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MASTER'S THESIS

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Summary

This paper presents a design and implementation of a monitor to display the status of real-time simulation and modelling for discrete event dynamic systems, DEDS. The modelling and simulation of DEDS in this thesis are implemented using two kinds tools called Petri net and GpenSIM. Petri Nets are tools that are widely used now a day to model and simulate discrete events of concurrent and dynamic systems. [1] Petri net has a graphical formalism that is getting popularity in recent years as a tool for representing complex mathematical and analytical interactions (like synchronization, concurrency, atomicity, sequential and conflict control) among physical components or activities in DEDS. [1] Besides a Petri net can be primarily used for analyzing and modeling the dynamic and concurrent behavior of distributed systems where there is a discrete event flow. GPenSim, where this thesis will rely on, is a general purpose Petri net simulation tool used to model and simulate systems of discrete events that are designed using a Petri Net tool. In this thesis, a human computer interaction (HCI) tool for GpenSIM is also introduced. This is because of the fact that GPenSIM doesn't provide a method to display the simulation process on a graphical display unit. The newly implemented HCI tool is used for displaying the status of the running GpenSIM file on a monitor screen; it has also an enhanced tool that helps the user to easily control the Real-Time simulation process. To illustrate the application of Real-Time simulation and modelling using Petri net and to test the newly developed HCI tool for GpenSIM, it has also been implemented different kind of real life models in some application areas like industry, traffic light signal and door alarm. In this thesis, NXT intelligent brick with sensors have been used to show how GpenSIM works for modelling the real life system run on Real-Time and also to illustrate the modelling power of a Petri net by testing the newly implemented display tool. The NXT Intelligent brick is a simple robotic device that is built for educational purpose. [2] The device is used to get a Real-Time data from different sensor nodes on Real-Time.

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Notations

P-N	Petri net
PN	Structure data type in GPenSIM.
R-T	Real-Time
DEDS	Discrete event Dynamic Systems
GPenSIM	General Purpose Petri net simulator
gpensim	GPenSIM system file
MSF	Main simulation file
PDF	Petri net Definition file
TDF	transitional definition file
HCI	Human computer interaction
NXT	LEGO Mindstrom microcontroller device
MATLAB GUIDE	A MATLAB graphical user interface layout designer tool
GCBO	a MATLAB variable automatically created each time a callback is executed, and returns the handle of the object.
gcf	A MATLAB command creates an empty figure.
GUI.m	Background MATLAB script file for R-T monitor display.
GUI.fig	MATLAB designer layout file for R-T monitor display
Real_PTtime_select.m	Background MATLAB script file to select places and transitions.
Real_PTtime_select.fig	MATLAB designer layout file for Real_PTtime_select.m
FCS	firing condition satisfied
θ,ϕ, λ	Measuring parameters
γ , β, α	Symbols that denote Events
δ , t, Γ	Symbols that denote time frame
gui_singleton	GUIDE command to control the number of opened gui windows
Callback	The background event handling function in MATLAB GUIDE
GUI	The Main display in the new implemented R-T monitor
gui	graphical user interface

Chapter 1

1. Introduction

The field of Simulation and modelling is one of the rapidly developing area in computer science. [3] Different scientific areas introduce the need for modelling and simulation according to their basic necessities. It is well known that computers have changed the way we used to live not only by assisting on the day to day activities but also by letting to model the actual system and enable us to predict about the future work. The technique of modelling real life activities is called simulation and modelling. It is obvious that most part of our day to day activities, starting from counting time notion, are more or less related to mathematics. Since mathematical formulations have powerful tools to represent the actual system and our day to day activities that are associated with Real-Time, systems can be modeled using mathematical tools based on a Real-Time. The terms "modeling" and "simulation" are often used interchangeably. Thus this thesis discusses about the basic method of modellings and simulation using the appropriate tools in Real-Time. The implementations were carried out on a MATLAB studio using a MATLAB language. It has also been used an NXT Mindstrom microcontroller with different types of sensors to get a Real-Time data input from some sensor nodes. The simulations were designed and implemented using a GPenSIM and Petri net tools. The current version of GPenSIM runs in two modes, these are using either:

1) Simulated clock
2) Real-time clock

When the real-time clock is used, the simulation is actually performing real-time control activity, like reading sensor (input) data, making control policy, and then feeding the actuators (outputs) with control (output) data. The idea was adapted from the work of prof. Davidrajuh 'GPenSIM in Real-Time'.

1.1 Motivation

The task of designing, evaluating, developing a discrete event dynamics systems, DEDS, in a Real-Time systems requires a deep knowledge of modelling and decision making rules for an intelligent system. One might get it very difficult to design a DEDS unless a proper tool is used. But using the available tools like Petri net and the simulation software gpensim, it can be simplified; even can one develop a system that is more dynamic and intelligent. The

Petri net model for Fuzzy, Adaptive and Expert System Controller, integrated into the GPenSIM Simulation Tool Kit, has greatly facilitated this task.

Usually, the proving of validity of models is an interesting task, because even if an excellent simulator is running on an excellent hardware, the simulation results of inaccurate model will never be valid. Especially for real-time simulation, the data of R-T simulation are large and needs a proper management to achieve validity. For a DEDS, one of the ways that we can improve the performance of a simulation and modelling is that if it is possible to watch the movement of every tokens and the status of each event during a simulation process. Even it would be very easy to control the process by putting the unwanted redundant information into the background and making only the valuable units visible for the user.

1.2 Goal of the thesis

The main objective of the thesis was roughly discussed in the summery section above. The current version of GPenSIM doesn't have a method to display the Real-Time simulation process of DEDS on a visual interaction unit, HCI tool. I.e. it doesn't have a mechanism to graphically display the status of every transition and their associated input/output places, and the number of tokens in every place during every simulation cycle. Besides; GPenSIM lacks a method to control the speed and process of the simulation. The current version of GPenSIM stores the simulation results in some form of ASCII dump file, log file and the result is displayed using a MATLAB command window. Similarly the status of the simulation is displayed using the normal MATLAB 'disp' function. This is quite infeasible when we think of Real-Time systems where the actual progress of the simulation is running on a Real-Time. If we consider a system with a lot of sensors and actuators which are running on real-time, It would be better to have a method to capture the ongoing process rather than going back and evaluating the damped ASCII code files. A good example is simulation in industrial application where there are different production line and the status of the lines are represented as Petri net transitions. It would be tedious and impractical if we let the simulation file to be stored as a dump log file and retrieve it for analysis, thus the best way would be designing a visual aid tool to interact with the background system and to see the actual ongoing progress.

The newly implemented tool acquires GPenSIM to have an enhanced tool to work with the simulation operation of the P-N model, i.e. there is a control button on the interface unit which would help the user to control the ongoing system with time by watching the progress on a single display. Generally, since time is a key value in Real-Time simulation, it can be very difficult to overview the results of a simulation that are only presented in a text log file, especially for larger models, it can be more complicated.

The following figures show the difference between the two results, i.e. the result of the current GPenSIM simulation and the newly implemented tool.

For the example mentioned above, suppose we have three production lines that read input from a source input and put the result on a buffer.

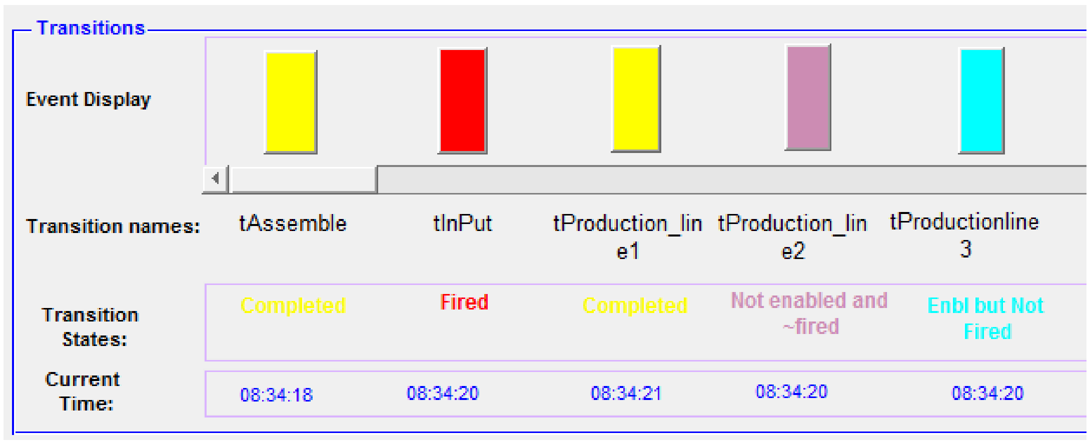
The ASCII dump file is:

```
======= State Diagram =======
**    Time: 08:34:03   **
State:0 (Initial State): (no tokens)
At start ....
At time: 08:34:03,  Enabled transitions are:    tInPut
At time: 08:34:03,  Firing transitions are:     tInPut

**    Time: 08:34:09   **
State: 1
Fired Transition: tInPut
pInout_Buff +
pInout_Buff +
pInout_Buff +
pInout_Buff +
pInout_Buff +
Current State: pInout_Buff
Virtual tokens: (no tokens)

Right after new state-1 ....
At  time:  08:34:10,   Enabled  transitions  are:      tInPut     tProduction_line1     tProduction_line2
tProductionline3
At time: 08:34:10,  Firing transitions are:     tInPut   tProduction_line1

**    Time: 08:34:11   **
State: 2
Fired Transition: tProduction_line1
pOutPut1 +
pOutPut1 +
pOutPut1 +
pOutPut1 +
Current State: pOutPut1
Virtual tokens: (no tokens)

Right after new state-2 ....
At time: 08:34:11,  Enabled transitions are:    tInPut
At time: 08:34:11,  Firing transitions are:     tInPut
Virtual tokens: (no tokens)
                                        •
                                        •
                                        •
```

```
**    Time: 08:34:20   **
State: 12
Fired Transition: tInPut
pInout_Buff +
pInout_Buff + 2pOutPut1 +
pInout_Buff + 2pOutPut1 +
pInout_Buff + 2pOutPut1 +
pInout_Buff + 2pOutPut1 + pOutput_Buffer +
Current State: pInout_Buff + 2pOutPut1 + pOutput_Buffer
Virtual tokens: (no tokens)

Right after new state-12 ....
At time: 08:34:20,  Enabled transitions are:    tInPut    tProduction_line1    tProduction_line2
tProductionline3
At time: 08:34:20,  Firing transitions are:    tInPut   tProduction_line1

                                        •

                                        •

                                        •

**    Time: 08:34:32   **
State: 24
Fired Transition: tProduction_line2
3pOutPut1 +
3pOutPut1 + 2pOutput2 +
3pOutPut1 + 2pOutput2 +
3pOutPut1 + 2pOutput2 + 2pOutput_Buffer +
Current State: 3pOutPut1 + 2pOutput2 + 2pOutput_Buffer
Virtual tokens: (no tokens)

Right after new state-24 ....
At time: 08:34:32,  Enabled transitions are:    tInPut
At time: 08:34:32,  Firing transitions are:    tInPut
```

The above text is taken from a large gpensim simulation result as a sample, as it is very large text and takes a large area to show on this paper. As stated above, GPenSIM stores this result as a log file and printed on a MATLAB command window.

The associated result on a newly implemented R-T monitor would be as follow.

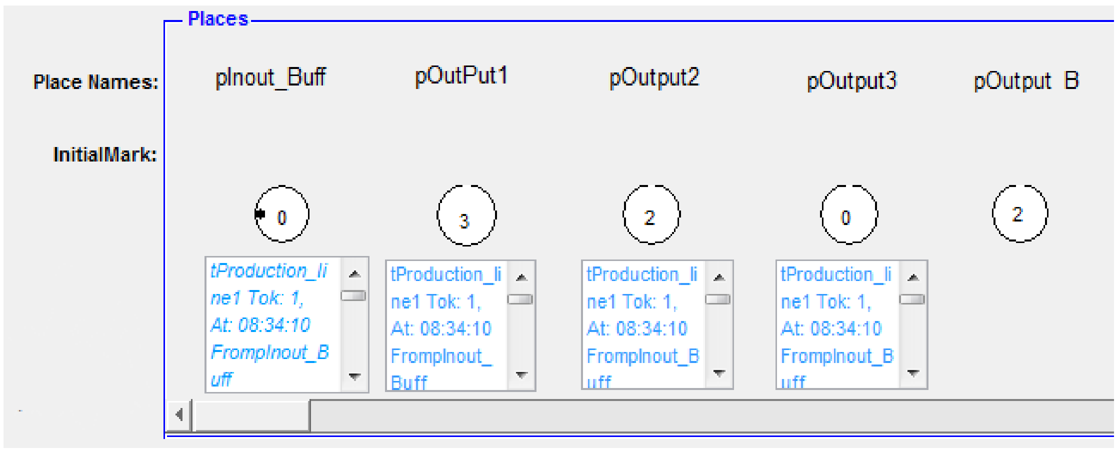

Transitions

Event Display

Transition names:	tAssemble	tInPut	tProduction_line1	tProduction_line2	tProductionline3
Transition States:	Completed	Fired	Completed	Not enabled and ~fired	Enbl but Not Fired
Current Time:	08:34:18	08:34:20	08:34:21	08:34:20	08:34:20

Fig. I. Sample output of Transitional panel on R-T *display*

Also it is possible to display the number of token in every places during the simulation process. On the newly implemented R-T monitor, it would be like the following picture.


Places

Place Names:	pInout_Buff	pOutPut1	pOutput2	pOutput3	pOutput_B
InitialMark:	0	3	2	0	2
	tProduction_line1 Tok: 1, At: 08:34:10 FromplInout_Buff	tProduction_line1 Tok: 1, At: 08:34:10 FromplInout_Buff	tProduction_line1 Tok: 1, At: 08:34:10 FromplInout_Buff	tProduction_line1 Tok: 1, At: 08:34:10 FromplInout_Buff	

Fig. II. Sample output of place panel on R-T display

There are also control button that help to control the simulation where the previous version of GpenSIM doesn't provide a method to control the simulation, like pause, stop, continue.

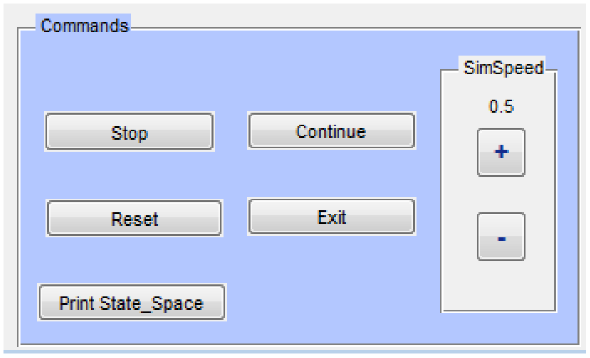


Fig. III. Control buttons on the new R-T monitor

The tool also provides a push button to display the result of the dump file.

The following picture shows how the newly R-T-monitor system help to display and control the status of the Real-Time simulation of a traffic light signal on a single monitor.

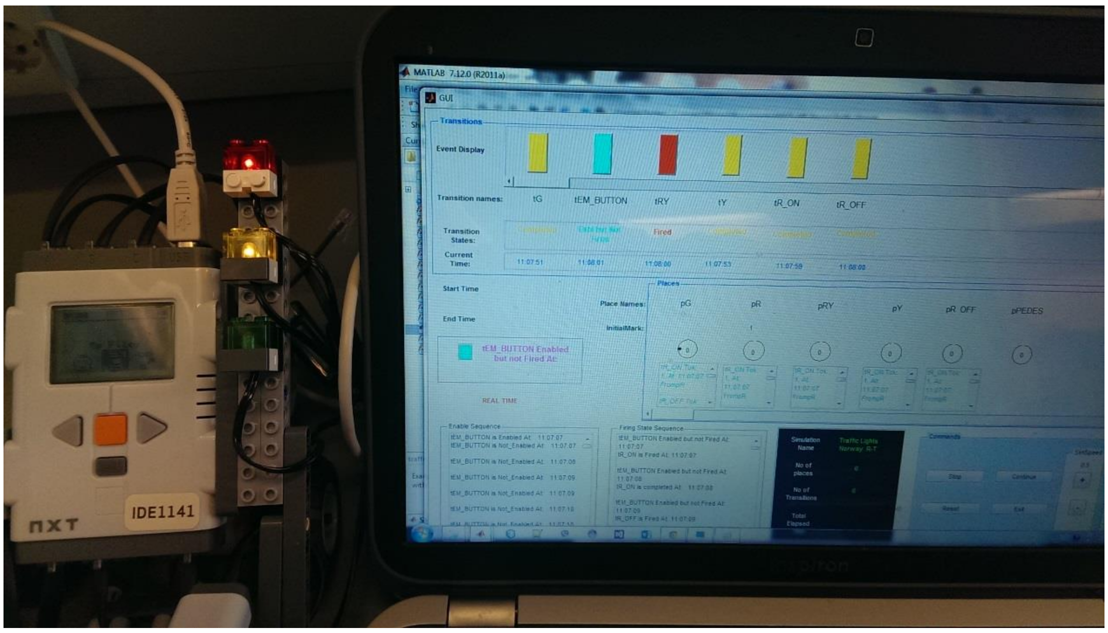


Fig. IV. Sample picture of the newly implemented R-T monitor system

1.3 Adaptations

The source code for the R-T-monitor are embedded inside a GPenSIM system, hence some part of GPenSIM source code are added to this paper with proper citations. Also for testing the R-T system, the idea of modelling traffic light signal using NXT are taken from the course, discrete simulation and performance analysis with some slight modifications.

