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A Novel Adaptive Approach for Home Care Ambient Intelligent Environments with an Emotion-Aware System

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***Abstract*— The elderly population worldwide has an increasing expectation of well-being and life expectancy. The monitoring of elderly people on an individual basis, in a medical sense, will not be a viable proposition in the future. The infrastructure available is not adequate to meet all expectations and subsequently people will continue to live at home with inadequate care. Prior research has shown an accelerated need for the expansion in the Ambient Intelligence (AmI) domain and to that end we present a novel learning technique for intelligent agents that are embedded in Ambient Intelligent Environments (AIEs). A novel agent that combines an emotion recognition system with a fuzzy logic based learning and adaptation technique provides for an automated self-learning system that constantly adapts to individual requirements. This agent, entitled Health Adaptive Emotion Fuzzy Agent (HAOEFA), has the ability to model and learn the user behaviour in order to control the environment on their behalf with respect to his/her emotional preferences. In addition, the agent incorporates temporal adaption in order to facilitate changing behaviour and preferences within the environment. The results show that such architecture can both provide monitoring and ambient environmental control features such that users with limited physical or cognitive functions can have their well-being advanced with limited external resources.**

Keywords: Fuzzy Logic Systems, Ambient Assisted Living Systems, Adaptive Intelligent Agents, Ambient Intelligent Home Care Environments, Well-being.

I. INTRODUCTION

The world is being overtaken by different demographic trends that will affect the human life over the coming years. One of these trends is labelled as global ageing where in the next few decades it promises to affect everything from business psychology and workforce productivity to the shape of the family and the direction of global capital flows [1]. For instance, according to the Office for National Statistics (ONS) [2] the percentage of the population aged 65 and over within the UK has increased from 15% in 1984 to 16% in 2009, which is an increase of 1.7 million people. More important is in the same period of time, the percentage of the population aged under 16 decreased from 21% to 19%. Future estimation were calculated where it presents that by the year 2034, 23% of the population is projected to be aged 65 and over compared to 18% aged under 16. Also, a chart presented by the HelpAge International [3, 4] showed in Fig. 1 shows different world countries in different regions ageing around the globe as years pass. The vertical axis measures the percentage of each country's population between 65-79 years, the horizontal axis measures shows the countries' population get "older" as they move upwards and across the years [4].

Fast ageing of populations is presenting different challenges for developed and developing countries. These challenges include economic challenges, strains on pension and social security systems, bigger demand on long-term care as well as health care, and bigger demand for trained-health workforce. To address such challenges computer scientists attempted to develop a variety of interactive systems that can communicate with humans as well as helping people through their daily life activities. So, the use of new technologies such as ambient sensors can help doctors to monitor certain activities of elderly people within their houses in order to collect more information about the person. It can help them to understand the alteration of the human well-being status.

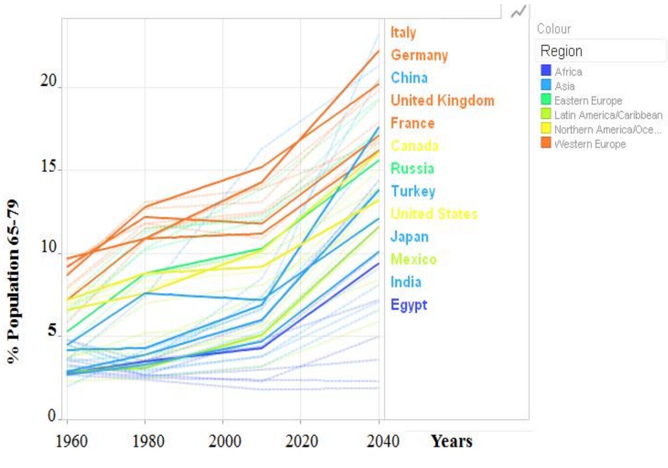

Figure 1. World population over the years [4]

With intelligent home care assistance, care providers can use these aspects and functionalities of sensors (such as kitchen sensor activated, fridge door opened, cold water run for 20 seconds, kettle switched on for 60 seconds) in order to clearly understand the individual's wellbeing current state, as well as answering judgmental questions (such as “is occupant sleeping regularly”, “has the occupant any repeating eating disorder in the last few months”, etc.) [5].

