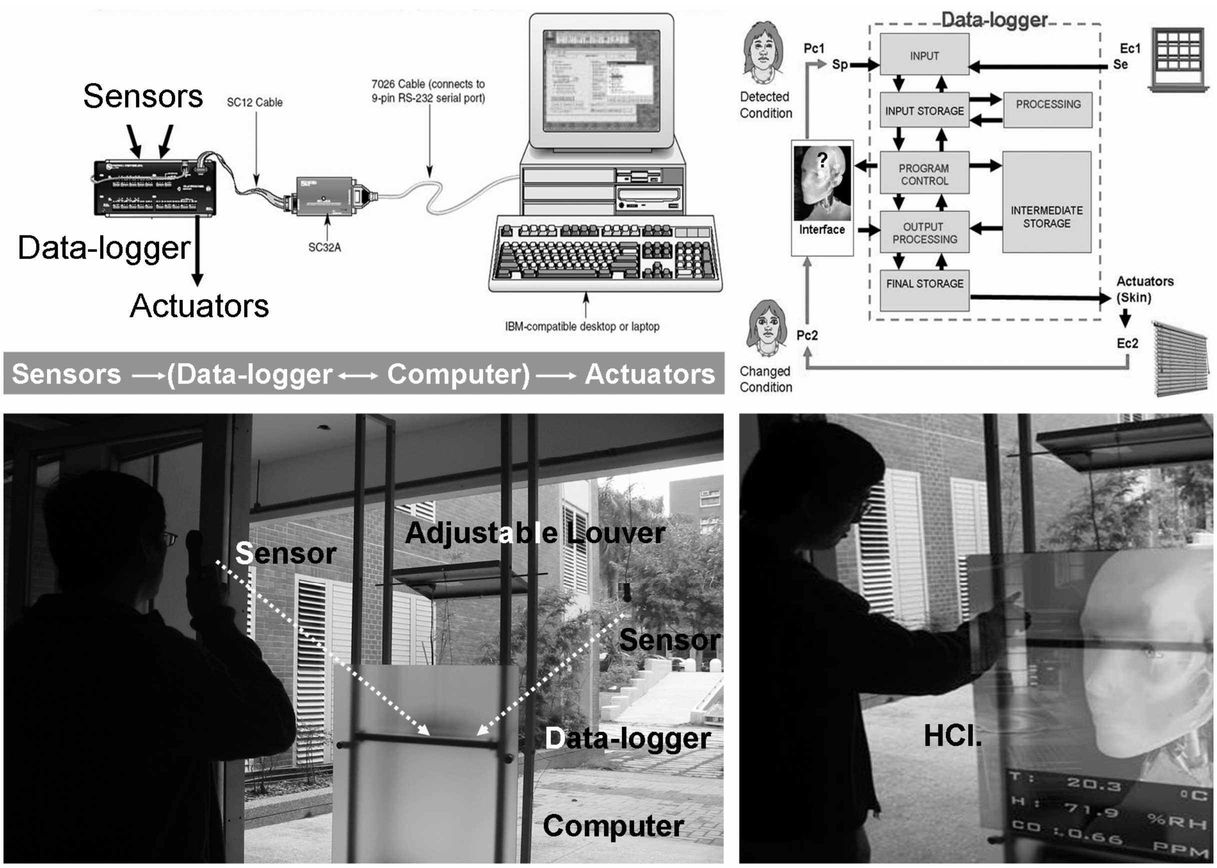


Fig. 2: Smart skin with agent-based interface.

Toward an adaptive and aware house, the research question is “how can a smart skin be embedded with agents for adaptation and awareness?” The purpose of this paper is to build agent-based smart skins and perform simulations for evaluation. However, these smart skins still lacked the ability to adapt to complex, uncertain, and multi-users' requirements with rule-based reasoning [6]. We therefore propose different versions of smart skins with “fuzzy logic inference" that are able to deal with complex and uncertain problems, and also possess a more advanced learning capability that can enhance their predication abilities with a "neuro-fuzzy" algorithm.

