Smart Home Environment - Concepts and Solutions

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***Abstract*—Smart home environments are environments that try to facilitate the life of the user in many different ways and make it more comfortable by using technology. This paper deals with the realization of such an environment and which benefits may arise from. Also it discuess why such a development is desirable.**

I. Introduction

The home is an important place for the people. It not only affects the overall quality of life, but is also a place where many people (especially older) spend a large part of their time. It is self-evident that constantly improving and developing this area of life takes an important role. A step in this direction are the so-called smart home environments.

A smart home is generally referred to a fully equipped environment with sensors and different technology, which has its goal to help the user in as many conceivable situations and assisting him.

To understand in which ways a smart home can improve the life of the inhabitant lets take a look at the following example:

A "normal" Home:
Like every monday the inhabitant of a home arrives at 18:00 pm. He prepares a coffee with the coffeemachine like every day and turns on the heating. After that he takes a shower. When he finished he takes his coffee and is watching the tv newscast. At 19:30 pm he turns on the computer in the workroom, check his mails and surfs the internet. Before he goes to bed, he reduces the heating and looks at his favorite TV shows in the bedroom until he falls asleep.

To see how a smart home environment could improve the quality of life we will show you the same daily routine in a smart home environment:

A "smart" Home:
Like every monday the inhabitant of a smart home arrives at 18:00 pm in an already well temperatured home.After taking a shower and he takes his already automatically prepared coffee. At 19:00 pm the television turns on and switches to the tv newscast. After the tv newscast a friendly voice informs the inhabitant about some new unread mails and automatically turns on the computer. Later that evening while the inhabitant wants to go to bed the system lowering the heating and turns on the television in the bedroom for his favourite tv shows.

These examples show that a smart home environment could improve the comfort of the inhabitant. But the comfort is not the only improvement by such a system. It could also saves energy (e.g. by an automatic temperature control or automatically switching off unused power sources like lights or televisions) and it could increase the safety (e.g. If you have forgotten to turn the cooker off when leaving the home).

The following parts of this paper will dealing with smart home environments. At first this paper shows which are the important parts of a smart home and defines what to understand under this term. After that this paper takes a closer look into some of the important parts of a smart home and discribes some solutions for it.

II. Smart Home Environment

To deal with the topic we have to define how to understand a Smart Home Environment. Frances Aldrich defined a smart home in his publication [1] as following:

"A "smart home" can be defined as a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond" [1]

This definition describes the goals of a smart home and firmly holds some important points. On the one hand a smart home is packed with various technologies and sensors to gather information about the current status in the smart home (e.g. where is the user located, what does the occupant do, current temperature etc.) and the other hand the target of such a house is to increase the quality of life of the user.

But its still hard to define where to draw the line, because its subjectivly. For example is it correct to call a residence a "smart home" if it simply just uses motion sensors to decide wether to switch on or off the lights? To make sure that a smart home is more than just a sensor and a light switch we could change the definition a little bit:

A "smart home" can be defined as a residence equipped with a wide scope of computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment in many ways through the management of technology within the home and connections to the world beyond

Now we can take a closer look at the single components of a smart home environment. First we need a bunch of sensors etc. to gather information about current conditions. An example of a home equipped with different sensors is shown in figure 1.

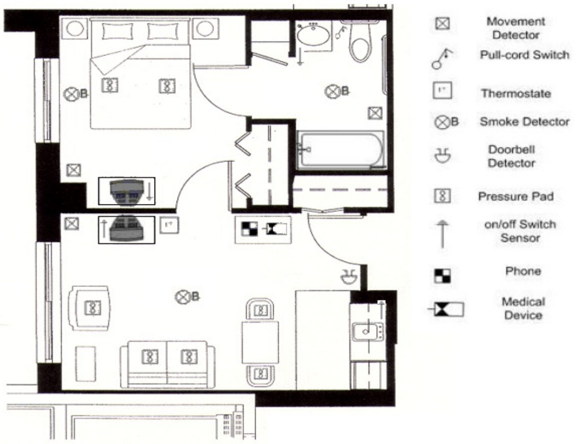

Fig. 1. a Home equipped with many Sensors and other technical equippment

As you can see in the picture 1 this home is enriched with many sensors and devices e.g. Movement Detectors, Thermostates, Smoke Detectors, Pressure Pads and a Medical Device. In a Smart Home enriched with such devices the inhabitant can benefits in many ways. For example the comfort of an automated temperaturecontrol, also the economic effect of self-controlled light-switches just to name two examples. And also the benefits in security by a smoke detector and the medical devices (e.g. blood pressure monitor) and many more.

