AGENT-BASED SMART SKINS

fuzzy-logic and neuro-fuzzy approaches to smart house design

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Abstract. Recent developments in sensor, computing, and information and communication technologies have inspired the creation of new smart devices and environments. This paper proposes a "smart skin" that is capable of actively inferring and detecting normal or abnormal status, making optimal decisions, and learning to adapt its functions to map environmental variations to occupant 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 systems. Prototypes are demonstrated and further discussion is made.

1. Background and Goals

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 three key functions of a smart house include: (1) a smart skin, (2) smart care, and (3) smart life (Chiu, 2005). The purpose of this paper is to build agent-based smart skins and perform simulations for evaluation. Prior research indicates that agent-based smart skins with rules can be established for use in environmental awareness, and their description, "PE-SCAP," is helpful for preliminary evaluation. However, these smart skins still lacked the ability to adapt to complex, uncertain, and multi-users' requirements with rule-based reasoning (Chiu and Chen, 2005). 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.

The recent development of smart houses has led in two directions: (1) A general emphasis on active and automatic intelligent control supporting environmental sustainability (Wigginton, 2002); 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 (Belchior, 2005).

People's interests and the goals of environmental sustainability are not always identical however. Designers and occupants are constantly confused about the choice of appropriate advanced technologies, and how to deal with them. The Adaptive House (Mozer, 2005) adopted a central neural network control system called ACHE (Adaptive Control of Home Environment) in order to satisfy residents' needs and conserving energy. There nevertheless existed two problems causing its neural network algorithm tend to converge on a low-energy cost, low-discomfort solution: The first was the implementation using X10 controls, which were painfully slow to respond, and the second was misuse by residents. Another case involving the computing mechanism is the rule-based control approach used by the test-bed at Vienna University of Technology, (Mahdavi, 2005). This system provided a syntactic framework of distributed nodes, which constituted information processing and decision making points. The system required a control system able to integrate and coordinate the operation of multiple devices and their controllers, and control functionalities were therefore distributed among multiple meta-controllers in a structured fashion. Since, however, modules are hard to distinguish in such a framework, it was difficult to describe and configure them separately.

This paper proposes a theoretical framework for “environmentally aware agents” in a distributed intelligent environment, and uses “Smart Skins” as an example. Smart skins are able to use prior knowledge to process rule-based fuzzy-logic inference, and can decrease the difference between prediction and real status with the assistance of neuro-fuzzy algorithm learning, thereby enhancing awareness of context and ability to map perceptions to actions (Mari, 2000). Each agent is a well-defined smart module, and the agents can cooperate and interact with each other to complete and achieve their designed objectives.

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 (Chiu and Chen, 2005).

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, (Wooldridge, 1999). This event-driven agent model must consist of three basic parts: a sensor, computational mechanism, and an actuator (Russell, 2003). 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.

A smart skin's "fuzzy logic" operations rely on the following steps: (Step 1) System design encompasses: (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>THEN<Actions>" to be represented as "matrix rules"; and (3) Defuzzification: identification of an appropriate defuzzification method. CoM (Center of Maximum) was mostly adopted (Fig. 1). (Step 2) Off-Line Optimization, (Step 3) On-Line Optimization, and (Step 4) Implementation: The software's optimized assembly code generation implements the fuzzy logic system on the target hardware platform. The "Neuro-Fuzzy" error back propagation function can improve and optimize the fuzzy logic system by training components of the system using a supervised learning algorithm based on sample data, and adjusting their DoS (Degree-of-Support) values for optimum mapping of inputs to outputs (Altrock,1995), (Fig. 2).

