Resident-Aware Green Home

Ahlam Elkilani, Bayan Elsheikh Ali, Rasha Abu Romman, Amjed Al-mousa, Belal Sababha

Abstract**—**The amount of energy the world uses doubles every 20 years. Green homes play an important role in reducing the residential energy demand. This paper presents a platform that is intended to learn the behavior of home residents and build a profile about their habits and actions. The proposed resident aware home controller intervenes in the operation of home appliances in order to save energy without compromising the convenience of the residents. The presented platform can be used to simulate the actions and movements happening inside a home. The paper includes several optimization techniques that are meant to save energy in the home. In addition, several test scenarios are presented that show how the controller works. Moreover, this paper shows the computed actual savings when each of the presented techniques is implemented in a typical home. The test scenarios have validated that the techniques developed are capable of effectively saving energy at homes.

Keywords**—**Green Home, Resident Aware, Resident Profile, Activity Learning, Machine Learning.

I. Introduction

THE amount of energy the world uses doubles every 20 years [1]. Green homes play an important role in reducing the residential energy demand. In this paper, the presented platform is designed to learn the behavior of the home residents and build a profile about their habits and actions. The resident aware home controller will intervene in the operation of the home appliances to save energy, with one main restriction is that this intervention will not compromise the convenience of the home residents. The system relies on a set of information gathered by a complex array of sensors spread through the home. In this research, the focus is not on the physical implementation of the system, but rather on the intelligent algorithms it will use to optimize the energy usage. The platform built can be used to simulate the actions and movements happening inside the home.

To properly accomplish this task, three families' activities have been researched to create model families with expected activities. The energy consuming devices that existed in these families homes' has been investigated and ranked as well.

In addition to building the platform, several optimization techniques have been created that are meant to save energy depending on who exists in what room and what is being done. The actual saving by each of these techniques when implemented in a typical home has been computed as well.

The paper is organized in six sections. In Section II, a review of related work on similar activity learning models is presented. Section III details the design of the platform. Section IV discusses each optimization technique and its algorithm. Section V, presents the findings and simulation results. Finally Section VI concludes the paper.

A. Elkilani, B. Elsheikh Ali and R. Abu Romman are undergraduate engineering students at Princess Sumaya University for Technology. Amman, 11941, Jordan.

A. Al-Mousa and B. Sababha are IEEE Senior members and assistant professors at Computer Engineering Department, King Abdullah II Faculty for Engineering, Princess Sumaya University for Technology, Amman 11941, Jordan (phone: +962-6-5359949, e-mail: a.almousa@psut.edu.jo) .

II. Related Work

This work combines home automation and green homes yet provide convenience. Energy is saved through the control of home appliances without using remote controls. A smart system which is residential aware is the one that makes decisions according to residents' behaviors.

Diane J. Cook [2] has investigated a system that learns generalized models for common activities that span multiple environment settings and resident types. Activity of daily living (ADL) Recognition is done by applying some machine learning models such as naïve Bayes classifiers, decision trees, and Markov models. Diane [2] accomplishes the use of algorithm design as a component of a complete system that performs functional assessment of adults in their everyday environments. This type of automated assessment also provides a mechanism for evaluating the effectiveness of alternative health interventions.

Yu-Chen ho et al. [3] address the problem of learning human daily activities in a dynamic environment. Traditionally considered environments are static to simplify modeling and the learning process. The model is capable of learning new behaviors and introduces changes to current learned behaviors without the need for a retraining process.

Vazquez and Kastner [4] present the concept of ThinkHome, where user profiles are created to optimize the energy usage in these smart residences. The system collects each resident preferred temperature; both as a recent history and seasonal preferences. It then uses this data along with an algorithm developed to predict the most suitable temperature based on the room occupancy.

In [5] Chi Zhang and Gruver use distributed multi-agent model to detect the daily living activities of home residents. The agents extract the patterns locally without having a centralized system for decision making. The model assumes the use of RFIDs to track the movement and actions of the residents. After daily activities are recorded, a light weight clustering algorithm is used to produce the models of the daily activities. Meanwhile, Huynh [6] has investigated the use of wearable sensors to recognize human activity in applications like healthcare, elderly care, and personal fitness. The activity tracked includes the user's location and the state of the environment. This knowledge can help computer applications adapt to user needs depending on the current situation.

