International Journal of Smart Electrical Engineering, Vol.5, No.2,Spring 2016
pp. 93:99

ISSN: 2251-9246
EISSN: 2345-6221

Integrated Fuzzy Control of Temperature, Light and Emergency Conditions for Smart Home Application

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Abstract

Smart home is composed of several controllers with different plants in control. If each controller works independently, without considering the mutual effect of the others in the control process, the whole system could definitely not converge to an optimum desired status and may not ever reach the demanded condition. According to the mentioned problem a new approach is presented in this paper using an integrated fuzzy controller in order to control light, temperature and emergency conditions in a realistic MATLAB Simulink simulation. The obtained results represent the presented approach and fuzzy model to be able and easy to implement the controller for smart home applications.

Keywords: Smart Home, Fuzzy Control, Integrated Control System, Heat Flow Control, Lighting Control

1. Introduction

Occupant's convenience and energy efficiency are two primary concerns which should be considered in designing a smart home. Smart home can be programmed based on environmental parameters such as the climate, location and occupant's behaviour.

A) Thermal Control:

Nowadays different automatic operations are performed in a smart home. In order to optimize energy consumption, one of the most important automatic systems is smart heating control. This is related to the large energy consumption of the heating systems which could easily be decreased with a smart heating controller. In order to reach this goal, the heating system with a controller should be modelled and different types of the control approach should be tested using computer simulations. The most controlling method that is used in heating system controllers is PI and PID Controllers. As adaptive controllers offer the possibility to tune them automatically, optimizing parameters of a PI Controller for proper control in different condition is a difficult task, because usually no process model is available and challenging issues like "actuator saturation" have to be taken into account [1]. Another method for designing a controller is the thermodynamic model of a house using complex mathematical functions. [2]

The output of this controller has many variations in order to reach the set point. The obtained model could be optimized by PID Controller but as previously explained optimizing PID Controller needs complex calculations. Some researchers used Fuzzy and Fuzzy PID [3] [4] Controller in order to solve the problems of non-linearity, large delay and time variation of heating furnace [5] [6]. But the input parameters of the controller are not considered properly as it should be for a real plant.

B) Smart Lighting Control

One of the most common control systems in smart home is the smart lighting controller that has an important role in decreasing energy consumption. There are many presented researches with different approaches for designing smart lighting controller but nowadays fuzzy controllers are the great alternative for most widely reported PID Controllers because of flexibility, online response, simple design and good performance [7]. One of the most important issues for the Fuzzy Lighting Controller is its input parameters. For example in some researches the output of controller depends on the number of people who cannot be affected sufficiently in order to reduce their level of energy consumption [8].

Today researchers are trying to use solar energy and light to provide supplemental light. In these models external luminance, global and diffuse solar radiation, position of blinds, the status of light [9~12] or Outdoor Horizontal Illumination, Window Parameters, Solar Altitude Angle, Solar Azimuth Angle and Day-Light factors [13~14] are considered as “input” and the rotation of window blind is considered as “output” parameters of the controller systems.

C) Fire Alarm System

Another factor that involved in smart home standards is the fire alarm system. According to complexity of signals and parameters of “fire”, efforts have done to raise the discretion in order to reduce the errors of fire alarms and detect it properly.

Designs of fire detection and alarm systems are based on different approaches such as Neural Network, Fuzzy Neural Network, Fuzzy Logic and Image Processing [15~20].

Neural Network and Image Processing Techniques may have errors in detecting fire and their results are not very reliable because the main problem of these methods is the dynamic nature, movement and variation of fire flame in the area. As a result, detecting these issues requires the use of complex mathematical models and calculations.

This paper presents a Fuzzy Controller as an integrated controller for thermal, lighting and fire detection and all-effective parameters are considered as inputs for each plant individually. In particular, the overlapping function such as the effect of natural outdoor light and fire on the indoor temperature, and the effect of natural outdoor light intensity on indoor light, have been considered.

2. Method

This paper presents the structure of integrated controller that is able to monitor and control emergency conditions, lighting and heating processes simultaneously.

Heating, lighting, blind and fire-alarms are simulated with MATLAB Simulink and the relationships between each of these systems are intended as well. As previously mentioned, different parts of the system is not independent, despite the entire system being synchronized to a converging stable point.