1.4 Chapters review

- *Chapter 1* is about the introduction of the thesis work, motivation, adaptation and the statement of problems.
- *Chapter 2* is about the background of the project work idea. I.e. it briefly describe the definition and types of simulation and modelling with some examples, and also the need to use them in modern life. It also discusses about modelling a discrete event dynamic systems, basic Petri net theory, and GPenSIM.
- *Chapter 3* is about the Real-Time simulation and modelling of Real-Time system. It describes about different kinds of petri net modelling in R-T GPenSIM. This chapter also has example of modelling real-time P-N model. I.e. Petri net in industrial application, in

house security, door alarm using NXT and Traffic signal system using NXT intelligent Brick.

- *Chapter 4* is about the designing a Real-Time monitor, R-T monitors, for GPenSIM. It describes how the design was done and also describes about a MATLAB GUIDE, a tool that the R-T monitor were designed and implemented.
- *Chapter 5* is about the implementation of the thesis work. It deeply describes every steps that were taken to implement the system with some code snippets and flowcharts.
- *Chapter 6* is the testing results of the simulation and modeling of systems in chapter 3 and displaying their live real-time simulation of on the new implemented R-T monitor interface, HCI.
- *Chapter 7* is discusses about the general methods and approaches that were taken to implement the system, also discusses about the drawbacks of the newly implanted system and suggests further improvement about the system. Finally this chapter concludes the thesis work in few paragraphs.

Chapter 2

2. Background

2.1 Systems, modelling and simulation

Simulation and modelling have been applied in a wide range of areas like applied science, social science and engineering ranging from economic forecast up to space shuttle design. Modelling and simulation are two symbiotic terms in the computing world where one of them follows the other by a logical coincidence. Modelling is a process of creating and presenting a mathematical symbol or formula that resemble the actual real life system by gathering and analysing all the necessary information about how the system behaves without actually testing it in real life, i.e. a model is a representation of the construction and working of some system of interest [4]. The following picture shows how to model a system.

The three basic things that we should consider while we work with simulation and modelling are:-

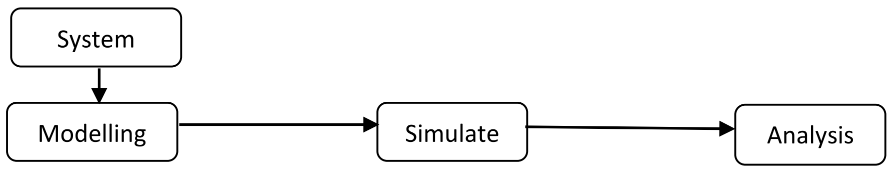


Fig.1. Relation between System and M&S

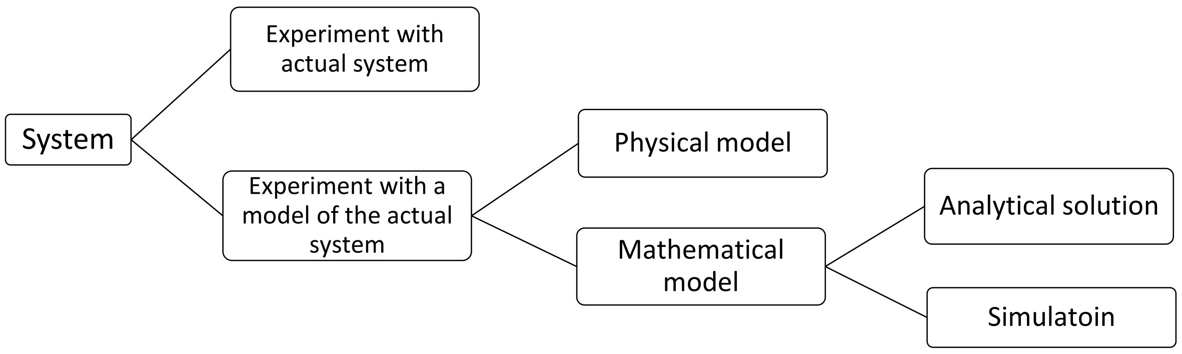
System: A system is a group of objects that are interconnected in some form of logical interaction to accomplish some purpose.

Model: Constructing a conceptual framework that describes a real system. [4]

Simulation: Perform experiments using computer by different implementation tools of the model.

Analysis: make conclusions from the output that assist in decision making process.

As it can be seen, systems, models, simulation and analysis have some interaction. And their interaction can be categorized in a hierarchical order as show below. [5]



System
Experiment with actual system
Experiment with a model of the actual system
Physical model
Mathematical model
Analytical solution
Simulatoin

Fig. 2. Hierarchy of modelling and simulating a system

An example of modelling is a reservoir model in the oil and gas industry. The engineers use a computer program to model the actual system in order to estimate the potential of their reservoir capacity. And also they would get accurate performance predictions for hydrocarbon content. Besides the risk analyst can also use some simulated data in order to analyses the risk and genuinely manage it. [6] In oil and gas industry, the mobility can be defined by lambda. This λ Is defined as the ratio of effective permeability of the fluid to its viscosity. For example if there is a fluid i. The mobility λi is defined as $\lambda_i = {}^{k_i}/_{\mu_i}$. A mobility ratio is a ratio of the mobility of the *displacing* phase to the mobility of the *displaced* phase. [7] The following mathematical modelling shows the mobility ratio of oil in an oil reservoir.

$$M = \frac{\lambda o}{\lambda w} = \frac{{}^{\mu o}/_{ko}}{{}^{\mu w}/_{kw}}$$

Since one purpose of modelling is to enable the system analyst to predict the effect of behavioural changes to the system. A model should be simple and easily understandable. A good model should acquire realism and simplicity. Even if the system is very large, it should always consider a modular approach to the whole system. This can be achieved by dividing the whole system into subsystems and sub modules. Modular approach also acquires optimization. [8]

Modelling can be represented mathematically using formulas or symbolically using some figures. When we design a model, we should always realize the distributed probability function. These help the system to have an accurate resemblance of the whole system with some standard error.

Beyond designing a model, we can also add more features to the existing model in order to make it more artificially intelligent and to add features like HCI, human machine interface. This, along with a simulation and modelling, would result in a precise control system that has all round features.

Systems can be analyzed based on the following criteria and can be decided in what way a system can be modelled. [9]

Deterministic or Stochastic

It is always important to analyze whether the model contain stochastic elements or not. If the system contains a discrete flow we can add random variables. Randomness is always easy to add to discrete event systems, DES.

Static or Dynamic

We should also analyze the behaviors of the system. Whether it is dynamic or static.

Continuous or Discrete

Does the system state evolve continuously or only at discrete points in time?

Continuous: Continues event dynamic system simulation. Uses classical mechanics

Discrete: queuing, inventory, machine shop models, discrete event dynamic system simulation. [9]

Real-Time or simulated time

Based on their event time, systems can be differentiated as Real-Time and simulated time.

2.2 Discrete events dynamic systems (DEDS)

DEDS are one kind of systems that under goes a discrete event property. Usually they are used to model and optimize systems with complex processes and distributed systems where there is a discrete data flow. This can also provide capabilities for analyzing and optimizing event-driven communication using hybrid system models, agent-based models, state charts, and process flows. There are several tools that can be used to model and simulate discrete event systems. Some of the tools that can be used are *Automata*, *State flow*, and *Petri nets at a higher level and so on.* The lack of well structure integrity (hierarchy) in Automata is a serious shortcoming for modeling large systems since a large and complex system should be decomposed into sub models and systems. [10] The state flow is a mechanism used in Simulink. MATLAB simulation tools and Simulink can also provide tools to model and simulate DEDS, but their intension is not particularly designed to simulate discrete event systems. So in every direction, the most powerful tool to model DES is Petri Net. One of the most fascinating features of Petri net tools are functions for exporting Petri nets to other tools and for importing nets from another tool. Besides; Petri net provides concurrency, parallelism and synchronization. [11].

DEDS covers all aspects of discrete event flows that include theory and formal models like; Petri-Nets, supervisory control, Min-Max-plus algebra, discrete simulations, performance analysis, optimization, and optimal control. [12] The basic terms in discrete systems are events, loops or cycles. Discrete event flows can be modelled using different kinds of mathematical methods, some mathematical models that can model the discrete flow are;

A Markov chain: It is one of method that can model a discrete event flow. (I.e. it is a series of random values) [13]. MC is a mathematical method that undergoes transitions from one state to another on a state space. It is a random process usually characterized as memory less. We can also use binomial distribution to simulate the random discrete flow. E.g. the following figure shows a discrete flow of a simulated random numbers in some specific time.

$$y(t) = (x + a)^n = \sum_{t=0}^{n} \binom{n}{k} x^t a^{n-t}$$

A binomial distribution function is a good explanation of discrete event flows. The result for tasted t values is shown below.

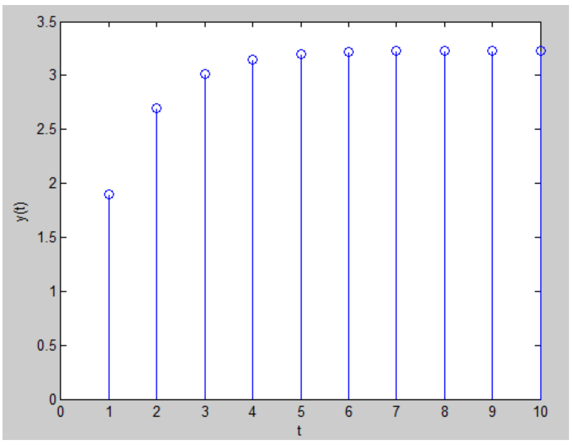


Fig. 3. Discrete event vs time simulation

The potential of a discrete event model is described by its: [14]

- Ability to compress time, expand time
- Ability to control sources of variation,

- Avoids errors in measurement, $SD = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$, Where x is each score, $\bar{x}$ is mean value for n terms
- Ability to stop and review
- Ability to restore system state
- Facilitates replication
- The modeler can easily control level of the details.

2.3 Continuous event time simulation

It is one kind of modelling and simulation technique used in modelling an object whose behavior is continuous. A good example for continuous simulation is a life time simulation of studying spontaneous flow of a liquid state. The exponential distribution function gives continues time results of events for a given period of time. This can be denoted by

$y(t) = e^{\gamma \pi t}$, t=0:0.001:1, γ is constant rate, t is continuous time.

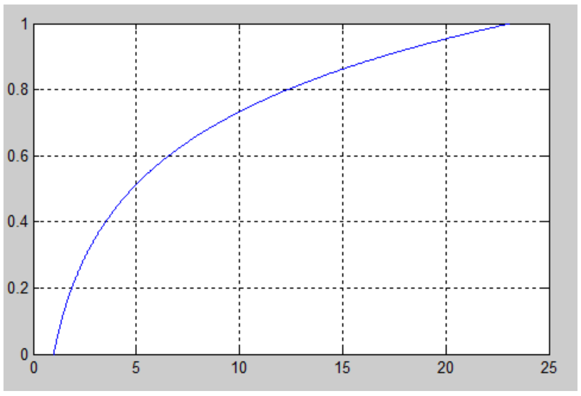


Fig. 4. Continues time simulation result

2.4 Petri Net

Petri Net is one of the widely used tools to model a discrete time event systems. A Petri Net is a flexible tool that can be used to model any type of real life system. It is identified as a ***bipartite directed graph*** denoted by three types of objects [15]. These objects are called **places**, **transitions**, and directed **arcs** connecting places and transitions. The places are denoted by (circles), transitions are denoted by (bars), and directed arcs denoted by an arrow that connects the places and transitions. [31]

$$G = (V, E)$$

Where V are graph vertices and E are edges or arcs in Petri net model.

$V=P \cup T$, And $P \cap T = \phi$

Where P is a finite set of places and T is a finite set of transitions.

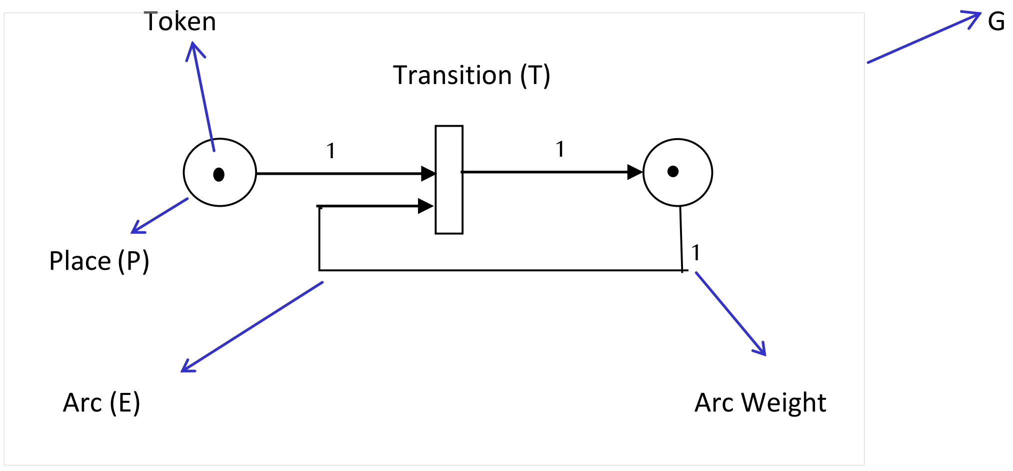


Fig. 5. A simple Petri Net model with a dot token marking

Number of tokens in a petri net model can also be represented by number. The numbers inside a small circle, places, show the total number of tokens in those places. Here note that the numbers would be changed as a transition fires, i.e. as the event is altered.

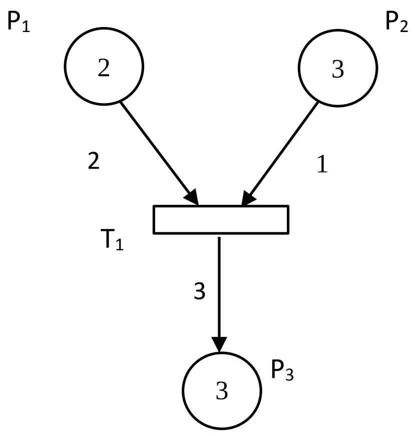


Fig. 6. A Petri net model with number of tokens denoted by number

2.4.1 Places

A place in a petri net model is used as an input or output area to the model. It can represent a buffer area, or a passive element. It is used to initialize or accept tokens. The role of a place varied in different types of activities. Some roles of a place are list below. [16]

• In communication systems, a place can act as a type of **communication medium**, like a telephone line, middleman, or a communication network, routers, switches, and so on.

• It can also act as a **buffer**: for example, in a hard disk, conveyor belt, depot, queue or a post bin and so on.

- To denote **geographical location**, like a place in a warehouse, office or hospital;
- To denote the **state or the state condition**: for example, the location of an elevator is, or the condition that a specialist is available for a particular moment.

2.4.2 Transition

Transitions are event driven conditions where events are actions which take place in the system. In a petri net, the occurrence of an event is controlled and managed by the current state of the system. Similarly the transition has some common roles in DES. A transition can fire only if it is enabled. A transition is enabled if the number of tokens in the input place is greater than or equal to the arc weight. [17] A transition can be used as:

- An **event**: for example, a transaction, a database search activity, starting an operation, the death of a patient, the switching system of a traffic light.
- **Transformation of an object to another form**, like accepting a product, updating a database record, or updating a document file;
- **Transportation of objects**: like transporting goods, or sending a file.

a. Enabled Transitions

A transition $t_j \in T$ in a Petri net is said to be enabled. [18]

$$\text{If } x(p_i) \geq w(p_i, t_j) \ \text{ for all} p_i \in I\left(t_j\right).$$

The transition t1 in figure 2 is enabled, since the numbers of tokens in the input places p1 is 2 and p2 is 3 are at least as large as the weight of the arcs connecting them to t1.

b. Fired Transitions

As far as the transition is enabled and all the preconditions are fulfilled, the transition will fire. Literally it means it will take a token from the input place and put it to the output place. This also shows that an event has occurred.

2.4.3 Arcs

Arcs are connections or paths between a place and a transition or vise verse. The role of an arc is.

- As a Link: an arc can act as a link in communication and data transfer modelling. Simply it is a connection.
- As a bandwidth: - it can also act as a bandwidth in communication Medias.
- As a work flow management. An arc in a Petri net graph can be used to model the mechanism of workflow in industrial areas.

2.4.4 Arc Weight

The arc weight is the maximum capacity of the arc that can fire number of tokens at the same time. For example if the arc weight is 2, the maximum number of tokens that can be fired is less than or equal to 2.

2.4.5 Tokens

Tokens are input elements. Tokens can be fired to show an event has occurred and is passed to the next part. The role of a token can also be described as:

- **Physical object**, like a product, a part of a system, a manufacturing drug, a person.
- **Information objects**, for example an email message, a signal, a report, a file, a packet, a data frame.
- **Collection of objects**, for example a vehicle that carries products for delivery, a warehouse with stored parts, or an address of a file.
- An **indicator of a state**, for example the indicator of the traffic signal, or the state of an object.