Such techniques of intelligent data monitoring, information clustering and analysis can enable doctors to make accurate diagnosis before it is “late”, and by “late” it is meant the doctor was able to identify accurately the current situation before it reaches a critical state [6]. These efforts of advancing technology to pervade everyday life and to foster wide availability and acceptance was yielded in 1991 when Mark Weiser [7] introduced his vision of ubiquitous computing in his famous article "The Computer for the 21st Century" [7]. Thus, different approaches developed have attempted to help decreasing the global ageing trend where applications such as Tele-care systems developed by Martin et al. [5] tries to produce emergency alerts system that helps in critical situations. Also, research scientists in the Ambient Intelligent Center (AMIC) located in the German University in Cairo [8] have developed an AIE that can learn, and model the user behaviour as well as adapt to the changes of his needs, habits, and gestures in an invisible none interrupting way. In Essex, the Computational Intelligence Centre research team [9] used a soft computing approach based on computational intelligence techniques in order to control the environment on the user behalf and adapt to his/her needs. According to Riva [10] the Intelligent Mixed Reality (IMR) is the most determined illustration to ambience intelligence where it can be invasively integrated and embedded into physical real life environments. It will allow the user to interact with other persons and the environment itself in a usual way. The Research group in University of Bristol identified the three generations of telecare as the first generation systems are typically for “panic alarms situations” such as falling on the ground, the second generation systems are more complicated where they use sensors to detect needed assistance in certain situations and send alarm to family members, friends or to a monitoring agency. Finally, the third generation vision where it tries to predict early warnings for possible emergency situations by observing intrusively significant changes in the person’s “well-being” [5, 11].

Most of the research in the intelligent environments field is focused on controlling and adapting the environment to its user according to their behaviour preferences [12], less focus has been given to the user emotional state within the environment. Therefore, this paper aspect is to show a developed embedded intelligent agent that has the ability to understand the user behaviour in a real-life physical environment pervasively. In addition to, the emotions recognition that take place over time in order to understand the domain of the word well-being and how does it affect the user behavioural actions within the environment. For instance, a person notices that his house has been burglarised. The person assesses the situation, which triggers anger. His heart rate, respiration rate starts to increase rapidly. Consequently, the person contacts the police. Such a situation handling strategy shapes the emotional reactions by adjusting the link between a person and their environment [13].

Various experiments had took place in which the intelligent agent has learned the user behaviour and their emotions during an extended experiment of 14 consecutive days in Glamorgan intelligent home care (Glam i-HomeCare) that acts like a real world AIE test bed. The rest of this paper is structured as follows. In Section II, we will introduce our test bed for AIEs which is the Glam i-HomeCare. Section III presents a description of the life-long learning and adaptation agent entitled HAOEFA. Section IV presents the experiments and results obtained while testing HAOEFA in the environment. Finally, Section V provides the conclusion and future work.

II. GLAMORGAN I-HOMECARE OVERVIEW

The Glam i-HomeCare is one of the real physical AIE test beds shown in Fig. 2, located in the University of Glamorgan. It aims at Home Care AIEs where it looks like any other ordinary room containing furniture. However, it consists of a big number of embedded actuators, processors and sensors that are connected to each other through an assorted network [14]. The Glam i-HomeCare is a single user space that can be used in a wide range of activities such as reading books, watching TV, and eating dinner, etc.

Figure 2. The Glam i-HomeCare Environment

Any networked computer that can run a standard Java process can access the Glam i-HomeCare easily. Thus, this multimedia PC shown in Fig. 2 can also act as an interface controlling the actuators inside room wirelessly. The Glam i-HomeCare Network Infrastructure shown in Fig. 3 is equipped with various embedded actuators and sensors that consists of: date, time of day, internal light level sensor, external light level sensor, internal temperature sensor, external temperature sensor and an occupancy sensor. The developed agent can control four dimmable floor standing up lights and the TV inside the room. These actuators and sensors are embedded within the room infrastructure in order to keep the user completely unaware of the intelligent infrastructure developed, which is required to reach the main aim of AIEs [15].

