Dynamically Controlling Exterior and Interior Window Coverings through IoT for Environmental Friendly Smart Homes

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***Abstract*— Energy saving using smart home is of paramount importance to reduce heating and cooling energy consumption, and promote sustainable environment. Awnings and blinds have exhibited their effectiveness to reduce heating gain in summer and cooling loss in winter, respectively. Awnings are more effective to reduce heat gain in summer than blinds, while the opposite is true in winter. There exist many approaches in the current literature to remotely control flat curtains and blinds. However, up to our knowledge, no automatic technique is available in the literature, which can dynamically control the orientation of an exterior covering so that it can act like a blind in winter and an awning in summer. In this paper, we propose an automatic on-demand system to control the orientation and size of such exterior covering, and the turning air conditioners, heaters and lights on and off considering the rate of change of room temperature, and its lighting condition. We also discuss the properties and design of such exterior covering. A simulation model was developed to analysis the performance of our approach in terms of energy savings both in summer and winter.**

Keywords—smart homes; IoT; environmenal friendly home

I. INTRODUCTION

Global warming is regarded as the greatest threat for the wellbeing and existence of human and animal lives on earth. Greenhouse emission gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour (H_2O) are directly contributing to increasing extreme weathers linked to the overall temperature increase around the world termed as impact of global warming (http://www.livescience.com/37821-greenhouse-gases.html). Temperature has been rising sharply around the world. For example, in 2016, Kuwait, USA and India had highest temperatures as 129.2, 126 and 123.8 degrees Fahrenheit, respectively. These heat waves enforce the people to stay inside the homes with air conditioner. As a consequence, the use and sale of air conditioners are increasing rapidly. For example, the sale of air conditioners had been double between 2007 and 2012. This ever increasing use is putting the pressure on power stations to generate more electrical energy during peak demands. This is mainly to cope with the sharp increase of demands due to weather fluctuations and therefore, increasing greenhouse gas emissions. In addition, this is leading to increased spending (e.g., billions of dollars) for the development of infrastructure for electricity generation to cope up with these challenges. This is equally applicable to extreme cold weathers resulting in increased usage of heating energy. As a whole, the weather patterns are becoming more erratic and resulting in frequent extreme events within short periods. To manage the demand and also the usage when and where it needs for reduction of heating and air-conditioning energy consumptions through smarter houses and automated systems is becoming more and more important for today's world. To address these issues, significant research has been going on. This includes development of energy efficient, healthy and environmental friendly smart home using mainly wireless and Internet of Things (IoT) based communications and Artificial Intelligence technologies [1].

A system to monitor the health of a patient residing in a smart home healthcare environment is presented in [2]. Wearable sensors are used to obtain the values of the body parameters, while audio and video are utilised to observe the patient activities and body's condition. Another project on smart home uses wireless sensors and actuators to assist the residences in their daily activities. Abnormal actives are recognized using the information received from wireless sensors, while actuators perform assistive and recovery actions for those abnormal activates. Where there doesn't exist sufficient signal strength, mobile agents are instructed to move sensors and actuators at the target locations [3].

To minimise the daily energy consumption costs, scheduling technique for energy use from different sources such as generators, renewable energy sources (e.g., solar panels), battery storages and electronic vehicles has been investigated. Dynamic variations of the power generated by the renewable sources have also been considered in producing an energy schedule [4]. To enhance the experience of living in a home and save energy, a number of prototypes of a smart home are proposed [5] [6]. For example, in [5], fan's speed including its start and stop, and opening and closing a curtain and electronic door are remotely regulated by an apps installed in an Android phone. DC and servo motors are used to control fans and solenoids and stepper motors are used for operating electronic doors and curtains.

It is clearly evident from the literature that vertical or horizontal flat type window blinds are effective in reducing heat gains in summer and heat losses in winter. 45% heat gains can be reduced by using highly reflective blinds in summer. Awnings are more effective than blinds as in summer and up to 77% decrease of heat gains can be achieved. It is also possible to use adjustable awnings in the winter to make the home warmer with the sun light [7]. Since awnings aren't efficient like insulated blinds to reduce the heat loss in winter, to achieve the energy savings in both summer and winter, there is a need to design an exterior covering to act like an awning in summer and an insulated blind in winter. This is achievable by changing the orientation or roll up of an external covering automatically by using programmable servo motors. In the literature, various techniques are available to close and open curtains and blinds with a remote controller. However, up to our knowledge, no such automatic approach exists to control an exterior covering which can moderately scale from an insulated blind to an awning based on the needs of the house. In this paper, we propose such a technique considering the room temperature, light intensity and daily weather forecast, and analyse it in terms of energy savings from air conditioners, heaters and lights using simulations.

