Persona-based Adaptation in a Smart Green Home

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***Abstract*—In this paper we present the vision of the GoGreen project on a smart home that is capable of decreasing energy consumption while at the same time increasing user comfort. To identify the main challenges we introduce a general model for intelligent homes that describes the current state, the target state and the transition. A key point in the project's vision is the concept of personas and entities to model groups of individuals and their preferences. A second key point is the strategy of coaching the users towards the global system goals by adapting the environment.**

***Index Terms*—intelligent homes, energy-saving technology, learning human preferences**

I. INTRODUCTION

One of today's main challenges is how to deal with the increasing demand of energy on one hand and the decreasing supply of fossil fuel sources on the other. In the Netherlands for example, energy consumption has been growing continuously over the last decade. Figures show, that this increase can mainly be attributed to the consumption of electricity [1].

Basically, there are two ways of dealing with the expected shortage of energy sources: looking for alternative sources of energy and trying to decrease energy consumption. A possible way of generating energy is by harvesting solar or wind power in ordinary houses. The energy that is generated in this way can be more than the amount that can be consumed in the house. Either this energy has to be stored in the house or it has to be fed back into the power grid. Energy suppliers deal with this varying demand and supply of energy by creating a so-called Smart Grid.

The best way to save energy is to switch off all appliances. This will make the house very unattractive to live in however. More realistic energy saving strategies ask for home owners to become aware of all appliances that use energy in their home and to switch off all appliances that aren't necessary at the moment. This can be hard to achieve. One can forget about some appliances, or sometimes co-residents do not share the same mindset of energy reduction. Some external aid is often required.

Both the rise of the Smart Grid and the need for an external aid can be dealt with by turning the house into a smart home that takes care of these concerns. This is the goal of the GoGreen project that forms the base of our research. This intelligent green home will be able to make a trade-off between energy reduction and comfort. The latter is very important. If the quality of life in one's home decreases drastically, the chances that the system will be used are minimal. We want to create an intelligent environment that learns from the preferences of its users and adapts the power consumption of the various appliances that are present. This will increase the feeling of comfort for its users while at the same time reducing the energy consumption.

In order to be able to create an intelligent home that meets the demands that we have posed and to identify the choices that have to be made for the design, we have created a model that describes the phases that are generally present in smart homes. This model will be described in section II. The three phases of the model will be discussed in sections III and IV. These sections describe the state of the art, followed by a description of the GoGreen vision on the concerning phase. In this vision, the concept of *personas* plays a large role. This concept will be explained in section III. We will conclude this article with conclusions and future research directions for our project.

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II. MODEL

In the recent past there have been quite a few research projects that aim to create an intelligent home or office environment. Noteworthy in this respect are the CASAS project of Washington State University, the AHRI project of the Georgia Technical University and Michael Mozer's Neural Network House. In order to learn as much as possible from these projects, we have developed a model that describes the main concerns for smart homes. This model is depicted in figure 1. First, an assessment of the current situation has to be made. Second, the desired or target state has to be determined. Finally, a transition strategy has to be devised and executed in order to reach the target state. In this section we will briefly describe each of these phases.

A. Current Situation

Starting point of the intelligent home is making an assessment of the current state. Not all data that can be extracted from the environment are equally important for making a correct assessment. The relevant parts of the available data have to be selected, ordered and processed in order to create

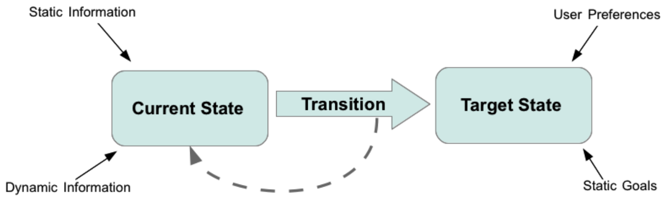

Figure 1. Flow of Intelligent Home Systems

information. This results in a notion of the people that are present, the activities that they are performing and of the room in which these activities take place. It also includes a notion of the appliances that are present and their current state.

We distinguish two types of information: static information and dynamic information. Static information concerns the type of information that does not change or only does so on rare occasions. This includes locations of sensors and appliances and the type of sensors that produce the data. Dynamic information is derived from sensor data (movement, sound, temperature) and from on-line sources (weather forecast, agendas of home inhabitants). Dynamic data also includes temporal information (current time, day of week, holidays etc). With respect to dynamic information not only the present state is important, but the history of events can be stored as well. This allows the system to predict events that are likely to take place in the near future, which is important input for the transition phase.

There are several issues when collecting information using sensors. In many cases, the data that are collected are unreliable and incomplete. This may be due to lossy connections or malfunctioning hardware. Another issue is the diversity in sensor data. There is a large variation in the type of data and the frequency at which the data is sampled. The intelligent home has to be able to analyze incoming data and find strategies that deal with this diversity and unreliability. An intelligent and learning system is necessary to deal with these challenges.

B. Target State

For an intelligent home to be effective, it is necessary to include a notion of a desired state. This desired state is derived from the system's goals. After these goals have been established, the target state can be derived. There are two types of goals: global system goals and user preferences.