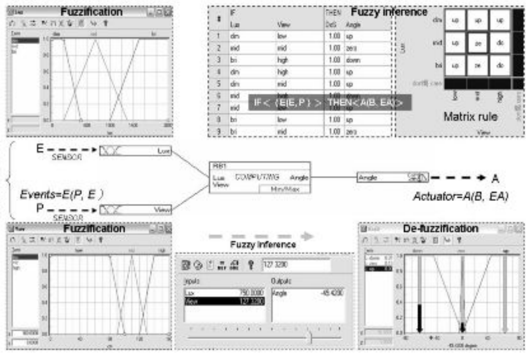


Figure 1 Smart module and fuzzy logic inference

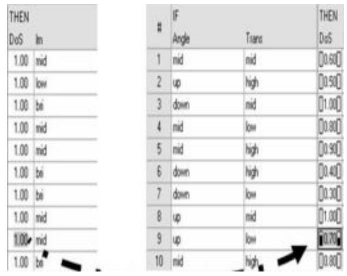


Figure 2 DoS values adjusted after training

2.2 SOCIETY OF AGENTS

Agents are able to coordinate their relationships, hierarchies, and enclosure, and to process their cooperative activities using the same protocol (Minsky, 1988). The interactions of “one to one,” “one to many,” and “many to many” are not only constrained among agents but also among agents and their users with the assistance of interface agents (Chiu and Chen, 2005).

3. Implementation and Verification

3.1 TASK AND ELEMENTARY CONDITIONS

The experimental task consisted of indoor lighting adjustment. “Fuzzy-TECH” software was used to simulate the smart skin’s fuzzy-logic inference and neuro-fuzzy learning. All smart skin modules were simplified as two input terminals and one output terminal, and all linguistic variables were simplified as three terms.

3.2 SETTING USERS’ ATTRIBUTIONS AND ACTIVITY CATEGORIES:

The purpose of setting users’ attributions and activity categories is to verify implementation of the adaptive design. 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 general tasks, e.g. reading and writing, and “Bright”- for close work such as sewing and clinical 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 clinical care and resting.

3.3 SETTING UP ENVIRONMENTAL CONDITIONS AND THE FRAMEWORK FOR EXPERIMENTAL PROCESSES:

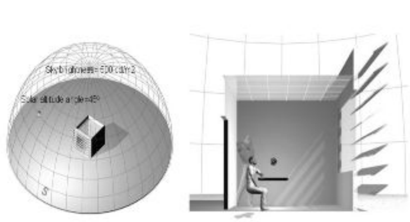


Figure 3 Experimental environment

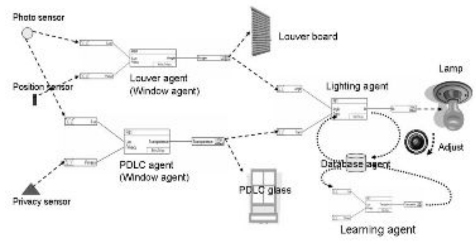


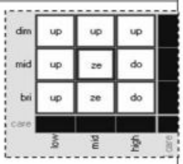
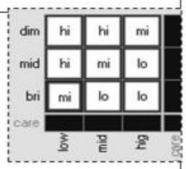
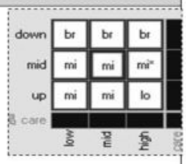
Figure 4 Smart skin interactions