The fuzzy logic controller has some advantages compared to other controllers like PI, PID, Neural Network or Fuzzy Neural Network such as simplicity in design and appropriate response [8], therefore all controlling systems in this paper are designed considering this approach.

D) Home Thermal Model

Intelligent heating control systems are so highly regarded that could have a significant impact in reducing energy consumption. With the use of smart thermal control it is possible to get to 45% energy saving annually.

Temperature can be controlled using various parameters. For example, some of these systems are time-dependent, sensitive to the presence of people and user-configurable toward reaching the desired temperature. On the other hand, several others in control plants can affect the temperature in a room. All these factors must be considered in a comprehensive control system.

Here a temperature control system based on Fuzzy Controller is designed to work according to the occupant’s set point. The outdoor temperature and light can also affect the temperature; these parameters are considered as inputs for the controller system.

The overall purpose of the system is to set the user’s required temperature as the object and that the main goal to be reaching the set point, at the shortest time and lowest energy consumption. The general trend is to compare the room temperature with the set point and if the difference is more than one centigrade, the controlling system would start working. The current temperature of the room and the outdoor light are considered as input variables of the Fuzzy System. Outputs of Fuzzy Controller are determined according to the room temperature and the heating effect of the outdoor light.

The output of Fuzzy Controller is considered as the input of a heater subsystem that establish the flow of heat in the room according to equation (1).

$$\frac{dQ}{dT} = (\mathrm{T_{heater}} - \mathrm{T_{room}}).\mathrm{Mdot.C} \tag{1}$$

$\frac{dQ}{dT}$ = *The heat flow from the heater to the room*

C= Heat capacity of air in constant pressure

M_{dot} = *Air mass flow rate through heater*

T_{heater} = *Temperature of air from heater*

T_{room} = *Current room temperature*

Heat losses and the temperature time derivative are expressed by Equation (2) and (3).

 ISSN: 2251-9246
EISSN: 2345-6221

$$\left(\frac{\mathrm{dQ}}{\mathrm{dT}}\right)\mathrm{losses} = \frac{\mathrm{T_{room}} - \mathrm{T_{out}}}{\mathrm{R_{eq}}} \quad (2)$$

$$\frac{dT_{room}}{dt} = \frac{1}{M_{air}}.C.\left(\frac{dQheater}{dt} - \frac{dQlosses}{dt}\right) \quad (3)$$

T_{out} = Out-door Temperature

M_{air} =Mass of air inside the house

R_{eq} = Equivalent thermal resistance of house

After calculating the amount of heat losses and its effect, the internal temperature is specified. Room temperature is compared with the set point, if the difference is more than one centigrade the loop will be performed again. When the difference is less than one degree the heater is turned off by sending the proper command to relay. The fuzzy input parameters are considered as follow:

- *Room Temperature: {freezing, cool, warm, hot}*
- *Cover: {sunny, partly cloudy, night}*

The fuzzy rules are shown in Table 1 and the whole heating control algorithm is shown in Figure 1 as well.

Table.1.
Fuzzy rules of Heating System

$\mathbf{T_{room}}$/Cover	Freezing	Cool	Warm	Hot
Sunny	Hot	Hot	Hot	Warm
Partly Cloudy	Hot	Hot	Hot	Warm
Night	Hot	Hot	Hot	warm

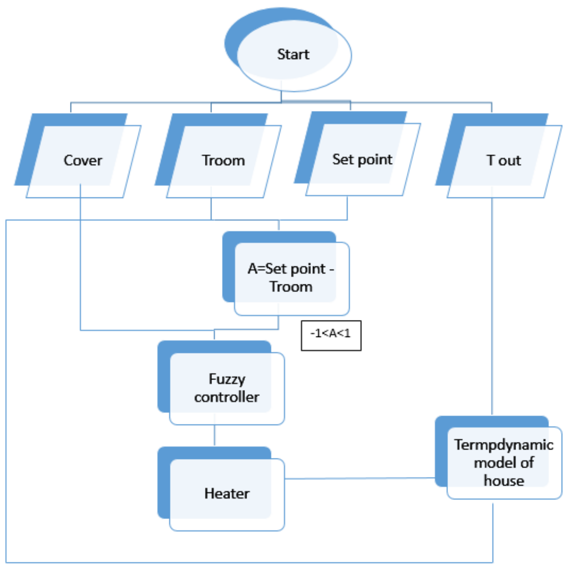

Fig. 1. Heating Control Algorithm

E) Lighting Control System

Intelligent lighting control systems have a very significant role in reducing energy consumption as far as statistics have announced this reduction up to 80% [21].In this part a smart lighting control have been designed which tries to provide interior lighting by use of natural light and then complete the deficiency of set point by dimmer.