The next important part is a managment software which connects the sensors and devices and evaluate the information. The problem here is how to interpret the gathered information and how to make a descision. This paper will now show two different concepts of a managment software, which could solve these problems.

III. Concepts and Solutions

When you want to design a Smart Home Environment you need to connect different sensors and gadgets to gather data from user and need an instance to handle them. It is important that the system can understand the context of an action. A simple example to illustrate this would be:

The Inhabitant dimms the light slightly at 18:00 pm to watch television.

For the system it is not only important that the inhabitant dimmed the light at 18:00 pm. The system also have to know that he dimmed the light to watching television. The understanding of the context of an action is not really easy and many researchers established different ways of handeling these type of information. This paper will present two different aproaches to this problem and will show how they could work.

The first theoretical considerations about the context of an action where performed by Juan Carlos Augusto and Paul Mccullagh in their paper about an ambient intelligence. [2]

A. Ambient Intelligence

Juan Carlos Augusto and Paul McCullagh thought about an instance to connect every part of a residence and the missing link to the world beyond. As a result they come to the conclusion to introduce the concept of an ambient intelligence (AmI) to connect every part part of a smart home, which means the User, the Sensors, the Network etc.

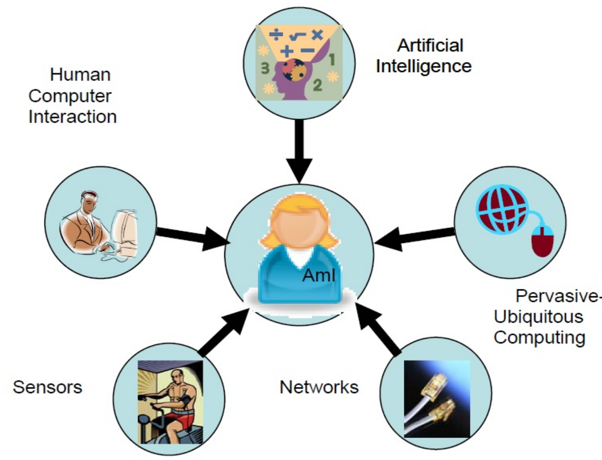

Fig. 2. Relation in between AmI and other areas in Computing Science [2]

To handle an environment the Ambient Intelligence should be able to gather many sorts of information. You can part the type of information in 5 types: Who, Where, What, When and Why.

Who: *Describes who is doing something and which relation has this user to other users in the system. This question can not only used to identify human actors. It could also describe elements like pets, robots and other interesting elements in the system.*

Where: *The location of the object of interest (pets, robots etc.) or an user in the system at each moment during the system operation.*

When: *The timeline of different activities is also important for an overview about the system. The association of different activities with a corresponding time can help the system to understand the daily routine of an inhabitant and support this one. Back to access the example from the introduction, the system could not adjust the temperature of the home if it not know when the inhabitant coming back from work.*

What: *The identification of different activities and tasks a user is performing is important for the system to provide help if required. This part is not really easy because of nearly unlimited different scenarios that can follow an special action.*

Why: *The hardest challenge for an ambient intelligence is the understanding of intentions and goals behind different activities. But it is also the most important question for a system which wants to anticipate the needs of an user.*

With these information the concept of an ambient intelligence should be able to learn by saving different gathered information and interpret the gathered data in a way that serves the comforts of an inhabitant.

The concept of an Ambient Intelligence can not only used for smart homes but also for other environments where people live and interact with it.

To make sure how this could work we need to understand how an Ambient Intelligence is able to make decisions and learn. Therefor it is important to clarify the flow of the data within such a system.