Several tools have been built to make monitoring and visualizing ADL easier. In [7] Rashidi P. and Diane Cook introduced an adaptive smart home system named CASAS. The system utilizes machine learning to discover patterns in the user behavior. These discovered patterns can be used later on for automation purposes. The system still allows home residents to intervene to change and remove these proposed automations. In addition, Chao Chen and Dawadi [8] present a web based visualization system CASASviz that is capable of collecting data from a network of home sensors along with recognized residents' behavioral patterns, and then present them in a visual manner. The collected data is represented on the web in a form of behavior graphs that allow users to understand their behavior patterns within the smart environment.

In the previous papers, the authors try to record and learn activities inside the smart residence and use that to developed models of the residents' regular daily activities. Among these papers only [4] focuses on the use of these models for energy optimization. Still, [4] has focused on a single idea, which is figuring a comfortable room temperature. In this work, several techniques are presented that make use of the residents' daily activity patterns. All of these techniques are focused on optimizing energy usage.

III. System Design

This project relies on performing high level simulations of what is happening inside a home. The system does not deal with the physical implementation of data acquisition, sensory network nor how devices are turned on or off.

The resident aware system consists of a network of sensors to collect data. The system also includes a programmable controller to behave as the brain of the system. A relay network that is able to turn on/off devices is also used. The system is implemented using MATLAB version 7.12.0.635(R2011a) 32-bit and using Simulink modules.

A. Sensors

In this system, six types of sensors are used; each sensor type and the data recorded from each sensor are discussed in detail in this section. The values stored are used later in the decision making process. The values are organized in six tables with default values that get updated while the controller is running. The sensors are:

1) Motion Detection Sensors

This device has the ability to quantify motion and alert the system about any movement, within a stipulated range, in the surroundings. This can be implemented by using ultrasonic sound waves to track any movement in the specified range. The table associated with this sensor consists of five fields, see Table I:

- The room where the motion is detected.
- A flag if there is a motion detected in the room.
- The last time a motion occurred in the room.
- The last time the room was checked and no motion existed.
- Finally, a room specific timeout period. This timeout specifies how long to wait for each room before an action is executed.

TABLE I
Motion Detection information

Room	Motion	Last_Time_Motion Timestamp	Last_Time_No_Motion Timestamp	Max_Time_Out (s)
Master Bedroom	0	41650.95	41650.90	10
Bedroom_1	0	41650.44	41650.70	10
				10
Bedroom_2	1	41650.94	41650.90	10
				5
				5
Master_Bathroom	0	41650.45	41650.25	5
Bathroom_1	0	41650.65	41650.25	5
Bathroom_2	1	41650.65	41650.55	5
Living Room	0	41650.45	41650.30	15
Guest Room	0	41649.95	41650.39	10
Kitchen	0	41650.90	41650.39	10

2) Existence Detection Sensors

Sensors are used to detect the presence of residents in the different rooms of the house. The existence table has very similar structure and fields like the motion table, but instead of being related to last time motion was detected in the room, they are tied to last time someone existed in that room.

3) Noise Detection Sensors

Sensors used to detect sounds inside different rooms, with a range that covers the room dimensions where it is located. Again, the noise detection table has very similar structure and fields like the motion table, but instead of being related to last time motion was detected in the room, they are tied to last time noise was detected in the room.

4) Resident Recognition Sensors

Those sensors are used to detect the presence of specific individuals in the house for each room. These sensors could be implemented using either Radio Frequency ID (RFID) by having each resident carry a RF tag, or by using face recognition techniques, done by setting cameras around the house. The data will be stored in a table that keeps track of all residents of the house as well as strangers. The table consists of five fields, shown in Table II:

- The person, names of people or IDs may be used.
- The second field is the current room where a resident exists at the moment.
- The third field determines the preferred temperature for the resident.
- The fourth field is the last time the resident was at home.
- The last field is the maximum time out period to check against, when the resident existence is being checked.