II. Proposed System

Through Internet (WiFi) or wireless communications, the proposed system can remotely and automatically control curtains, exterior coverings, air conditioners and heaters for the intuitively selected activation period of the day based on needs of the home for control of heat and light. The needs of the home are defined in this paper using three levels of temperature and light intensity such as high, medium and low. The values of high, medium and low, and the period for which the system uses the automatic control can be set at any time and from anywhere based on the needs of home occupants and their preferences. In this paper, climate zones are divided into two seasons – (i) warm and (ii) cool. The duration of these two seasons can be set by user of the system.

A. Overview of the proposed system

The proposed system consists of three subsystems – (i) sensing, (ii) WiFi and (iii) controller as shown in Figure 1. Sensing component consists of temperature and light intensity sensors. Our proposed system receives weather forecast such as the maximum and minimum forecasted day temperatures and their predicted time of that day from Internet through WiFi. Since exterior coverings are more effective in reducing heat gain during summer than interior coverings, our proposed exterior covering consists of two layers – (i) an awning and (ii) an external blind to exploit the benefits of both awning and blind. An awning can be moved including rotation to place a position so that it can prevent the sun glare entering into home in the summer, while the blind can be used to reduce the heat gain and transmission in summer and winter, respectively. Servo motors attached to the exterior coverings are used to do this according to the control signal received from a controller. The properties and design of the curtain and exterior covering are detailed in Section B.

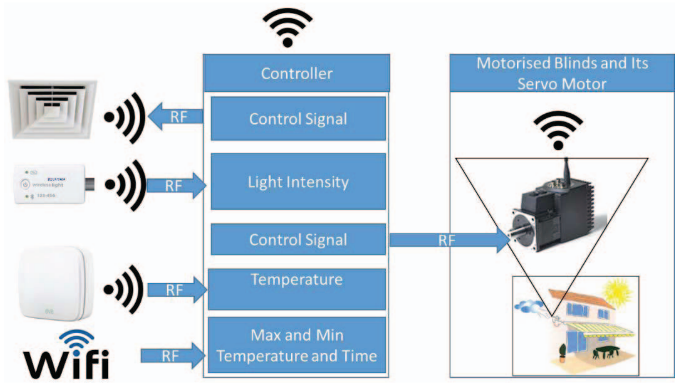

Figure 1: Schematic diagram of the proposed environmental friendly smart home

Table 1: Symbols and their purposes used in algorithms

Symbols	Descriptions
T_r	Room temperature
t_r	Time of the room temperate
T_h	Daily highest temperate
T_l	Daily lowest temperate
t_h	Time of the daily highest temperate
t_l	Time of the daily lowest temperate
L_i	Indoor light intensity
W	Warm season
C	Cool season

Considering the temperature received from WiFi and sensors and indoor light intensity information, the controller of the system generates and sends the essential control signals to the exterior coverings, curtains, air conditioners, heaters and lights. The details on how the system controls these items in warm and cool seasons are presented in Algorithms 1-3. For example, for the warmer season, Step 1 of Algorithm 1 calculates the expected rate of temperature increase, r. If r is greater than or equal to high, Step 2 of Algorithm 1 uses awnings, blinds and curtains in such a way so that sunlight penetration and indoor light intensity is optimised. Similar approach is adopted except the use of awnings when r is greater than or equal to medium. Otherwise, for sunlight penetration and indoor light intensity, curtains and blinds are opened. If the room temperature T_r (see Step 3) and indoor light intensity L_i (see Step 4) are greater than medium, air conditioners and lights are turned on, respectively. Otherwise, they remain off. Algorithm 2 does the similar activities to Algorithm 1 for the cooler season. Algorithm 3 determines whether the time belongs to either the warmer or cooler seasons. Based on this and if the activation period set by a user belongs to automatic activation period, it uses either Algorithm 1 or Algorithm 2.

Algorithm 1: Control curtains, exterior coverings, air conditioners and indoor lights in warm season

1. Calculate the average rate of day temperature increase using the information of temperature obtained from home WiFi device:

$$r = \frac{(T_h - T_l)}{(t_h - t_l)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

2. Control the curtains and the exterior coverings using servo motors:
   If $r \geq high$
   Close the curtains
   Adjust the orientation and size of awnings, and adjust the position of blinds so that the UV penetration is minimised and indoor light intensity is maximised
   Else If $r \geq medium$
   Close the curtains
   Adjust the position of blinds so that the UV penetration is minimised and indoor light intensity is maximised
   Else
   Open the curtains
   Open the blinds so that sunlight penetration and indoor light intensity is maximised
3. Control air conditioners considering the room temperature:
   If $T_r > medium$
   Turn the air conditioners on
   Else If $T_r \leq low$
   Turn the air conditioners off
4. Control the indoor lights considering indoor illumination:
   If $L_i > medium$
   Turn the lights off
   Else If $L_i \leq low$
   Turn the lights on

