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Techniques for Smart Home Automation Framework Using Petrinets

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ABSTRACT: In this paper a modified framework for achieving Smart Home Automation is attempted using Petrinets. The main features of the study done is relevant to the design of a control framework to ensure optimum temperature control. For this purpose, the control framework, is achieved in three stages. The three stages attempted in this paper are based on the detection of user in the first stage and a identification process for detecting the number of users in the second stage and finally a control process in the third stage to achieve the preferred temperature to be set in the area depending on the number of users. For the first and second stage a unique model is developed in Petrinet environment comprising of Discrete, Continuous and Hybrid Petrinets for effective understanding. The discrete Petrinet model gives a clear understanding of all the stages and process flow with respect to the operation. Based on the understanding about the total working, the above system is modelled using continuous Petrinet which helps in understanding frequency operation along with qualitative analysis. Finally the total system is analysed as hybrid systems using hybrid Petrinet to give understanding. For regulation of temperature a Proportional-Integral-Derivative (PID) controller is considered in this paper in the final stage. By incorporating this framework it is highly easy to understand the interconnections between the sensing and actuating devices and thus help as a tool for the users to configure the framework depending on the their needs and functionality.

KEYWORDS: Control framework, Discrete Petrinets, Continuous Petrinets, Hybrid Petrinets, PID

I. INTRODUCTION

The concepts of Petrinets as developed by Dr. Carl Adam Petri during 1939 were highly helpful in modeling systems related to Computer Science, Manufacturing sectors, Logistics etc. The main advantages of using Petrinets lie in the easiness in developing and understanding the working flow based on the users knowledge and requirements. Most important aspect of Petrinet modeling is the formalism of a strong Mathematical background to represent the working which is combined with a graphical representation in order to understand the dynamic behavior of systems. Petrinets are as such a Bipartite directed graph comprising of three types of objects which are the Places (P), Transitions (T) and directed arcs. The places are represented by circles, the transitions by rectangular boxes and the arcs are shown as directed arcs which are nothing but the connections of either places to transitions or vice versa. In literature the transition of any Petrinet forms the focal point or junction point with the places connected to them form the input place and output place depending on the flow. For understanding the flow or actions taken place tokens are placed in the places. Now as per the theory, when a transition fires or in other words when an operation begins the start is identified by the presence of a token in the input place of the place/transition combination and the successful completion of the operation is when the token moves from input place and reaches the corresponding output place. Hence as the token moves from input place to output place the operation can be analyzed visually along with mathematical values and also using graphical representations. For achieving the mathematical and graphical representations the distribution of the tokens in the net structure as termed as marking which can be classified into input and output markings.

By modelling systems using Petrinets, frequency analysis, mathematical modeling, graphical analysis can be done effectively. In this paper, three types of Petrinets have been utilized for modeling the processes. They are Discrete Petrinets, Continuous Petrinets and Hybrid Petrinets. Discrete Petrinets are used for the modeling the logic

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involved in the process flow. Continuous Petrinets are used for the frequency analysis and for mathematical modeling of the dynamics of the process flow. And Hybrid Petrinets which Combination of Discrete and Continuous Petrinets are helpful in providing the total information of the process flow and for the performing total performance analysis. The typical applications of Petrinets are in Business modeling, Diagnosis and Simulation and systems etc.

II. SYSTEM DESCRIPTION AND MODELLING

As mentioned in the previous section the first stage of the framework devised in this paper is an identification process to check the user's presence in the room and is shown in Fig 1.