This experiment employed a "window agent" as an example of a smart skin, and the window agent was divided into two sub-agents, "louver panel agent" and "PDLC glass agent," in order to investigate the possibilities of the agents' mutual cooperation. The experimental space was a 3.6 x 3.6 x 3.6 m^3 interior, facing south, and with daylight on one side. The solar altitude angle was fixed at 45°, and the brightness was controlled at 500cd/m^2 outdoor. The window was leaved at a height of 90cm, and its size was 2.7 (w) x 1.8 (h) m^2. Furniture including sofa, couch, table chair etc. was placed indoors temporarily to support different types of activity processes (Fig. 3). The "louver panel agent" enabled the adjustment the panels' angle according to the height level of a resident's field of view and the illumination intensity. The "PDLC glass agent" enabled adjustment of "the degree of glass transparency" according to residents' "privacy needs" (Chiu, 2005), and the illumination intensity. In addition, a lamp agent was used to further test the agents' interactive ability. The lamp agent enabled prediction and adjustment of the lamp's brightness in response to indoor illumination. And if the lighting did not suit residents' needs, it could be adjusted by turning a knob on the left wall. Furthermore, with assistance from a "data-based agent"—a learning agent applying a neuro-fuzzy algorithm for data training—the system could adjust DoS values to enhance its ability to make predictions (Fig. 4). For different purposes, smart skins can be implemented in three steps: (1) SK-A, smart module and fuzzy logic inference, (2) SK-B, agents' society, their interaction and cooperation, and (3) SK-C, Neuro-fuzzy algorithm for learning. Each steps' PE-SCAP description is listed on Table 1, and fuzzy logic inference plans are listed in Table 2.

TABLE 1 Smart skins' PE-SCPE descriptions

Environmental Agents	People	Environment	Agent-based Smart Skin			
			Architecture			Program
	Performance Measure	Environment	Sensors	Computing Device	Actuators	Program
Individual Agent ***SK-A-1:*** Louver board ***SK-A-2:*** PDLC	***SK-A-1:*** Illumination, View ***SK-A-2:*** Illumination, Privacy	Building's Outdoor and Interior	***SK-A-1:*** Photo X1, PositionX2 ***SK-A-2:*** Photox1, Privacy knob	Data-logger + Computer	***SK-A-1:*** Rotation Angle of Shading panel ***SK-A-2:*** Transparenc e of PDLC	EDLOG Fuzzy Logic in Fuzzy Tech
Agents' Interaction ***SK-B:*** Louver board PDLC Lamp	Illumination, Lighting Privacy	Building's Outdoor and Interior	Photox1, PositionX2 Privacy knob	Data-logger + Computer	Photo panel Indoor lighting	EDLOG Fuzzy Logic in Fuzzy Tech
Agents' Learning ***SK-C:*** Lamp Data-based Learning	Lighting, Its adaptive Behavior and Learning	Building's Outdoor and Interior	Photo X1	Data-logger + Computer	Dos. Value adjusted	EDLOG Neuro-Fuzzy in Fuzzy Tech

TABLE 2 Agents' fuzzy logic inference plans

	IF <E(P, E)> Input	THEN <A(B, EA)> Output	Matrix Rule
Window Agent			
Louver board 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)	

4. Conclusions and Recommendations

This paper shows 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, "degree of privacy" can best be grasped and judged by experienced human operators, and is difficult for a computer to judge.

(2) Prior knowledge database: Building a scientific prior knowledge database will help to determine designs' fuzzy inference capabilities. Predictions are based on statistical regularities in the behaviors and preferences of residents, (Mozer, 2005), and these regularities could be represented in plans or sub-plans of fuzzy-logic inference or in their "DoS" values.

(3) Historical data: An environment's user comfort requirements depends not only on qualitative and quantitative analyses, but also on users' different types, genders, ages, identities, physiological reactions and psychological feelings. Information should be presented in historical records after analysis, e.g. if a smart window is closed often, this denotes that the indoor space may be used mostly for "leisure" and the lighting requirement is "dim." If the PDLC glass appears opaque often, this reflects high privacy indoor activities, and we can therefore speculate that the resident may not be in good health. The resident may need frequent rest, but may not have received clinical care, where "clinical care" requires high-intensity illumination.

In summary, a smart skin is capable of "flexible" autonomous, adaptive action, and should eliminate excessive over-complex human-computer interfaces so as to improve life independence. The use of neuro-fuzzy technology allows such a system to combine the benefits of rule-based fuzzy-logic with a neural net learning algorithm in order to enhance the system's context-aware rationality, reliability, and ability to make prediction. The system can therefore add a "human-centric" aspect to a "living machine."

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