TABLE II
RESIDENT PROFILE TABLE

Person	Room	Preferred Temp (C)	Last_Time_Available Timestamp	TimeOut Period (s)
Father Bedroom	3	18	41649.65	10
Mother	2	22	41650.65	10 10
				10
Son	1	19	41650.55	5
				5
Baby	3	25	41650.45	5
Stranger	4	0	41650.45	10

5) Temperature Sensors:

These are regular temperature sensors measuring temperature inside each room. Data will be stored in a table which contains two fields:

- The Room ID
- The current measured temperature in Celsius degrees in that room.

6) Device Status Sensors

These sensors detect the status of the device whether it is ON or OFF. The data is stored in a table which contains six fields, shown in Table III:

- The room name.
- The status of the device whether it's turned ON or OFF.
- The third field is the last time when the device was ON.
- The fourth field is the last time when the device was OFF.
- The fifth field is the maximum timeout for each device before an action can be executed.
- The sixth field is the room ID of where the device is located.
- Finally, the seventh field is the level/speed of the devices that have multi-level settings.

TABLE III
DEVICE STATUS TABLE

Device	Device_Status	Last_Time Device_ON Timestamp	Last_Time Device_OFF Timestamp	Device_Timeout (s)	Room_ID	Device_Level
AC Bedroom	0	41650.65	41650.55	10	7	3
TV	1	41650.45	41650.30	15	7 10	
		41649.95			7	
Receiver	1		41650.39	10	5	
					5	
Heater	1	41650.65	41650.55	0	5	2
Light_BD_1	0	41650.45	41650.30	10	2	
Light_BD_2	1	41649.95	41650.39	10	3	

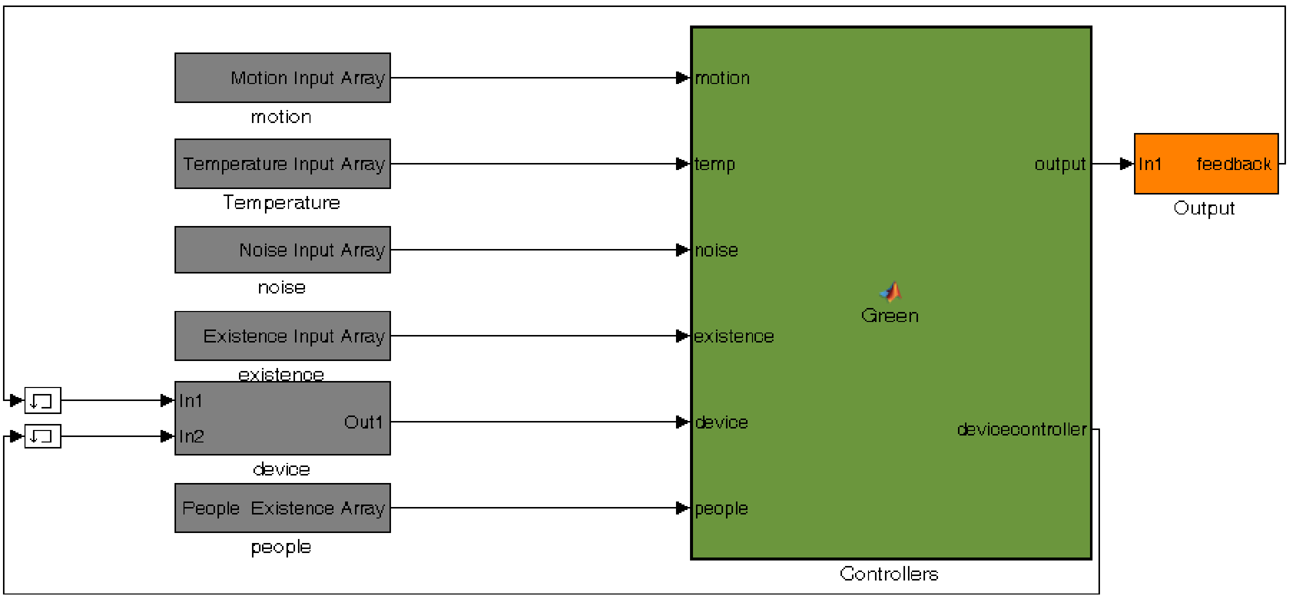

Fig. 1 System Block Diagram

B. The Controller

The controller has been built using MATLAB code as a function block that got embedded inside the Simulink environment. The controller takes sensors signals as inputs and processes them. The controller has two output arrays one for feedback control and the second is for controlling the appliances, see Fig. 1.