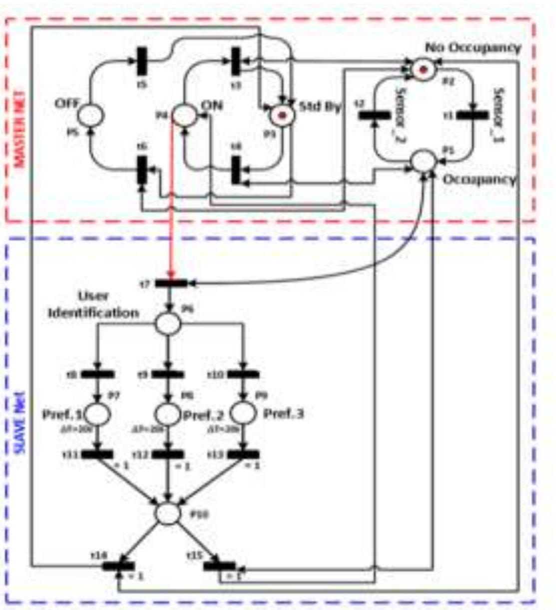

Figure 1. Identification Framework structure using Petrinets

Here as shown in in Figure 1 there is master net and slave net. Master net has ON state, Standby state and OFF state. Master net goes to ON state when any user is identified in the room. And if no new user is identified, the master net will be in standby state. Here, the referral temperature will be maintained in 30^0C.

The working of the slave network starts begins with the ON state condition in the master net and this is followed by the start of the user identification process. Three case studies have been discussed which is as follows: The first case is the identification of the first user followed by which the respective temperature T_1 of first user will be processed and sent as input to the third stage process. The second case is the identification of the second user and the subsequent temperature T_2 will be similarly be sent as input to the third stage process. The third case is the identification of the first and second users simultaneously along with temperature T_3 which will be processed in the third stage. In the third stage of the process the preferred temperatures as sent will be processed and based on the developed system function the preferred temperature will be made as the set point to reach and the output will try to track the set point in order to achieve the closed loop control. During the first stage as the occupancy is detected in the room the identification process begins which follows as the second stage and finally the same is followed by the processing of the preferred temperature of the identified users as the third stage. Moreover, when there is nil occupancy detected then the framework will be totally in the standby mode. The Framework diagram as shown in Figure 1 works based on these all conditions. This type of proposed system has the required control framework.

III. SOFTWARE REALIZATION

In this paper, for modeling and analysis an open source software Sirphyco tool is used. The main reason for developing the models using Sirphyco tool is that Mathematical modeling, Simulation and Analysis can be done

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simultaneously. The three types i.e. Discrete, Continuous, Hybrid petrinets models developed in Sirphyco are shown in Figures 2, 3 and 4 respectively.

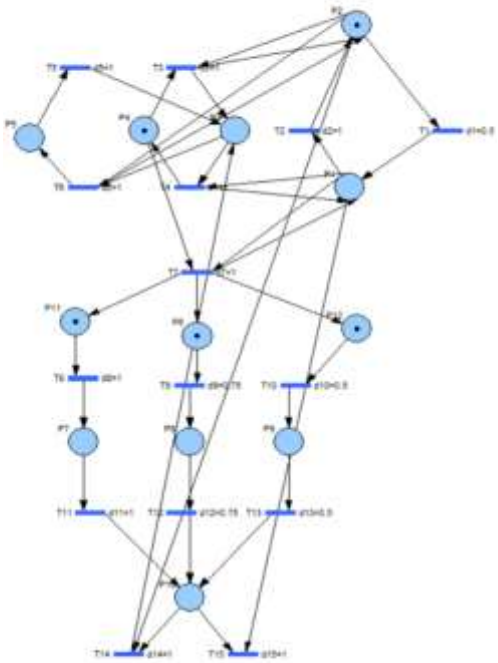
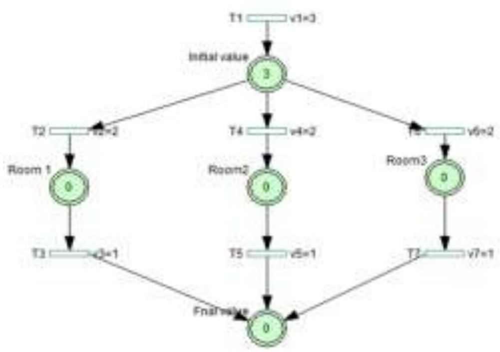


Figure 2. Framework diagram in Sirphyco using Discrete Petrinets

As discussed earlier the model developed in Sirphyco using Discrete Petrinets is shown in Figure 2. The model comprises of 12 Places shown in circles and 15 Transitions shown as rectangular boxes and are interconnected using directed arcs. This model works similar to the normal flow diagram based on the conditions.

The development of the model framework using Continuous Petrinets are shown in Figures 3a and 3b respectively. Using this model the frequency of flow of persons in the rooms can be identified and modeled as a process flow. Figure 3a depicts the model developed in Sirphyco before simulation and similarly Figure 3b shows the working of the model after simulation.



