Personal e-Comfort Modelling and Management based on Multi-Agent System and Internet of Things Network

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Keywords: Internet of Things, Multi-Agent Systems, Comfort Management, Ubiquitous Computing.

Abstract: In this paper a new approach to complex comfort management is presented, aiming in automatic treatment of different comfort parameters by means of Internet-of-Things devices and multi-agent system. The paper presents a new model of e-comfort, based on common treatment of all the parameters as identified across the Maslow's hierarchy of needs. Next, a new architecture of e-comfort management is discussed, based on two layers: low-level layer of IoT devices, representing at-the-place possibilities of the system, and upper layer of software agents, formulating and negotiating the needs and expectations of human users.

1 INTRODUCTION

Comfort is often provided in homes or places of work by automation systems connecting actuators (shutters, lights, heating, etc.) and sensors and linking them together through scenarios and/or rules. Typical scenarios define rules triggering the execution of one or several actuators according to an event. The event can be based on time (when it is 6:30 AM, execute the "wake-up" scenario), can be a result of a direct interaction with the user, e.g., while pushing a button (physical on the wall or virtual on an interface) or the value reached by a sensor (when the inside temperature is more than 25°C, switch on the air conditioner).

The above notion of comfort is quite straightforward and not deep enough. Comfort is not only a set or rules or predefined scenarios, comfort is equilibrium between the needs of the user and his/her environment. Users want to be comfortable without taking a lot of time to perfectly adjust settings of their environment. The home automation system has to anticipate the needs of the users in order to reach a comfortable environment. The idea behind is to automatically provide comfort at certain level as Weiser's good servant rules (Weiser 1991) based on ubiquitous computing. This kind of e-comfort and fully manageable conditions at-a-place would be done via smart IoT devices able to coordinate themselves to bring intelligent assistantship and switch-less or hands-free home.

The goal of the paper is to propose a new way of complex comfort management, having a set of devices at one end, and human needs and expectations at the other end. The idea is to manage the comfort automatically based on the fuzzy-declared parameters and available at-the-place devices, to minimize manual activities of a user. The paper is the first step towards such automatization, aiming in the presentation of the way of comfort modelling and controlling.

The remainder of the text is organized as follows. In Section 2 we discuss basic comfort elements that should be taken into consideration. Then, Section 3 describes how these elements are used to model the comfort in a complex and uniform way. Section 4 briefly describes system architecture, and Section 5 provides some conclusions and directions for the future work.

2 COMFORT ELEMENTS

Comfort is surely not a simple and costless goal to achieve. On the contrary, we see the notion of comfort as extremely complex and embroiled. Thus, we devote this section to a description and discussion on the components of the whole term, in division to physical conditions of the comfort, psychological aspects, economics aspects, and

Gateau B. and Rykowski J..
Personal e-Comfort Modelling and Management based on Multi-Agent System and Internet of Things Network.
DOI: 10.5220/0005229900830089
In *Proceedings of the 5th International Conference on Pervasive and Embedded Computing and Communication Systems* (PECCS-2015), pages 83-89
ISBN: 978-989-758-084-0

safety/security conditions, these are enumerated and briefly discussed below.

Due to the well-known theory of self-motivation, people tend to live in so called comfort zone – our everyday home&work environment. Comfort zone determines our way of live, our friends and any other social contacts, our customs, beliefs, imagination, goals etc. Within our comfort zone, we feel safe and secured, and we tend to keep this situation stable. Sometimes we are forced to go out from the comfort zone, to the adaptation zone – there, we do not like the situation and we tend to change it, keeping closer to the missing comfort. This is a positive trend, as we are active and make several efforts on inducing the changes – to us, or to the environment. However, sometimes the change is so critical we land in the panic zone – there, we are not able to react to the changes and go back to the comfort zone, and we need some help and assistance.

Anyway, the overall goal of keeping ourselves in the comfort zone is achieved by:

- understanding of what “comfort” means to every one of us, and
- addressing some external assistance to help us to go out from the panic and adaptation zones.

As mentioned before, we consider the comfort as a balance between the user and his environment. We are constantly evolving in changing contexts. By context we mean “any information that can be used to characterize the situation of an entity”. Here, the entity is the user and the information that characterizes the situation is the one that can be compared to the user’s needs to be comfortable. Thus, it is crucial to identify our needs and expectations related with comfort, in as many its aspects and possible, and explain these to the assistants – humans and recently intelligent devices/places – in order to improve the unwanted situation. The first step towards such identification is to classify all possible sub-notions of comfort, to be personalized in the second step towards optimal adaptation to individuals, situations, places etc. To this goal, in this section we discuss several aspects of the comfort, starting from the physical conditions (natural and close environment), and finishing on some psychological and social aspects.