A token indicates whether a certain condition is fulfilled or not. I.e. if the place contains a token then we can conclude that the next firing state is that place by seeing the token.

2.4.6 Mathematical representation of a Petri Net

A Petri net can also be described mathematically as follow. [19]

$$N = [P, T, I, O]$$

Where:

P is the finite set of places, $P = \{p1, p2, p3, p4 \ldots p_L\}$, where $L > 0$

T is the finite set of transitions, $T = \{t1, t2, t3 \ldots t_m\}$, where $m > 0$

$P \cap T = \phi$, the place and transitions are disjoint properties or objects. I.e. $P \cap \phi$ is always 0.

$N \subseteq (P \times T) \cup (T \times P)$ is flow relationship, the Union of the relation between places and transitions. I.e. it is the Petri net model of the set.

$I: P \times T \to N$, Is an input function that defines a set of directed arcs from P to T,

Where N= {0, 1, 2, 3, 4 . . .}

$O: T \times P \to N$, is an output function that defines a set of directed arcs from T to P.

A marked Petri net is denoted by.

(N, M_0), where N is the Petri net model and M_0 is the initial marking.

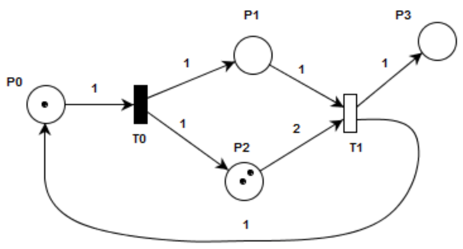
The initial marking is the number of token at the start of the model before entering to a firing state. Marking μ is an assignment of tokens to the places of Petri net at [19] μ = μ1, μ2, μ3 … μn.

For example; M_0 = [2 3 3] is an initial mark for Figure 6.

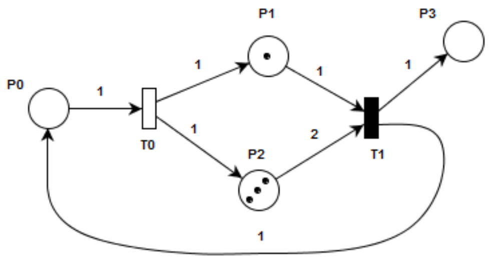
A Petri Net was designed to give models the specification of process synchronization, asynchronous events, concurrent operations, and conflict or resource sharing for a variety of manufacturing automated systems at a discrete events level. [20]

2.4.7 Firing Sequence and firing time

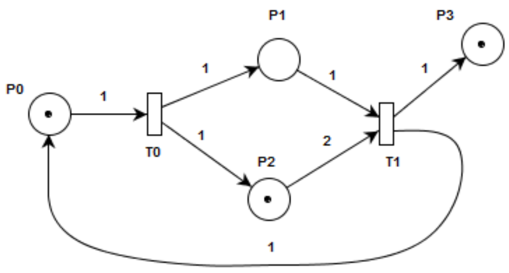
The firing sequence of a transition depends on different techniques. In GPenSIM When there are more than one enabled transitions, the firing sequence is made by the transitional definition file.



Step 1. T0 is enabled and can fire



Step 2. T1 is enabled and can fire



Step 3. T0 is enabled again after t1 fires

Fig. 7. Firing sequence

The firing time of a P-N denotes for how long the transition can fire. For example if it is 3, the transition will fire for 3 seconds.

2.5 Extended Petri net

A pure or an ordinary Petri net, the one that has been explained so far, can be expanded to other types of Petri net to increase the modelling performance. As mentioned above P-Ns can be used to model a wide variety of systems. However, there may be systems which cannot be properly modeled as P-Ns, meaning there may be limits on the modeling power of P-Ns. [24] some of the extended Petri net are:

2.5.1 Timed Petri Nets

The basic Petri net models don’t have any mechanism to deal with the duration of system activities. [21, 24, 40] But adding timing parameter to the Petri net model addresses this issue. A deterministic times are created with transitions. This is used to achieve a better sequence and control of the model. In this thesis, timed P-N are used.

2.5.2 Stochastic Timed Petri Nets

Stochastic time delays with transitions. A stochastic Petri net (SP-N) is a Petri net where each transition is associated with an exponentially distributed random variable that expresses the delay from the enabling to the firing of the transition. [22]

2.5.3 Color Petri net (CPN)

CPN is representing of tokens with different types of colors. CPN is a well-organized and suited modelling approach for systems that consists of a number of quite different tokens or processes that interact and synchronize. Good examples of CPN application areas are communications, automated production control systems, distributed systems, work flow management analysis. [20]

2.6 GPenSIM

GpenSIM is a tool for modeling and simulating the discrete event systems (DEDS). GpenSIM is integrated inside a MATLAB platform, and thus have access to the built in MATLAB functions. GpenSIM defines the Petri net graph in the Petri net definition files. The results of a simulation are shown in a MATLAB file. In GpenSIM systems can be divided into modules. These are static part and dynamic parts. The static part contains a Petri net Definition file. If we have different modules, the pdf can be divided in two different types of Petri net definition files. Similarly the main simulation file contains a dynamic part of a GpenSIM. In this approach a complex systems become more transparent and can be easily evaluated. The simulation results in GpenSIM are displayed in a text format. The main advantage of a GpenSIM is its reduction in resource managements. The ordinary Petri net model shows all the detail information in the frontline. But in GPenSIM the resource are pushed to the back ground, so that one can see a clear image of the model. GpenSIM can model and analyses any type of Petri net file. Its integration with a MATLAB environment makes it more flexible and powerful to analyze the properties of a Petri net model. [25]

To install a GPenSIM, one must download the zipped file from the owner’s web site. The website also provides a handy manual that makes anyone to learn fast how to use GPenSIM. Since GPenSIM works in MATLAB platform, it must be unzipped in to the MATLAB folder, or the user should set the root path inside the MATLAB file menu to GPenSIM. The installation step is available in appendix section of this paper. After installing the GPenSIM, the program can be tested by writing GPenSIM in the MATLAB command window.

```
>> GPenSIM
--------
GPenSIM version 8.0;   Last update: August 2013
(C) Reggie.Davidrajuh@uis.no
http://www.davidrajuh.net/gpensim
--------
>>
```

2.6.1 The Structure of GPenSIM

GPenSIM, as discussed above is a tool to model and simulate a Petri net graph. The tool consists of two main modules and one user defined module. The two main modules are the main simulation file (MSF), and the Petri net definition files (PDF) and the transitional definition file as user defined module. The main simulation file consists of dynamic details like initial markings, firing times, global variables and so on of the P-N model. GPenSIM uses a modular approach to model a Petri net graph. The Petri net definition file consists of the Petri net properties like set of places, set of transitions and set of arcs. [26]
The Architecture of the GPenSIM is shown below in figure 12. It shows how GPenSIM is integrated with the MATLAB tool boxes.

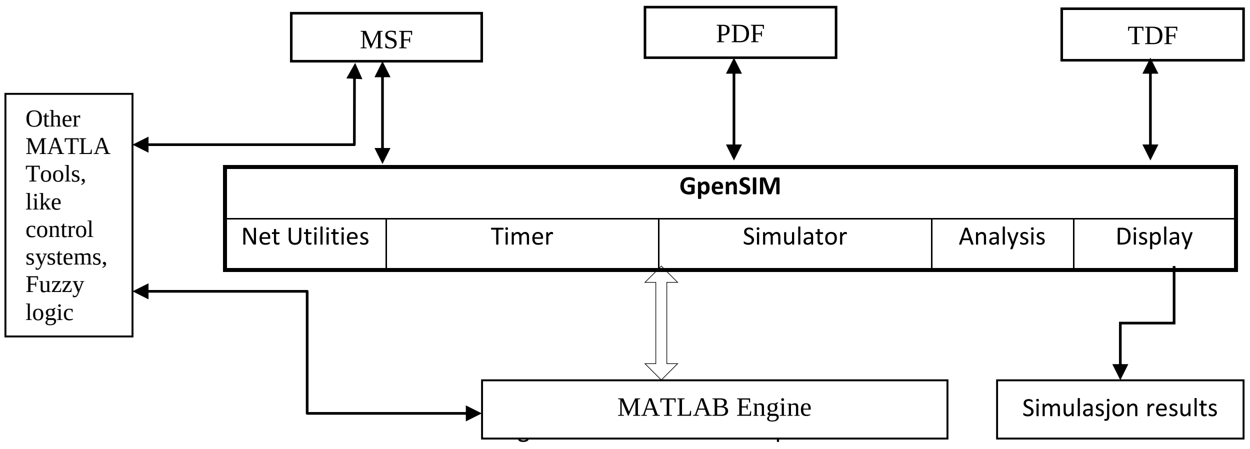


Fig. 8. General Structure of GpenSIM [25]

A new tool has been under construction in order to develop a graphical user interface for GPenSIM. The new project will have a visual interface tool as shown below.

GPenSIM operational files

The following figure shows how GpenSIM operates to model and simulate P-N models.

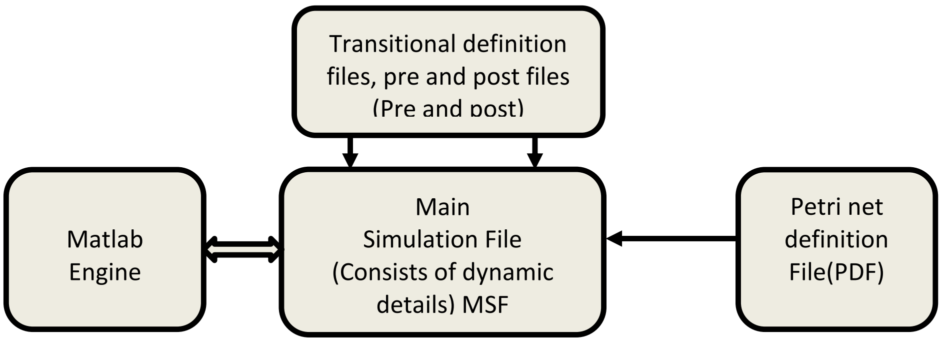

Transitional definition files, pre and post files (Pre and post)
Matlab Engine
Main Simulation File (Consists of dynamic details) MSF
Petri net definition File(PDF)

Fig. 9. Basic GpenSIM Operations

2.6.2 The main simulation file (MSF file)

The main simulation file consists of dynamic codes like the initial dynamics, the initial token states, and functions to display and control Petri net properties on the command window.

The different files (main simulation file MSF, Petri net definition files PDFs, and transition definition files TDFs) can access and exchange global data using global variable called global_info. [26] The 'global_info' can also be used to control the condition of a TDF by semaphore. The global info variable can be accessed by the Petri net definition file, main simulation file, and transitional definition files.

2.6.3 The Petri net definition file (PDF file)

The PDF in GPenSIM consists of the set of places, the set of transitions and the set of arcs. It has also a set of Inhibitor arcs. The good thing with GPenSIM is it supports an inhibitor arc. The PDF file in GPenSIM is denoted by '_def.' where the user can write the PDF name by adding the '_def.' file where it is saved as a MATLAB file. [22, 26]

2.6.4 The transitional definition file

The transitional definition file consists of two files, these are called pre and post files. The pre-condition consists of a user defined functions that shows an event which happens before a firing state of the transition. In this part, we can infer different kind of rules that controls the control activities of the simulation. Similarly the post condition consists of a user defined functions that shows a post events, which happens after a firing state of the transition.

An example of a pre and post file for the above is shown below.

```
function [fire, transition] = COMMON_PRE(transition)
global global_info;
if strcmp(transition.name,'processNewMSG')
    fire = eq(global_info.semafor, 1);
else
    fire = eq(global_info.semafor,0);
end
```

We use a COMMON_PRE file if we have transitions that have a common pre event of a transition. On the above code, the Common pre file accepts a transition and fires according to their sequence. Note that pre and post conditions are user defined function. Similarly for a post condition we use a common post file.

```
function [fire, transition] = COMMON_POST(transition)

global global_info;
if strcmp(transition.name,'processNewMSG')
   global_info.semafor = 0;
else
    global_info.semafor = 1;
end
```

GPenSIM also provides different kinds of Petri net analysis tools, like colored Petri net, resource management, project scheduling, internal clock, Coverability tree, prioritizing transitions, measuring activation time, stochastic timing, modular modelling approach and many different optional tools to analyze and control the performance of the given Petri net model.

Generally GPenSIM can serve from modelling and simulating up to analyzing a discrete event system.

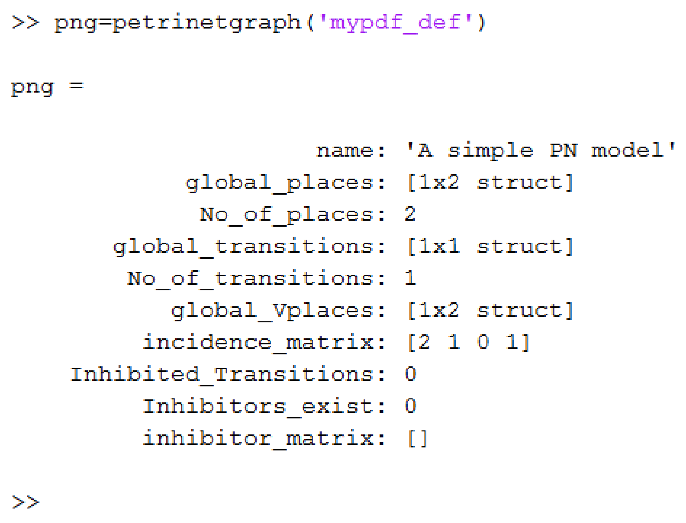
The steps used in designing a GPenSIM code are shown below:

Step1. Create the Petri net definition files, PDF, or modules.

-Identify and write the basic elements of a Petri net graph: the places,

-Identify the basic elements of a Petri net graph: the transitions, and

-Connecting the elements with arcs. I.e. connect the places and transition based on the P-N rule. The following picture shows the structure of the pdf file. The '**Petrinetgraph**' is a gpensim build in command to road the pdf file from the drive. Note that we use this file in main simulation file.



```
>> png=petrinetgraph('mypdf_def')

png = 

                      name: 'A simple PN model'
             global_places: [1x2 struct]
               No_of_places: 2
        global_transitions: [1x1 struct]
          No_of_transitions: 1
            global_Vplaces: [1x2 struct]
          incidence_matrix: [2 1 0 1]
      Inhibited_Transitions: 0
          Inhibitors_exist: 0
          inhibitor_matrix: []

>>
```

Note that ‘mypdf_def’ refers to the Petri net definition file.

Step2. Create the transitional definition files, i.e. _pre and _post files.

Step3. Create the main simulation files.

- Identify the global variables, i.e. make some policies.
- Load the pdf file. Using the above command:

```
>>png=petrinetgraph ('mypdf_def')
```

The png returns the set of places, set of arcs and set of transitions. If there are more than one pdf files, i.e. modular approach. The calling will we as below.

```
>>png=petrinetgraph({‘mypdf1_def’,’mypdf2_def’,’
    mypdf2_def’})
```

- Declare the initial dynamics. The initial marking and firing times of the simulation. Usually the dynamic systems are denoted as ‘dyn’ in gpensim. The initial dynamics are declared as:

```
>>dyn.m0 = {‘p1’, 20,’p2’, 15,’p3’, 6},
```

Here the “m0” denotes the initial marking or the number of tokens at the starting point. Here note that we don’t need to declare for every place in the model. I.e. we can declare this only for places that have tokens at the beginning.

Similarly, the initial dynamics contains firing time of a transition. For example if we want the transition to fire for 6 seconds, we can write declare the firing time as,

```
>>dyn.ft = {‘t1’, 6,’allothers’, 1}
```

“allothers” refer to the rest of transition. It serves as a default firing time.

After declaring the two cell arrays, the next step is packing them into the initial dynamics pack. This is denoted as.

```
>>pni = initialdynamics (png, dyn)
```

- Call the gpensim file. Using a ‘gpensim’ command by passing the “pni” and “dyn” struct variables.

  ```
  >>sim = gpensim (pni)
  ```

  Then the ‘gpensim’ will compile the inputs and process the simulation file by calling the tdf files and gives an output. The output file can be represented either using a plot or print state space to print out the simulation result in ASCII code.

  .

Chapter 3

3. Overview of Real-time simulation and some application

Time, event and cycle (loop) are key terms in simulation and modelling. Some events occurred for a specific period of time interval and some events may occur as a cyclic event. Thus, to simulate a model we need to define the time interval in which one event has happened. The two types of time in simulation are simulated time and real-time. Based on these, we can simulate any kind of model weather it is discrete or continuous. When we consider a type of simulation and modelling, we intended to calculate the overwhelmed time venture of the two events. In this chapter we will see different types of R-T models on different application areas.

3.1 Real-Time simulation and modelling

Real-Time simulation and modelling exists on different application areas. It is one type of simulation and modelling technique that is applied for different kinds of control activities in addition to simulating systems in real-time. It can be used in both discrete and continuous event simulations.

A simulation can be modelled using a stochastic and simulated time in order to predict some imaginary system however when we think of Real-Time applications, the feasibility of a real-time simulation is unquestionable.