Occupant's interests and the goals of environmental sustainability are not always identical however. It has proven difficult for designers to select appropriate technologies and determine algorithms and control conditions when creating intelligent environments. For example, the TU Vienna Test-bed [8] employs a rule-based control system in which meta-controllers must be added as the number of devices increases. This system consists of a distributed, hierarchical control node framework. The fact that it is not easy to distinguish modules in the system increases the difficulty of control and rule description. In another example, Adaptive Home [10] employs Adaptive Control of Home Environment (ACHE) to strike a balance between maximum user comfort and minimum energy consumption. However, because the central control system's X-10 controller is often slow to respond or out of order, and also because of improper operation, the neural system tends to make learning errors and converge on a state of low energy consumption and low comfort. After examining the advantages and disadvantages of these two cases, this study proposes the use of a fuzzy logic and neuro-fuzzy system as a computing mechanism. This type of system can use prior knowledge and fuzzy logic to make inferences, while also employing neuro-fuzzy learning to reduce the error between inferences and reality.

In summary, this study proposes the establishment of agent-based smart skins, and suggests the use of a fuzzy logic and neuro-fuzzy system as the intelligent agents' computing mechanism. Each agent is a well-defined smart module (Fig. 3), and the agents can cooperate and interact with each other to complete and achieve their designed objectives. This system can employ inference and learning to implement adaptive actions and functions, and the agent-based control system can be divided into two layers; the first layer consists of the computing mechanism and planning of independent agents, and the second layer consists of a description of the agent community interaction mode.

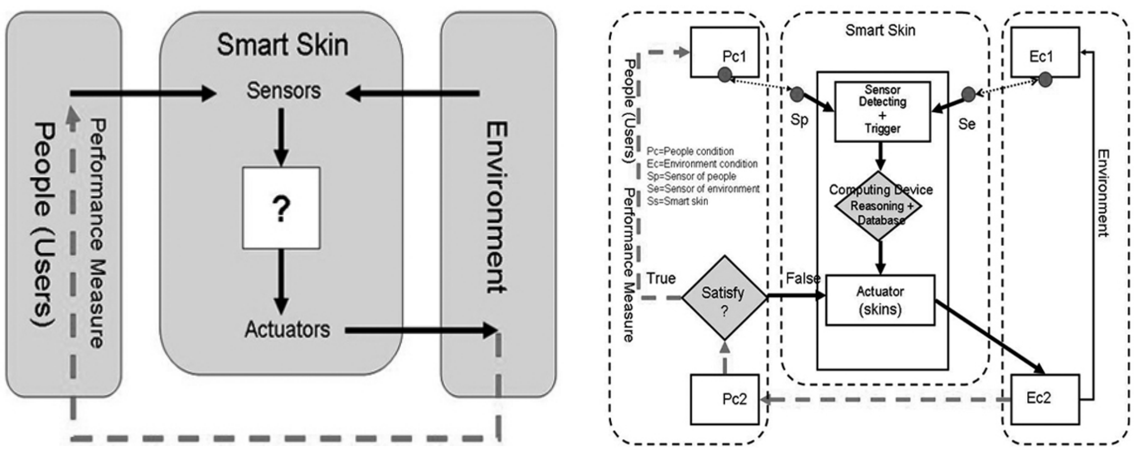


Fig. 3: Smart skins framework.

2. FRAMEWORK: AGENT-BASED SMART SKINS FOR ENVIRONMENTAL AWARENESS

A smart skin, as a communicative interface between residents and their surroundings, should perceive both human physiological and psychological needs and also environmental variations; it should further be capable of reasoning in order to implement, trigger, or stop actions involving a building's envelope or its parts in order to modify conditions so as to facilitate the residents' amenity and heath and also meet the needs of environmental sustainability. Depending on its design objectives, the smart skin can be composed of an agent or agents [4].