According to well-known Maslow’s theory on the hierarchy of human needs, our behaviour (and indirectly – the comfort) is determined by a level of fulfilling the needs. The needs create a hierarchy, to be fulfilled in certain order. A need provokes certain actions to fulfil it. Maslow's hierarchy of needs is often portrayed in the shape of a pyramid with the largest, most fundamental levels of needs at the bottom and the need for self-actualization at the top (Fig. 1) (Maslow 2014). Starting from the bottom of the pyramid, physical conditions of the comfort are related with our natural environment and its measurable parameters – temperature, air flow, humidity, lightness, etc. These conditions are directly perceptible by the senses: sight, hearing, touch, including sense of temperature, smell, taste, balance and more. Thus, a natural trend is to link the comfort aspects to the senses, as depicted below.

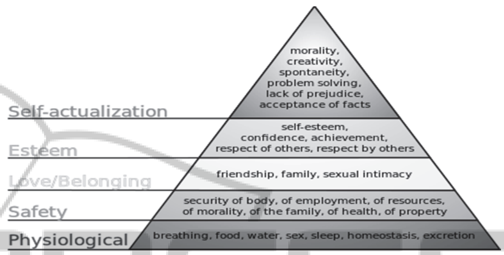

Figure 1: Maslow’s hierarchy of needs.

2.1 Thermal Comfort

Thermal control is mainly related with the sensitivity of our skin towards the detection of external temperature. Humans may exist and be functional in a wide range of the temperature – starting from -100°C (in clothes, or for a very short period, however) to +100°C (for a very short period, or well protected by special fire suit). The thermal comfort zone is very special for particular humans, however, most of us see an air temperature around 22°C as optimal. Thermal control is strongly related with air flow and drafts, temperature gradient, clothes, etc. This topic was addressed many times by the researches working in different domains, perhaps the work (PhD thesis and further books) of Ole Fanger is the most completed in that area (Fanger 1970).

Maintaining thermal comfort for occupants of buildings or other enclosures is one of the important goals of HVAC (heating, ventilation, and air conditioning) systems – c.f. the description for air-conditioning comfort below.

2.2 Ventilation and Air-Conditioning Comfort

Addressed to closed environments such as buildings, ventilating (the V in HVAC acronym) is the process of "changing" or replacing air in any space to provide high indoor air quality (i.e. to control temperature, replenish oxygen, or remove moisture, odours, smoke, heat, dust, airborne bacteria, and carbon dioxide). Ventilation is used to remove unpleasant smells and excessive moisture, introduce outside air, to keep interior building air circulating, and to prevent stagnation of the interior air. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. It is one of the most important factors for maintaining acceptable indoor air quality in buildings. Methods for ventilating a building may be divided into mechanical/forced and natural types (Ventilation 2014).

Complementary to the ventilation, air conditioning is the process of altering the properties of air (primarily temperature and humidity) to more favourable conditions, typically with the aim of distributing the conditioned air to an occupied space to improve comfort. In the most general sense, air conditioning can refer to any form of technology, heating, cooling, de-humidification, humidification, cleaning, ventilation, or air movement that modifies the condition of air (McDowall, 2006).

2.3 Humidity/Hygrometric Comfort

Humidity is the amount of water vapour in the air. Humans are sensitive to humid air because the human body uses evaporative cooling as the primary mechanism to regulate temperature. Under humid conditions, the rate at which perspiration evaporates on the skin is lower than it would be under arid conditions. Because humans perceive the rate of heat transfer from the body rather than temperature itself, we feel warmer when the relative humidity is high than when it is low. Some people experience difficulty breathing in high humidity environments. Some cases may possibly be related to respiratory conditions such as asthma, while others may be the product of anxiety. Sufferers will often hyperventilate in response, causing sensations of numbness, faintness, and loss of concentration, among others (Humidity 2014).

Above-mentioned air conditioning reduces discomfort not only by reducing temperature, but also by reducing humidity. In winter, heating cold outdoor air can decrease relative humidity levels indoor to below 30%, leading to discomfort such as dry skin and excessive thirst.