In real-time simulation time is everything. For instance we may be interested in guaranteeing that the nth occurrence of some event γ takes place before a deadline time Γ. Hence the simulation time can be denoted as. [27]

$$T_{\alpha,n} \leq \Gamma(\gamma)$$

The performance measurement is denoted by: $P[T_{\alpha,n} \leq \Gamma(\gamma)]$

Similarly for discrete event time it can be expressed as:

Let $X_n(\theta)$ denote a time interval between two events of a given type. For example $X_n(\theta)$ denotes nth lifetime of event α, defined as the interval from the instance when α is activated until the time it occurs and the first subsequent occurrence of another event β. Similarly we can define another event $Y_n(\theta)$. Both event X and Y depends on the parameter,θ. Finally Γ can be some random value. We can develop a method to calculate their probability for $[X_n(\theta) + Y_n(\theta) > R]$ as.

$$L_n(\theta) = 1[X_n(\theta) + Y_n(\theta) > \Gamma(\gamma)]$$

An example of a real-time simulator is an airplane pilot simulator where the main simulator control unit reads every sensor and actuators data live and compile it using a simulation engine. Here we need to mind that one can simulate any type of model, which are suitable for discrete event flow, using a real-time or a simulated time.

Since GPenSIM is used to simulate and model discrete event systems, the focus of the thesis will be only the real-time in discrete event dynamic systems. Note that GPenSIM runs both in simulation clock and real-time clock.

3.2 Real-Time Simulation using GPenSIM

GPenSIM uses two kinds of timing for timing event. It uses a real-time or simulated time. [29] There are different kinds of tools that can be used to model and simulate systems in real-time. MATLAB provides different kinds of tools like SimEvents and SIMULINK in order to perform simulation. Both tools are capable of performing real-time control activities and allow incorporation of diverse tools like fuzzy, neural net, etc. and libraries. However, these two tools are general purpose simulation tools and are not Petri net based. [28] The need for Petri net based simulator because of the many benefits of using Petri nets (such as possessing simple graphical representation as well as strong linear algebraic representation that allows mathematical analysis both on the structural and on the behavioural front) for modelling and simulation of discrete events. LabView is another good tool that can be defined as a real-time control simulator; however, "LabView" is not based on Petri nets either. Generally there isn't a single tool that is purposely designed for simulating Petri net based with real-time capability and allows an easy integration of diverse tools and techniques in the models of discrete event dynamic system. [29]

A real-time Petri net model consists of:

$$RTPN = (P - N, SE, CE, Time)$$

Terms	Description
P-N	P-N is used for graphical Petri net model, i.e. Ordinary P-N.
SE	The Extension for system resource. It is defined as SE = (R, Ω, o, t, X, Y), R-set of system resources, R= {R1,R2, …} Ω-set of executable operations, Ω= {a1, a2, a3, …} o-the partitioning of the operations into subsets that can be executed by the individual resources. o: R $\rightarrow$2Ω t-the set of timing that are taken for operations, t: R× Ω $\rightarrow$N+ X, Y are input and output components.

CE	Stands for the Color Extension of a P-N model, it functions as - overloading tokens with some data to differentiate one token from another - map transitions to logic functions
Time	Time=[PTime,TTime], TTime : Set of transition time, i.e. firing time, it is the time taken by transitions to fire. Firing time can deterministic or stochastic. PTime: The time taken by places to hold a token. Holding time can deterministic or stochastic. [29]

Table. 1. Real-Time Petri net components

According to GPenSIM formalism, the design issue of a real-time in GPenSIM considers three main design approaches. These are:

- Realizing 'token game' in gpensim structure: by a method like 'as soon as possible, ASAP firing', 'delayed firing', or by 'aging'.
- Realize a way to model events: Consider the options; either events by places or event by transitions.
- Analyze a way to interact with the external environment of the model: Is it either thorough 'places' or by 'transition'.

A **token game** in GpenSIM is defined as consumption of input tokens and creation of output tokens within a specific range of firing time.

The following figure shows firing time, t=n, for a token game.

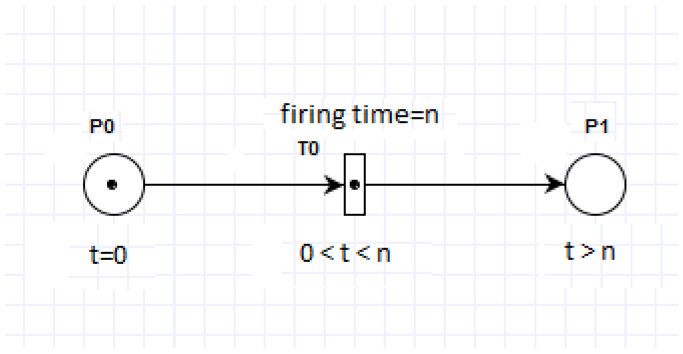


Fig. 10. Token gaming

The above figure shows that at time t=0, t0 is enabled as the input place has enough tokens to be consumed and ready to fire. Between the given firing time n, the amount of token that are equal to the arc weight, bandwidth, will be fired in to the output place p1. Token gaming simply shows the condition of disappearance and reemerging of tokens by the transition.

3.2.1 Real-Time simulation in Industrial application

The demand of real-time modelling and simulation in industrial are steadily increasing. Different companies prefer to have a model and simulate it before starting to plant a machine. Even more companies prefer to do more than just modelling, simulating and analysis. They added different features to control the simulation in real-time, i.e. they do the simulation in real-time. A good example is a workflow modelling of CNC machine using Petri net. A workflow model can be simulated using a Petri net. We can consider an example of a machine control from CNC and feeds to different robots.

The actual model is

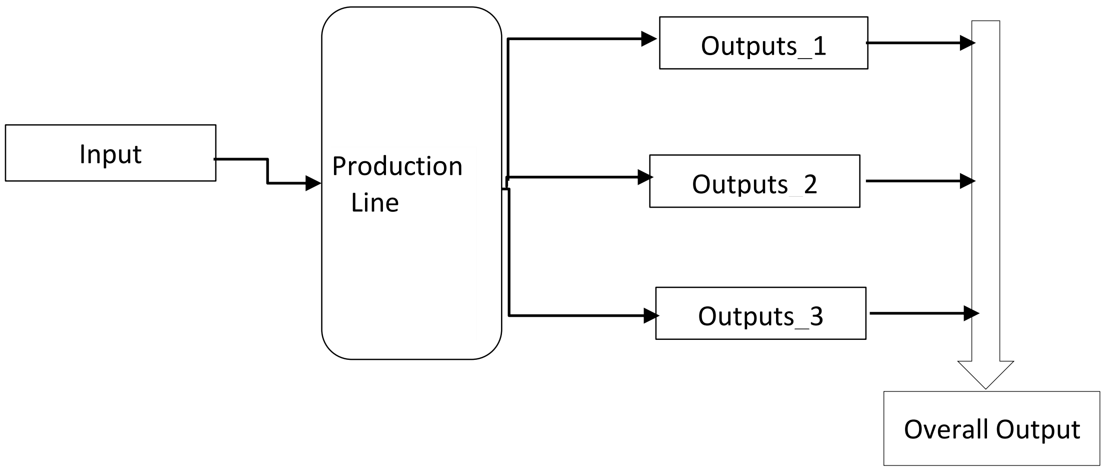


Fig. 11. Real life model of Production line

From the above real life model, we can induce a P-N model of the production facility is shown below.

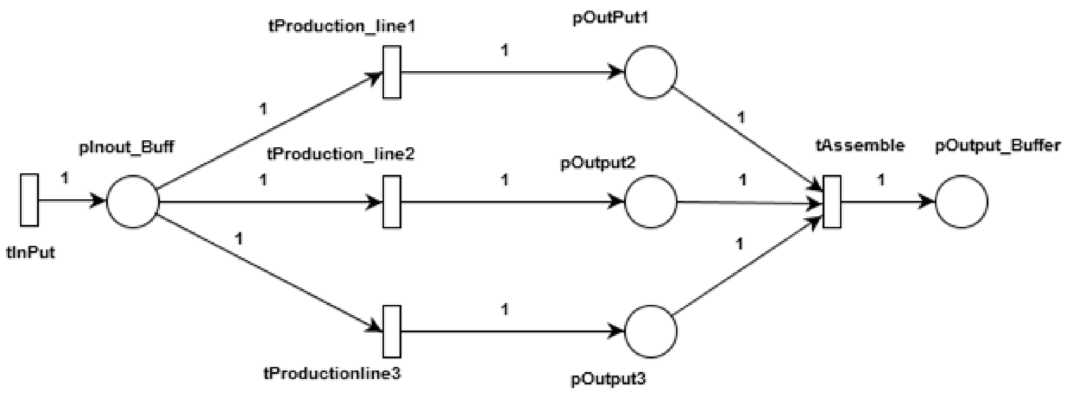


Fig. 12. P-N model for production line

As we can see on the above Petri net model, the system has three production lines where all of them have the same input source. The three transitions, tProduction_line1, tProduction_line2, and tProduction_line3 have different methods to choose color tokens from the input. Based on the preconditions of the production line, every production line uses different kinds of rules to fire an input token. Assume a color P-N to identify the tokens to each production line. The tokens are denoted by different colors say 'A', 'B', 'C', or 'D' and are used rotationally and the 'tInPut' generates those tokens and stored in 'pInput_Buff'. The implementation part will be clearly described on chapter 5. Section 5.2.1

3.2.2 Real-Time simulation in room security

As it is mentioned above, we can simulate any kind of discrete event flow using Petri net hence GPenSIM. In this part, modelling for the usual entrance gate security system will also emphasize the concept of real-time modelling using GPenSIM. The model for such system is available at. [41]

Fig. 13. Entrance handle with keypad

The real life model of an alarm system using three modules is shown below.

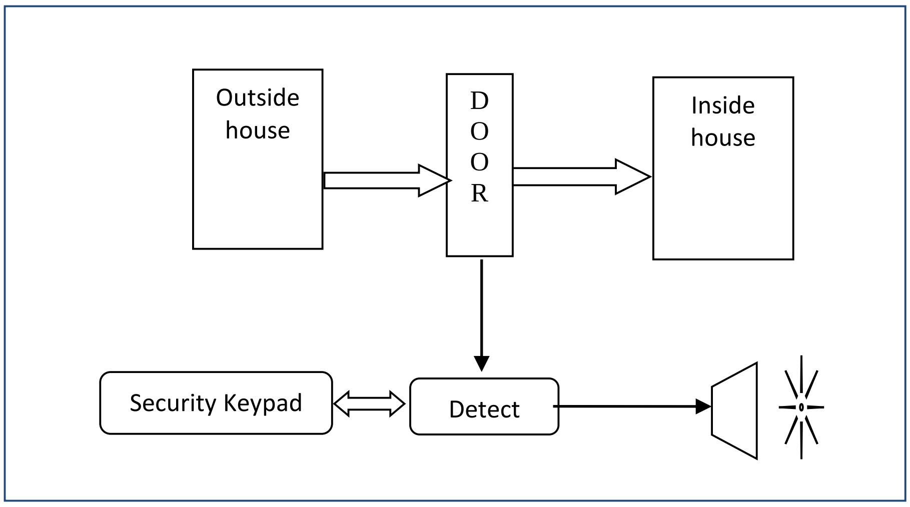


Fig. 14. Actual model of a house alarm system with keypad

The following algorithm will give a brief steps about the working principle of an alarm system.

The algorithm

- If the alarm is on and ready to detect
    - Check if the entrance is ready and closed,
        - When opened, read and save the current time δ_1.
            - Enter the combination password within 120 second (2 min).
        - If the entry code is not entered within the current real-time, δ_1+2min, or if the entered code mismatches with the stored codes. (after three trials)
            - Trigger the alarm signal.
        - If code is correct, keep on the cycle.
- To disarm the alarm and stop the ringing tone
    - Enter the combination code in the keypad.
    - Else continue ringing.
- To trigger the alarm again, store the next time δ_2
    - Enter the 'exist_combination' code. The entrance alarm will be armed after some delay at time δ_2**,** so that the new time will be the current time.

      The time interval with every firing will be

$$\Delta\delta = \delta_2 - \delta_1$$

We can use time P-N to define the behavior of the above model, the basic sub modules for the above are.

Entrance door model

For a simple door model, it can be started by designing a model without a condition to check if the door was already opened. It is because of the fact that the door might be opened and it should be rechecked the existing door.

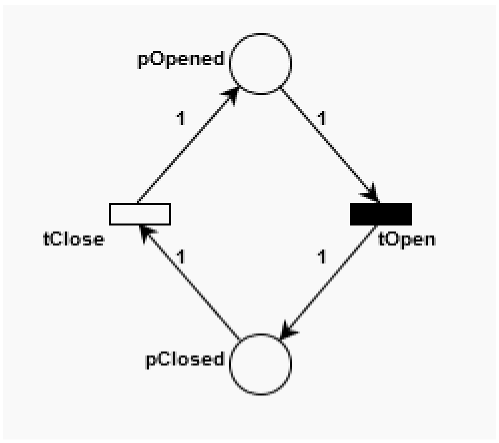


Fig. 15. Simple door model using Petri net

The above model checks only the status of the door. Weather it is opened or not, to make it more intelligent, The door model can be redesigned as shown below by adding a feature to check if the door is already opened or not.

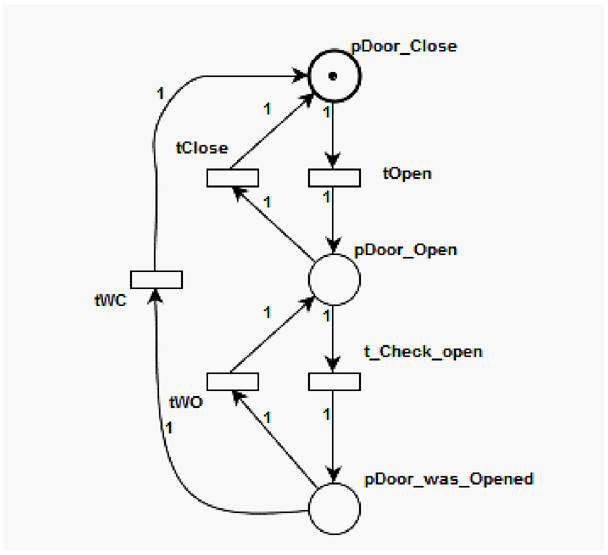


Fig. 16. Door condition model with previously opened door status

The Petri net definition file for a door model will be.

Alarm model

The alarm model consists of three places and four transitions. After opening the door, if the person didn't enter the correct code within a given range of time, Δt, the alarm will start ringing. This is only if the alarm is set to 'Armed'. If the alarm is not set or 'disarmed', it will be off or needs to be armed otherwise anybody can enter to the house.

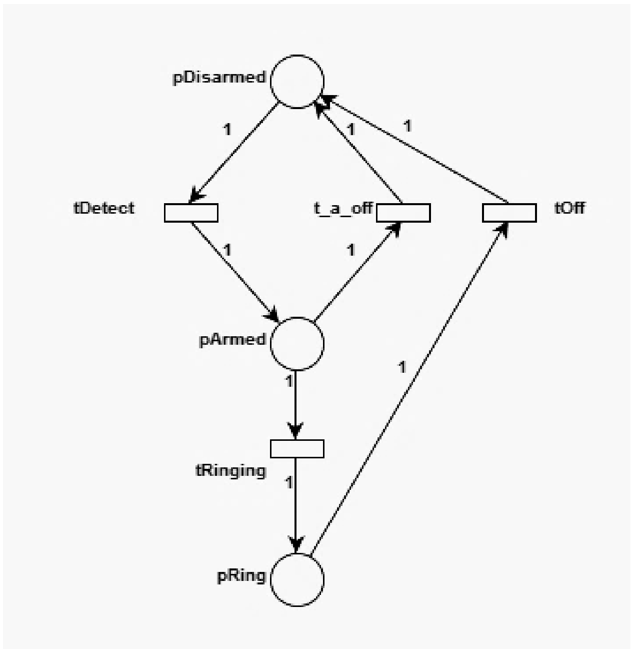


Fig. 17. Alarm model using P-N

The Petri net definition file using GPenSIM for the above model is shown below

Keypad model

The keypad has two transitions each of them with two transitions to fire from an idle token event that has been stored inside the 'pBuffer' place. The 'tExit' generates a token that armed the alarm.

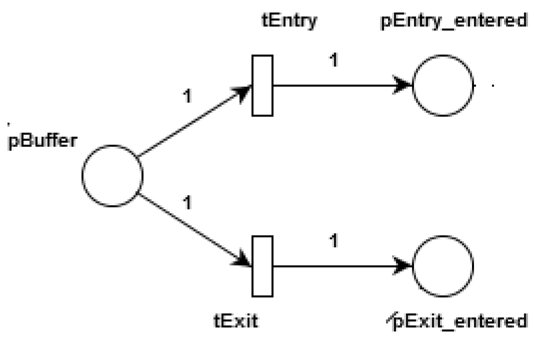


Fig. 18. Model of keypad

The Petri net model for the above system is shown below.

The overall model

The combined system model will look like as follow. There are three modules, and in the picture below the blue highlighted border color show the sub models of the whole system.