The details of the controller will be explained along with the optimization techniques in the next section.

C. The Relay Network

This is just an output array that emulates turning ON/OFF the different devices.

IV. Optimization Techniques

At the initial phase of this research, data on the power consumption in a typical home has been collected. In addition to this, the power dissipation information, the location, the usage time and frequency of usages of different devices in a typical house has been recorded as well. This enabled focusing on devices that have the highest power consumption.

In addition to this a model family that included: a father, a mother, a son and a baby girl was proposed to be the residents of a the sample house which consists of 9 rooms (living room, guest room, kitchen, master bedroom, two bed rooms, master bathroom and two bathrooms), see Fig. 2.

Fig. 2 Model Home Layout

Also, daily activity scenarios are created for each one of the residents that included their habits and life routines. Actions that are done daily and consume power were considered in an attempt to find ideas to reduce the power consumption. This resulted in seven optimization techniques that were implemented and tested. In this paper however, only four of these optimization techniques are discussed, which are:

A. Resident Falls Asleep in Front of the TV

Forgetting TV, DVD and satellite box turned ON could consume tens of dollars per year. Here when TV is on in the living room and someone exists in the room but with no motion (likely asleep), the system calculates the timeout period for how long it should wait before turning the TV off. This timeout factor is different between different residents. And it should be updated based on user's actions.

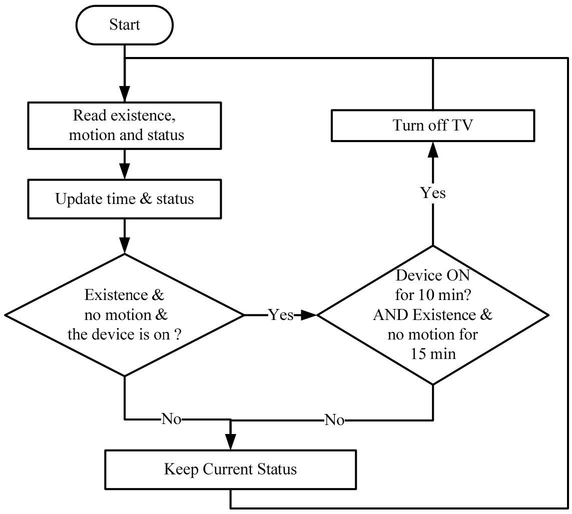

Fig. 3 Sleeping in front of TV flow chart

The most important thing here is that the system needs to build a user profile about who is likely to fall asleep while watching TV and who is not.

The algorithm calculates the difference between the current time and the last time no existence occurred and the difference between the current time and the last time motion occurred and the difference between the current time and the last time TV was OFF. If the three time differences are equal to or greater than the timeout for the current resident then it will turn the TV off, see Fig. 3.

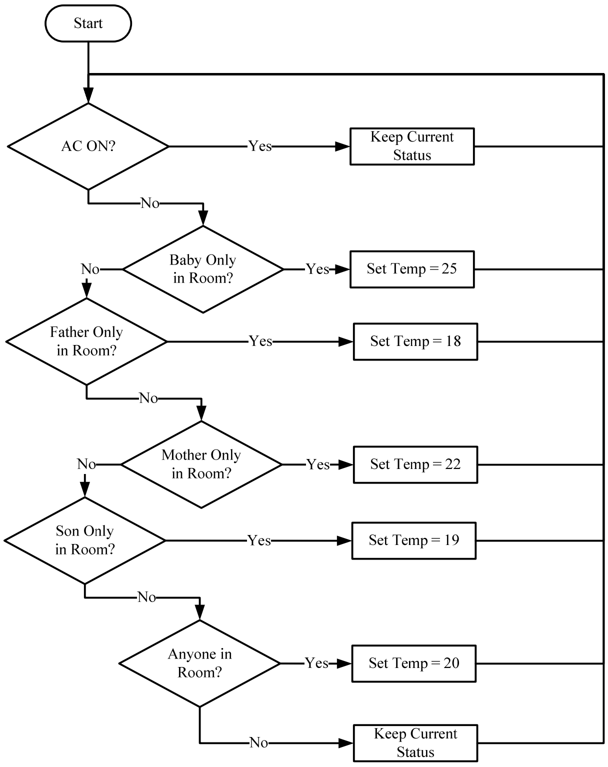

Fig. 4 AC adjustment in living room

B. AC Adjustment Based On Residents in the Living Room

When the AC is ON and there are residents in the living room the system will recognize who are there and do the following:

If one resident is in the living room the system will set the AC temperature to his/her preferred temperature. If there was more than one resident in the living room the temperature will be set to an average of their preferred temperatures. The only exception to this case is that if there is a baby in the room, and then it will be set strictly to the baby's preferred temperature, see Fig. 4.

C. Turning off Devices that Are Left on

Some products consume energy even when they are off. Their "standby" consumption can be equivalent to that of a 75 or 100 watt light bulb running continuously [9], [10]. There is very little that can be done about this. However, a great amount of energy can be saved by turning devices off if they are mistakenly left ON.

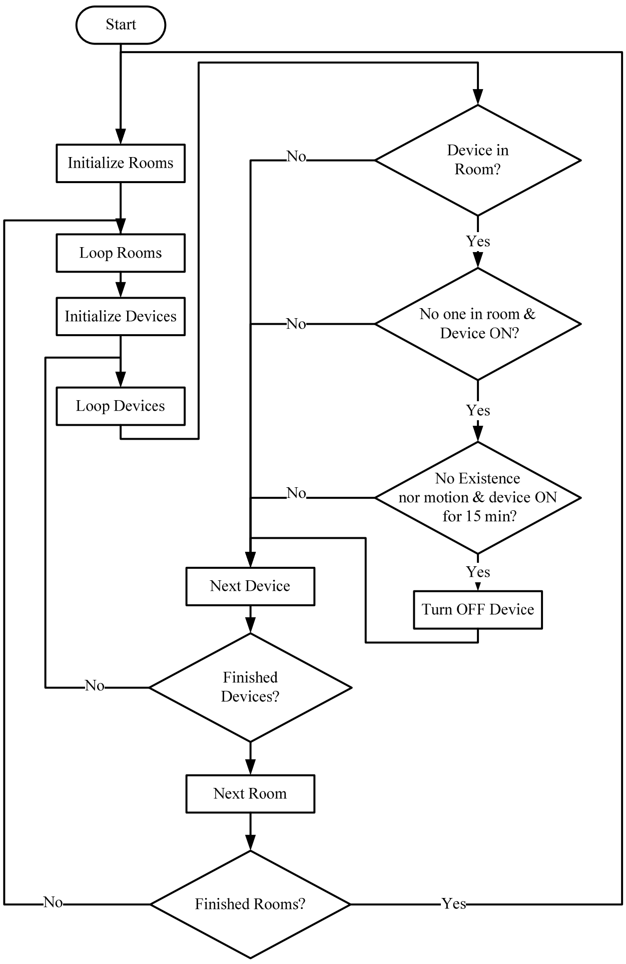

Fig. 5 Turning off unused devices flow chart

For example some lights use about 120-240 watts per hour. This is roughly half the amount used to power a large computer. This means you can save an hour's work by just shutting off a light. In this technique, most of the devices in the house will be turned off automatically after a period of time if there was no one in the room it is located in. The algorithm will work as shown in Fig. 5. The algorithm will be applied to all rooms with different timeouts depending on the room and the device.