Although the Glam i-HomeCare environment looks like any other room, the walls and the celling hide numerous networked embedded devices residing on two different networks. Since, it is essential to manage the access of the devices, gateways between different networks critical components in such systems, while combining appropriate granularity with security. Glam i-HomeCare network architecture provides the diverse infrastructure present in ubiquitous computing environments that allow us to improve network independent solutions [16].

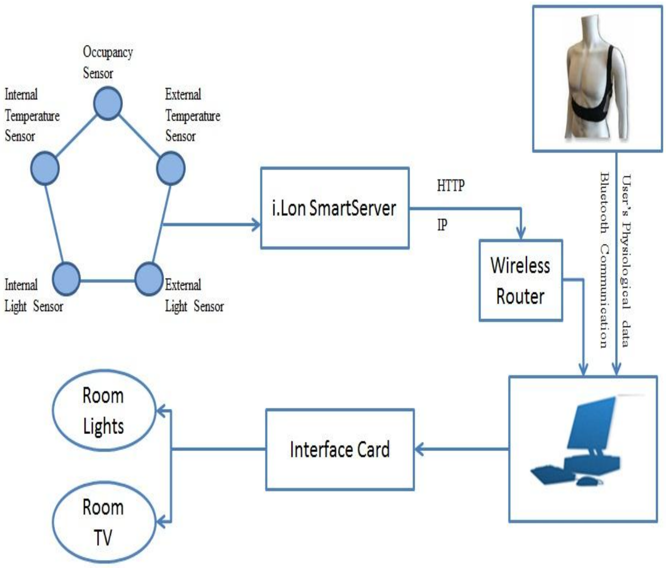

Figure 3. Glam i-HomeCare Network Infrastructure

Fig. 4 shows photos of the various sensors located in the Glam i-HomeCare where its values are displayed on our fuzzy agent interface shown in Fig. 7(b) that operates from the standard multimedia PC in the room presented in Fig. 2.

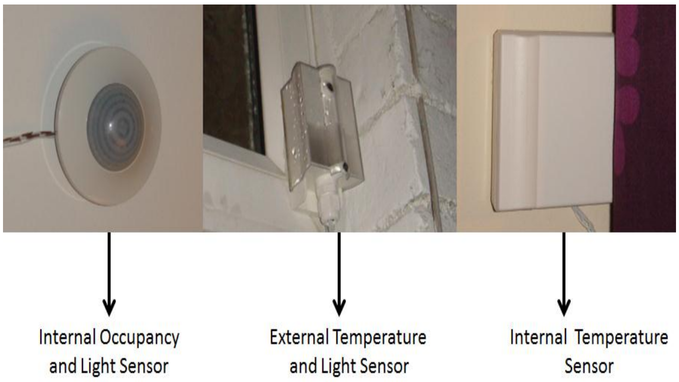

Figure 4. Glam i-HomeCare Sensors

III. The Health Adaptive Online Emotion Fuzzy Agent (HAOEFA)

The proposed agent, entitled as Health Adaptive Online Emotion Fuzzy Agent (HAOEFA), is a Type-1 Fuzzy Logic Controller (FLC). HAOEFA uses an unsupervised methodology to extract fuzzy membership functions and fuzzy rule sets from the data gathered during the learning process, in order to build a fuzzy logic controller that will be capable of learning and modelling the user's behaviour while taking in consideration his/her emotional preferences. These data are gathered by monitoring the user interaction inside the real life environment over a certain period of time. HAOEFA allows its interface to take controls actions in the Glam i-HomeCare environment based on the present situation (state of inputs) and the user emotional state. Additionally, the adaptive agent have the ability to control and manage the room on behalf of the user as well as allowing the rules set to be extended online and adapted over time, achieving a life-long learning technique that adjust to environmental changes and user's behaviour adjusting to it. The HAOEFA consist of the five following phases as shown in Fig. 5:

1. Monitoring the user's behavior and capturing the input/output data that are associated with user's actions with in the environment.
2. Extraction of fuzzy membership functions from the data.
3. Extraction of the user emotional states.
4. Extraction of the fuzzy rules from the captured data.
5. The agent controls the AIE on behalf of the user
6. Life-long learning and adaptation mechanism.