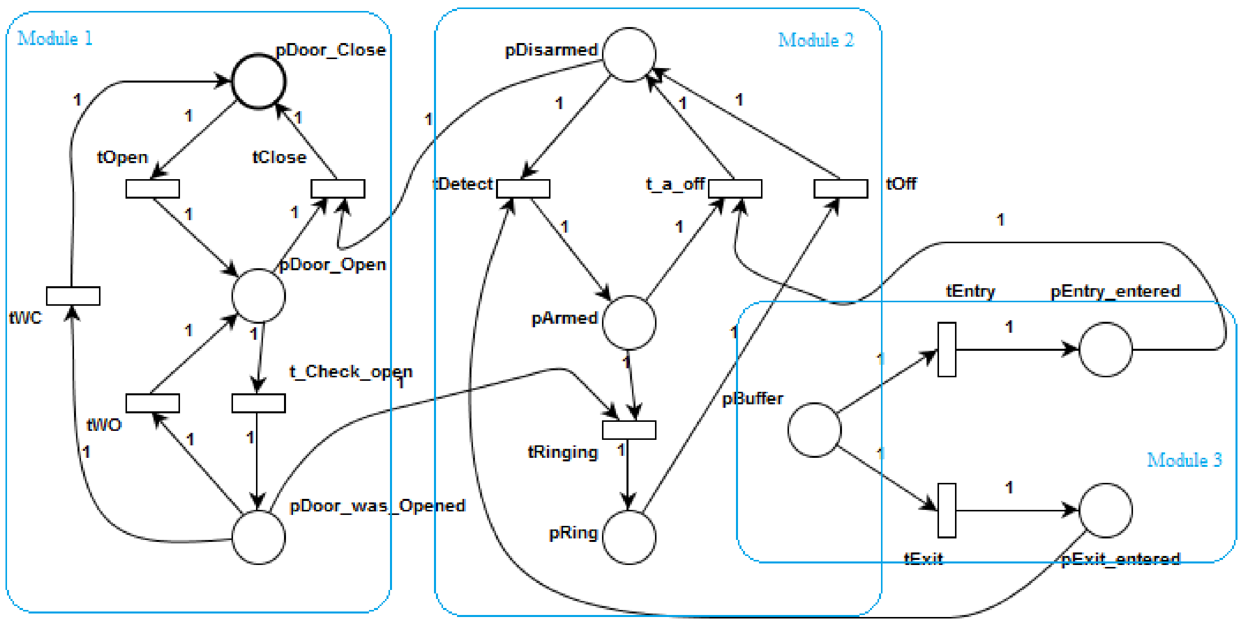


Fig. 19 The overall alarm system model

Now the above model is a simple model, to make it more intelligent we can add a sensor instead of the combination and wait time. Section 3.3.2 introduces a method by adding a sensor and NXT device.

3.3 Real-Time simulation and modelling using NXT machine

3.3.1 NXT Mindstrom device.

The NXT Mindstrom is a multipurpose microcontroller device that has multi functionality. The device can be used to model robots, traffic lights, material sorting, and different types of sensor based systems. The NXT device components can be bought in a form of a pack. The packs contain different types of equipment that are used for educational purpose. In addition to the main microcontroller unit (NXT brick) there are different cables, building Lego bricks, different sensors like; ultrasonic, light sensor, sound sensor, tough input sensor, light lamps, and small tires if someone wants to build a simple robot or vehicle and so on. [38]

The main components are:-

a. Hardware

  – NXT intelligent brick microcontroller

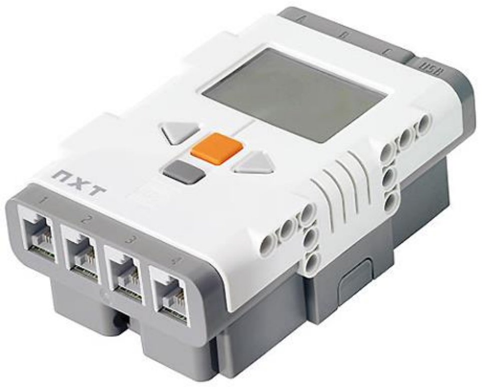


Fig. 20. NXT intelligent brick [43]

This device is the main microcontroller unit and it has a firmware which can be integrated with many platforms (open source) and can be coded by different programming languages. The NXT brick contains ports to take input and output, processor unit, memory, Bluetooth card, LCD display.

- Main processor: Atmel® 32-bit ARM® processor, AT91SAM7S256
- 256 KB FLASH, 64 KB RAM,48 MHz
- Bluetooth wireless communication CSR BlueCoreTM 4 v2.0 +EDR System
- USB 2.0 communication Full speed port (12 Mbit/s)

        - Four input port, three output port, 6-wirecables
        - 100 x 64 pixel LCD graphical display
    - Sensors
        - Ultrasonic sensor
        - Sound sensor
        - Touch input sensor
        - Light sensor
    - Connecting Cables
        - USB cable
    - Building bricks
        - Different kind of Lego building bricks to build the support. This are taken from LEGO toys.
- Software
    - RWTH- Mindstrom.
    - Fantom driver.
    - NeXttool

3.3.2 Door alarm system using NXT

A door alarm system can be modeled using NXT intelligent Brick and GPenSIM based on a predesigned Petri net model. The following shows a clear image of the model concept.

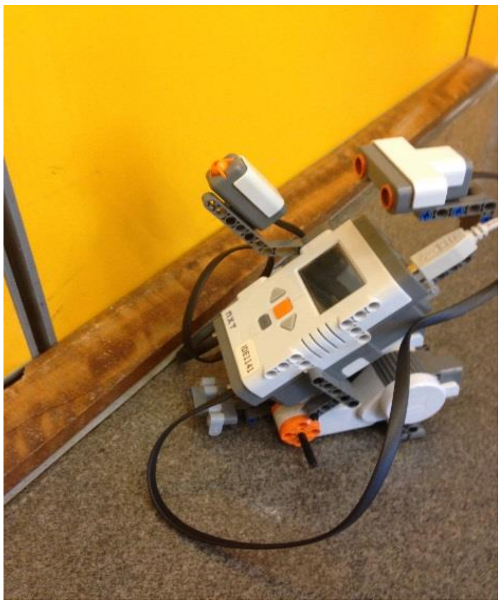


Fig. 21. A door alarm model using NXT and ultrasonic sensor

The real life model of the above picture is shown below.

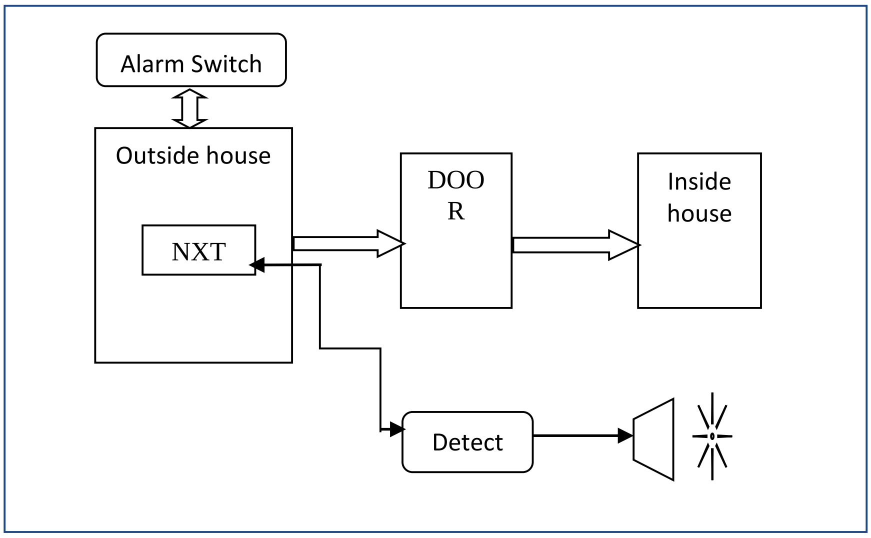


Fig. 22. Model of door alarm system using flowchart

To model the system using NXT, we required the following equipment.

1. NXT brick microcontroller

The NXT brick microcontroller has port to interface to PC and also ports to interface the touch input sensor and the ultrasonic sensor. The main purpose of the NXT intelligent Brick is that is takes input from the PC and detects the passing by object based on the pre-defined Petri net model.

2. NXT ultrasonic sensor

The ultrasonic sensor in NXT is used to sense any object and also capable of calculating the distance of the object from the sensor node. The ultrasonic sensor is used in this code as a sensing node of an object who intended to cross the door. The ultrasonic sensor Measures the distance between the NXT Ultrasonic Sensor and the nearest object in front of the sensor. The sensor can detect objects from approximately 5 to 255 centimeters away.

Fig. 23. NXT Ultrasonic sensor

The sensor detects objects that are in some angle. It is possible to calibrate the ultrasonic measuring degree.

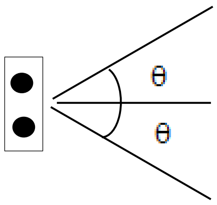


Fig. 24. Angular range of ultrasonic sensor detection

3. Touch input sensor.

   This input button is used to reset the alarm. It restarts the operation of the alarm system. The NXT touch input sensor works when a user presses the orange button. The NXT brick has four input ports and read this sensor input and makes an output.

Fig. 25. Reset button, NXT touch input sensor

The flowchart for the alarm system is shown below

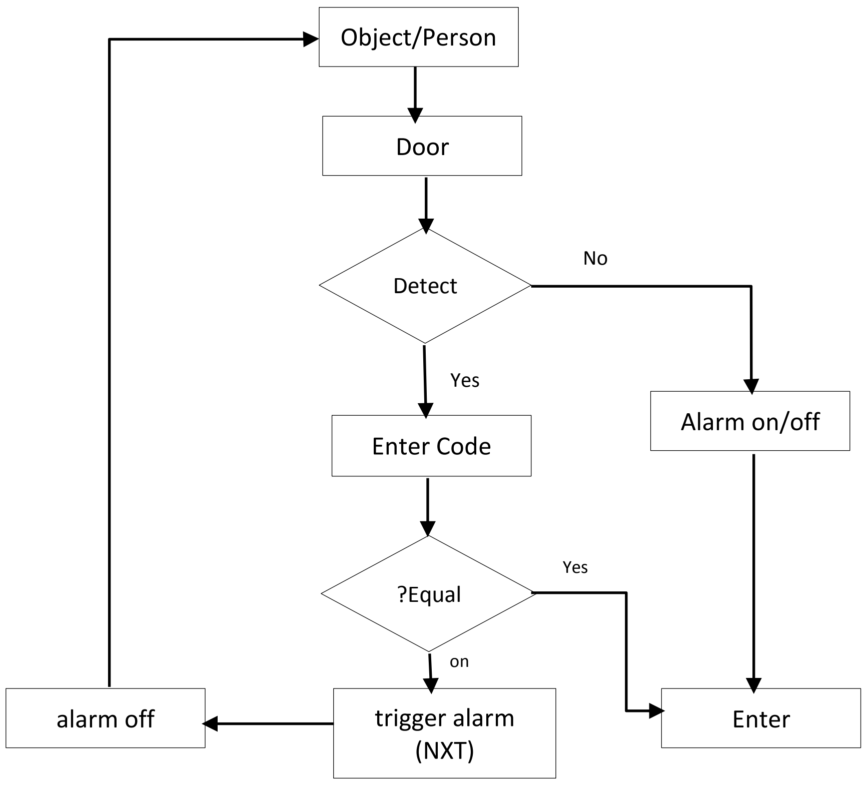


Fig. 26. Flow chart of Door alarm system using NXT

- And the Petri net model for the above flow chart will be as shown below.

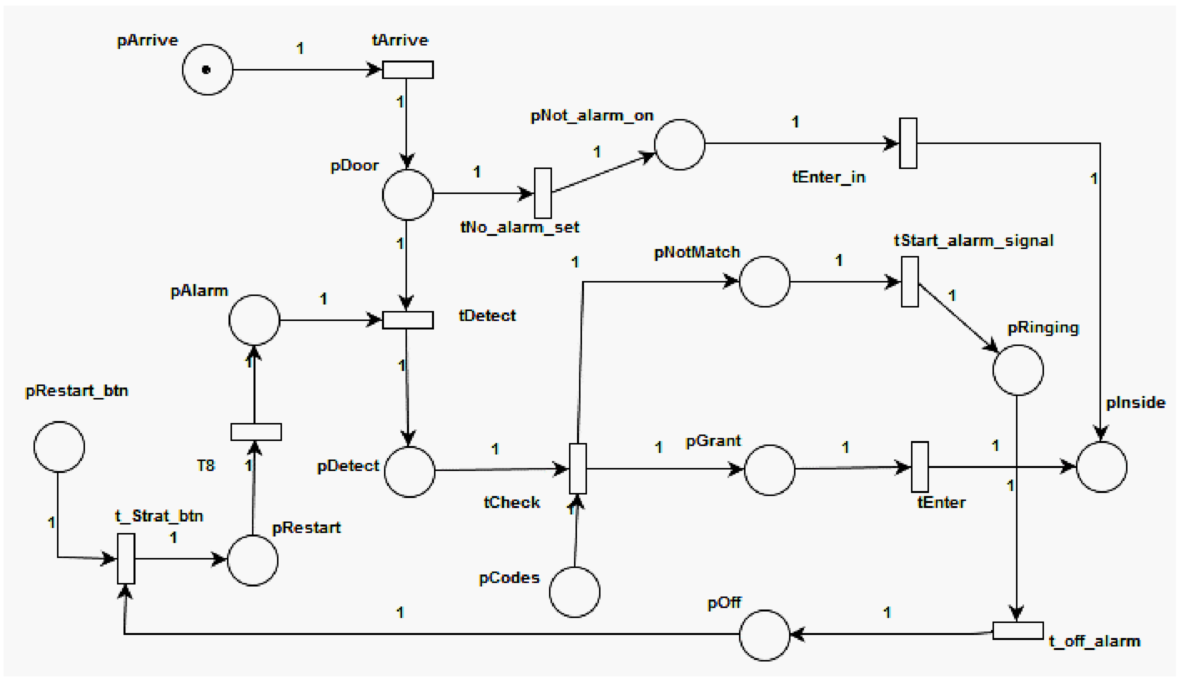
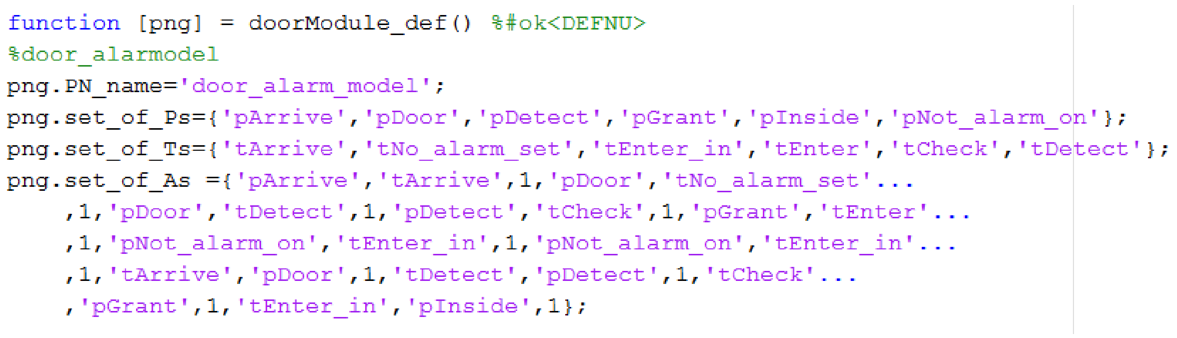


Fig. 27. A Petri net model of door alarm system

The whole system can be divided in to two modules and each of them will be called in the main simulation file. The first module is to model the door and the second one is to model the NXT sensor.

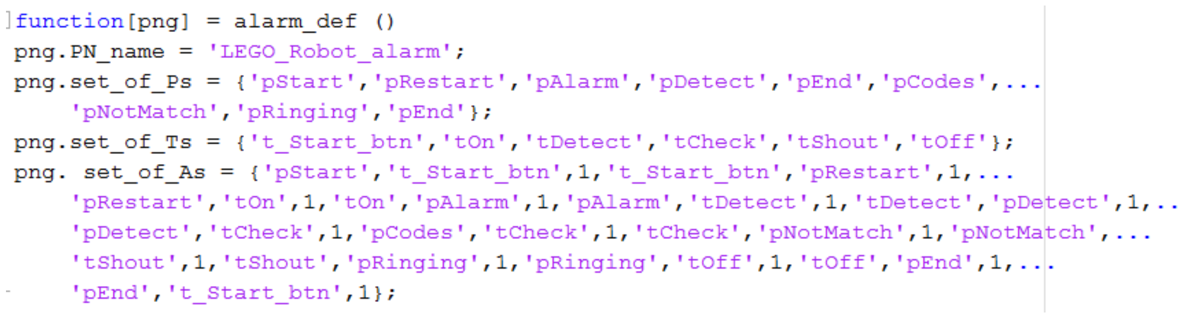
The static P-N of the door alarm model is shown below.



```
function [png] = doorModule_def() %#ok<DEFNU>
%door_alarmmodel
png.PN_name='door_alarm_model';
png.set_of_Ps={'pArrive','pDoor','pDetect','pGrant','pInside','pNot_alarm_on'};
png.set_of_Ts={'tArrive','tNo_alarm_set','tEnter_in','tEnter','tCheck','tDetect'};
png.set_of_As ={'pArrive','tArrive',1,'pDoor','tNo_alarm_set'...
    ,1,'pDoor','tDetect',1,'pDetect','tCheck',1,'pGrant','tEnter'...
    ,1,'pNot_alarm_on','tEnter_in',1,'pNot_alarm_on','tEnter_in'...
    ,1,'tArrive','pDoor',1,'tDetect','pDetect',1,'tCheck'...
    ,'pGrant',1,'tEnter_in','pInside',1};
```

Similarly the static P-N of the NXT ultrasonic sensor is shown below.

