A Multi-Sensory Approach Integrating User Preferences

Lahcene Aid, Lynda Zaoui, and Sid Ahmed Mostefaoui

***Abstract*—The creation and maintenance of a comfortable internal environment is one of the major concerns of the smart home designers. Indoor comfort depends on the individual's physiology and psychology. It is essential to have a full understanding of occupants' satisfaction in order to maintain a comfortable indoor environment. However, it is important to develop a model that adapt to the user's desires and needs. This paper presents a novel multi-sensory approach based on the DEVS (Discrete Event System Specification) and the theory of fuzzy logic for modeling and simulation of occupant's preferences. The approach takes into consideration the interrelations between all senses namely the thermal, visual, acoustical and olfactory sensory systems on the sensation of global comfort.**

***Index Terms*—Comfort, devs, fuzzy logic, modeling, smart home.**

I. Introduction

Most of the works examining the issue of comfort of building's occupants in indoor environments were focused on thermal comfort [1]-[4]. Ensuring, or even maximizing occupants' thermal comfort alone is not sufficient for their overall satisfaction. Moreover, the perception of indoor environment quality is influenced by many aspects such as air quality, ventilation, lighting, and noise.

Occupants in buildings are exposed simultaneously to all indoor environmental parameters (thermal, visual, acoustic environment and air quality) and their evaluation of the indoor environment is influenced by the combined effect of different environmental parameters. On the one hand, several studies have indicated that people tend to reject automatic systems when the control algorithm does not respect their personal preferences [5].On the other hand, incorporating and integrating user preferences in an automatic control algorithm is a complex task.

Users are not able to specify what values are acceptable to them in terms of absolute numbers. Therefore, user preferences have to be captured indirectly. The main goal of this paper is to propose a model using the DEVS formalism integrated with the theory of fuzzy logic to describe and simulate a complex system of user's preferences.

One of the few works done in this area is a primitive approach proposed by Vainio et al. [6], where a fuzzy controller adjusts the weights of a few predefined factors that determine whether performing a specific action is in accordance with the user's preferences or not, e.g. turning on the lamp if the light level is less than a certain amount. However, they do not take into account that the user's evaluation of the indoor environment is influenced by the combined effect of different environmental parameters.

This paper is organized as follows: The next section gives an overview of the basic concepts of DEVS and the theory of fuzzy logic. In Section III, we present the Smart Home DOMUS. In Section IV, we describe our model of the user's preferences. The last section concludes our work.

II. Background

In this section we introduce the formalism DEVS and some essential concepts, terminology, and arithmetic of fuzzy sets and fuzzy logic.

A. The Devs Formalism

BP Zeigler defined in [7], a formal specification of discrete event models. This formalism was introduced as an abstract universal formalism independent of the implementation. The DEVS formalism is based on the definition of two types of models: atomic models and coupled models. The atomic models used to represent the basic behavior of the system. Coupled models are defined by a set of sub atomic models and / or coupled models to represent the internal structure of the system through coupling between models.

The atomic model provides an autonomous description of system behavior, defined by states and input/output functions and internal transitions of the model. The evolution of the model is done by state change according to external stimuli (via an input) or internal (via a transition function). These state changes are intended to determine the behavioral response of the system to these stimuli.

Formally, an atomic model M is specified by a 7-uplet:

$$AM=(X, Y, S, \delta_{int}, \delta_{ext}, \lambda, ta) \quad (1)$$

where

X: is the set of external events (input).

Y: is the set of output events.

S: is the set of states.

δ_{int} int : $S \rightarrow S$ is the internal transition function caused by the occurrence of internal events.

δ_{ext} ext: $Q \times X \rightarrow S$ is the external transition function caused by the occurrence of external events where

$Q = \{(s,e)|s \in S, 0 \leq e \leq ta(s)\}$: total states and e describes the elapsed time since the system made a transition to the current state s.

$\lambda : S \rightarrow Y$ is the output function

ta: time-advance, the function of lifetime of state, represents the maximum time during which the model remains in a state.

Fig. 1 shows the description of a DEVS atomic model.

To describe a more complex system we interconnect

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several atomic models to form a coupled model. This new model can be used as a base model in a higher level description is the hierarchical aspect of the formalism [8].