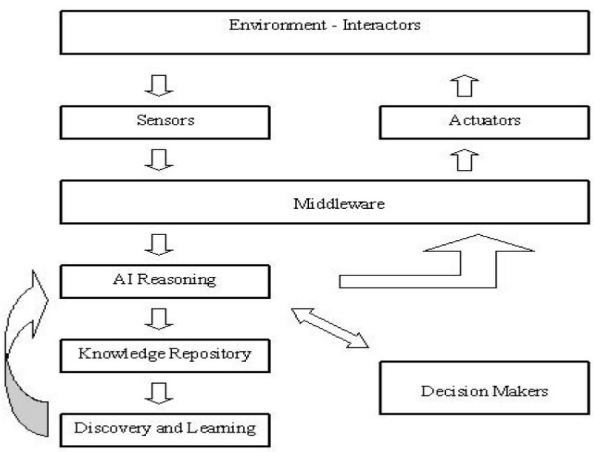

Fig. 3. Flow of information and general architecture of an AmI system. [2]

In picture 3 you can see a typical dataflow of an ambient intelligence system. There you can see how the interactors (e.g. a human) interacts with the sensors and send the data to the middleware, which processes the data from different devices to help the following processes to handle the data. Every case of interaction will be saved in the Knowledge Repository to make recourse to it at later decisions. This way we can see how ambient intelligence could work.

The concept of an ambient intelligence is based on the principle of understanding the intentions and goals behind different activities of an inhabitant, but mostly it is not easy to say why a user acts like this. Therefor the next part of this paper will deal with the work of Tinghuai Ma, Yong-Deak Kim, Qiang Ma, Maili Tang and Weican Zhou [3] who designed a model to store different data to ease the work of the instance who take the decisions. This system is called a context based reasoning system which relies mostly on past activities of an user to find suitable solution.

B. Context Based Reasoning for a Smart Home

Like already shown in the last part of this paper it is important to know the habits of the inhabitant and store them to ease the work of a instance like a decision-maker. Because a designer can't divine every situation an inhabitant could provoke, its important for a 'smart home' to learn and increase its database with different situations. Tinghuai Ma, Yong-Deak Kim, Qiang Ma, Maili Tang and Weican Zhou designed a contex based database to store different situations and bother with how they can distinguish different situations. This concept uses different algorithms to figure out which could be the best solution for a problem.

1) The Database: They divided a context into 3 main categories: environment, user's activity and user's physiological state. In a 'smart home environment' you can divide the context into three dimensions: time, environment and person. All categories with its own subcategories. A typical sample is shown in the table at figure 4 with the 3 different dimensions and their typical subcatigories.

Also important to notice is, that they assumed at the beginning that all stored information can be simplified with numeric parameters instead of abstract values to be able to compare values.

CONTEXT CATEGORIES AND ENTITIES IN SMART HOME

Time	time	second/Minute/Hour/Day/Week/Month/Season
	Time sequences	Event occurring Sequence
Environment	location	Bedroom/Bathroom/Kitchen/Dining room/Living room
	status	Leaving/Staying/Entering
	temperature	Environment's temperature
Person	ID	Person's ID
	Profile	Name/Gender/Age
	Habit	Sports/News/Warm/...

Fig. 4. Divided data of a Situation [3]

A Context Based Reasoning System just have to compare an occuring Situation with already saved ones now and if already one exists, act like before or on otherwise if no rule exists, create a new rule and save the data. This way the system can develop further to serve the needs of an inhabitant.

Now the only issues which you need to handle are the representation of a case for comparison, the comparison of those cases, the retrival of cases and the reuse of solutions. To compare cases they designed a database where they can store the important data in 5 tables as seen in picture 5.

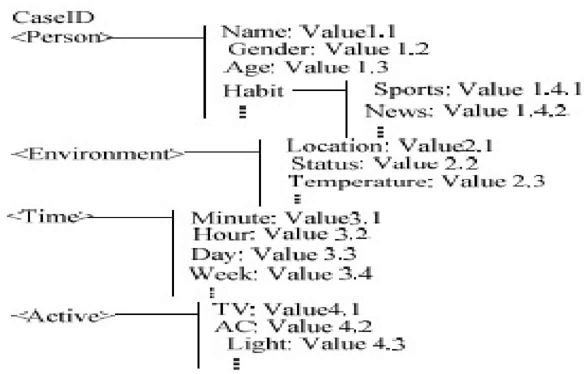

Fig. 5. Representation of context in frame form [3]

In figure 5 you can see how they stored a single case and at the top of that they used a casetable which stored the case by the use of a *caseID, personID, habitID, environmentID, activID* and *time*.