2.4 Gases and Smells/Odours

Smell sense is responsible for the detection of certain chemical compounds dissolved in the air – not only gases, but also liquids and solids. Historically, this sense is the most archaic one – first living organisms on Earth were equipment with such detectors for communication and self-security. Human smell sense is not as efficient as the one for some animals, anyway, we are able to detect several compounds, some of them are neutral for our health, some of them (un)pleasant, and some dangerous, especially at higher concentration. Unfortunately, humans are not able to detect some very dangerous compounds such as carbon oxide and dioxide. Thus, broadening smell sense to detect all the unwanted and dangerous components in the air is a very desired part of the comfort zone.

Most heating, ventilation and air conditioning systems (HVAC) re-circulate a significant portion of the indoor air to maintain comfort and reduce energy costs associated with heating or cooling outside air. When occupants and building operators sense air coming out of an air supply duct, it's virtually impossible to judge how much of this air is simply re-circulated air and how much is outside air. Current technology allows easy and relatively inexpensive measurement of carbon dioxide (CO_2) as an indicator to help ensure ventilation systems (for high density occupancy zones) are delivering the recommended minimum quantities of outside air to the building's occupants (Prill 2000). CO_2 is a natural product of human respiration whose rate can be predicted based on an occupant's age and activity level. Beginning as early as 1916 (Mechanical Engineer's Handbook by McGraw-Hill) and found in the New York City Building Code of 1929, CO_2 of 800 to 1,000 ppm and 1,000 ppm respectively were recommended. However, the key point is that CO_2 levels are good predictors or surrogates for human emitted bioeffluents (i.e., odours) that are considered undesirable for the overall human comfort inside conditioned spaces. Thus CO_2 is a surrogate for levels of other bioeffluents that cause odours that are likely to be viewed as unacceptable by others in the space, not because of their presence as a direct health hazard (Petty 2014).

2.5 Visual and Light Comfort

Light, mainly detected by the sight sense, is crucial for human feeling of the comfort. Humans used to act in the day-night cycle, with sunlight marking the period of the activity, and darkness indicating the period of the rest. Both are needed for our health, and both may vary and depend on very individual preferences, including the mood, company, etc. Global tendency is to achieve the level and quality of the light as close to natural (sun, outdoor) one as it is possible (thermal temperature and spectrum, distributed sources and background light, lightness, etc.). Historically, lights and lightness control is the fundamental issue for any modern (not to say "intelligent") building, starting from simply dimmers, via light scenes, to nowadays LED-based "walls of light" with distributed sources of the light, fully controlled with respect to spectrum, intensity, direction of the light beam, etc. Thus, a lot of research has been already devoted to this aspect, resulting in plenty of systems, norms, regulations, standards, etc. Anyway, optimum lighting is crucial for good sense of the comfort.

2.6 Acoustical Comfort

Noise and sound background is an essential element of our life. It is hard to imagine we cannot hear anything at the moment, thus for most of people such silence is not a comfortable situation. On the contrary, too much noise is also not needed, as it is usually very disturbing.

Source of noise are internal of the home/building, inside the same room or from others rooms or could come from outside of the home/building. It is influenced by first of all the insulation used for external wall and the windows from one side and for the internal walls and door from other side. The user can act on the environment to reduce the noise as, for instance, closing doors and windows.

For those who do not like too much noise – there are basically three ways to avoid it. The first one is passive: walk away of the noise emitter. Surely, this simple approach is not efficient in many cases, such as a small room or a crowded place. Second approach is to do some simple things to reduce the noise, such as closing the windows mentioned above. And third, we may apply some advanced technical solutions, for example active headphones. Such a device generates sound of the same intensity but in opposite phase, thus somehow enduring source of noise. It is questionable if such generation is healthy or not, but in some cases it cannot be avoided (such as ear protectors for ground handling staff at an airport, construction workers, etc.).

By contrast, user could like to have a soft background noise as classical or relaxing music for a studious and focused environment or loud music. It depends on the user's needs and preferences but also on the type of activity he is doing. For those who do not like silence – this condition is correlated with background "noise" such as music/TV programme.