Algorithm 2: Control curtains, exterior coverings, heaters and indoor lights in cool season

1. Calculate the average rate of room temperature drop using the information of temperature obtained from home WiFi device:
   If $T_r > T_l$

$$r = \frac{(T_r - T_l)}{(t_r - t_l)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

   Else

$$r = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

2. Control the curtains and exterior coverings using servo motors:
   If $r \geq high$
   Close the curtains
   Drop both awnings and blinds so that temperature transmission from home to outside is minimised
   Else If $r \geq medium$
   Close the curtains
   Adjust the position of blinds so that temperature transmission from home to outside is minimised
   Else
   Open the curtains
   Open the blinds so that sunlight penetration and indoor light intensity is maximised
3. Control heaters considering the room temperature:
   If $T_r < low$
   Turn the heaters on
   Else If $T_r \geq medium$
   Turn the heaters off
4. Control the indoor lights considering indoor illumination:
   If $L_i > medium$
   Turn the lights off
   Else If $L_i \leq low$
   Turn the lights on

Algorithm 3: Control curtains, exterior coverings, air conditioners, heaters and indoor lights

1. Determine season considering the current system's date
2. Activate the components based on the values of the home and environmental parameters:
   If the time is within automatic activation period set by a home occupant
   If $season = W$
   Do the activities following Algorithm 1
   Else If $season = C$
   Do the activities following Algorithm 2
   Else
   Do the activities according to manual setting

B. The Design of Exterior and Interior Coverings

In our smart home system, energy savings are obtained by using an intelligent automatic system to control three layers of window coverings, air conditioners and heaters. As shown in

Figure 2 below, the three layers of window covering include an awning, an exterior blind, and interior sliding curtain. All these coverings are motorized and can be controlled manually or by the automatic control program of the smart home.

Awning

Window awnings are more effective in reducing heat gain in summer than blinds. According to the research of the U.S. Department of Energy's (DOE), window awnings can reduce solar heat gain in the summer in the U.S. by up to 65% on south-facing windows and 77% on west-facing windows (http://energy.gov/energysaver/energy-efficient-window-treatments). In our intelligent smart home system, the window awning is designed to be retractable and rotatable so that only the window is covered in shade while as much room as possible is allowed between the awning and the window so that hot air won't be trapped. The awning can adjusted for its orientation and size automatically according to the height of the sun and the direction of sunlight. In summer, it reduces the heat to enter the room through the window and at the same time reduce the loss of light intensity inside the room. In the winter, the retractable awning will be rolled up to let the sum warm the house in sunny days.

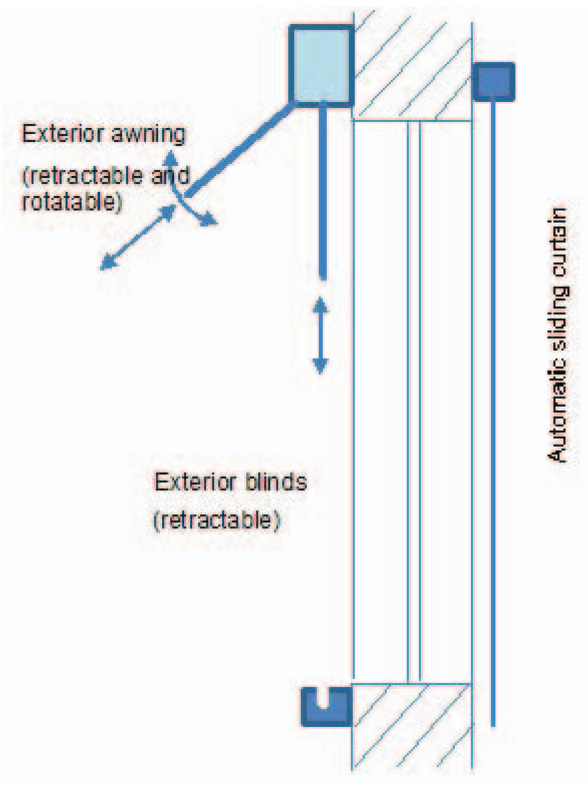

Figure 2: Window coverings

III. Simulation Results

Simulation is run and analysed to calculate the energy consumed by both conventional and energy savings from our proposed system. We use a number of parameters and their values of a smart home considering a various scenarios for each simulation season. The symbols of these parameters and their purposes are presented in Table 2.