(a)

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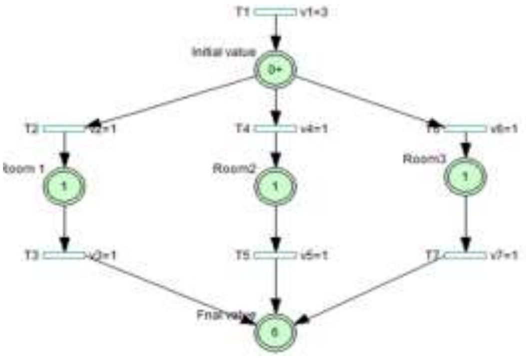
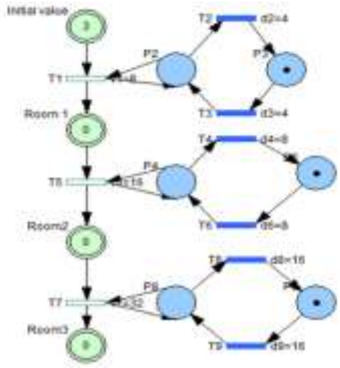


(b)

Figure 3. Continuous Petrinets flow diagram in Sirphyco (a) Before Simulation and (b) After Simulation

The development and analysis of a combined mathematical framework for better and efficient understanding and is done through Hybrid Petrinets wherein the models developed are given in Figures 4a and 4b. The model effectively depicts the flow of the persons from a particular room as modelled as Continuous Petrinets and the control is through a logic as modelled using Discrete Petrinets. The combination is as referred to as Hybrid Petrinets and is shown in Figures 4a and 4b respectively.

As discussed earlier the model before simulation as developed in Sirphyco is shown in Figure 4a whereas the model after simulation is shown in Fgure 4b.



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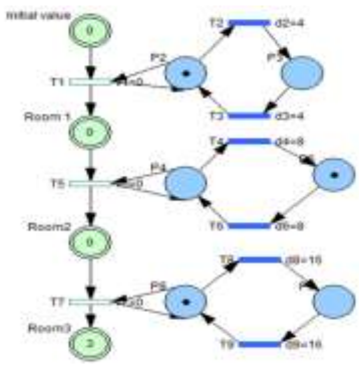

(b)

Figure 4. Hybrid Petrinets flow diagram in Sirphyco (a) Before Simulation and (b) After Simulation

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IV. RESULTS AND DISCUSSION

As discussed in the earlier sections the models developed using Discrete, Continuous and Hybrid Petrinets are highly helpful in analysing the both graphically and mathematically. The simulated graphical output of the output places for the model developed using Continuous Petrinet is shown in Fig 5.

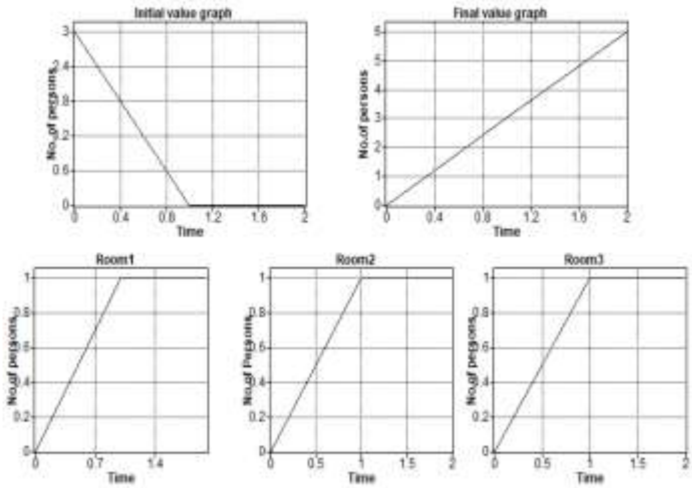
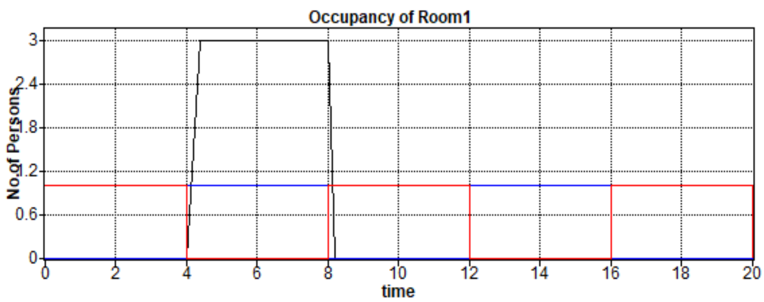
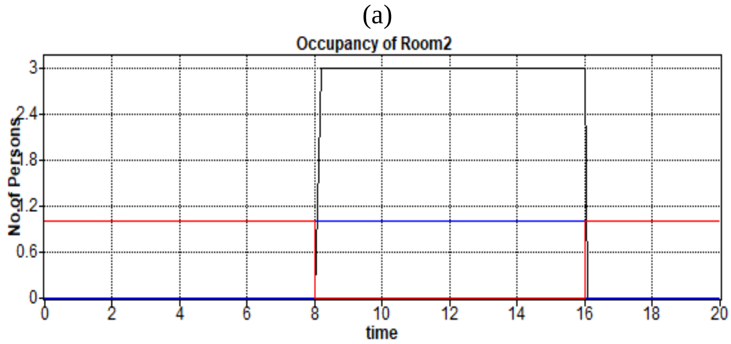