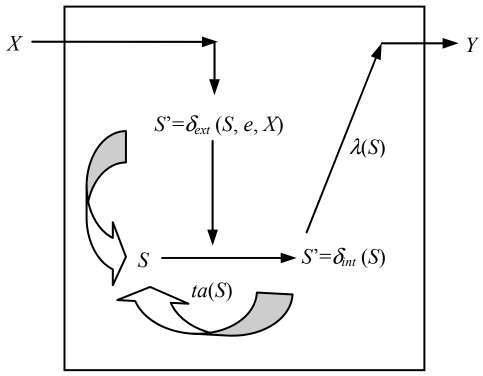

Fig. 1. Description of a DEVS atomic model

A coupled DEVS model named CM is a structure:

$$<X, Y, D, \{M_d / d \in D\}, EIC, EOC, IC> \quad (2)$$

where

X: set of possible inputs of the coupled model.

Y: set of possible outputs of the coupled model.

D: set of names associated to the model components.

M_d: set of the coupled model components, these components are either atomic or coupled DEVS model.

EIC: set of External Input Coupling.

EOC: set of External Output Coupling.

IC: set of internal couplings.

Fig. 2 shows the description of a couple DEVS model.

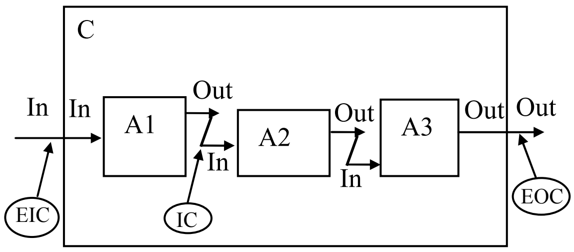

Fig. 2. Description of a coupled DEVS

B. Fuzzy Logic

Fuzzy systems theory is based on uncertainty and on imprecision. Uncertainty is very natural to humans and people usually make decisions based on indiscrete observations [9].

Linguistic variables are used in fuzzy systems as a method for performing calculations. The values of linguistic variables can be presented using membership functions (MFs). The MF is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. Many different types of MF curves are available for these applications such as triangular, trapezoidal, Gaussian distribution curve etc.

Fuzzy inference systems (FIS) are one of the most famous applications of fuzzy logic and fuzzy sets theory [10].

The realization of an inference system consists of three steps: fuzzification, fuzzy rule inference and defuzzification.

Fuzzification consists of transforming a real measured value into fuzzy values of linguistic variables. These fuzzy values receive a degree of membership based on the real value and the respective membership function.

The second step is called fuzzy rule inference whereby some sets of fuzzy logic operators and production rules are defined. The most common rule is called IF-THEN rule which can be used to formulate the conditional statements that comprise fuzzy logic.

Last, the defuzzification process is to convert the output of the fuzzy rules into a scalar, non-fuzzy value.

III. Description of the DOMUS Smart Home

As part of the Carnot institute LSI, the MultiCom research group [11] built a prototype of a smart apartment (40^2).This apartment consists of a set of pieces embodying a classic apartment (office, bedroom, bathroom and kitchen with dining room) and has a real furniture; A pictures of the DOMUS smart home is shown in fig. 3. The entire apartment is controlled by a home automation system. This home automation system also allows interaction with tangible objects and collection activity traces.

Fig. 3. The DOMUS smart home

IV. Preference Model Construction

Modeling and simulation with DEVS has become a reference to the question of coupling of heterogeneous models. The classic DEVS formalism does not take into account inaccuracy and uncertainty on the events and the states. On the other hand, the multi-formalism DEVS enables the integration of many other formalisms or modeling methods. However, the integration of fuzzy logic is the best choice, as humans perceive their environment with fuzzy variables.

A. Experimental Data Set

Experimental data set is the most significant part of a research. To develop our model, we have used the Multicom Domus Dataset [12]; a total of 20 people (8 males, 12 females) were asked to participate in the research work. They were asked to spend about 1 hour and a half in the intelligent flat. The experiment was divided in 3 slots of 20 to 30 minutes, each one of them in a specific room with a specific activity. Also, inhabitants were asked to fill a form every five minutes in order to understand their perception of comfort with a sensorial semantic (see Table I) and a technical semantic (see Table II). Each of these variables was presented in the form of a Likert scale to the inhabitant. Answers were transposed into quantitative data for analysis, ranging from 0 for « very unpleasant » to 10 for « very pleasant ».