Global system goals are determined at the design phase of the system and are generally the primary reason to create the system. Example goals are providing assistance with everyday tasks for elderly people, detection of anomalous behavior for patients and reducing energy consumption.

For many systems the approach of only taking into account the global system goals works fine. However people generally want to remain in control of the environment in their own homes. It is hardly acceptable to have a system that autonomously makes decisions that reduce the feeling of comfort and well-being. Even though people agree with the general goals of the home automation system, they want to be able to adjust it to their own preferences.

In order to properly derive the desired target state from global and personal goals an intelligent system is necessary for this phase as well. A challenge that has to be solved by this intelligence is how to achieve the system goals and taking into account personal preferences.

C. Transition

Transition describes the effort that is needed to reach the target state. Some observations have to be made. First, not all transition mechanisms guarantee that the target state is reached. For many implementations, it may be enough if the situation changes *towards* the target. This may be the case if changing the environment into the target state is too expensive. The second observation is that the transition influences the current state. Because of this, the transition strategy may have to be altered several times during the actual transition. For this reason, the mechanism that creates this strategy has to be a learning system as well.

III. Current State

The result of the assessment of the current situation can take many forms. For the GoGreen project the most important aspects are identification, localization and activity discovery.

A. Identification

Identification can be done in a number of ways. In systems that target one-person households, the identification is trivial. If a person is detected, it is safe to say that this is the inhabitant. When more people are involved the easiest way to identify is by using some wearable device that can be detected by a sensor. Although the technical part of using this approach towards identification is rather straightforward, there are several objections to this approach. As described by Rashidi [2], people are generally reluctant to wear sensors. A possible solution for this is to design the sensors in such a way, that they are attractive to wear, for example by embedding them in some kind of jewelery. This does not solve the second objection, namely that this solution requires people to wear the sensors at all times. In practice, however, people tend to forget to put on the wearable, lose it or even swap it by somebody else's wearable by accident.

A different approach for identification is to use passive sensors. This type of sensors can be embedded in the environment. For higher acceptance with users it is preferred to have these sensors blend in with the environment as much as possible. A good example is described by Alpert and Allen [3] who analyze the sounds of footsteps on a staircase to identify persons based on their gait. Sound can also be used for voice recognition [4]. Other passive biometrics include facial recognition (using video) [5] and body size and shape (using infrared, ultrasonic and pressure sensors) [6]. For some applications only the current number of persons has to be known. An example of this is the research described by Crandall [7], where infrared movement sensors are used to keep track of the number of people and their whereabouts.

B. Localization

When solving the problem of identifying persons, in many cases the problem of localization is solved at the same time. If the position of the sensors that are concerned is known, the system can derive the global position as soon as the identification has taken place. This accuracy is of course dependent on the type and range of the sensor that is being used. A low accuracy is not necessarily a problem. In many cases it is enough for the system to know in what room a person is. This can be achieved using infrared motion sensors [7], RFID readers that are located in doorways [8] or vibration sensors [9].

There are a number of possibilities to determine the location even more accurately. Bian et al. [10] install a number of arrays of microphones at known locations. Using the time of delay of the sounds that are produced by inhabitants the system is able to determine the position of this person with an accuracy well below one meter. The approach taken by the Gator Tech Smart House is to install a smart floor, that consists of tiles that are approximately 40 x 40 cm. Each tile contains a pressure sensor in the center of the tile that can detect any slight pressure anywhere on the tile [11]. This allows the house to detect movement of people or pets and the (re-)placement of objects.

C. Activity Discovery

For many smart home projects it is important to be able to discern what the inhabitants are doing. In health care for example, the frequency that activities of daily living (ADL) are performed is an important metric for determining the person's health. An overall decrease of activity may indicate that the person has fallen ill. This may also be the case if the person starts using the toilet more often. A good example of identifying activities is given by Chen et al. [12]. They leverage the sounds that are produced in a bathroom to recognize whether the bathroom user is showering, washing hands, flushing the toilet, urinating or sighing. In another project, Crandall uses the sequence of events that are generated by motion sensors to determine the activity that is being performed [7]. In the research by Kim et al. [13] video data are used to extract poses of the observed person. Activities can then be derived by analyzing the sequence of these poses.

D. GoGreen Assessment of the Current Situation

A conclusion that can be drawn from the research projects we studied, is that the technology that is necessary for gathering detailed information in smart homes is usually obtrusive by nature. In some cases the house even has to be partially rebuilt to install the desired technology. For the GoGreen project, we want to make the solution attractive, easily installable for home owners, privacy-aware and cost-friendly. This has the consequence, that we have to deal with less accurate sensors for identification, localization, activity discovery and mapping. The previous paragraphs show however, that these simple sensors can still be used to retrieve rich information.