Figure 5. Results of the model developed using Continuous Petrinets

The Hybrid Petrinets as shown in Fig. 3 is used for the total performance analysis. This model since is a combination of both Discrete and Continuous Petrinets, it gives a better depiction of the process flow. The simulation output obtained for the Hybrid Petrinet model is shown in Figures 6a, 6b and 6c respectively.



(a)



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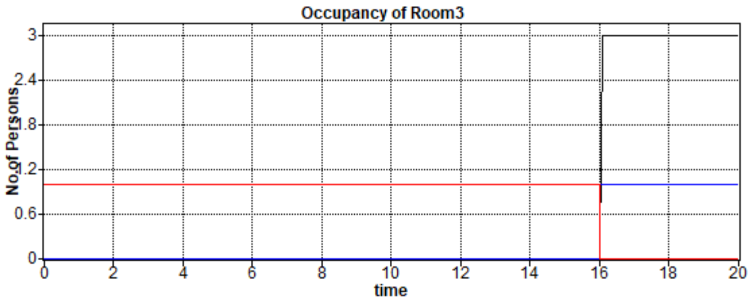

(c)

Figure 6. Results of model developed using Hybrid Petrinets

For performng mathematical analysis which is another important aspect of Petrinet model the concept of matrices are used. Hence the analysis of the models developed can be done by developing the three matrices namely, Pre-incidence matrix, Post–incidence matrix and Incidence matrix as denoted as W^-, W^+ and W. The developed matrices usng the above are shown in Figures 7a, 7b and 7c respectively.

The Pre-incidence matrix have p*t values. p indicates number of places and t indicates number of transitions. Each element in the matrix of size [i,j] will be 1 if the subsequent transition i has input from position j. Similarly each element of the matrix will be 0 if position i has no input from position j. Likewise the same methods are followed in the case of Post-incidence matrix wherein the matrix the 1 and 0 will be with respect the output connection of every transition. The incidence matrix W is obtained by subtracting W^- from W^+ and is computed and given as

$$(W^+) – (W^-) = W.$$

Hence,

$W^- =$

□	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15
p1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
p2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
p3	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
p4	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
p5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
p6	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
p7	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
p8	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
p9	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
p10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1

(a)

$W^+ =$

□	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15
p1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
p2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
p3	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0
p4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
p5	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
p6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
p7	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
p8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
p9	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
p10	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0

(b)

W=

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□	t1	t2	t3	t4	t5	t6	t7	t8	t9	t10	t11	t12	t13	t14	t15
p1	1	−1	0	0	0	0	0	0	0	0	0	0	0	0	0
p2	−1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
p3	0	0	1	−1	1	−1	0	0	0	0	0	0	0	1	0
p4	0	0	−1	1	0	0	−1	0	0	0	0	0	0	0	1
p5	0	0	0	0	−1	1	0	0	0	0	0	0	0	0	0
p6	0	0	0	0	0	0	1	−1	−1	−1	0	0	0	0	0
p7	0	0	0	0	0	0	0	1	0	0	−1	0	0	0	0
p8	0	0	0	0	0	0	0	0	1	0	0	−1	0	0	0
p9	0	0	0	0	0	0	0	0	0	1	0	0	−1	0	0
p10	0	0	0	0	0	0	0	0	0	0	1	1	1	−1	−1