Now after we make sure how they built up their database we can take a look at the comparison of cases. Because they organized their tables on two levels the comparison of cases is also divided into two levels. The local accordance and the global accordance.

2) Local Accordance: The local similarity deal with the tables person, habit, environment and active. Those tables can contain some different type of values such as boolean or numerical values. Normally every kind of value needs a diffrent equation to compare them, but in a general form you can express it as:

$$dis(A_j(c), A_j(c')) = \frac{|A_j(c) - A_j(c')|}{dom(A_j)}$$

The two different cases in this equation are expressed with c and c' and $A_j(c)$ describes A_j's value while $dom(A_j)$ is used for the maximum difference of two values. The solution of this equation lies within 0 and 1 which describes the similarity of the two attributes of a case on a local level.

As the second part of the low level similarity we compare the whole tables within two cases. Because not every attribute has the same importance for the comparison they introduced a value called weigth (ξ) for each attribute. This way you can now compare two tables with following equation:

$$dis(T_i(c), T_i(c')) = \sum_j \xi_j dis(A_j(c), A_j(c'))$$

The only table which needs a special equation is the time slot which can be expressed with the following equation:

$$dis(T(c), T(c')) = \frac{|T(c) - T(c')|}{60x24}$$

This shows us the differences in the timetable on a minute level and is used to represent the differences between the time stamps.

3) Global Accordance: The similarity of whole cases is the top level similarity and is meant to compare two full cases. Since we can compare single tables the global accordance of two cases is just described with:

$$dis(c, c') = \sum_i \omega_i dis(T_i(c), T_i(c'))$$

like ξ within the equation of the table similarity, ω is used to weight the importance of different tables. The result of the Global Accordance is a value between 0 and 1, where a perfect match is indicated by a 0 and a total mismatch as a 1. Now the only point left for their case base reasoning system is to find the best solution for a case to ensure the comforts of the inhabitants.

4) Finding a Solution: Because the case comparison isn't absolutly definite, when two different existing cases have the same global accordance in relation to the actually situation, it is not trivial to find a solution. Also in a context based reasoning systems the primary choice could be a combination of cases. A simple example could be that the first single nearest neighbor is the best choice for the current situation. If such a solution is not accurate enough for the actual case it would also be possible to combine different similarly solutions of previous cases.

5) Context Based Reasoning System: The System itself based on *"similar problems have similar solutions" [3]* and the normal cases with filled in data are generated by the data which is taken from the sensors and so on and normally the user is not allowed to interact with the database itself. But if the system didn't take the right choice, the inhabitants are able to adjust the case for different circumstances and the system will store it as a new case. For example if the system sets the temperature not as the inhabitants wish it, the inhabitants can control the temperature manually and the context based reasoning system will adapt the case with the new data to act according to the needs of the inhabitants.

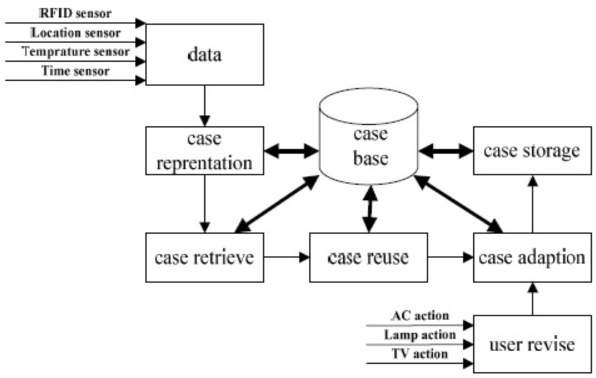

Fig. 6. CBR System Framework in smart home [3]

In Figure 6 you can see how a typical context based reasoning system framework is working. You can see how the system gather their data from the sensors and where the data is handled. Also you can see what is discribed in the last part that the user can act with the system through the production of new cases. This way the context based reasoning system will learn and develop further to a system which mostly will find a good solution for actual cases.