The questionnaire was implemented in an electronic and mobile way (fig. 4) in order to facilitate the user's annotations [13].

TABLE I: USER'S PERCEPTIONS QUESTIONNAIRE

Name	(Likert) Scale legend
Global comfort	Very unpleasant to very pleasant
Thermal comfort	Very unpleasant to very pleasant
Lighting comfort	Very unpleasant to very pleasant
Air quality	Very unpleasant to very pleasant
Acoustic comfort	Very unpleasant to very pleasant

TABLE II: USER'S FEELINGS QUESTIONNAIRE

Name	(Likert) Scale legend
Temperature	Very cold to very hot
Humidity	Very humid to very dry
Luminosity	Very dark to very bright
Ventilation / air speed	Very slow to very high
Smell	Very unpleasant to very pleasant
Noise level	Very low to very high
Agreeableness of background noise	Very unpleasant to very pleasant

Fig. 4. Interface of questionnaire

B. Structure of the User's Preferences with DEVS

To specify the preference system we have divided it on five sub-systems as shown in the fig.5, where:

X_T is the set inputs of the thermal preferences model = {External Temperature, Internal Temperature, Air speed, Humidity , Window position, Ventilation speed, Lamp, Venetian blinds position, Thermostat, Time, weekday}

X_V is the set inputs of the visual preferences model = {Internal Luminosity, External Luminosity, Venetian blinds position, Lamp, Time, weekday}.

X_A is the set inputs of the acoustic preferences model = {Noise Level, Ventilation speed, Window position, Door position, Time, weekday}.

X_O is the set inputs of the olfactory preferences model = {Air speed, Ventilation, Door position, C02- Concentration, Window position, Time, weekday}.

C. Formal Specification of the Preferences

The user's preferences model is a coupled DEVS model composed of five atomic models namely Thermal preferences model, visual preferences model, Acoustic preferences model, olfactory preferences model and Global comfort model.

Preferences=<*X, Y, D,* $\{M_d | d \in D\}$*, EIC, EOC, IC, SELECT*> (3)

where

$X = \{(p,v) / p \in IPorts, v \in X_p\}$ is the set of inputs.

$Y = \{(p,v) / p \in OPorts, v \in Y_p\}$ is the set of output.

D set of names associated to the model components.

D={Thermal preferences, Visual preferences, Acoustic preferences, Olfactory preferences, Global comfort}.

M_d: set of the coupled model components.

$M_{Thermal\ preferences}$ is the sub-system of the thermal user's preferences.

$M_{Visual\ preferences}$ is the sub-system of the Visual user's preferences.

$M_{Acoustic\ preferences}$ is the sub-system of the Acoustic user's preferences.

$M_{Olfactory\ preferences}$ is the sub-system of the olfactory user's preferences.

$M_{Global\ comfort}$ is the sub-system of the user's global comfort.

EIC={((Preference, input), (Thermal preferences, input)), ((Preference, input), (Visual preferences, input)), ((Preference, input), (Acoustic preferences, input)), ((Preference, input), (Olfactory preferences, input)), ((Preference, input), (Global comfort, input))}.

EOC={((Global comfort, output), (Preference, output))}.

IC={((Thermal preferences, output), (Global comfort, input)), ((Visual preferences, output), (Global comfort, input)), ((Acoustic preferences, output), (Global comfort, input)), ((Olfactory preferences, output), (Global comfort, input))}.

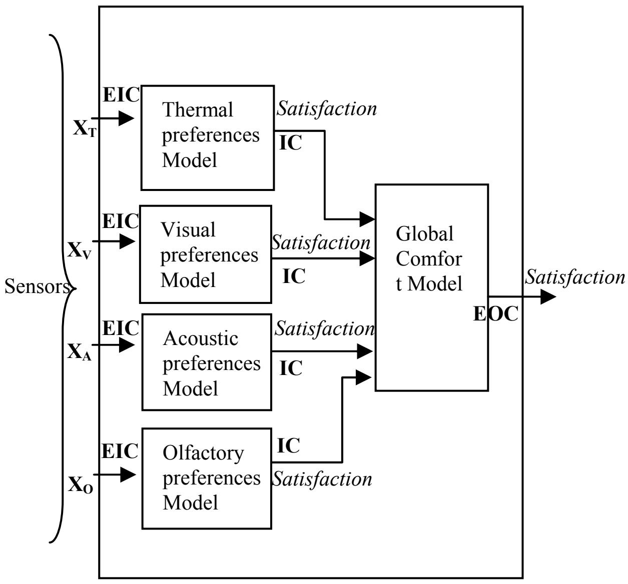

Fig. 5. Structure of the user's preferences coupled DEVS model.