(c)

Figure 7. Depiction of development with respect to (a) Pre-incidence, (b) Post-incidence and (c) Incidence matrices

Through analyzing the models as discussed in Figure 4 using the mathematical relations as shown in Figure 7, the place/transition values are obtained based on the time and is shown in Table 1. The performance evaluation of the models developed can be done developing a suitable Markovian Structure for the appropriate model and then analyzing the performance using the analysis criteria's.

Time in Seconds	T1	P1	P12	P2	P3	T2	T3	T5	P5	P4	P6	T4	T6	T7	P7	P8	P9	T8	T9
0	8	0	3	0	1	4	4	16	0	0	1	8	8	32	0	0	1	16	16
4	8	0	3	1	0	1	0	0	0	0	1	0	1	0	0	0	1	0	1
4	0	3	0	1	0	1	0	0	0	0	1	0	1	0	0	0	1	0	1
8	0	3	0	0	1	0	1	16	0	1	0	1	0	0	0	0	1	0	1
8	0	0	0	0	1	0	1	0	3	1	0	1	0	0	0	0	1	0	1
12	0	0	0	1	0	1	0	0	3	1	0	1	0	0	0	0	1	0	1
16	0	0	0	0	1	0	1	0	3	0	1	0	1	32	0	1	0	1	0
16	0	0	0	0	1	0	1	0	0	0	1	0	1	0	3	1	0	1	0
20	0	0	0	1	0	1	0	0	0	0	1	0	1	0	3	1	0	1	0

Table1: Output values of Places/Transitions for Fig.4

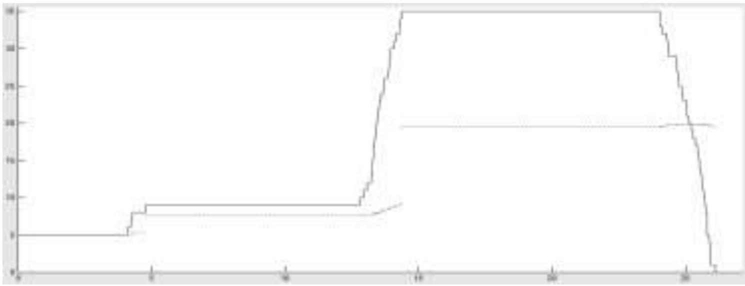
For analyzing the performance of the Places shown in Fig.4, the output values obtained are given in Table 2 which comprises of the parameters such as Arrival distance, Arrival time and Queue length. Similarly, for analyzing the performance of the Transitions for the same model the parameters such as Service time, Service distance and Utilization would be highly useful and the output details obtained based on the same are given in Table 2.

Table2: Output values of the Markovian structure for the models shown in Fig.4

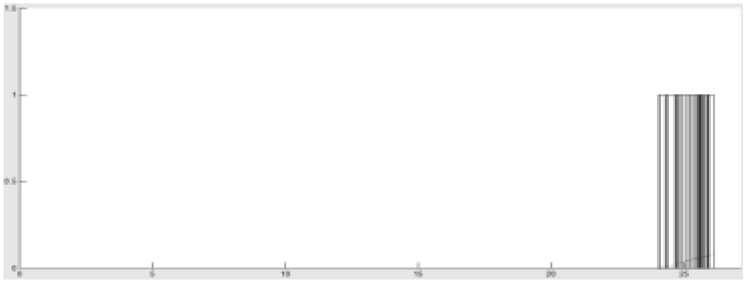
Place /Transition	Arrival distance	Arrival time	Queue Length	Service Time	Service distance	Utilization
P12	3.2	0.01	0.93	---	---	---
P5	15.98	7.98	0.92	---	---	---
P7	31.98	15.98	0.92	---	---	---

T1	---	---	---	0.01	3.99	0.979
T5	---	---	---	0.01	7.99	0.989
T7	---	---	---	0.01	15.99	0.988

Similarly the based on the output values given in Table 2 the output graphs for the performance parameters queue length and utilization are shown in Figure 8a and Figure 8b respectively.