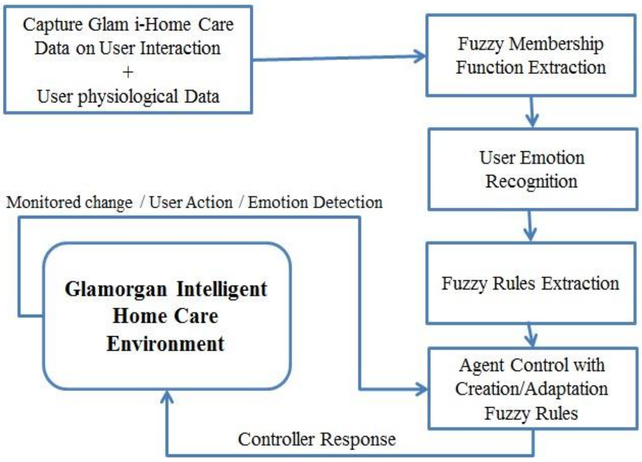

Figure 5. HAOEFA Flow Diagram.

As presented in Fig. 5, the last two phases of this algorithm are control loops that once started, it receives the environment inputs as changes of sensor values. Subsequently, HAOEFA produces the right control response based on the set of learned rules. Moreover, if the user is not satisfied by the agent control, he/she can take over with a simple change to the system Graphical user interface (GUI) that will lead to a modification in their environment behavioural actions. Therefore, the rules learned by the system will be adapted to the new preference instantly.

A. *Input/Output Data Capture*

In the learning process the agent displays the different sensor values shown in Fig. 7(b) and monitors the user actions in the room. Every five minutes the agent records a "snapshot" of the current sensor values. For instance, a snapshot of the Glam i-HomeCare environment would look like the following statement:

Occ	Int_Light	Ext_Light	Int_Temp	Ext_Temp	Hour	Heart_Rt	Body_Temp	Body_Mov	Resp_Rt	B_Orient	Emotion
1	853	61895	15.46	20.69	12.5	68	28.5	16	19.2	18	0
1	853	61895	15.36	21.05	12.5	67	28.5	16	19	18	0
1	725	61895	15.36	21.35	12.5	58	28.6	16	19.9	18	0

where Occupancy will be equal to 1 if the user is in the room, else it's going to be 0, the internal and external light levels are measured in LUX, internal and external temperatures are measured in degree Celsius (°C), the hour is the time of the day. In addition, the agent captures the measurements of the heart rate, skin temperature, respiration rate, and body posture using a wireless belt that that user wears around his chest. In the learning process the system won't be able to detect the user emotional state, but once the adaptation process takes place, HAOEFA will be able to interpret the emotions of the user such as happy, angry and Neutral.

It also observes the outputs (actuator states with new values of which any actuators were modified by the user). For instance, the output or the action of the user that took place for the input or the situation discussed previously in the snapshot taken is:

ACTION_Light_value	Action_TV_value
0	0
0	0
0	0

where the ACTION_Light_value are the control light values of the lights in the room where they range from 0 to 100 (0 equals off, 50 equals to halfway, and 100 is on). The TV value is either 0 or 1 (0 equals off, and 1 is on). All these inputs are recorded by the agent in order to model the user behavior, detect his/her emotional state while living in the Glam i-HomeCare.