The controlled actuators in this part are blind and dimmer. In fact, it is trying to set the desired light by adjusting the blind and dimmer simultaneously in order to reach the desired set point. This system has three inputs which is sensed by sensors. The first input is the room luminance which is shown as LSF (Light Sensor in Front) in this paper. Next input is outdoor luminance that passes through the window from outdoor to indoor which is shown by LSB (Light Sensor in Behind) and the last input is the desired light which is set by user as a set point.

Three cases is intended to define for various conditions which has its own subsystems. The total algorithm of lighting system has been shown in Figure 2.

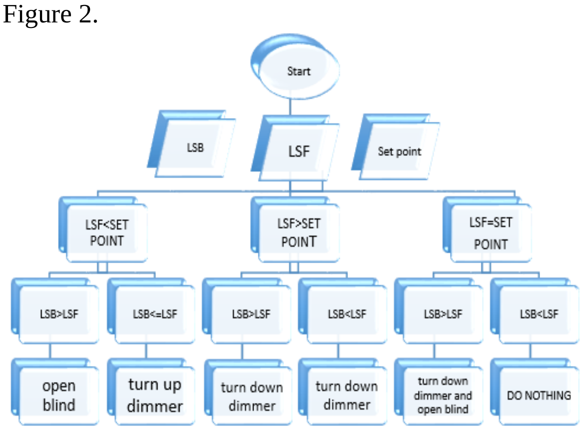

Fig. 2. The Lighting Controller Algorithm

First scenario is considered as the LSF is less than the set point, so two conditions could takes place as follows:

If LSB> LSF

In this case that the LSF is less than set point and the outdoor light intensity is more than indoor luminance; first the blind should be opened as much as necessary to make maximum use of natural light for lighting up.

If LSB<=LSF

In this case it is not possible to use natural light to lighting up indoor luminance so dimmer should be turned up as much as the user needs. Considering if LSF is more than the set point, then the system faces two conditions.

If LSB<LSF

In the case that LSF is more than the set point and outdoor light intensity is more than indoor luminance, the dimmer should be turned down at first. Then if LSF is still more than the set point the dimmer must be turned off and the blind to be adjusted to minimum position in order to reach the set point.

In third condition LSF and the set point are equal so two cases must be investigated:

LSB>LSF

In this case the dimmer turned off and the blind opened.

LSB<LSF

Now the system is in the best condition and there is nothing special to do. Each of the mentioned conditions, are simulated in MATLAB Simulink and the controller is designed with fuzzy logic. The inputs variable of blind controller is at first the difference between LSF and the Set Point and the second one is the LSB. Membership function of LSB are defined from 0 to 1000 lux and the difference between LSF and set point that is shown by ERR is defined from -700 to +700 lux.

The membership functions of input and outputs of blind fuzzy controller are defined as follow:

– *LSB= {Small Small, Small, Small Medium, Medium, Medium Large, Large, Large Large}*
– *ERR= {Large Negative, Medium Negative, Small Negative, Zero, Positive Small, Positive Medium, Positive Large}*
– *Blind (bp) = {Close, Small Close, Medium, Small Medium, Small Open, Open}*

The rules of blind controller are shown in Table 2. The input variable of dimmer controller is just ERR=LSF - Set Point and the rules of fuzzy dimmer controller are shown in Table 3.

Table.2.
Fuzzy rules of Blind Controller

LSB / ERR	SS	S	SM	M	ML	L	LL
LN	NONE	SO	SO	O	O	O	NONE
MN	NONE	O	SO	O	O	O	SO
SN	NONE	SM	SO	SM	SO	SM	SM
ZE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
PS	NONE	NONE	SC	M	NONE	SC	SC
PM	NONE	NONE	SC	SO	SC	SC	C
PL	NONE	SC	C	C	C	C	C

Table.3.
Fuzzy rules of Dimmer Controller

Err	LN	MN	SN	ZE	PS	PM	PL
Dim	LP	P	SP	ZE	SN	N	LN

These fuzzy rules that were described above pertain to cases that the LSF and Set Point have big differences but in case of equality the fuzzy rules have been changed. In this mode in order to decrease energy consumption, first the dimmer must turn and try to reach the set point by adjusting the blind afterwards. The inputs of blind controller are ERR and Dimmer status that are shown in Figure 3-4 and 5. The fuzzy rules of this case are shown in Table 4.