The main simulation file and the transitional definition files are described in the implementation section.



```
function[png] = alarm_def ()
png.PN_name = 'LEGO_Robot_alarm';
png.set_of_Ps = {'pStart','pRestart','pAlarm','pDetect','pEnd','pCodes',...
    'pNotMatch','pRinging','pEnd'};
png.set_of_Ts = {'t_Start_btn','tOn','tDetect','tCheck','tShout','tOff'};
png. set_of_As = {'pStart','t_Start_btn',1,'t_Start_btn','pRestart',1,...
    'pRestart','tOn',1,'tOn','pAlarm',1,'pAlarm','tDetect',1,'tDetect','pDetect',1,..
    'pDetect','tCheck',1,'pCodes','tCheck',1,'tCheck','pNotMatch',1,'pNotMatch',...
    'tShout',1,'tShout','pRinging',1,'pRinging','tOff',1,'tOff','pEnd',1,...
    'pEnd','t_Start_btn',1};
```

3.3.3 Traffic light system modeled using NXT intelligent Brick

Fig. 28. A Traffic light system

The traffic light system model designed using an NXT is shown in the following picture.

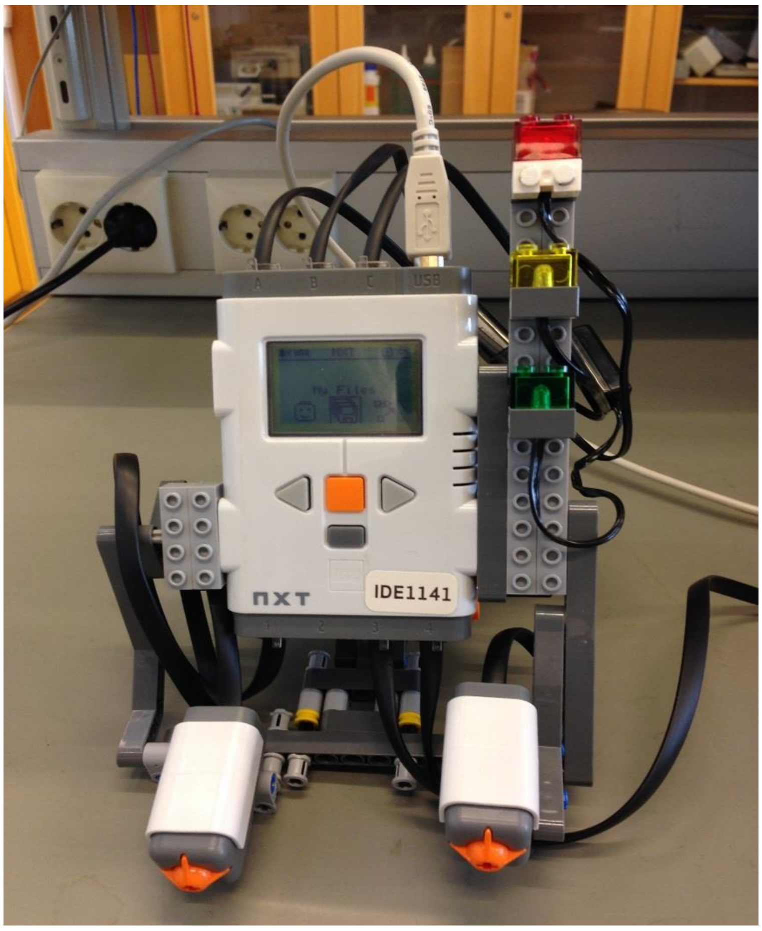


Fig. 29. Traffic light model using NXT

The following model shows a traffic light system designed using NXT and Matlab. It is the resemblance of the above model. The model was taken from the work of Norwegian traffic light system from UiS. [29,39]

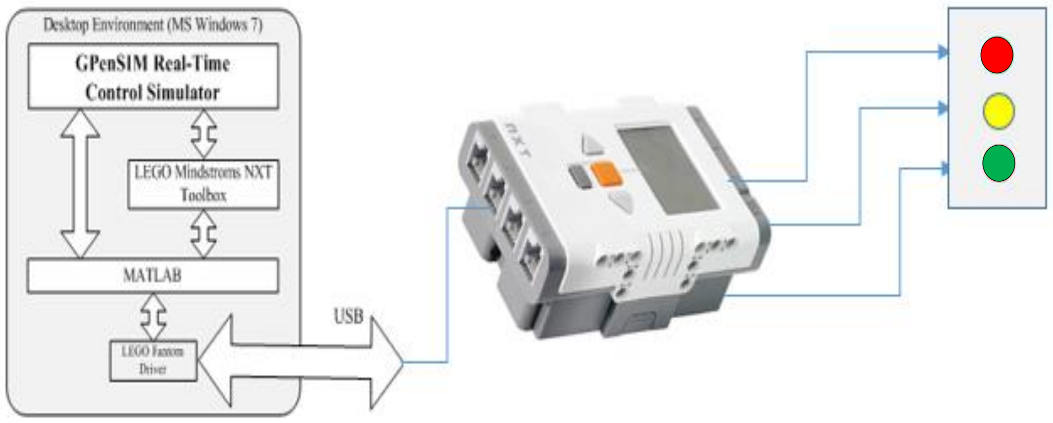

Desktop Environment (MS Windows 7)
GPenSIM Real-Time Control Simulator
LEGO Mindstroms NXT Toolbox
MATLAB
LEGO Fantom Driver
USB

Fig. 30. Integration of Traffic signal system with GpenSIM

The model uses different kind's components NXT components. The components that are used in the model are list below:

- NXT brick, the main microcontroller unit.
- A usb 2.0 cable to connect the device with a PC.
- Two NXT touch input sensor.
- Three output light cables.

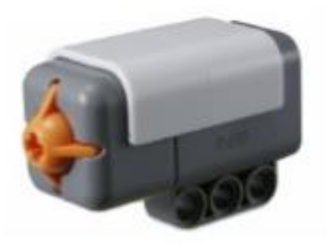


Fig. 31. NXT Touch button sensor

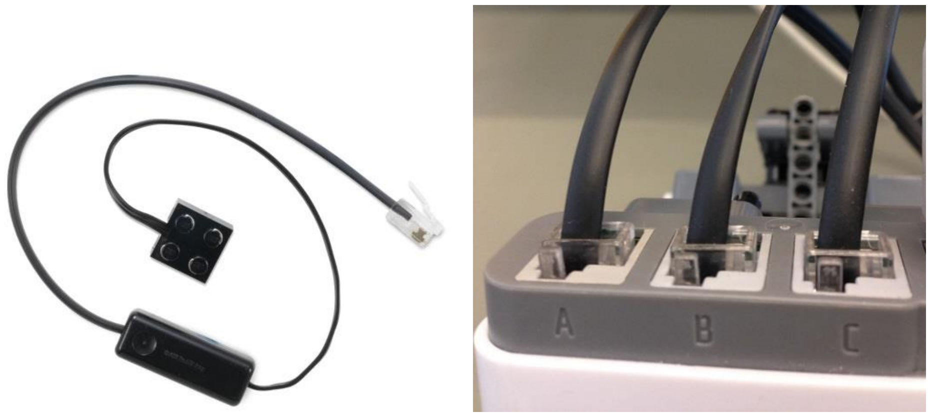


Fig. 32. A cable to connect light displays to the NXT intelligent Brick.

The model consists of three sub models, where each of them has different interaction with the NXT ports. The sub-modules are;

1. Normal cycle: This presents a normal cycle of a traffic signal in a junction. The standard cycles of a traffic signal is:

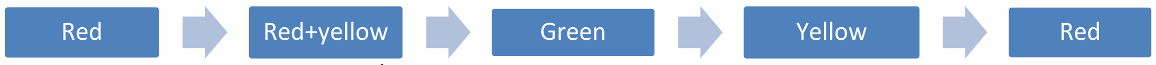


fig. 33. Traffic lighting cycle

These are the status when the lights bubs that turns on at the same time t.

The ordinary P-N model for the above steps is shown below.

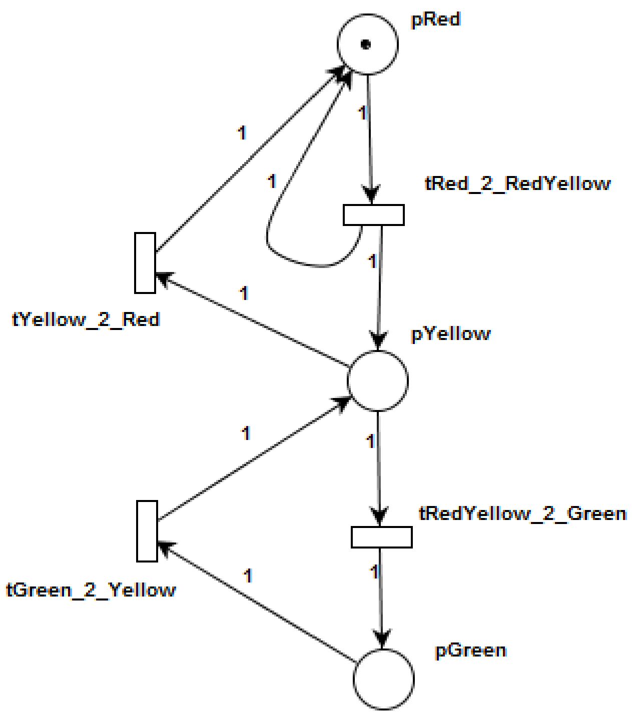


Fig. 34. P-N model for traffic light cycle

The module can be redesigned as shown below.

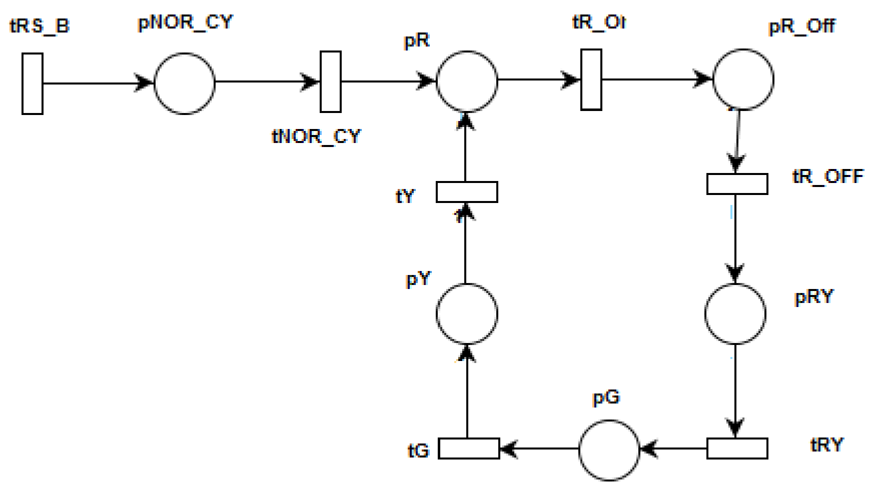


Fig. 35. Module for normal cycle

2. Pedestrian interrupt: If a pedestrian want to cross the road, he presses the "PEDESTRIAN-CROSSING" button on the traffic pole, which is the NXT touch sensor 2 in the NXT model.

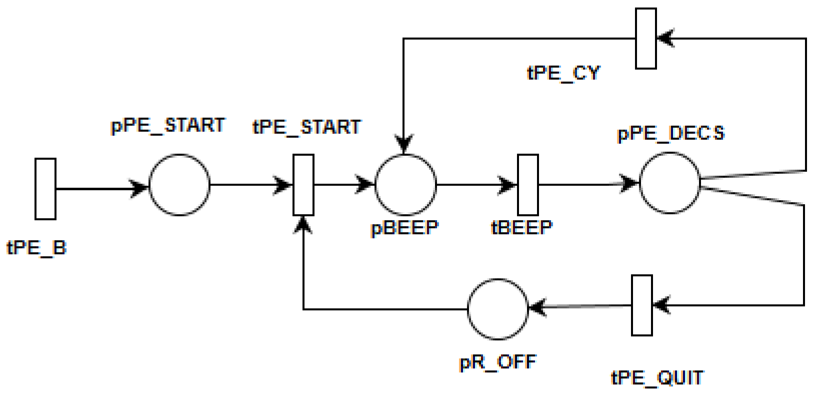


Fig. 36. P-N model for pedestrian module

3. Emergency blink:

   The emergency blink frequently displays yellow light. The transition 'tEM_START' fires when the user touches the input touch sensor for emergency blink. The cycle that is shown in the model below perform this operation. The cycle operates until the loop finishes, then it return to the normal cycle.

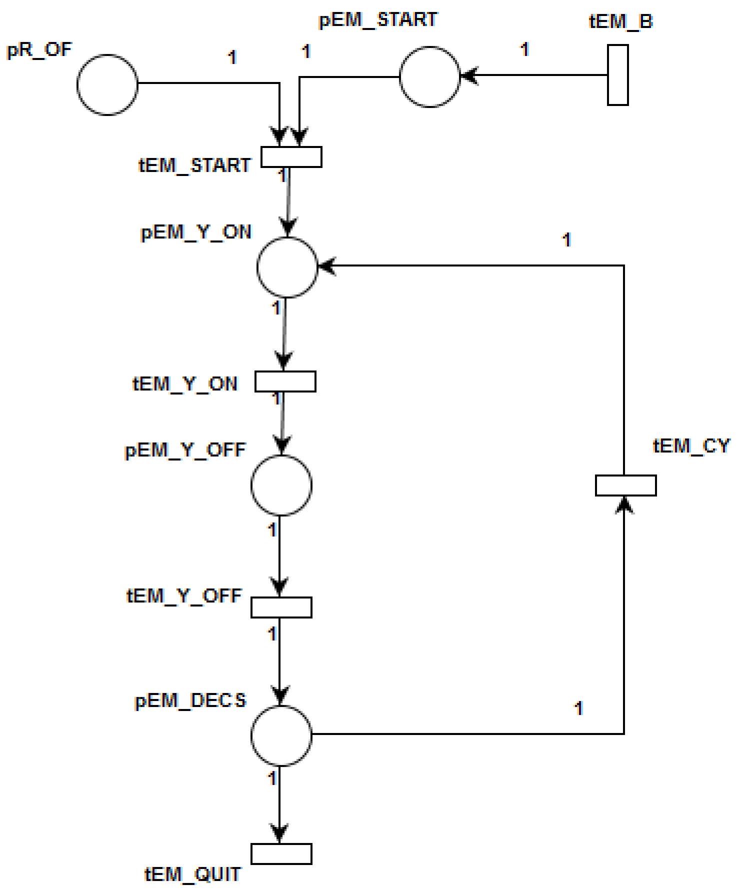


Fig. 37. P-N model for emergency blink

4. The overall model is

The system uses a modular approach. All the above sub-system models' combines to make a complete traffic light model. The P-N model that shows the overall system is shown below.

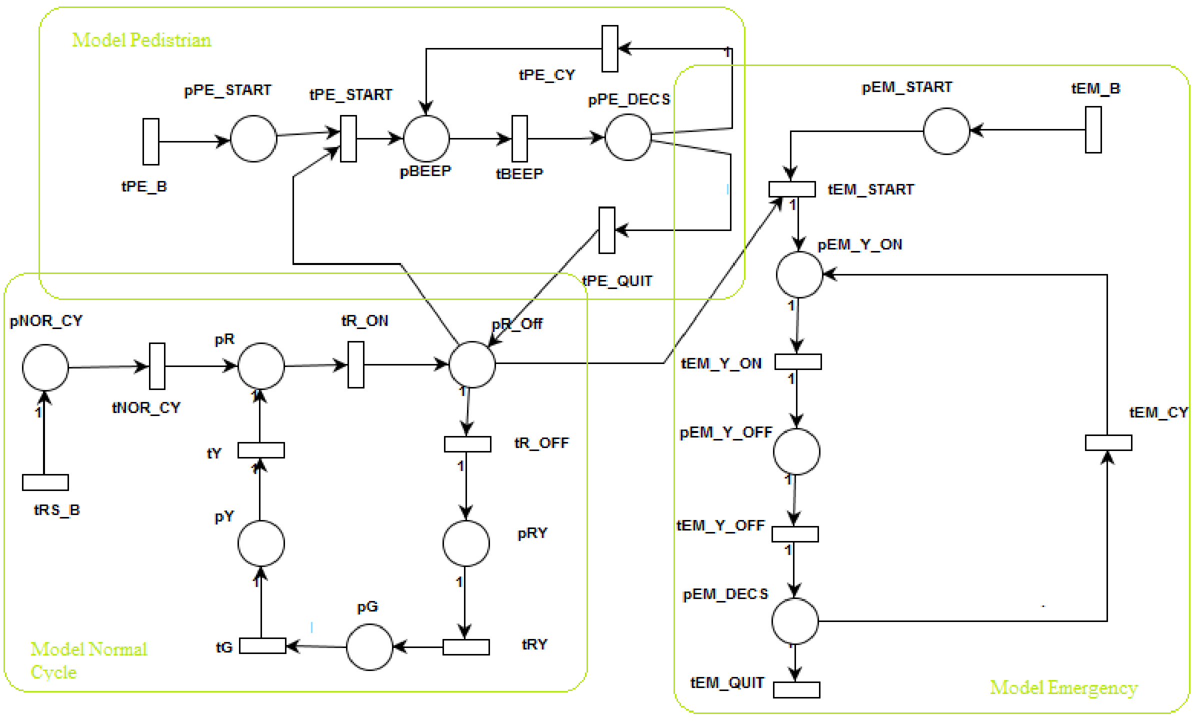


Fig. 38. A complete model of a traffic light system

The traffic light signal model consists of NXT equipment. To interface the NXT to a MATLAB we need to install different kinds of drivers and set up the Bluetooth connection of the main working station with the NXT device.