B. Extraction of Fuzzy Rule Sets

The proposed agent combines the set of membership functions with the input/output data so that it can model the behavior of the user in order to extract the fuzzy rules. This fuzzy rule extraction methodology used by the HAOEFA extracts multi-input multi-output rule that describe the relation between y = $(y_1 ,..., y_k)$ and x = $(x_1 , \dots , x_n)^T$ as in (1):

$$if\ x_1\ is\ A_1^{(l)}\ and\ \dots\ and\ x_n\ is\ A_n^{(l)}\ then\ y_1 \text{ is } \mathrm{B}_1^{(l)} \text{and} \dots \text{and } \mathrm{y_n} \text{ is } \mathrm{B}_\mathrm{n}^{(l)} \quad (1)$$

where l = 1, 2, ... , M, and M is the number of rules and l is the index of rules. There are V fuzzy sets A_s^q, q = 1, ... , V, defined for each input x_s. There are W fuzzy sets B_c^h, h = 1, ... , W defined for each output y_c [9].

C. The Emotion Recognition System

Emotion recognition computing systems should operate in a similar way to how humans recognize emotions during communication. Thus, detecting people emotions during conversations could lead to an intelligent human to human interaction. For example, a person notices that a friend is feeling sad so he turns off the music being played instantly. Inspired by this idea the intelligence of HAOEFA is not only limited to the environment conditions, weather, time, etc. but it also includes the recognition of the user emotional state as it tries to achieve a certain level of comfortably within the environment by controlling it on the user's behalf. In addition, it monitors the user's health indicators as an attempt to better understand the user's well-being over time.

During Glam i-HomeCare experiments, the user wears the equivital belt which uses Bluetooth communication to measure the physiological conditions of the human body. Following the learning period and the extraction of the fuzzy membership functions for the FLC, HAOEFA is able to identify the user emotions by monitoring the user physiological data where it detects any changes that occurs in a real-time mode. Consequently, the agent starts controlling the environment on the user behalf. For instance, play some music while the user is happy. Currently, only "angry", "happy" and "neutral" emotions are being considered since more differentiated emotion recognition would lead to lower accuracies [14, 17].

D. The Agent Controller

The proposed agent uses singleton fuzzification, max-product composition, product implication and height defuzzification, as it maps a crisp input n into a crisp output y = f(x) where it applies as in (2) as follows:

$$\mathrm{y(x)} = \mathrm{f_s(x)} = \frac{\sum_{l=1}^{M} y^{-l} \prod_{i=1}^{n} \mu_{F_i^l}(x_i)}{\sum_{l=1}^{M} \prod_{i=1}^{n} \mu_{F_i^l}(x_i)} \quad (2)$$

where M is the total number of rules in the rule base, y-l is the maximum membership value point in the ith rule output fuzzy Bl, $\prod_{i=1}^{n} \mu\, F_i^l\, (x_i)$ set is the product of the membership values of each rule's input fuzzy sets, and n is the number of inputs. As to get multiple outputs, equation (2) is repeated for each output parameter. Consequently, after extracting the membership function and building the set of rules from the user's environment multi-input/output data. The agent has learned and modeled the user behavior. Consequently, HAOEFA starts controlling the environment on the user's behalf with respect to their needs and emotional state by monitoring the Glam i-HomeCare environment input values (such as sensors and emotional state) and as a result it controls the actuators based on the rule model built before from the user interactions that have been made during the learning process in the intelligent environment.

E. Life Long Learning and Online adaptation

In the above subsection, we have explained how the agent can learn the user behaviors. Nevertheless, HAOEFA is a flexible system, where the initially learned rules can be easily extended to change both existing rules as well as adding new rules as user's behavior might alter or change over time. The agent allows capturing wide range of various values for each input and output constrains. This methodology offers a continuous operation even if a gradual change in the environment exists (such as temperature drop off in winter). If, however, a significant alteration in the environment or the user's behavior acquires, that has not been introduced to the system during the learning phase. Consequently, the agent will intelligently create new rules that satisfy the current state in an unobtrusive way in order to extend its behavior to satisfy the user [14].