C. Summery

The two presented ways of dealing with the gathered data are not the only ways how a system for a smart home environment could work. But they show one of the most important parts. When a system can handle the incoming data it can serve the needs of the inhabitant. Researchers introduced many ways of dealing with these type of data. For example Chao-Lin Wu, Chun-Feng Liao and Li-Chen Fu presented a system based on different agents which deal with different areas of a smart home to provide services efficiently and appropriately [4]. Another solution where introduced by Juan C. Augusto and Chris D. Nugent who worked with a system based on different rules in the form ”Event-Condition-Action”.[5]

There exist many different solutions for the development of a smart home environment. But they all consists of 3 important parts as shown in figure 7.

The Environment: *The home equipped with different type of technology (e.g. sensors, presureplates etc.) which gathering data about the usage and the activities in this area.*

The Database: *A storage for the gathered and arranged data of the system. This could be for example a collection of different rules or a collection of already finished situations depending on the system used by the smart home environment.*

The Decision Maker: *A instance which handle the gathered data and interacts with the database. These part of the system is responsible for the systems reaction and interacts with the environment to serve the needs of an user.*

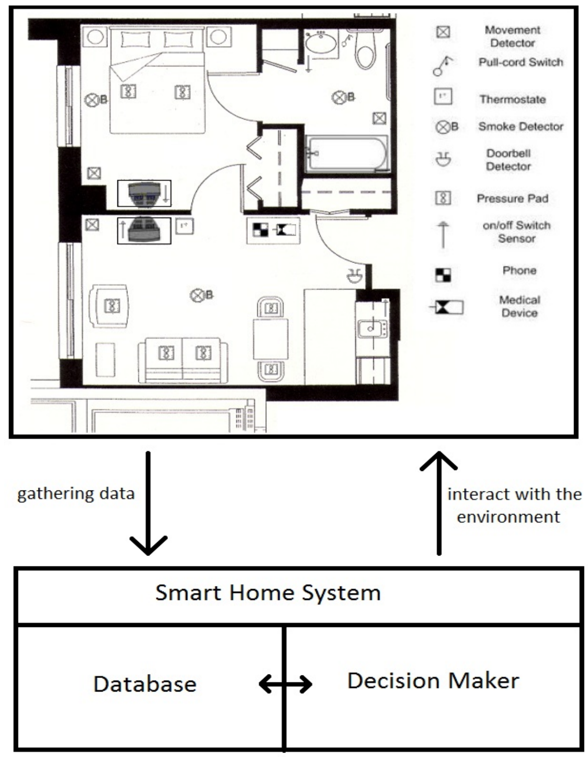

Fig. 7. Representation of context in frame form [3]

IV. Related Work

Because the area of smart home research is spreading about a large area it is not possible to mention every single concept or solution for a smart home environment. But there are also some valuable articles and papers about this topic which helped to deal with the topic of smart home environments. First to mention the article from C. Nugent, D. Finlay, R. Davies, H. Wang, H. Zheng, J. Hallberg, K. Synnes and M. Mulvenna who introduced homeML which is an open standard for the exchange of data within a smart home environment [6]. Also interesting is the empirical evaluation of three different user interfaces to interact with the smart home environment by Tiiu Koskela and Kaisa Väänänen-Vainio-Mattila[7]. Another one is an article about the needs of an user and what people value within their smart home environment by Victoria Haines, Val Mitchell, Catherine Cooper und Martin Maguire[8]. Another article about a Case-Base-Reasoning-System which deals with the opportunities of such a system by David Leake, Ana Maguitman and Thomas Reichherzer [9]. D.J. Cook, M. Youngblood, E.O., III Heierman, K. Gopalratnam, S. Rao, A. Litvin and F. Khawaja designed a architecture called MavHome and describing it in their article[10] .

These are just a few examples of these area of research and it is shown that it is already possible to create an environment which tries to serve the needs of an inhabitant.

V. Conclusion

In this paper just presented two different concepts of a 'smart home environment' in detail, but there are much more approaches by the researchers and developers to evolve an environment equipped with computing and information technology to design a residence or environment which improves the lifestyle of inhabitants and user.

The mainly problem is to create a system which nearly always fits with the expectations of the users, but still there exist good approaches for learning and self-evolving systems which can adjust to the needs of the users. As already said the improvements of comfort, security, economy and so on are worth for further research. But not only the lifestyle is affected by this technology. Its also able to help people with a physical handicap or older people to manage their daily routine easier and much more comfortable and therefor we can look forward to new inventions in this part of technology.

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