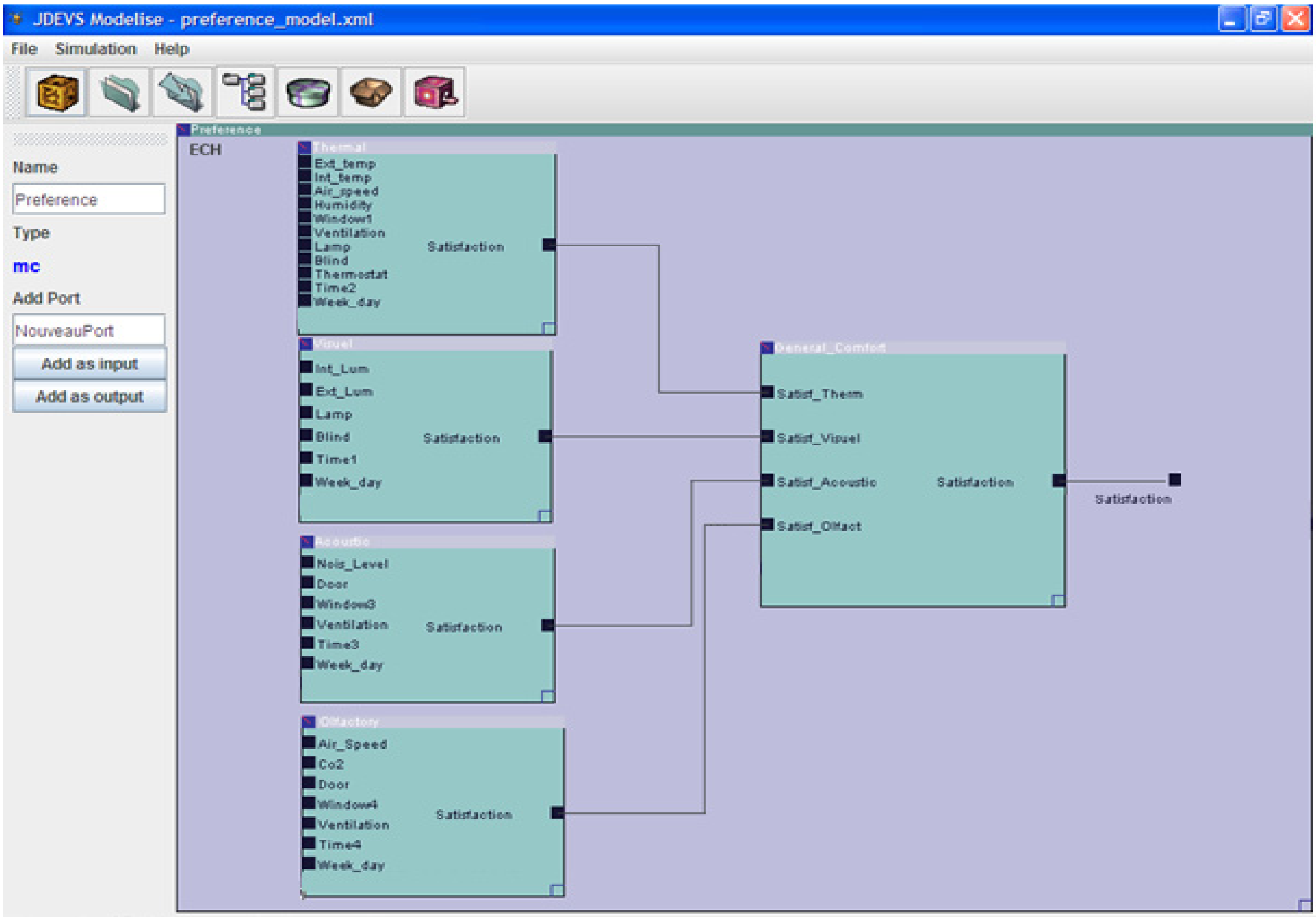

Fig. 6. Representation of the model under JDEVS.