2.1 Single Agent

An agent must be capable of "flexible" autonomous actions in order to meet its design objectives, where flexibility means three capabilities: (1) reaction, (2) pro-action, and (3) interaction, [14]. Reaction refers to immediate action taken by an agent without computing after receiving information. Pro-action refers to action taken following computing after receiving information. Interaction refers to communication between an agent and other agents or an occupant via a human-computer interface. This event-driven agent model [11] must consist of three basic parts: a sensor, computational mechanism, and an actuator [12]. Therefore, according to definition of a smart skin, the representation of an environmental awareness agent shall be composed of at least two input terminals respectively able to sense events from the “Environment” (E) or “People” (P). And at least one output terminal shall be connected to an actuator, a component of the “Building’s envelope” (B) or the other “Environmental awareness agents” (EA). An actuator employing smart design or made of smart materials enables the system to implement adaptive behaviors. The operations of a smart skin's “fuzzy logic” rely on the following steps:

- (Step-1) System design: (1) Fuzzification: Definition of linguistic variables and types of membership functions; (2) Inference: creation of rule-based plans and sub-plans and enabling “IF < Events (E, A) > THEN < Actions (B, EA) > ” to be represented as “matrix rules”; and (3) De-fuzzification: identification of an appropriate de-fuzzification method. CoM (Center of Maximum) was mostly adopted (Fig. 4).
- (Step-2) Off-Line Optimization : The use of pre-recorded data from the process or a process simulation written in a programming language to optimize a system.
- (Step-3) Implementation: The software’s optimized assembly code generation implements the fuzzy logic system on the target hardware platform.

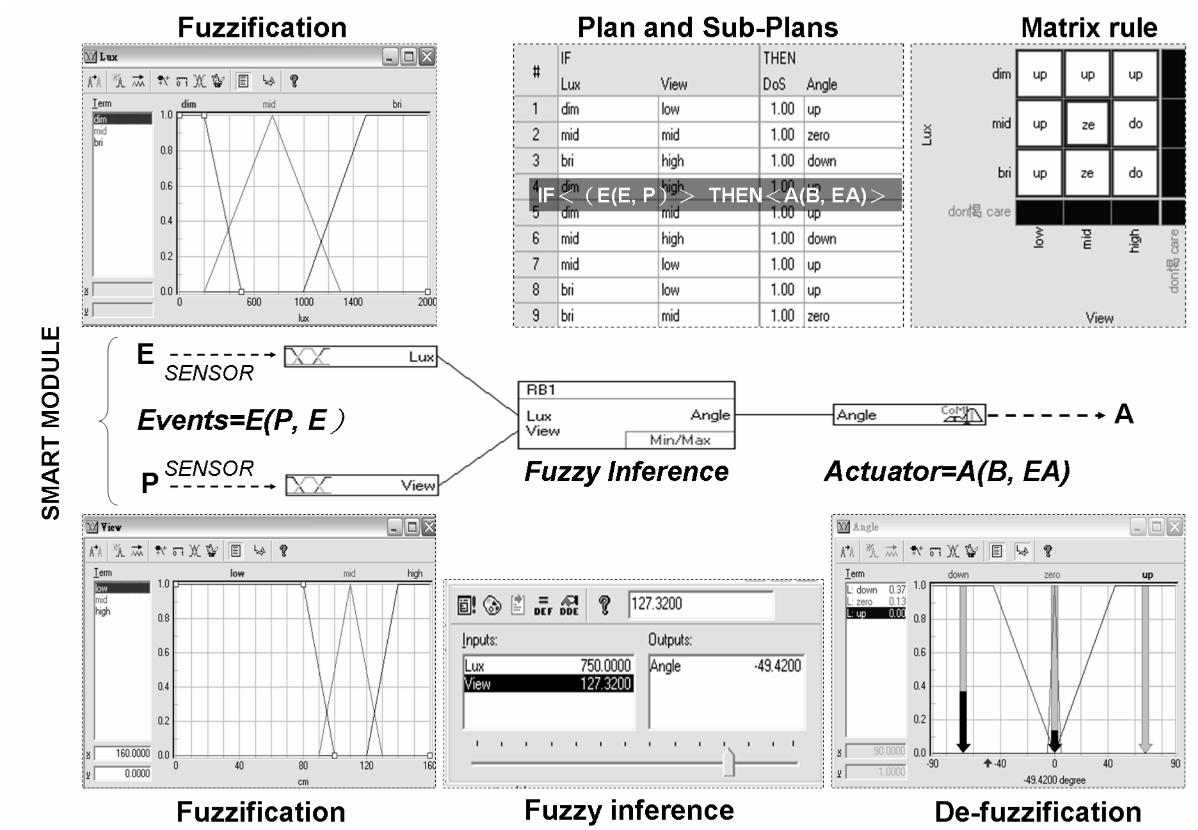


Fig. 4: Smart module and fuzzy logic inference.