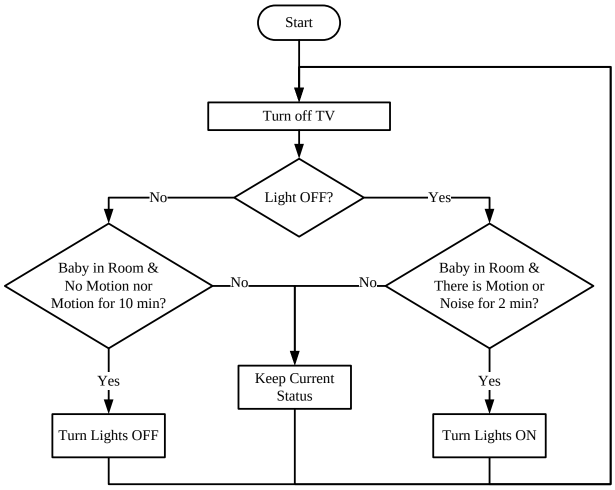

Fig. 6 Baby room lights flow chart

D. Turning Off Lights in Baby's Bedroom after She Sleeps

Since babies are afraid to sleep in dark, usually lights in the kids' bedroom are kept ON. When the system detects that the baby is in the room with no motion or noise it will assume that it is asleep and the lights will be turned off after a period of time. Next, if the system detects a noise and a motion at the same time it will assume that the baby has woken up and responds by turning ON the light. The detailed algorithm is shown in Fig. 6.

V. RESULTS

To validate the algorithm several test case scenarios were implemented as input to the system and observed the different results. The power saving in the house before and after using our system was calculated to prove its validity and benefit.

A. TV Is Turned off after Resident Falls Asleep:

Using this scenario, it can be seen in Fig. 7 that there was existence in the room, there was a motion in the room (0-5) minutes then it stopped afterwards. Scope (3) After 15 minutes of having someone in the room with no motion and TV was ON, the system turned the TV OFF. The device controller switched its value from 2 to 1, as the TV status changed, so the TV input status will be the feedback signal.

Assuming the rated power of the TV = 180 Watt [11]. In the case when resident falls asleep while TV is ON, for an average of 2 hours while its left turned ON. This will waste 360 Watt/Day. If the system is used then around 11 KW per month would be saved.

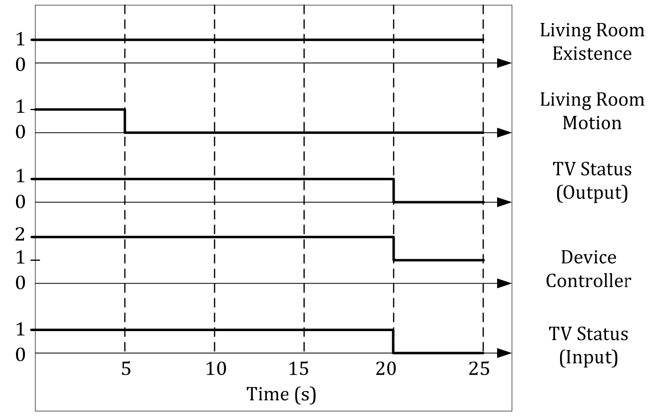

Fig. 7 Resident falls asleep scenario

B. AC Temperature Degree Is Set Based On the Resident in the Living Room:

AC temperature degree changes based on the resident in the living room as follows: As shown in Fig. 8, initially (0-5) minutes the father is the only one in the living room, the AC temperature is set to 17C, this is the preferred temperature degree for the father. Then the son is the only one in the living room, the temperature changes to his preferred temperature (19C). Between (10-15) minutes, the mother and the son and the baby are in the living room so the AC temperature is equal to 25C, this is the preferred temperature degree for the baby and it will be set regardless of the existence of the other residents. Finally, between (15-20) minutes the mother and the son are in the living room alone so the AC temperature is equals to 20C, which satisfies both of them.