Table 2: Symbols and their purposes used in simulation and performance analysis

Symbols	Descriptions
N_1	Number of air conditioners
N_2	Number of ducted heating zones
N_3	Number of lights
I_1	Idle time of an air conditioner
I_2	Idle time of a heater
I_3	Idle time of a light
e_1	Percentage of energy saved by an air conditioner
e_3	Percentage of energy saved or increased by a light
E_p	Total energy needed for our proposed system in kWh
E_1	Each air conditioner's energy usage in kWh
E_2	Each heater's energy usage in kWh
E_3	Each light's energy usage in kWh
A_1	Active time of an air conditioner
A_2	Active time of a heater
A_3	Active time of a light
e_2	Percentage of energy saved by a heater
E_c	Total energy needed for the conventional system in kWh
P	Percentage of improvements

Using these symbols, the total energy consumed by a conventional and our proposed systems can be defined as,

$$E_c = \sum_{i=1}^{3} N_i E_i A_i \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4) \text{ and}$$

$$E_p = \sum_{i=1}^{3} N_i \, (E_i - e_i) \, (A_i - I_i) \ldots \ldots \ldots \ldots \ldots \; (5),$$

respectively.

In the simulation, energy consumed by home appliances was assumed by following the guide for the amount of their respective energy consumptions for a typical home [8]. Heaters are not considered in Algorithm 1 for the warmer season because mainly air conditioners and light intensities need to be automatically activated in this season. For this, data for heaters are represented as "–"in Table 3. The simulation results and the data for four different scenarios of a warm season are shown in Table 3. We used idle time in simulation as because of the automatic movement and orientation of curtains and external coverings by our system, air conditioners and heaters will not remain on for the whole duration of automatic activation time termed as active time. For $e_1 = 0.15$ and $e_3 = 0.001$ i.e., 15%

and 1% energy saving for air conditioners and lights, respectively, our system achieved 35.64%, 31.93%, 35.50% and 35.53% energy saving for four scenarios.

Table 3: Simulated results for the warmer season assuming $e_1 = 0.15$, $e_3 = 0.001$, $I_1 = 2\ hrs$, $I_3 = 2\ hrs$, $A_1 = 8\ hrs$ and $A_3 = 7\ hrs$

N_1	E_1	N_2	E_2	N_3	E_3	E_c	E_p	P
2	1.5	-	-	20	0.015	26.10	16.80	35.64
1	1	-	-	30	0.05	18.50	12.59	31.93
3	1.6	-	-	30	0.02	42.60	27.48	35.50
4	1.3	-	-	25	0.025	45.98	29.64	35.53

Similarly, air conditioners weren't considered in the simulation for the cooler season. Table 4 shows the four scenarios and their simulation results and improvements (31.26%, 25.86%, 34.28% and 30.01%) from our proposed system. Note, $e_3 = -0.001$ and $I_3 = -2\ hrs$ are negative which indicates more energy and activation period are required by lights in the cooler season because of the darkness of the home created by the full covering with the curtains and blinds.

Table 4: Simulated results for the cooler season assuming $e_2 = 0.1$, $e_3 = -0.001$, $I_2 = 2\ hrs$, $I_3 = -2\ hrs$, $A_2 = 9\ hrs$ and $A_3 = 7\ hrs$

N_1	E_1	N_2	E_2	N_3	E_3	E_c	E_p	P
-	-	1	2	25	0.015	20.63	14.18	31.26
-	-	2	1.5	20	0.05	34.00	25.21	25.86
-	-	3	1.6	28	0.02	47.12	30.97	34.28
-	-	4	1	35	0.025	42.13	29.48	30.01

IV. CONCLUSIONS

This paper is mainly on of remote control based motorised programmable system for automatic activation of curtains and exterior coverings based on needs of the house for heating, air condition and lighting control. In this paper, we propose an automatic servo motor based technique to control the orientation and size of an exterior covering capable of improving the energy efficiency in both summer and winter. We also present the properties of materials needed and the design of such exterior covering. Simulation results have shown 34.65% and 30.25% of the average energy savings in summer and winter, respectively. In summary, the key benefits and purpose of this system are - keep home cool in summer; protection of inside environment from UV of sunlight and heat; allow sun light in day time; allow heat to enter room and to retain heat inside the room in the winter. This results in reduced energy consumption and therefore, reduced heating bill in winter. In summer it reduces heat to enter inside the room and also helps in retaining cold environment inside the room. This results in reduced energy consumption for air conditioning and therefor, reduced energy bill in summer. Our proposed system is able to be programmed to remember personal preferences of owners/ users for internal conditions of heating, cooling and light intensity. Timer can be programmed also to mimic occupancy of houses when nobody is in the building. This can provide added benefits for enhanced security of owners/ users. We will investigate the impact of exterior covering on air flow to and from the room for further enhancing living conditions and room environment as a further research.

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