The smart skin's neuro-fuzzy learning employs an error back propagation supervised learning algorithm, and relies on the adjustment of degree-of-support (DoS) to reduce the error between the predicted fuzzy inference value and the actual use value. This achieves optimized correspondence between input and output [1], (Fig. 5).

Trans	THEN DoS	Im
mid	1.00	mid
high	1.00	low
mid	1.00	bri
low	1.00	mid
high	1.00	mid
high	1.00	bri
low	1.00	bri
mid	1.00	mid
low	1.00	mid
high	1.00	bri

#	IF Angle	Trans	THEN DoS	Im
1	mid	mid	0.60	mid
2	up	high	0.50	low
3	down	mid	1.00	bri
4	mid	low	0.80	mid
5	mid	high	0.90	mid
6	down	high	0.40	bri
7	down	low	0.30	bri
8	up	mid	1.00	mid
9	up	low	0.70	mid
10	mid	high	0.80	bri

Fig. 5: Neuro-fuzzy learning: Adaptive DoS.

2.2 Society of Agents

Agent societies or agents and users can generate cooperative or coordinated interactive behaviors via common communications protocols, shared databases, messages, and human-computer interfaces [14], (Fig.6). The levels and subordination relationships of agents within a community are not fixed, and can be changed or reassembled to suit the task or overall goal [9]. We will perform testing and mode analysis in section 3.3.

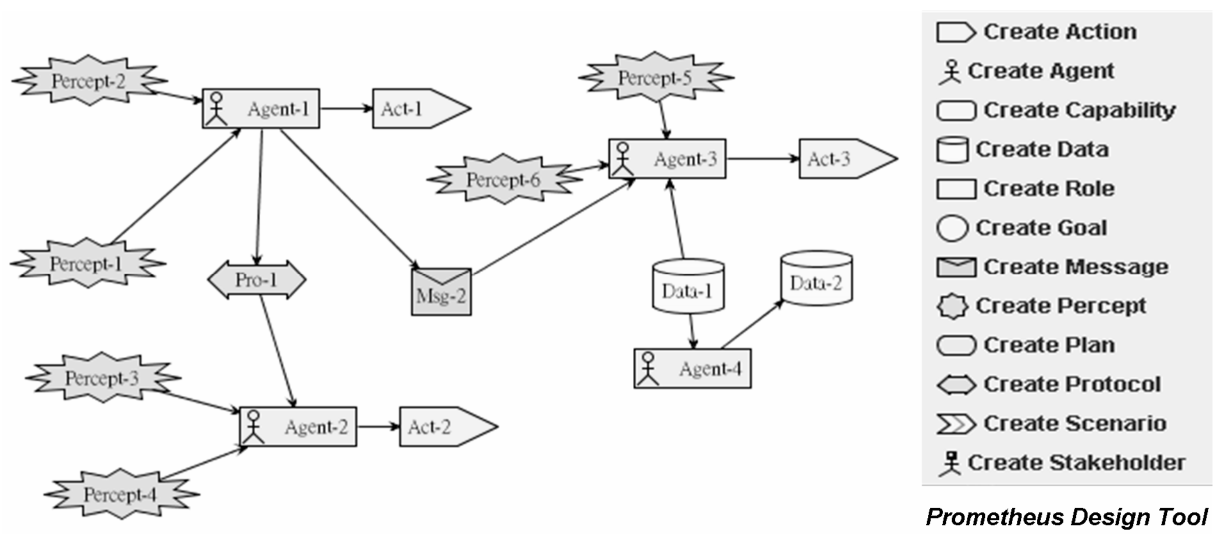


Fig. 6: Interactions in a community of agents.

3. IMPLEMENTATION AND VERIFICATION

The goal of this experiment is to test the ability of intelligent agents to perform tasks. This involves not just the individual actions of intelligent agents, but also the interaction of the user with an agent community.

3.1 Task and Elementary Conditions

The main task is the adjustment of indoor lighting. "Fuzzy-TECH" software is used to simulate the smart skin's fuzzy-logic inference and neuro-fuzzy learning. All smart skin modules are simplified as two input terminals and one output terminal, and all linguistic variables are uniformly reduced to three. (e.g., up, zero, and down, or low, mid, and high).