In other words, that the rule fired, and would therefore have contributed to the overall control response generated by the agent's FLC. The consequent membership functions that give the highest membership values to the user defined actuator values are selected to replace the consequent sets of all fired rules in the rule base [15]:

$$\mu_{B_c^{h*}}(y_c) \geq \mu_{B_c^h}(y_c) \qquad (3)$$

where $h = 1, 2, \dots, W$, and W is the number of fuzzy sets, B_c is chosen as B_c^{h*}, where $c = 1, 2, \dots, k$. The fired rules are therefore adapted to better reflect the user's updated actuator preferences given the current state of the environment and this leads to a grid of identified fuzzy set(s) for each input parameter. From this grid, new rules are constructed based on each unique combination of consecutive input fuzzy sets [15]. The consequent fuzzy sets for each of the new rules are determined as in (3). This allows new rules to be gradually added to the rule base. The agent will also add new rules when the currently monitored environmental state is undefined by the existing rules in the rule base; i.e., none of the existing rules fired. In this case, the agent will create new rules where the antecedent sets reflect the current input states of the environment and the consequent fuzzy sets are based on the current state of the actuators. The agent adopts life-long learning, where it adapts its rules as the state of the environment and the preferences of the user change over a significantly long period of time [14, 15].

IV. Experiments and Results

This section demonstrates the results obtained by the HAOEFA in the Glam i-HomeCare which is a real AmI test bed. In the beginning, we are going to introduce the scenario performed during experiments. Consequently, the HAOEFA results obtained in the Glam i-HomeCare will be presented, where the agent has learned and modeled the user behavior through a certain period of time. Afterwards, the agent controls the environment on the user behalf with respect to the user emotion preferences. The results were examined where the rules are compared with the readable format rules with user's journal parameters to guarantee that the agent has successfully learned the behavior the user was anticipating.

A. Glam i-HomeCare Scenario

The experiments scenario takes the following route: whenever a user enters the Glam i-HomeCare, there are several steps to be maintained as shown in Fig. 6. Firstly, the user enters the username and password in order to authenticate with an online server as shown in Fig. 7(a) as well as for the system to identify the user in action. Subsequently, on one hand, if the user is already registered with the Glam i-HomeCare, HAOEFA will start immediately to control the environment on the his/her behalf accordingly to the behavior learned and the emotion preference. It can be easily adapted online to whatever changes could happen wither in the environment or in the user behavior. On the second hand, if he/she is a new user to Glam i-HomeCare, the HAOEFA will start monitoring the user for x days as it enters the learning mode. The experiments presented in this section take a period of 14 days while the first day is the learning day then the agent start computing in order to build the rule base. Subsequently, HAOEFA will enter the live adaption online control phase for 13 more days where the agent controls the environment and whenever the user is unsatisfied with agent control he can easily adapt it using the Glam i-HomeCare GUI shown in Fig 7(b).

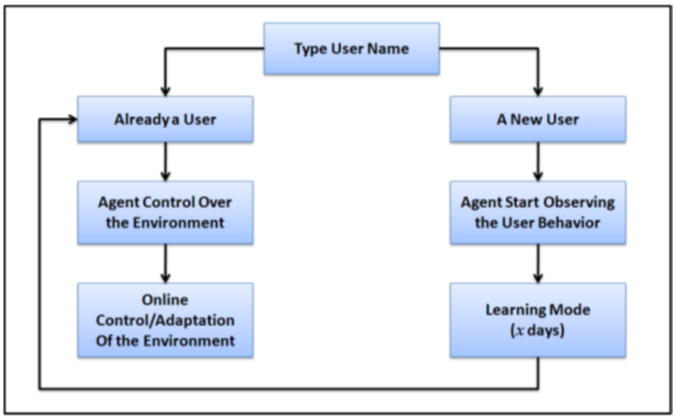

Figure 6. The Glam i-HomeCare Scenario

In addition, the user uses HAOEFA's GUI installed on the multimedia PC to monitor the real-time physiological body changes and the emotions recognized with it, as well as the display of the environment's sensors data while the agent the environment control taken as shown in Fig. 7(b). In order to test the agent capabilities a history record of the user decisions was saved in a journal and using a parsing tool that convert the .csv file containing the fuzzy rules sets into a readable format.