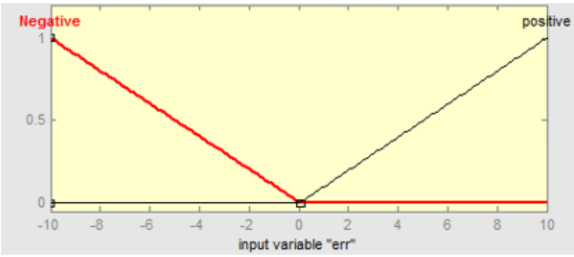

Fig. 3. First input variable of Blind Controller-Err

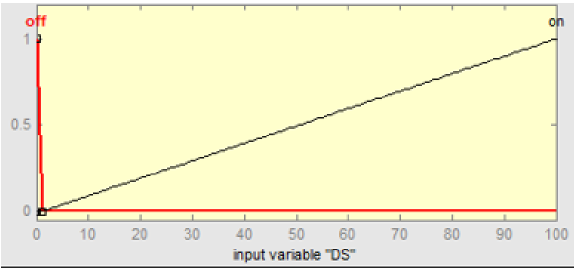

Fig. 4. Second input variable of Blind Controller-DS

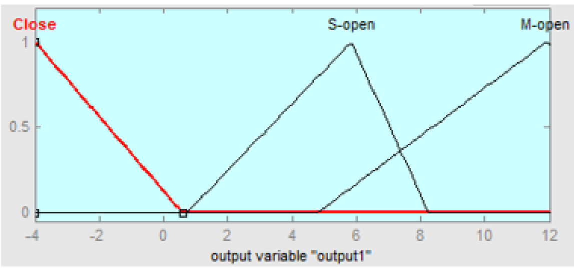

Fig. 5. Output variable of Blind Controller

Table.4.
Fuzzy rules of Blind Controller-LSF and set point are equal

Err/DS	Negative	Positive
Off	Small Open	Close
On	Medium open	Small Open

F) Fire Alarm System

Because fires can cause uncompensated damage, hence considering a fire alarm system in the building is necessary. A fire alarm system performing good, should identify fire in minimum time for urgent reaction.

In this paper a fire alarm system has been designed for three predicted conditions. The input variables of fuzzy controller are smoke intensity, temperature of the house and CO intensity. The sensors measure these parameters and send them to the fuzzy controller. According to the output of fuzzy controller three states have been considered for system:

- If the output takes less than 30 sec, there is no risk of fire.
- If the output takes more than 30 and less than 70 sec, the system switches to Pre-Alert Situation. In this state there is a probability of fire occurrence so the system checks the input parameters after a while. If the inputs are increasing the system announces the fire and performs necessary functions to extinguish it.
- If the output takes longer than 70 sec, the system announces fire risk and activates the fire extinguishing system, stops the heating control system and activates the fire alarm. The fire alarm control system is shown in Figure 6.

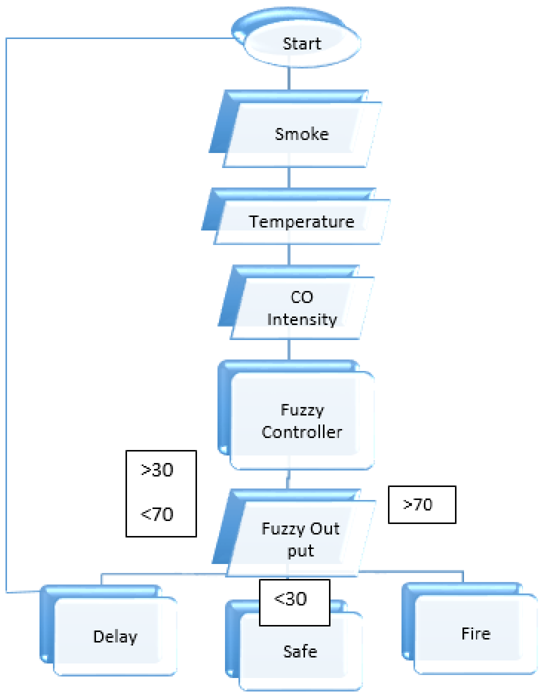

Fig. 6. Fire alarm system

3. Results

G) Results of Heating System:

In this part simulation results in MATLAB are presented for validation. Supposedly the input parameters of heating system are as follow:

- T_{room} = 15
- *Set point =20*
- T_{out} = 10
- *Cover = 50 (Partly cloudy)*

The output of heating system is shown in Figure 7.

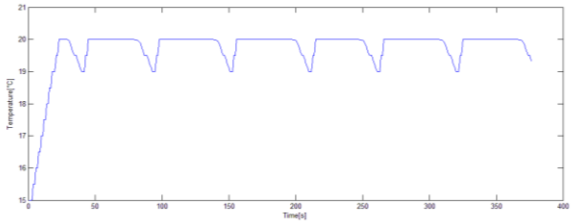

Fig. 7. Room temperature for set point =20 °C

According to the figure, the room temperature is 15 °C at first and the set point is 20 °C. When the room temperature reaches to the set point the relay turns the heating system off and after 7.5 minutes the room temperature decreases and when the difference between room temperature and set point are more than 1 °C the relay turns the system on and the loop starts again.
Another control scenario is shown as follows:

- T_{room} = 20
- *Set point =18*
- T_{out} = 10
- *Cover = 70 (Partly cloudy, Night)*

The output is presented in Figure 8.

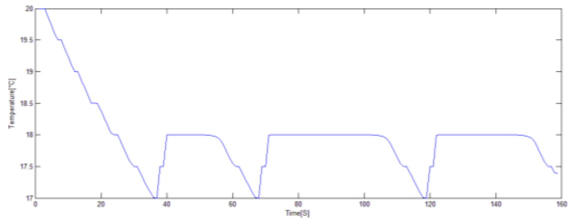

Fig. 8. Room temperature for set point =18°C

H) Results of lighting control system

In this part the output and performance of dimmer and blind are investigated in some examples. Suppose the inputs of lighting controller are as follow:

- *LSF = 100 LUX*
- *LSB = 150 LUX*
- *SET POINT = 250*

In this case LSF is less than set point and LSB is more than the LSF so the LSF should be increased, since the LSB is more than LSF first the system adjusts the blind to get the maximum luminance from natural light and then turns the dimmer on. The output of LSF is shown in Figure 8.

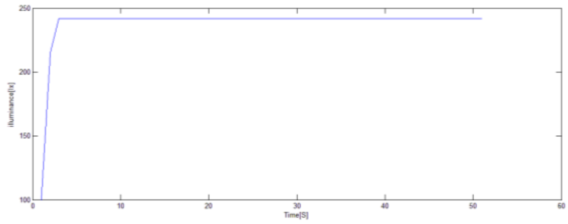

Fig. 9. LSF changes to get the 250 lux luminance

If the inputs are as follow. The LSF changes are shown in Figure 10.

- *LSF =300 LUX*
- *SET POINT = 100 LUX*
- *LSB = 50 LUX*

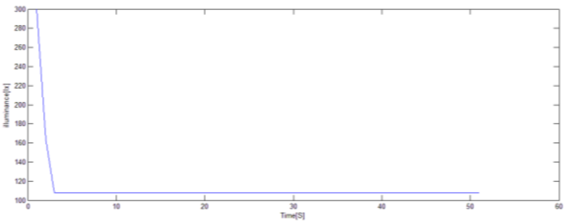

Fig. 10. LSF changes to get the 100 lux luminance

I) Results of fire alarm system

The inputs of fire alarm system are shown in Figure 11, 12 and 13 as well. The output of fuzzy controller is shown in Figure 14. According to Figure 13 the output of fuzzy controller is increasing and until this output is less than 30 there is no risk of fire, when it goes over 30 the system switches to pre-alert condition and after a while the inputs are checked again. If the fuzzy output is still in risk boundaries the fire alarm is activated, the heating system is switched off and the fire extinguishing system is activated. The delay in activating fire alarm is because of reduction in false positives of the fire alarm system which may cause unreasonable stress for users.