3.2 Setting Users' Attributions and Activity Types

The purpose of setting users' attributions and activity types is to test adaptive behavior at different smart levels. Residents ranged from adults aged 30 years old to seniors aged 70 years; the 30-person group consisted of equal numbers of men and women. Activity classifications were changed on the basis of focus. Lighting requirements are classified as "Dim"- for leisure, (e.g. rest and conversation), "Moderate"- for ordinary tasks, (e.g. reading and writing), and "Bright"- for precision tasks such as sewing and nursing care. Lighting can also be classified on the basis of privacy as "Low," (e.g. for conversation), "Moderate," (e.g. for reading, writing, and sewing), and "High," (e.g. for nursing care and resting).

Three smart levels of user experience-oriented awareness (1) Ordinary people (interface alert), (2) Healthy seniors (interface prompt and user selection), and (3) Disabled persons (proactive assistance) can be defined depending on whether there is a human-computer interface and on the adaptive behavior mode of the actuator. As shown in Table 1, the interface prompted interaction mode is suitable for ordinary people and healthy seniors. On the other hand, the disabled can employ the proactive assistance mode, where agents can perform inference and learning without the occupant having use the interface. (Note: Passive refers to when the user purposely adjusts the building's elements and the actuator operation is not controlled by agents. An example is when the user opens or closes the window without the use of agents.)

	User Types	Interface prompt	Adaptive actions
Level 1、Norm (Interface alert)	Ordinary people	Yes	Passive (User Driven)
Level 2、Aging (interface prompt and user selection)	Healthy seniors	Yes	Interactive
Level 3、Disability (Pro-active assistance)	Disabled persons or impaired seniors	No.	Reactive Pro-active

Tab. 1: Smart levels.

3.3 Setting up Environmental Conditions and the Framework for Experimental Processes

This experiment employed a "window agent" as an example of a smart skin, and in order to investigate the possibilities of the agents' mutual cooperation, the window agent was divided into two sub-agents, "louver panel agent" and "PDLC glass agent." The experimental room was a 3.6 x 3.6 x 3.6 m^3 interior, obtaining sunlight through a south-facing window. The solar altitude angle was fixed at 45°, and the sky brightness was set at 500cd/m^2 outdoor, (Fig. 7). The sill height was 90 cm above the floor, and the window opening was 2.7 (w) x 1.8 (h) m^2. Furniture including sofa, couch, table chair etc. was arranged indoors temporarily to facilitate the experiment (Fig. 8). The "louver board (LB) agent" adjusted the louver angle (down, zero, up) in accordance with indoor lighting needs (dim, mid, bright) and the user's visual needs (low, mid, high). The PDLC glass agent served to adjust the transparency of the PDLC glass in accordance with the indoor activity lighting needs (dim, mid, bright) and the user's privacy needs (low, mid, high). The fuzzy inference plan was as shown in Table 2. For instance, if the lighting need was high (bright) and visual need was low, the louver board would be adjusted up for more sunlight and visibility. Furthermore, the system interacted with another smart entity- a lamp agent. The system received information from the window agent via wireless signals, and adjusted lamp brightness in order to improve indoor illumination. In addition, the user could use a wall-mounted dial to adjust the lighting. The learning agent used a neuro-fuzzy training data set from the lamp use database to adjust the DoS of the lamp agent's fuzzy inferences and improve the lamp agent's predictive ability.

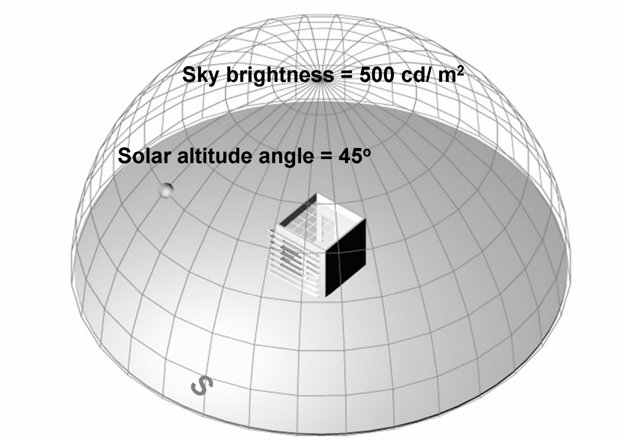


Fig. 7: environmental Setting.