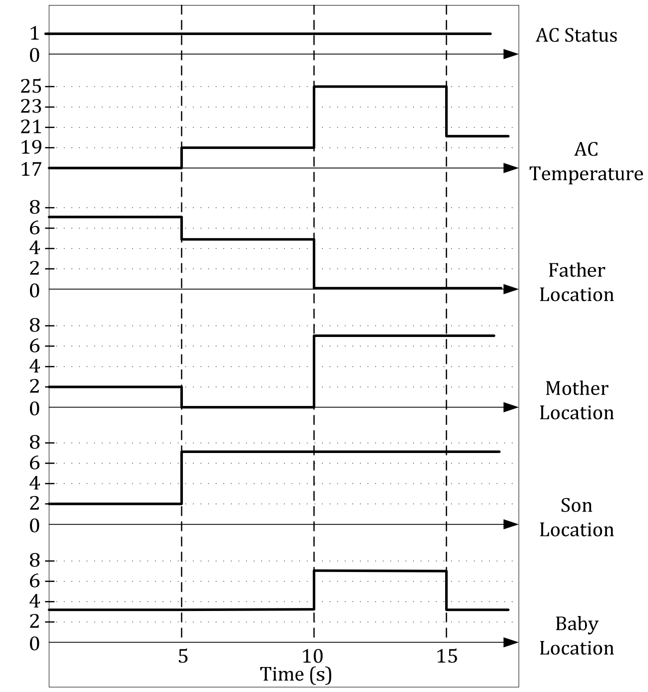

Fig. 8 AC temperature adjustment scenario

Assuming that the rated power consumption of the AC is 2000 Watts, a great power Loss is caused when the AC is left ON but no one is in the room and that is estimated to cause an average of 6 KW/Day of power wasted. When this system is used it is expected to cut the daily power wastage by 4800 Watts. This in turn saves an average monthly power use of 120 KW.

C. Light of the Kitchen Left Turned ON:

In this scenario, shown in Fig. 9, someone exists in the room between 0-5 minutes, and then it will show no existence afterwards. The light was ON in the room for 15 minutes, and then it was automatically switched OFF.

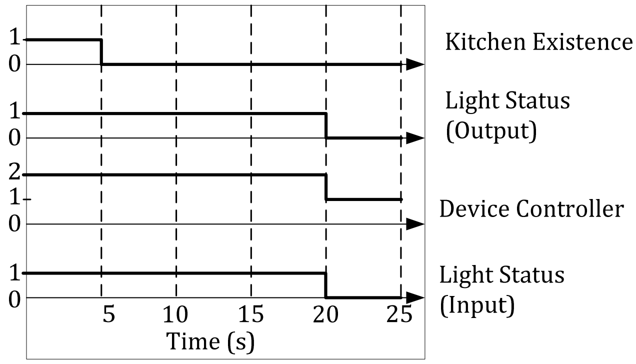

Fig. 9 Turning off lights that were left on scenario

D. Baby Room Lights Scenario

In this scenario, the baby exists in the room, with motion from 0-10 minutes, shown in Fig. 10. Then motion stops after 10 minutes. The noise sensor detects noise from 0-5 minutes, but it stops after 5 minutes. After 5 minutes of detecting no motion and no sound, the light was automatically turned OFF.

Assuming that the rated power of the light to be 100 Watt and since many times lights are left ON all night in kids' rooms, this could cause a waste of 1200 Watt/Day. But if turned OFF after the kid falls asleep this will save about 1150 Watt/Day. This is translated into a monthly saving of 34 KW.

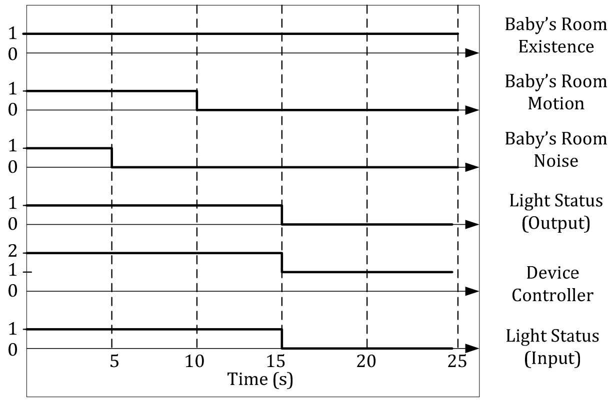

Fig. 10 Scenario of baby room lights

VI. Conclusion

In this paper, a platform that optimizes energy usage in modern homes has been designed and studied. Optimizations are based on residents' actions and behaviors. The system implemented seven optimization techniques to save energy. It keeps a profile for each resident and uses the profile to make sound decisions. The proposed system succeeded in reducing power consumption in the model home by taking suitable decisions. Decisions are designed to optimize power consumption and take into account residents' convenience. In addition to the system design, the paper has presented several test case scenarios that show how the system responds to residents' actions.

As continuation of this work one will be looking into using a fuzzy controller to adjust the weights of a few predefined factors that determine whether performing a specific action is in accordance with the user's preferences or not. Also the use of Neural Networks as a mean for adaptive learning of the residents' behavior will be a priority.

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