4. Conclusion

In this paper an integrated fuzzy controller for smart home application is presented which is able to consider the mutual effects of heating, lighting and fire alarm controllers. As it can be seen on Table 5, the presented is an approach to the more completed controllers than any PI, PID, Fuzzy or Neural Network controllers. According to this table there is no reference which has considered the overlapping functions in control process.

The presented approach shows that designing a controller with fuzzy logic is simpler and also has a faster response than other previously presented approaches. In-addition this paper describes a smart home with fuzzy logic controllers in which they are all linked together in order to make a more pernicious control. All environmental parameters that have an effect on controlling different parts of a smart home are considered as inputs for the system, such as Light, Heat and Smoke. In-addition the different parameters with overlapping functions such as the effect of the light and outdoor temperature on indoor heating, the effect of outdoor light intensity on indoor light intensity and the operation of whole system have been processed in emergency conditions and the fuzzy rules are optimized. This work is done for controlling a Hall by considering the mutual effects of under control processes on others. Developing the system using a sensor network for a larger building with different user set points will be done as our future case studies.

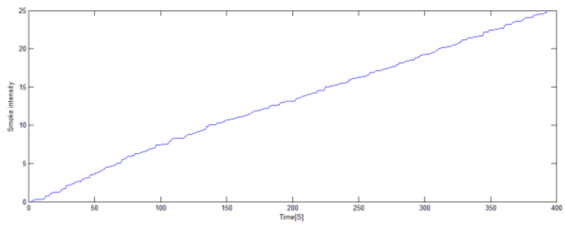

Fig. 11. Smoke changes over time

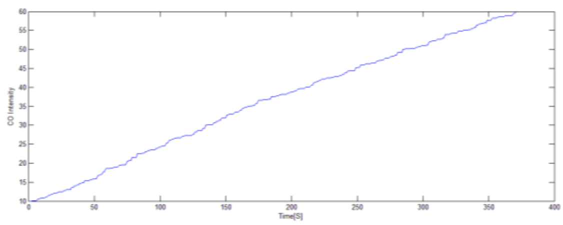

Fig. 12. CO gas changes over time

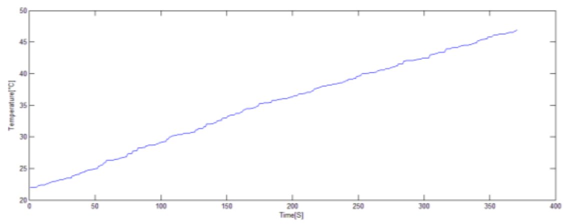

Fig. 13. Temperature changes over time

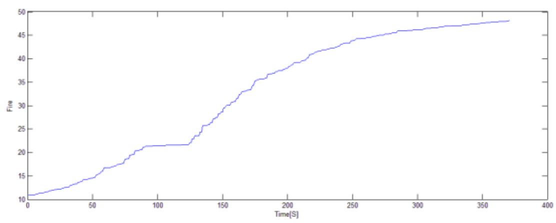

Fig. 14. Output of Fuzzy Controller

Table.5.
Performance Comparison of Smart Home Controllers

Control Process / Paper	**Temp Control**	**Light Control**	**Fire Alarm**	**Mutual Effect**
Adaptive PI Controller (Hensel, Vasyutynskyy, Ploennigs & Kabitzsch,2012)	*	-	-	-
Developing a Thermal Model for Residential Room(Kheir Mohamad,2012).	*	-	-	-
Fuzzy Logic Controller for Temperature Regulation Process(Ramanathan,2014)	*	-	-	-
Integral Control System of Indoor Environment in Continuously Occupied Space (Koˇsir ,Krainer & Kristl Z,2012)	*	*	-	Light Temp
Intelligent Fire Alarm System Based on Fuzzy Neural Network(Qiongfang & Dezhong,2009)	-	-	-	Fire , Temp
Design of Fire Detection and Alarm System Based on Intelligent Neural Network(Zhu & Zhang, 2011)	-	-	*	Fire, Temp
Fire Detection Mechanism Using Fuzzy Logic(Khanna & Kaur Cheema,2013)	-	-	*	Temp, light, Intensity on Fire
Presented Approach	*	*	*	Temp, Light, Fire

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