Chapter 4

4. Designing R-T monitor for GPenSIM

4.1 Human Computer Interactions, HCI

A human machine interaction, HCI, is a method of building a bridge between a human being and a computing machine. In recent times, after the introduction of personal computers, operating systems and text editors, the HCI tools become a rapidly developing tool. In these days, everything is getting more computerized; Human being becomes more potential user of computers. As the technology got more advanced, and computers get to be more available, there becomes some sort of need to shape the human interaction with computer. The cognitive science introduces a method to simplify the interaction between human and computer. Thus the idea of HCI has emerged from the broad project of cognitive engineering in the cognitive science. [30] One part of the cognitive science was the development of some scientific and well informative applications known as "cognitive engineering". HCI was one of the results of cognitive engineering. In order to communicate with a machine, there must be some sort of communication or connection mechanism. These are either by making some physical contact or some kind of sense contact. For example, keyboard is one kind of physical contact and eye sensor and RF technology are some kind of sense contact. At the background of the physical contacts, HCI provides tools that program the machine to do what a user has requested. This is literally called software. I.e. software is a background series of commands that interacts the user with the machine. The following figure shows how the **cognitive engineering** categorizes HCI with other science.

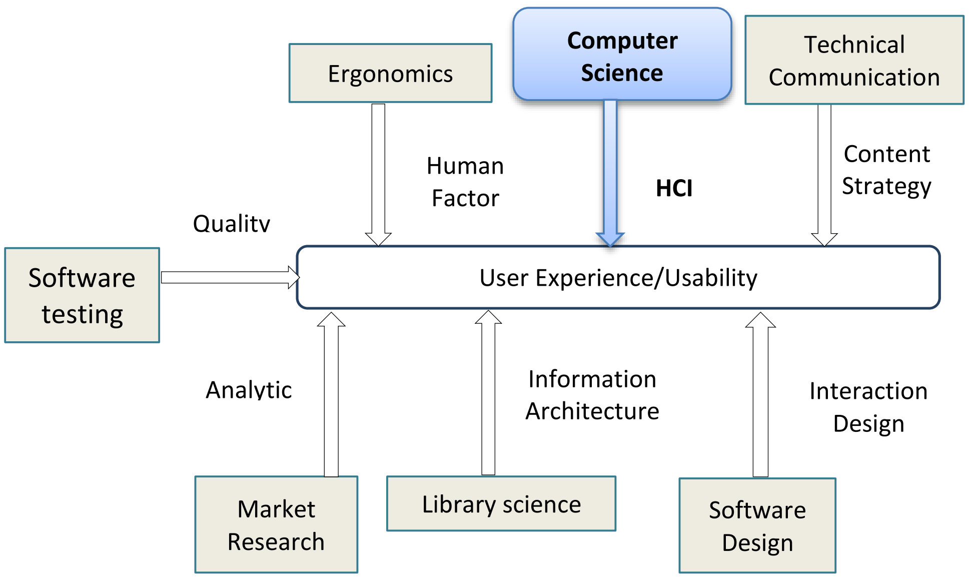


Fig. 39. Human machine interaction

There are different kinds of HCI methods. We need to mind that designing only a good graphical user interface doesn't mean we have a good HCI tool.

In order to have an effective HCI model, we need to develop a system that has a user-friendly user- interface, reliable connection or interface, a method to integrate with other tools and platforms and provide a method to analyse works that are performed at the background. There are different kinds of interfacing techniques; the most known one in the recent technologies is using a 'gui', i.e. graphical user interface. Different developing studios provide a graphical user interface tool which has a background call back with a specific programming language. It will be well described in the design section.

As it is discussed above, the HCI with a graphical view makes a human being closer to the computing world. Especially in areas where there is a need to visualize events that are performing in a real-time, the need for an HCI tool must be a prior requirement. Thus; HCI tools for simulation and modelling in real-time give a user more accurate and clear information about the simulation and even provides a graphical tool to control the simulation event.

4.2 Design R-T display system

The new implemented tool in this thesis has a graphical user interface (R-T monitor) which will serve as a display unit for the real-time control activities. The design method of the R-T monitor is designed based on the parameters of GPenSIM. I.e. it is designed based on the formalism of GPenSIM so that it would be embedded inside the structure of GPenSIM. The R-T-monitor system consists of two graphical user interfaces, these are:

a. The main form, **GUI.m**, to control and display the ongoing visual display unit called GUI, this also serve as a control unit for the real simulation system. The GUI gives all the necessary information about the status of selected transition and places. As it is mentioned on the statement of problems, it would be very practical if we are able to watch the transition of every live event. This gives GPenSIM a full HCI tool.
b. A window to select the desired transitions and places, **select_R-T_monitor.m**, from the overall ongoing simulation components, i.e. places and transitions.
   On the monitor, the reason that a user need to select some specific transitions and places is that when we work will a large systems, it is impractical to control all the conditions of the transitions and places simultaneously. GPenSIM is well known by its efficiency in modelling discrete systems that use a Petri net tool. Or simply it is a general purpose Petri net tool.
   AS it is mentioned above, the R-T monitor source code is embedded inside GPenSIM. The algorithm of an extended GPenSIM is shown below.
   The over view of the GUI in the system is

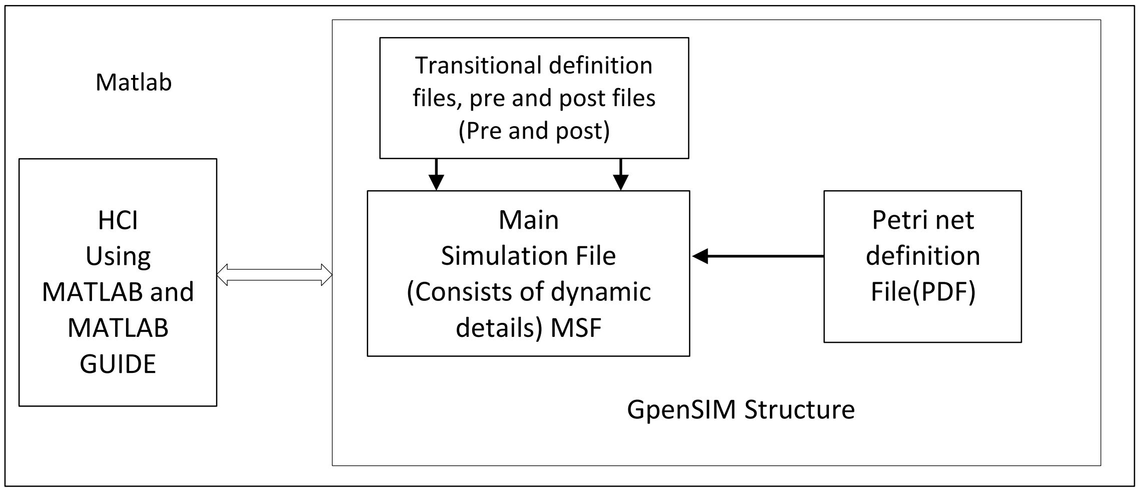

Matlab
Transitional definition files, pre and post files (Pre and post)
HCI Using MATLAB and MATLAB GUIDE
Main Simulation File (Consists of dynamic details) MSF
Petri net definition File(PDF)
GpenSIM Structure

Fig. 40. The over view of R-T monitor

4.3 User interfaces design

Though GpenSIM can model and simulate any type of Petri net model, it lacks a mechanism to have a graphical human machine interface, HCI tool. This tool is a system that makes the user to have a visual interaction with the background resources. GUI tools provide a method or class object called FORMs which has components like textboxes that are visible for humans. A user can easily interact with pre designed forms. The forms for graphical user interface are designed using MATLAB.

Here we should mind that we can use another tool to implement the GUI. The design of a GUI is very complicated and tricky unless a careful design approach is taken. Here in this thesis project, i intended to use a MATLAB GUI designer called GUIDE for implementation. It is obvious that most developing software platforms provide a tool to implement a graphical user interface. This is due to the rapid development of HCI. Based on this it has been taken some assessments on using different tools like java and visual studio.NET. But the better method to design a graphical user interface component for GPenSIM is GUIDE. MATLAB provide a tool for designing graphical user interface called GUIDE and the associated file extension is called **'.fig'** For example; **GUI.fig.** [32]

4.3.1 Graphical user interface (gui) basics.

Graphical user interface tools are tools that make a visual and graphical human machine interaction. Now a day's most software provides an efficient graphical tool to make the user more comfortable. Every GUI tools provide a method or class object called **FORMs**. I.e. A form is a class that its member functions are accessible throughout the class. All controls in the function are objects. In java and visual studio tools, a graphical user interface is called form, '**jForm'** or 'Form'. But in MATLAB, it is called figure. The figures in MATLAB GUIDE are usually denoted as '**gcf'**.

Forms are a graphical user interface tools through which a user interacts with the background source code. To make the system more useful and user friendly, the interface should have suitable controls for getting input data from the user. A MATLAB 'gui' form is called figure. As it is know that all MATLAB plots are named as figure1, figure2 and so on. This will be explained on the next section. A well designed gui should fulfil the following three criteria. [33]

Simplicity: should have unity, elegance and clarity.

Consistency: should have a good alignment, integrity with the back code and harmony.

Familiarity: It should be user friendly and charm.

4.3.2 MATLAB GUIDE

A MATLAB gui, is called GUIDE. It is an event driven programming tool developed by MATLAB in order to provide the users with a graphical user interface, GUI, development environment. [34] The GUI should behave in an understandable and predictable manner, so that a user knows what to expect when he or she performs an action. For example, when a mouse click occurs on a pushbutton, the GUI should initiate the action described on the label of the button. A MATLAB Guide has a lot of similarities with java applet. But MATLAB is a bit terrible. The advantage of using MATLAB guide over using java is that it contains libraries that perform functions needed for scientific computing. This is unquestionable. Most engineering and scientific areas prefer to use MATLAB languages; this is due to their flexibility and integrity with other MATLAB libraries. But still MATLAB has some weaknesses like it is only useable in math Works environment. It is like it has pros and cons. The other con is that MATLAB is very expensive software, these has been a headache for most of developers. [32]

- There are two ways of developing a graphical user interface in MATLAB. These are:

a. Using a MATLAB command 'UiControl '

The MATLAB Uicontrol creates a user interface, and returns a handle of the user interface component. For example if we want to create a pushbutton with its 'callback' function, 'pushbutton1_Callback', we can the command using 'Uicontrol' as below.

```
> h =uicontrol ('Style','pushbutton','Callback', @
pushbutton1_Callback);
```

h can be used to return the result so that it can be used with another function.

b. Using a toolbox called GUIDE

A MATLAB GUIDE is a MATLAB toolbox used to create a graphical user interface based on a MATLAB script file. A guide has a structure as shown below.

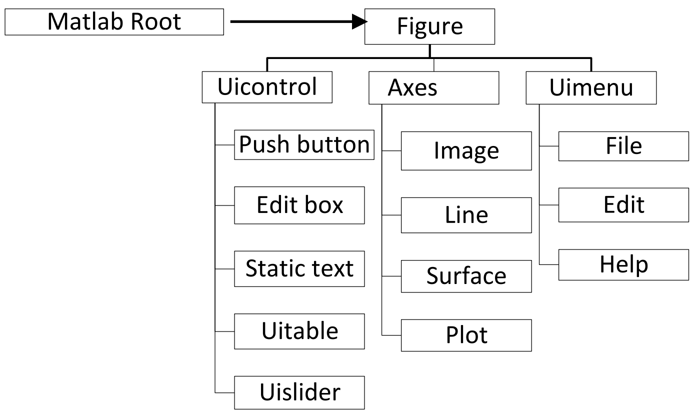


Fig. 41. MATLAB GUIDE tool components

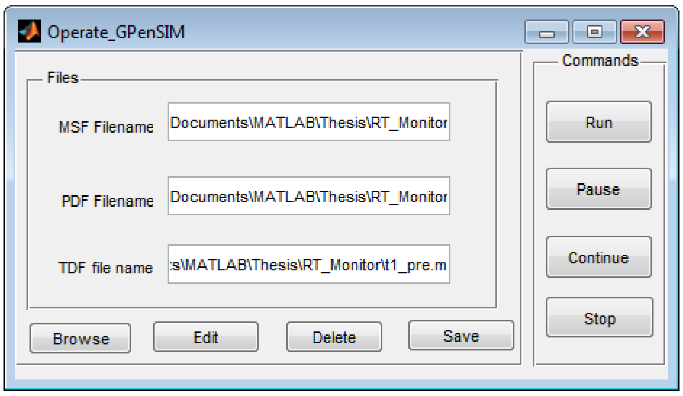
For working with a large system, the best way to work with a gui is a GUIDE. Because GUIDE by itself would minimize the mess by creating all call events and gives also a template. The three main components for MATLAB gui are:-

a. **Component or object**: Objects like Pushbutton, listbox, uitable, textbox and so on. Guide provides an easy drag and drop method in order to create a desired GUI component.

Fig. 42 Example of a component

b. Figures

Figures are window-forms in MATLAB. Any visual studio tool has form designer and in MATLAB these forms are called figures. In the normal MATLAB operation, figures are created automatically whenever the MATLAB plot function plots a data. Empty figures can also be created with the function 'figure ()' on the command window. It can also be used to plot any kind of gui components by adding the function arguments.


Operate_GPenSIM

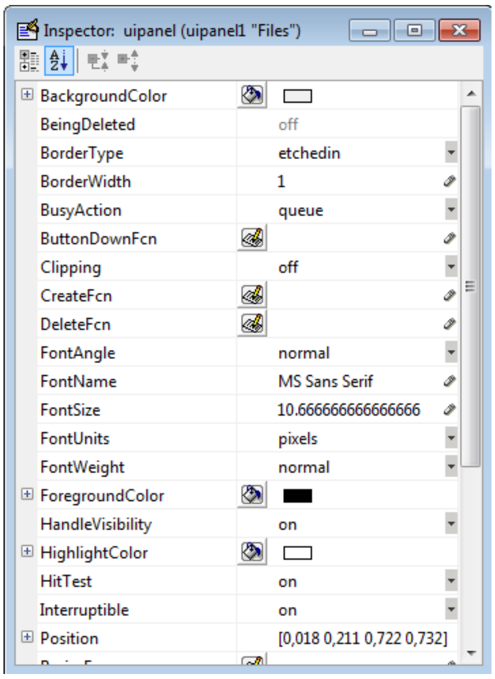
Files

MSF Filename	Documents\MATLAB\Thesis\RT_Monitor
PDF Filename	Documents\MATLAB\Thesis\RT_Monitor
TDF file name	:s\MATLAB\Thesis\RT_Monitor\t1_pre.m

Fig. 43. GPenSIM file Operation figure (Created for illustration)

c. Property inspector:

The MATLAB GUIDE provides a property inspector tool. From where we can inspect properties like background colour, component name and handle events. Almost every GUI providing software studios have a property inspector. The MATLAB GUIDE property inspector is shown below.


Inspector: uipanel (uipanel1 "Files")

BackgroundColor	▭
BeingDeleted	off
BorderType	etchedin
BorderWidth	1
BusyAction	queue
ButtonDownFcn	
Clipping	off
CreateFcn	
DeleteFcn	
FontAngle	normal
FontName	MS Sans Serif
FontSize	10.6666666666666
FontUnits	pixels
FontWeight	normal
ForegroundColor	■
HandleVisibility	on
HighlightColor	▭
HitTest	on
Interruptible	on
Position	[0,018 0,211 0,722 0,732]

Fig 44. MATLAB GUI designer property window

d. Callbacks

Finally, there must be some way to perform an action if a user clicks a mouse on a button or types information on a keyboard. A mouse click or a key press is an event, and the MATLAB program must respond to each event if the program is to perform its function. Every 'callback' function has a variable called 'handles' to handle each operation since the guide is an event driven program. Generally 'callback' function controls the behaviour of the gui figure and of individual components. MATLAB software calls a 'callback' in response to a particular event for a component or for the figure itself. [35]

The 'callback's are automatically created as the user selects tools and draws on the design layout tool. The 'callback's in any figure can be accessed by right click on the component on the designer view. Note that the method 'callback' is the main connector of the figure and the background program. Whenever some event happens, the 'callbacks' pass arguments to the three variables.