The complete dataset of 2880 instances acquired from the user's interactions in the Glam i–Home Care over the initial period of one day was used by HAOEFA to learn an initial FLC set of rules. The membership functions were built using fuzzy c-means and the results are shown in Fig. 8 (a) and (b). The agent then runs online for a further 13 days, during which it monitors the user's activities and controls the environment on their behalf. During this time, the user is allowed to override and adapt the agent's learned control responses, if it was necessary to modify and tune them further. As mentioned previously, one of the main characteristics of the Glam i-HomeCare System is that the user is always in control of the environment and capable of overriding the agent's control at any time and his instructions are executed immediately, in order to achieve the responsive property implied in the ambient intelligence vision.

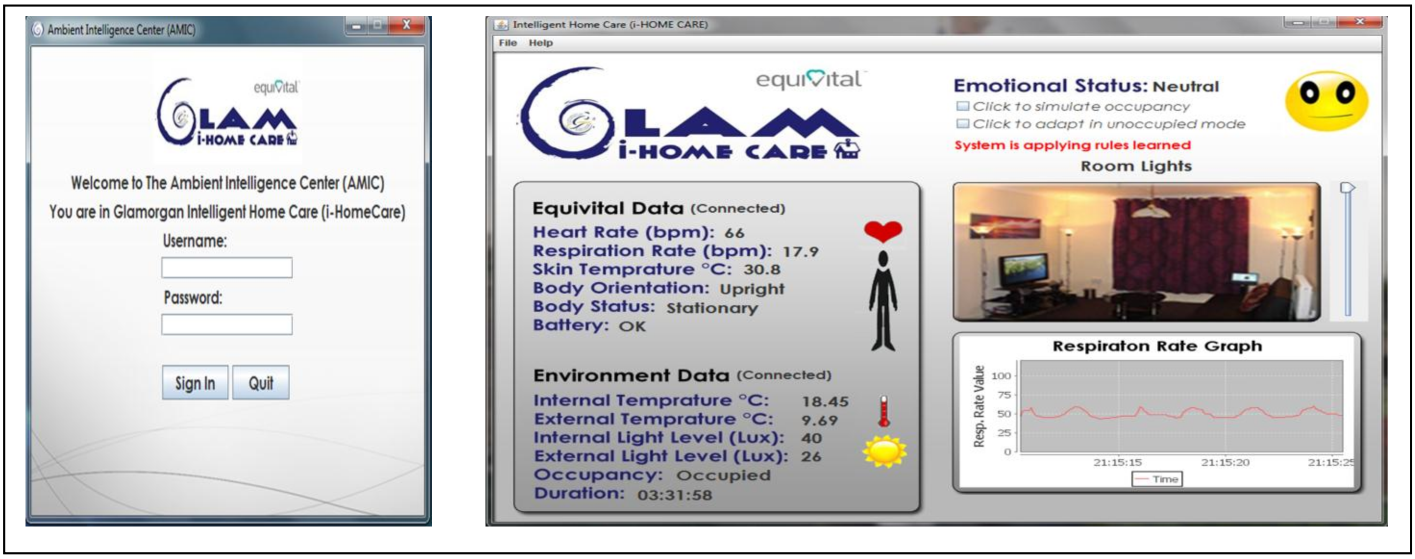

Figure 7. (a) User Login Screen (b) Glam i-Home Care Graphical User Interface

Thus, whenever changes to controls were made by the user, the agent received the request, generated new rules or adjusted previously learned rules, and allowed the action through. The performance of the agent could be gauged on the number of occasions when the user had to override the agent's control responses and adapt the rules over time, as this can reflect how satisfied the user is with the agent control actions.