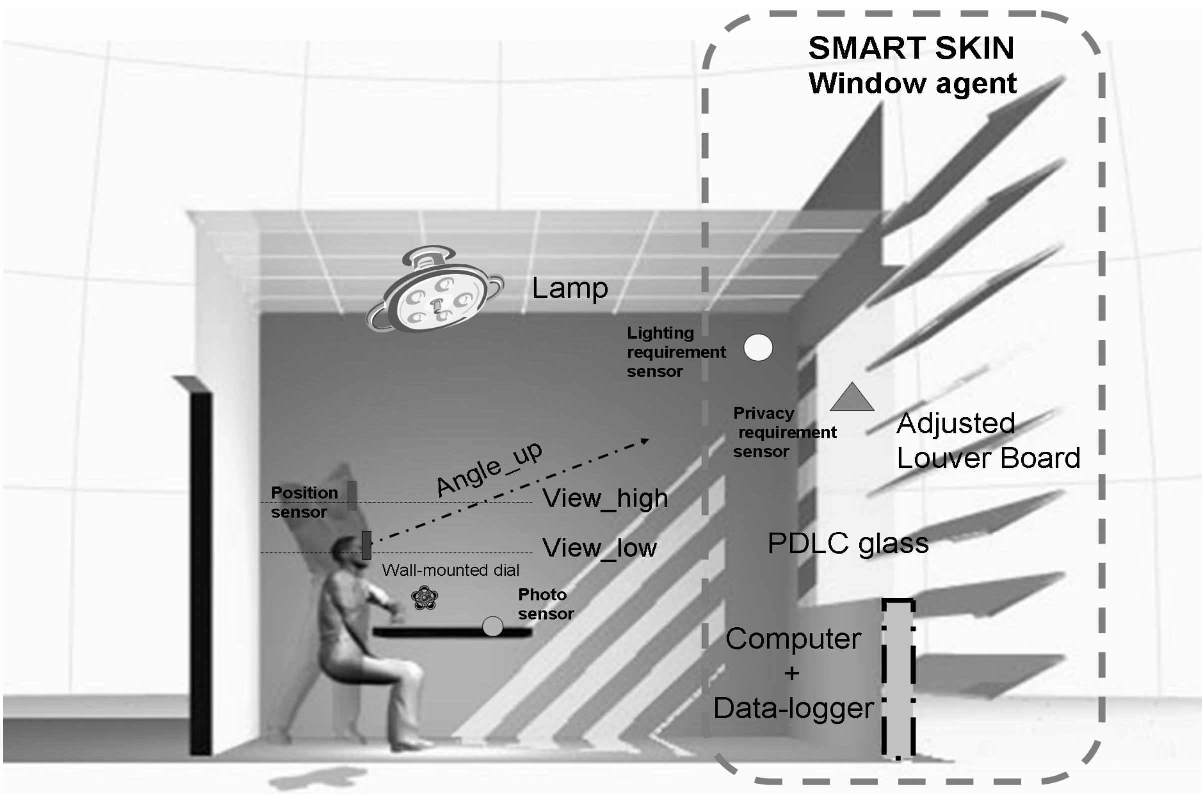
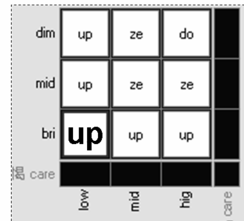
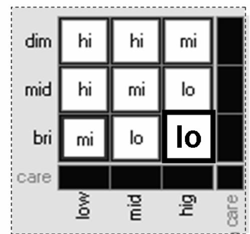
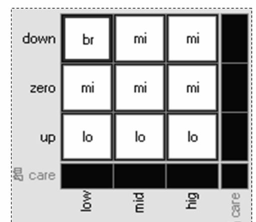


Fig. 8: Experimental room.