2.7 Other Comfort Aspects

The upper is level of the Maslow's pyramid of needs the more the needs are abstracted and related with psychology and sociology rather that physical conditions. Thus, it is quite hard to maintain these parameters by means of IoT devices. Anyway, some of them should be taken into consideration for complex comfort management, to enumerate at least:

- societal acceptance and the need for efficient communication with other people regardless place and time (mobile phones and VoIP communication tools well serve to this goal),
- leisure, free-time organization (even if seen by most of people as an evening in front of a TV),
- fear for bad activity, self-learning of new environments (including RTFM problems for new devices/technologies at home and work),
- stable economic situation,
- safety and security aspects, including personal security, alerting and anti-theft systems, etc.

3 COMFORT MODELING

As drawn from the list of comfort elements given in the previous section, there are two basic types of comfort aspects: those that reflect the (desired) state, and those that are a consequence of a fulfilment of a need. For the first group, we cannot simply express what we really want, but being in certain situation we may usually assess if we like it or not. For the second group, we are able in advance to define several strict demands, and further we can measure how far we are from the fulfilment of these demands. Thus, we may say that the notion of comfort is a summary of two aspects (Fig. 2):

- *contentment*, that could be define as a state of being contented, or happiness in one's situation,
- *satisfaction,* that could be seen as a fulfilment of a need (a desire).

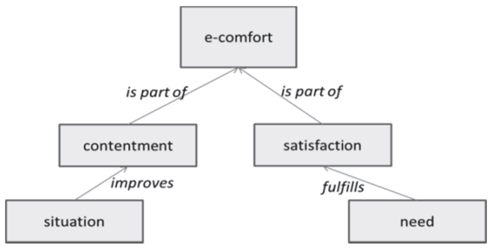

Figure 2: Modelling e-comfort as a summary of contentment and satisfaction.

The contentment in one's situation is however linked to the satisfaction of needs and is a function of factors. For instance, the International Standard ISO 7730:2005 (ISO 2014) says about the thermal comfort: "*A human being's thermal sensation is mainly related to the thermal balance of his or her body as a whole. This balance is influenced by physical activity and clothing, as well as the environmental parameters: air temperature, mean radiant temperature, air velocity and air humidity.*" So the fact that a human feels well in a certain situation is not only due to a fulfilment of a need relating to the air temperature, and some other parameters should be taken into account. These parameters composed the context in which the user is situated, namely air velocity, air humidity etc. If we generalize this idea to all comfort's components, we can see that e-comfort cannot be only a set of values setting the needs. If we take another example related to luminosity, user's needs cannot be restricted to light source and light intensity only, in all situations and places. Indeed, if the user prefers natural light as a light source, and the night comes, the user clearly cannot be fully satisfied. His needs are dependent on the time, the location and the activity (to mention a few basic factors). Similarly, if he is at work, at home or at sport place, the needs in term of light don't will be same. As he tends to read, cook, eat or watch TV, his needs evaluate towards these activities. At a sport place, some of the factors, such as luminosity, are not so important, while a temperature takes a role of a leading factor. In general, human preferences towards comfort strongly depend on the environment, or globally - a context, which constraints user's needs according to (among others) time, location and activity.

Dealing with the context is not a trivial task. Returning to the previous example, the user should be able to define needs composed by an ordered choice of light source and luminosity value (if a light source is the first choice, no matter the luminosity value, he/she will prefer natural light, or, if the first choice is related with an amount of luminosity, no matter from where the light comes, as long as there is enough light, the situation is seen as comfortable), linked to a contextual triplet {time * location * activity}. But even if we can strictly specify preferences for the same time, the same activity and the same location, how can we define a moment of optimum switch from natural light to the electrical one because of bad weather suddenly bringing dark clouds?

As we saw, the configuration of needs for the user could be very difficult. Our goal is to infer situations contenting the user from context. As define in (Naudet 2011) "*a situation is a known and pre-determined context which is composed of elements having a location and an interval of time and being measured (having value) coming from a sensor. A context concerns an entity (a user), having a status and an activity*". From that we deduce our representation of e-comfort (cf. Fig. 3) being an evaluation/measurement/assessment of a situation regarding needs (or needs regarding a situation). Situation and needs are composed of physical comfort components which complete the specification of a context based on (at least) the location, the activity and the identity of the user besides time period and/or current time.