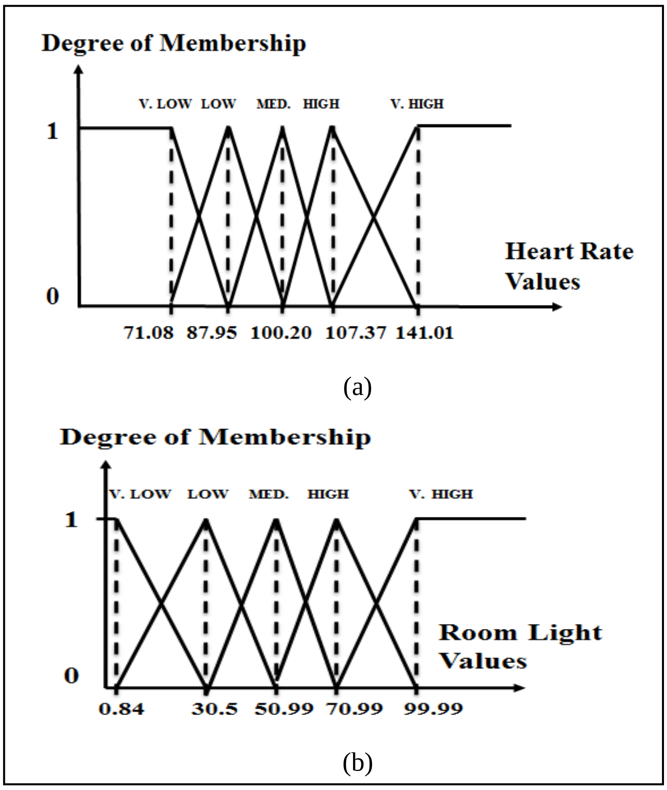

Figure 8. (a) User Heart Rate Membership Function (b) User Heart Rate Membership Function

The success of HAOEFA could be measured by the ability of understanding human dialogue words such as very low, low, medium, high, etc. as presented in the built membership of different attributes like heart rate and the control indoor room light shown in Fig. 8(a) and Fig. 8(b) respectively. In addition to, the monitoring of how efficient the agent adjusted the environment to the user's preferences where the user intervention was reduced over time. Fig. 9 shows a graph plotting the number of online rule adaptations against time measured in hours. The agent initially learned 16764 rules in the first 24 hours from the user's dataset and over the course of the subsequent rest of the days. It also demonstrates the number of the user's induced rule adaptations that occurred over the duration of the experiment, where 341 rules were added in the second day, and then 11 rules were added in the third day. Later, a total of 729 new rules were added by end of the seventh day. At that time, no more adaptations occurred which illustrate that HAOEFA was able to fully stabilize by the end of the first week. Moreover, given the theoretical maximum number of rules which is 15625000 rules, the agent generated a total of 17493 rules. This shows that HAOEFA was able model the user's behaviour within Glam i-HomeCare using 0.001% of the actual theoretical number using a nonintrusive technique to learn most of the user's preferences for various weather and environmental conditions over the duration of the first day of the experiment, including behavioural changes associated with user emotion changes.

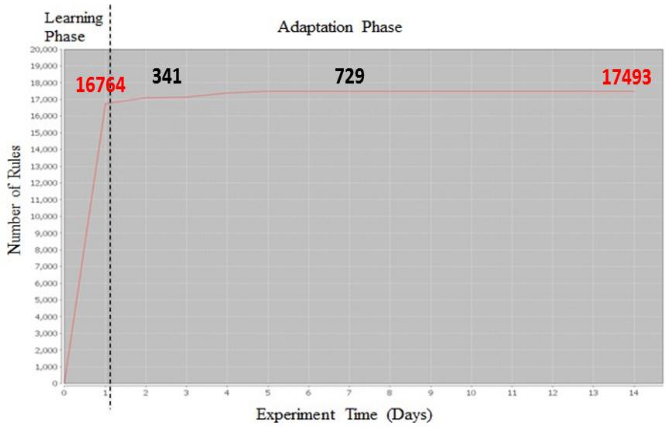

Figure 9. HAOEFA rules learned plotted against the experiment time.

V. CONCULISION AND FUTURE WORK

In Conclusion, the Glam i-HomeCare agent succeeded in interacting within a real life physical environment. HAOEFA has effectively produced the appropriate control responses based on its learned rules and the emotion preference of the user detected at a time. In the Future, more experiments will take place in order to enhance the emotional model and to add more emotions such as sadness, and fear to the agent. Over and above that, a more efficient Type-2 Fuzzy Logic agent will be developed in order to enhance the FLC to model the user behavior with respect to his emotional preference as an attempt to define the word "Well-Being" in order to help the elder people to live a better life in their homes with care they deserve.

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