	Input IF <E(P, E)>	Output THEN <A(B, EA)>	Matrix Rule
Window Agent			
L B Agent	Lux_dim=(1/0, 1/200, 0/500) Lux_mid=(0/200, 1/750, 0/1300) Lux_bri=(0/1000, 1/1500, 1/2000) X View_low=(1/0, 1/90, 0/100) View_mid=(0/90, 1/110, 0/130) View_hig=(0/120, 1/140,1/160)	Angle_Down=(1/-90,1/-45,0/0) Angle_Zero=(0/-5,1/0,0/5) Angle_Up=(0/0, 1/45, 1/90)	
PDLC Agent	Lux_dim=(1/0, 1/200, 0/500) Lux_mid=(0/200, 1/750, 0/1300) Lux_bri=(0/1000, 1/1500, 1/2000) X Privacy_low=(1/0, 1/200,0/300) Privacy_mid=(0/200, 1/300,0/400) Privacy_hig=(0/300, 1/400,1/500)	Trans_low=(1/0, 1/30, 0/50) Trans_mid=(0/30, 1/50, 0/70) Trans_hig=(0/50, 1/70, 1/100)	
Lamp Agent			
	Angle_Down=(1/-90,1/-45,0/0) Angle_Zero=(0/-5,1/0,0/5) Angle_Up=(0/0, 1/45, 1/90) X Trans_low=(1/0, 1/30, 0/50) Trans_mid=(0/30, 1/50, 0/70) Trans_hig=(0/50, 1/70, 1/100)	Im_low=(1/0,1/200, 0/500) Im_mid=(0/300,1/900, 0/1500) Im_bri=(0/1200,1/1800, 1/2400)	
Database Agent			
	Used Record of Lighting	To Learning Agent	
Learning Agent			
	Training set data from Databased Agent	Dos values are adjusted	

Tab. 2: Agents' fuzzy logic inference plans.

The experiment sought to analyze the interactive behavior of agent societies. Although the louver board intelligent agent and the PDLC glass intelligent agent are both window agents, they control different window functions; the former adjusts the visibility, while the latter controls privacy. However, with regard to the user's lighting needs, they constitute similar agents simultaneously performing the same tasks and also different tasks. And although the louver board agent and lamp agent are different types of agents, with regard to lighting, they are agents of different types performing the same task. Furthermore, the communication and cooperation between both the lamp agent and database and the learning agent constitutes agents of different types performing a sequence of different tasks with the same goal. (Fig. 9)