The Table III summarizes the linguistic variables used in the Fuzzification for the sensory inputs.

We have added two fuzzy inputs variables *weekday* and *Time*. The *Weekday* consists of seven non overlapping values, named by the weekdays. The linguistic output variable for each system is *Satisfaction* with five values: ‘very unpleasant’, ‘unpleasant’, ‘neutral’, ‘pleasant’ and ‘very pleasant’.

We have used the standard Mamdani fuzzy inference system [9]. Also, we have used the Multicom Domus Dataset to define the fuzzy rules and the fuzzy outputs are defuzzified by the center of gravity procedure.

A. Thermal Preferences Model

The formal specification of the Thermal preferences in DEVS is as follows:

$$\text{Thermal preferences} = (X, Y, S, \delta_{int}, \delta_{ext}, \lambda, ta) \quad (4)$$

where:

X={External Temperature, Internal Temperature, Air speed, Humidity , Window position, Ventilation speed, Lamp, Venetian blinds position, Thermostat, Time, weekday}.

Y={very unpleasant, unpleasant, neutral, pleasant, very pleasant}

S: Fuzzified values.

$\delta_{int}=\varnothing$.

δ_{ext} = FIS _thermal(X) fuzzy inference system, it receives input (X).

$ta = \infty$.

We have used the same specification for the other sub-systems (Visual preferences, Acoustic preferences, olfactory preferences, Global comfort) with some changes at the external transition function (δ_{ext}) and the inputs (X).

B. Representation of the Proposed Model Using the Modeling Tool JDEVS

Simulation tools have become essential. They allow to study and understand complexes actions that may be impossible to study in situ. Currently there are several modeling and simulation environments based on the DEVS formalism allowing the representation of different atomic or coupled DEVS models. We chose the environment JDEVS [14] as a tool for modeling and simulation for our proposal model.

JDEVS provides a different approach than the existing tools. In terms of flexibility and genericity of use, it can provide the high-level approach of a general formalism. In terms of features, abstraction, components and interfaces, JDEVS provides the advantages of a domain specific modelling environment. With JDEVS, it is also possible to specify, store, retrieve, couple and simulate different kinds of models without having to specify how those models should be simulated.

The Fig. 6 shows the proposed model of user’s preferences modeled on the environment JDEVS. This model consists of several atomic models.

The simulation shows the importance of a multi-sensory approach to ensure the comfort in the indoor environment and improve the level of the occupant’s satisfaction.

TABLE III: THE LINGUISTIC VARIABLES CORRESPONDING TO THE SENSORY DATA

FIS	Linguistic Variable	Values
Thermal_FIS	External Temperature	Cold, Cool, Slightly Cool, Neutral, Slightly Warm, Warm, Hot
	Internal Temperature	
	Air speed	Low, Medium , High
	Relative Humidity	Low, Medium , High
	Window position	Open , Closed
	Ventilation speed	Low, Medium , High
	Lamp	Off, On
	Venetian blinds position	Down, Medium, Up
	Thermostat	Low, Medium , High
Visual_FIS	Internal Luminosity	Very dark, Dark, Medium Bright, Bright Very Bright
	External Luminosity	
	Venetian blinds position	Down, Middle, Up
	Lamp	Off, On
Acoustic_FIS	Noise Level	Very Low, Low, Medium, High, Very High
	Window position	Open, Closed
	Ventilation speed	Low, Medium , High
	Door position	Open, Closed
Olfactif_FIS	Air speed	Slow, Medium, High
	Ventilation speed	Low, Medium , High
	Door position	Open, Closed
	C02- Concentration	Very Low, Low, Medium, High, Very High
	Window position	Open, Closed

V. CONCLUSION AND FUTURE WORK

In this paper, we presented the modeling and simulation of user preferences. We developed an original multi-sensory model able to ensure the satisfaction of occupants. Also, we combined the DEVS formalism and the theory of fuzzy logic to cope with the complexity of the system.

We developed an application using the tool for modeling and simulation JDEVS to simulate the user's preferences. As a future work, it would be very interesting to design a controller in order to update the fuzzy rules. It could be carried out by a feedback control strategy.

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