In order to deal with these less accurate sensor readings, we will adopt a new approach towards recognition of events and persons. Instead of aiming to identify individuals, we introduce the concept of personas. A persona is a model of individuals that share (physical) traits and preferences. Examples are "adult male", "young child" and "elderly woman". Before installation some information on these personas can already be present in the system, thus speeding up the time that is necessary for training the system. Based on actual measurements, the personas will be adapted. After learning, each persona will represent a number of actual people. Each individual is only represented by one persona however. For learning the actual preferences, a second layer is introduced. This layer consists of entities. An entity can consist of one

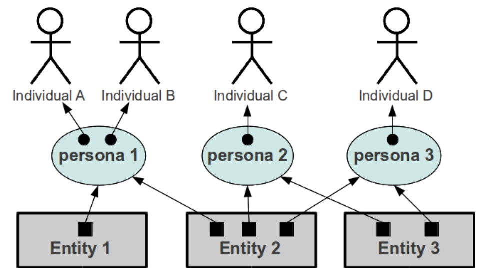

Figure 2. Personas and Entities

persona, or of a certain group of personas (figure 2). The reason we introduce this second layer, is that the preferences of a group of people often differs from the personal preferences of each of the individuals. For example: if John likes the lights to be turned on brightly but Susan likes them to be dimmed, they will have to reach a consensus on the brightness of the lights when they are together in one room. In this case we have the entity based on John's persona, the entity based on Susan's persona and the entity based on both personas, each with it's related preferences.

One of the advantages of using personas is that this increases the privacy level of the system. Even if the system would be compromised no detailed information on the persons that are being monitored is available as personas are linked to groups of persons instead of to individuals. This does not take away all concerns, but it is at least a step in the right direction.

IV. Transition and Target

Two phases of the model remain: transition and target. The main focus of this section will be transition. A few words have to be dedicated to the target state however. For the intelligent green home we envision that the target state will be derived from both global goals (sustainability) and personal preferences. There are projects that have succeeded in doing this, but no project has done if for homes with multiple residents. Further research will be necessary in order to be able to determine whether the existing strategies can be used for this project as well or whether a new learning strategy has to be devised. A part of the strategy that requires special attention is how to deal with changing target goals. The global goals will more or less remain the same, but personal preferences are very likely to change over time.

A. Transition Strategies

If the system has the means to influence the environment it can try to reach the target state using these means. We call this strategy "transition by adapting". The action that the system takes depends on the underlying strategy. If the system depends on one input only, the strategy is often simple. A good example is the thermostat: as long as the measured temperature is below the desired temperature, the system must heat. Otherwise the heating is turned off. The more variables are taken into account, the more complex the strategy becomes. An example of this is the GeoTherm project that uses mobile phones to track and predict movement patterns to automatically control the thermostat [14]. Another example is Michael Mozer's Neural Network House [15]. This house is capable of developing a strategy that takes both user preferences and electricity cost into account. During the learning phase, this house notices how the user is operating the various switches in the house. When the learning is done, the house automatically turns devices on and off, according to the location where the user is at that moment.

Not all systems have the possibility to influence the environment. In these cases, the goal of the system usually is to give users insight in the observed behavior. In this case, the system can praise users if they have managed to achieve certain goals or offer advice how to reach them. These mechanisms will coach the user towards behavior that is better aligned with the goals that have been set. We call this approach "transition by coaching". An example of this strategy is often seen in homes that have a smart electricity meter. The energy suppliers that install these meters usually provide an option to the owners to get insight in the energy consumption at a frequent interval. This consumption pattern can then be compared to an optimal usage pattern. If the consumption is too high, the system can offer some suggestions on how to decrease the electricity use. Another possibility is to use these data in an energy saving competition with friends or neighbors. The advantage of this type of system is, that the user is in full control of his surroundings. The initiative to be coached lies here with the user.

B. GoGreen Transition: Coaching by Adapting

There is a third option that we have not seen in literature yet: coaching by adapting. In this approach, the system automatically changes the environment, turning off all appliances that are unnecessarily turned on and only turning them on when required. The system learns from the user's reactions, adapting in a way that is in line with his preferences. However, this adaptation is strongly inclined towards the global system goals. In this way, the users deduce from the system behavior that it 'wants' them to behave in a more energy efficient way.

We believe that this approach is the best for the GoGreen project. As with many things, technology is only a part of the solution. For any technology to succeed, it is mandatory that it is supported by the users. By coaching behavioral change in residents, the expected result will be higher than when a pure technology solution is chosen.

An important issue when choosing this approach, is to ensure that this solution is still attractive to prospective users. A first stimulus to adopt this technology is the insight it gives the user in the amount of money that is saved by using the system and changing their behavior. Financial considerations form an important part of the human decision making process. A second stimulus is the customized environment. A house that reacts to people's presence in a way that is consistent with their preferences increases the experienced comfort.

V. Conclusions

We believe, that the use of personas and entities will be beneficial in achieving situation awareness for the intelligent green home. Not only will this make the recognition easier, it is better for privacy issues as well. In the next phase of the project we will further investigate how to use the available heterogeneous sensor data to create personas and how to deal with possibly unreliable connections to the sensors.

Furthermore, we see the the approach of coaching by adapting as the best for the GoGreen project. Further research has to be conducted to find the right balance between adapting towards the green goal and taking personal preferences into consideration. The actions that are taken by the home must eventually increase user satisfaction.

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