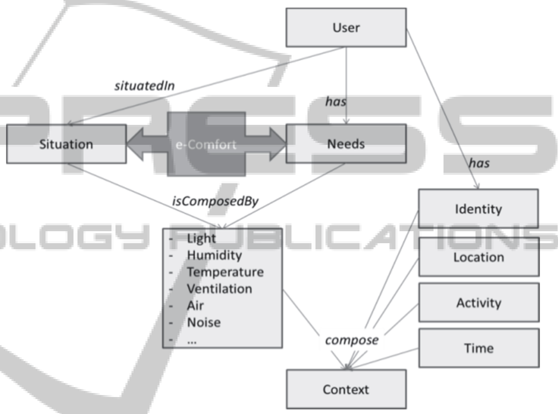

Figure 3: e-Comfort representation for a user.

4 TWO-LEVEL ARCHITECTURE

The general architecture of the system aims at controlling e-comfort at two layers (Fig. 4). The upper layer is based on a multi-agent system organized with the $Moise^{Inst}$ model (Boissier 2007). This level is responsible for comfort management,

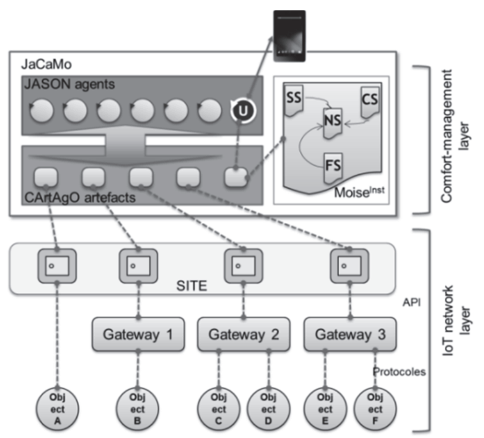

Figure 4: Layered system architecture.

including the storage of user-defined requirements to personalize the meaning of e-comfort (their needs) and their processing regarding the situation.

Comfort definition is represented by software agents in the form of fuzzy-assessed goals constrained by a set of value used as arguments and stored in the needs database. Goals are specified through the Functional Specification of Moise^{Inst}. As the goals are restricted by the capabilities of local IoT devices and thus usually to be reached partially only, the system places the users in "the most comfortable situation as possible", however, not necessary ideal from individual point of view. This solution is reasonable and similar to the one widely used for non-automated systems ("I'll do my best, but I cannot promise a lot").

The meaning of comfort is mapped by the agents to the requests for activation of IoT devices. The requests are addressed to the lower layer. The IoT devices are never addressed individually. Instead, the requests are mapped to an activation of a set (a conglomerate) of these IoT devices that are the most suitable to fulfil this request. For that, the Structural Specification of Moise^{Inst} defined roles played by agent representing IoT devices able to influence a specific category of needs (temperature for instance). The set of activated devices depends not only on the request, it is also adjusted according to the number and type of devices accessible at given location, and independent context of invocation. The above process is controlled by SITE (Semantic Internet-of-Things Environment) (Rykowski 2011) framework, originally designed to control dynamic and mobile IoT systems. SITE made it possible to propose an "intelligent" network capable of addressing functions (services) provided by the devices (including personal devices such as computers/ smartphones/tablets etc.) rather than the devices themselves, based on the semantic descriptions of devices' capabilities. It abstracts the way the devices are reached through gateways and other hardware able to communicate with the devices according to different protocols like Zigbee, EnOcean, Z-wave or even "traditional" WiFi, IR, Bluetooth, etc.

5 CONCLUSIONS

In this paper a new approach to complex comfort management is presented, aiming in automatic treatment of different comfort parameters by means of Internet-of-Things devices and multi-agent system. First, we discussed comfort parameters, based on Maslow's pyramid of needs. We concentrated on these parameters that may be controlled and managed by means of IoT devices: temperature, ventilation, humidity, noise and acoustic background, communication, safety and security, etc. Next, we propose a uniform way to model the comfort pointing out mutual dependency of several parameters (such as temperature and humidity), and overall context (such as place and time, but also a company of other people with different needs and expectations). To solve possible conflicts, we proposed two level architecture aimed in indirect control of IoT devices (SITE environment, lower layer) based on an ontology of device functions, and negotiations by means of software agents, being representatives of their human owners (upper layer). Currently, we work on the implementation based on SITE and Moise^{Inst} MAS environments, within the scope of GOLIATH (Goal Oriented Layered system for Interoperable Activities of Things) project.

ACKNOWLEDGEMENTS

This work is supported by the GOLIATH project jointly funded by the Poland NCBR and Luxembourg FNR Lead Agency agreement, under NCBR grant number POLLUX-II/1/2014 and Luxembourg National Research Fund grant number INTER/POLLUX/13/6335765.

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