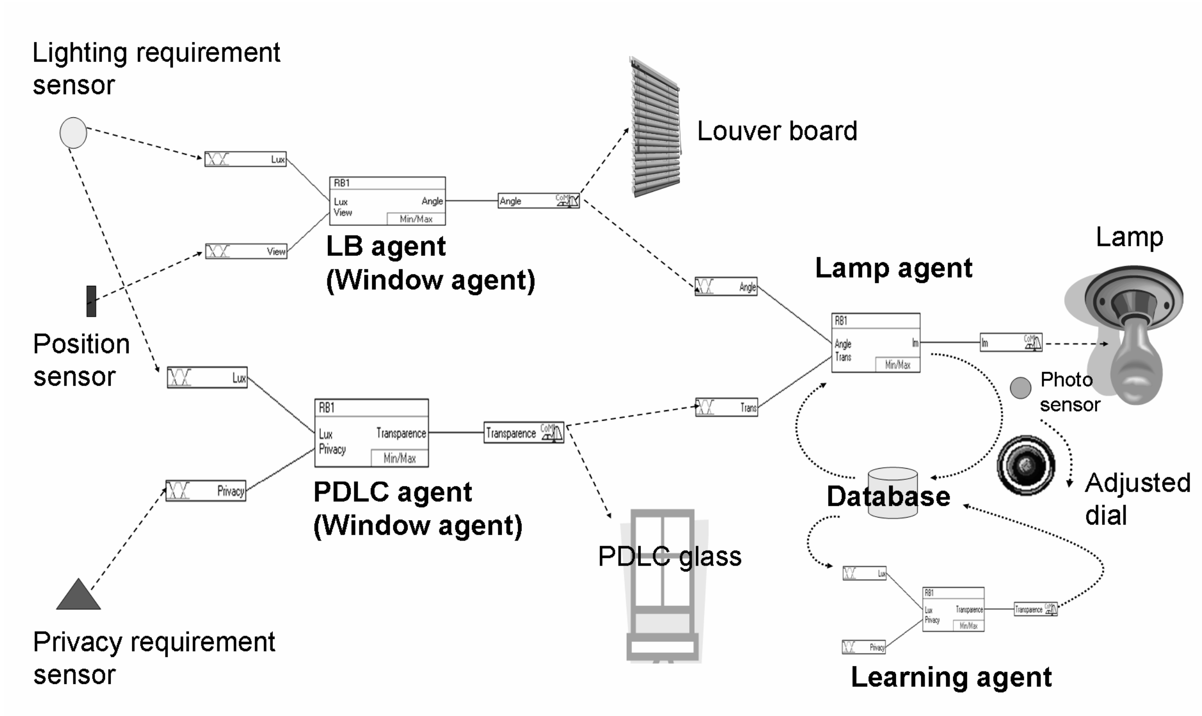


Fig. 9: Interaction and cooperation in an agent society.

4. CONCLUSIONS AND RECOMMENDATIONS

This paper demonstrates how intelligent agents employing fuzzy logic and neuro-fuzzy systems can be integrated to support environmental awareness. Major findings and suggestions are listed below:

(1) Activity detection: There is a need to learn more about how to retrieve valid information from other smart entities. In the current stage, "a degree of privacy need" can best be grasped and judged by experienced human operators, and is difficult for a computer to judge.

(2) Establishment of a prior knowledge database: Predictions are based on user preferences and habits, which are reflected in fuzzy inference plans or sub-plans, or in distribution of DoS. Prior knowledge is a prerequisite for fuzzy inference. For instance, before establishing a matrix rule for the louver board agent, it is necessary to know that people usually open the louver window more to obtain more light than to increase the visibility when the need for illumination is high. Further research should subject people's spatial perceptions and environmental behavior to scientific analysis.

(3) Historical data: User requirements of amenities depend not only on qualitative and quantitative analyses, but also on users' different types, genders, ages, identities, and different physiological reactions and psychological feelings. Information should be presented in historical records after analysis, For instance, the fact that a smart skin's louver window is usually closed may indicate that a space is currently often used for resting. On the other hand, the fact that the PDLC glass is usually not transparent indicates that the indoor activities require a high level of privacy, which may lead to the conclusion that the occupant is ill and needs more rest.

(4) Conflict resolution: The events perceived by agents and the tasks and target benefits of agent societies, are not necessarily identical. Cooperation and compromise in the case of conflict depend on reasonable inferences by the fuzzy inference plan. Taking the PDLC glass agent as an example, the occupant's illumination needs will be high (bright) when he or she is receiving nursing care, but he or she will also will also have a high need for privacy. In this case, should the PDLC glass increase transparency in order to admit more light? Or should it reduce transparency in order to provide more privacy? For instance, as can be seen from the second column of Table 3, when IF < Lux (bright) and Privacy (high) > THEN < Trans (low) >, the agent will reduce the

transparency of the PDLC glass to increase the occupant's privacy. But since there will be little natural light in the room, the lamp agent will then adjust the lamp brightness to provide the illumination needed for nursing care.

In conclusion, this study has proposed the use of intelligent agents to establish a smart system in a distributed intelligent environment. This system possesses autonomy and smart modules and can perform adaptive behavior, further realizing the flexibility and variation of a building. Relying on analysis of serial tasks for indoor lighting adjustment and depending on whether there is a human-computer interface and on the adaptive behavior mode of the actuator, the user experience-oriented three smart levels of (1) Ordinary people, (2) Healthy seniors, and (3) Disabled persons can be defined. In conjunction with rule-based inferences and artificial neural network learning, fuzzy inference and neuro-fuzzy technology can enhance the system's reasonableness, reliability, and predictive ability. Existing data logger technology was in this study to verify the establishment of a rule-based agent-based smart skin. Although the smart skin could handle simple situations, because no fuzzy logic-based data logger was available, software was used to test the theoretical feasibility of a fuzzy logic smart skin system, and modes of user experience-oriented awareness were derived. Future research should focus on practical applications involving hardware and software integration.

5. ACKNOWLEDGMENT:

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