(a)



(b)

Figure 8. Output graphs for performance parameters (a) Queue Length and (b) Utilization

The last part of the paper discusses the modeling and simulation of the closed loop transfer function of the process identified using a PID controller developed in MATLAB environment. PID controller is an Industrial Control system wherein a closed loop control loop mechanism employing feedback is widely adopted. By using a PID controller the accuracy and stability aspects of the process can also be analyzed which we be highly helpful from the user point of view. Here the main purpose of using a PID controller is used to regulate the temperature of the room of the respective user depending on the occupancy. Through the modeling and analysis done from above stages using Petrinet modeling, the details are fed as input to transfer function model developed along with the PID controller in closed loop. Based on the study, analysis and details obtained from the models developed in the Petrinet environment the transfer function for the system is identified as a first order function whose equation is **K/(s+a).** Here 'K' indicates the number of person in the room and 'a' indicates the time the person remains in the room. The transfer function model developed in MATLAB along with the simulated output response graph are shown in Figures 9a and 9b respectively.

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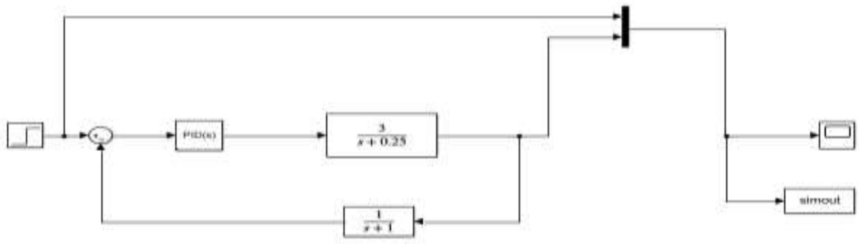
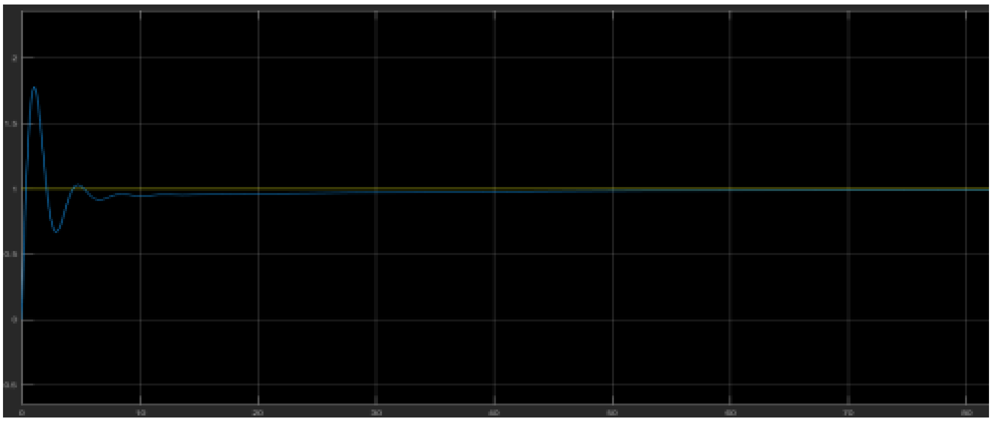


(a)



(b)

Figure 9. (a) Transfer Functon model of the system along with (b) Output response graph

From the details obtained and the analysis done using the above it can be understood that the analysis could be effectively utilized for the studies to be done for understanding energy consumption i.e. how it can be reduced and thus the how energy can be saved.

V. CONCLUSIONS:

In this paper an effective strategy to develop and energy-saving framework in order to achieve comfortable environment and an optimum temperature control thereby ensuring profitability is discussed. For this purpose the modelling and analysis are done in Petrinet environment wherein the process flow is modelled and analysed as Discrete, Continuous and Hybrid Petrinets. The Petrinet models developed were highly helpful in analyzing the framework structure which was followed with a temperature regulatory control framework developed n MATLAB and effectively analyzed to obtain the preferred regulated temperature through which the energy saving mechanisms can be devised and studied in the future.

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