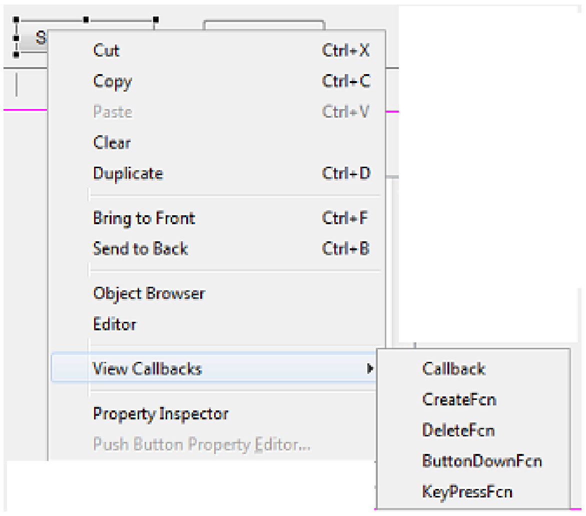


Fig. 45. A MATLAB GUIDE designer view

For example a 'callback' function for the above pushbutton is shown below.

```
function pushbutton1_Callback (hObject, eventdata, handles)

% hObject handle to pushbutton3 (see GCBO)
% eventdata reserved - to be defined in a future version of
MATLAB
% handles structure with handles and user data (see GUIDATA)
```

The comments are created by GUIDE as an annotation for the GUI component to inform what the variables are used for. These comments are optional and can be removed.

A MATLAB GUIDE by default creates a main function by passing two different types of variables called 'varargin' and 'varargout'. Every '_Callback' function passes at least three types of variables. A developer can choose which one is comfortable for his code. Note that each of them have different purposes. These are; ***hObject***, ***eventdata*** and ***handles***. If each of them is not used in the 'callback' function the guide will put an underline warning sign on each of them.

hObject: This variable handles the event of current operating object or component which creates a 'getcallbackobject' called GCBO. In MATLAB, the GCBO are dynamically created each time when a callback is executed. Their functionality is to get handle to current callback object [OBJECT, FIGURE] = GCBO and returns the handle of the object whose callback is currently executing and also the figure containing that object. [36]

eventdata: The event data in MATLAB take event handlings data and pass throughout the platform. These are reserved for future version of MATLAB.

handles: This method is the basic for MATLAB GUI events. When MATLAB creates a graphics object or component, it assigns an identifier to the object. [37] This identifier is called 'handle' and sometimes denoted as '**h**'. One can use the "handle" identifier variable to access the "hObject" properties with two built in functions called "set" and "get" functions. For example, the following quadratic statements create a graph and return an event data to a plot result object in a form of h:

$$x = 0{:}\,0.1{:}\,1$$
$$y = 2x^2 + x$$
$$h = plot(x, y)$$

We can use the handle event handler h to set and get the properties of the 'quadratic plot' object. For example, we can set its fore ground colour property as:

```
Set (h,'Color','red')
```

We can also specify the properties when we call the plotting function in another M-script file:

```
h = plot(x, y,'Color','red');
```

We can also get the object property by using a get function. And it will return the object and its possible values as numerical value which is an id for that component and its property.

A= get (gcf,'Color'), where gcf returns the current figure, and it stands for get current figure.

```
Will return
    ans=
         0.2 0.2 0.1
```

This value is the combination of one of the MATLAB colour RGB.

- In addition to the 'Callback' function, a MATLAB GUIDE also creates four types of functions with some templates.

  These are:

1. **Guiname**

   This is main function and created with some templates like struct. It will be discussed in detail in the implementation part.

   The main functions with two variables look like this

   ```
   function varargout = guiname(varargin)
   ```
2. **Guiname_OpenFcn**

   The prefix "guiname" before the underline score is the name of the figure and the suffix after the underscore is a built in function name for opening the figure file on run time. The function is used to open the figure just after the main function is run and it fills the 'handles.output' with proper arguments and a starting event. The function takes four arguments i.e. hObject, eventdata, handles and varargin.
3. **Guiname_Output**

   Similarly the prefix "guiname" before the underline score is the name of the figure and the suffix after the underscore is a built in function name for guide. The rest of the string "_OutputFcn" is a reserved word to export the event data.
4. **Componentname_Create**

   This function is created for every created component by gui. For example; if we create a pushbutton using a GUIDE. The GUIDE will automatically create a source code for the component to be created. Changing this function will make the component unresponsive.

4.4 R-T monitor user interfaces

The Real-Time display interface consists of three forms, each of the interfaces are invoked by GPenSIM according to their usage. A MATLAB provides a method to exchange GUI data in an object format.

4.4.1 Design of an interface to select a Real-Time places and transitions

The name 'Real_PTtime_select', which refers to Real Places and Transitions select, and is given because this graphical user interface is used to select real-time component, here in our case places and transitions of the Petri net definition files. This is to mean that we can specifically select the places and transitions from over all components of the real-time Petri net model. The need to minimize the number of places and transitions is that when we work with large systems and while there are plenty number of places and transitions in the model, we need to limit our focus only with some places and transitions at the same time.

Literally it is to mean that it is impractical to control and watch the overall activities of a large Petri net model within a single monitor. In this R-T monitor, the maximum number of places is set to be 7 and the maximum number of transitions is set to be 10.

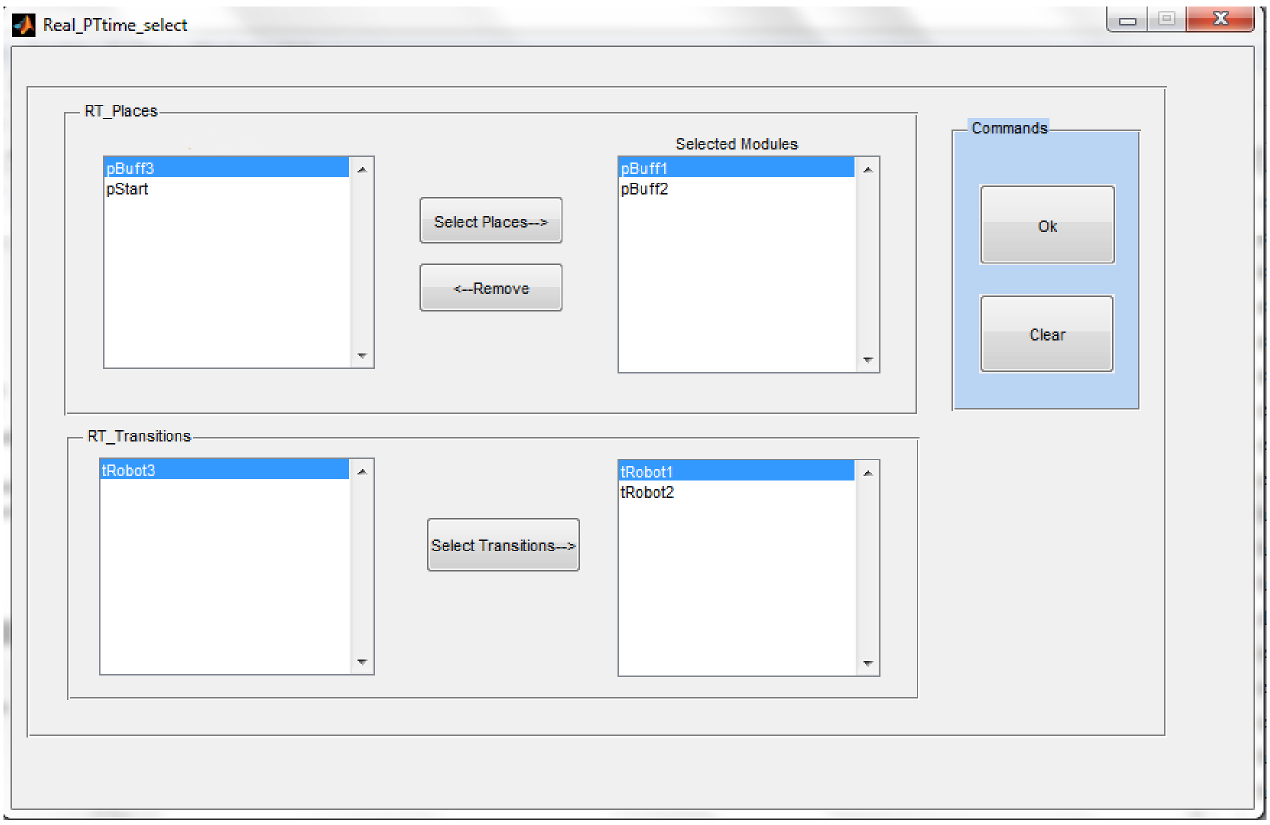


Fig. 46. Real-Time components' selector (Real_PTtime_select)

The R-T component selector has a graphical user interface with different push buttons and list boxes. In the figure above, the graphical interface has three separated panels. The first panel is called "RT_Places", the second panel is called "RT_transitions" and the third one is called a "command". Each of the first two panels consists of two push buttons named as "select places or transitions" and "remove" buttons and two list boxes.

The following figure shows the "RT_Places" panel. The design is the same for "RT_Transitions".

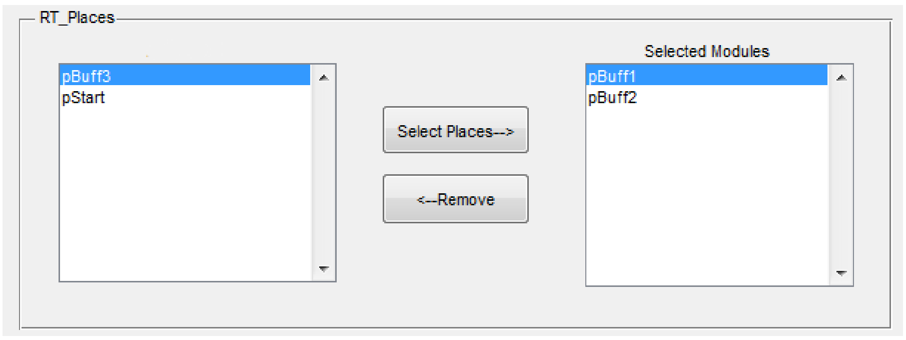


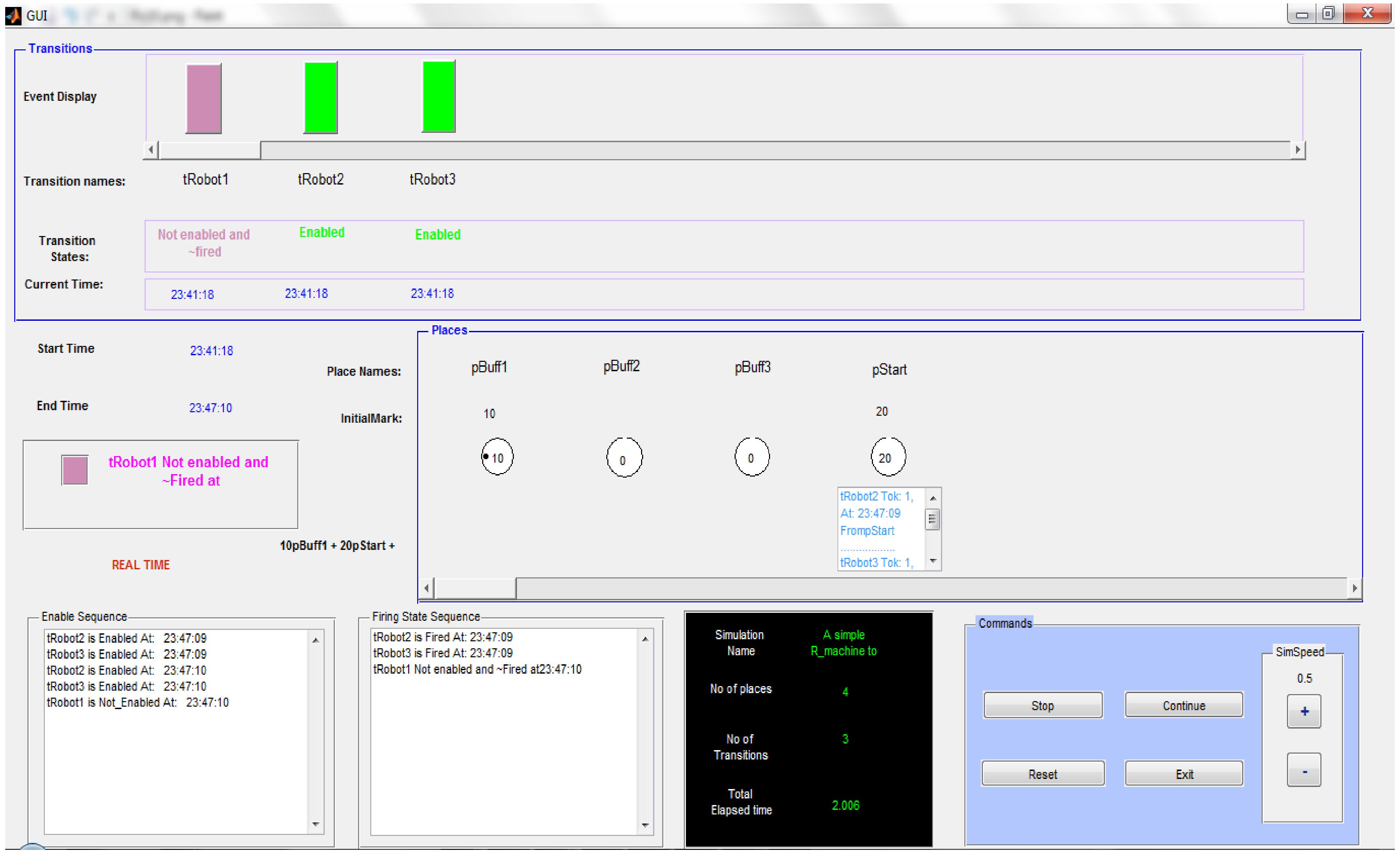
Fig. 47. R-T_places panel.

The first side, left side, list boxes automatically load all places and transitions from the global GPenSIM variables and by using the middle buttons; we can choose a selective places and transitions that we wanted to observe visually throughout the real-time simulation process. This has also been designed to have a remove button so that we can remove the unwanted but selected items so that the simulation won't be interrupted. The last command panel has two buttons "ok" and "clear". The 'ok' button saves the selected items from both panels, R-T_places and R-T_Transitions, right sided list boxes to set of real-time components and return to the simulation process. This user interface is implemented in aiming the user can easily select the real-time components easily from every modules without any ambiguity. The interface is embedded inside the GPenSIM tool and run whenever we start running a main simulation file.

4.4.2 Design of a graphical display system for Real-Time Monitor (GUI main)

This HCI form is the heart of the R-T monitor display. After we select the real-time component using 'Real_PTtime_select' form, this graphical display form appears and starts displaying the background process of the GPenSIM simulation process. The display unit is designed to acquire all the necessary information of the real-time component. As it is mentioned in the statement of problems, the main objective is to provide GPenSIM with Real-Time display unit that would show the simulation of the Petri net model. The GUI is embedded inside GPenSIM. When a main simulation file runs, it will also start running after we select the necessary R-T monitor elements. We know that GPenSIM runs in two modes, i.e. either in real-time or simulated time. So the GUI is designed to run in both modes, i.e. It runs both in the real-time and the non-real-time simulation modelling but it gives an information in what mode is the simulation running.

The following figure shows the whole GUI display unit. It has different kinds of components. The detail will be explained in the implementation part. To illustrate the interface design, as shown in the following figures,



Transition names: tRobot1 tRobot2 tRobot3

Transition States: Not enabled and ~fired | Enabled | Enabled

Current Time: 23:41:18 | 23:41:18 | 23:41:18

Start Time 23:41:18

End Time 23:47:10

tRobot1 Not enabled and ~Fired at

Place Names: pBuff1 pBuff2 pBuff3 pStart

InitialMark: 10 | | | 20

10 0 0 20

10pBuff1 + 20pStart +

```
tRobot2 Tok: 1,
At: 23:47:09
FrompStart
.................
tRobot3 Tok: 1,
```

Enable Sequence

```
tRobot2 is Enabled At:   23:47:09
tRobot3 is Enabled At:   23:47:09
tRobot2 is Enabled At:   23:47:10
tRobot3 is Enabled At:   23:47:10
tRobot1 is Not_Enabled At:   23:47:10
```

Firing State Sequence

```
tRobot2 is Fired At: 23:47:09
tRobot3 is Fired At: 23:47:09
tRobot1 Not enabled and ~Fired at23:47:10
```

Simulation Name	A simple R_machine to
No of places	4
No of Transitions	3
Total Elapsed time	2.006

SimSpeed 0.5

Fig 48   R-T monitor main window

The components of the R-T monitor are grouped in different panels. This gives clear information about the status of R-T elements and can easily be controlled. As shown on fig., there are seven panels. These are:

i. Transition panel

As the name implies, this panel consists of the selected elements of the real-time P-N model transitions. It contains detail information of every single transition. Here we need to remember that the panel consists of only the selected transitions.

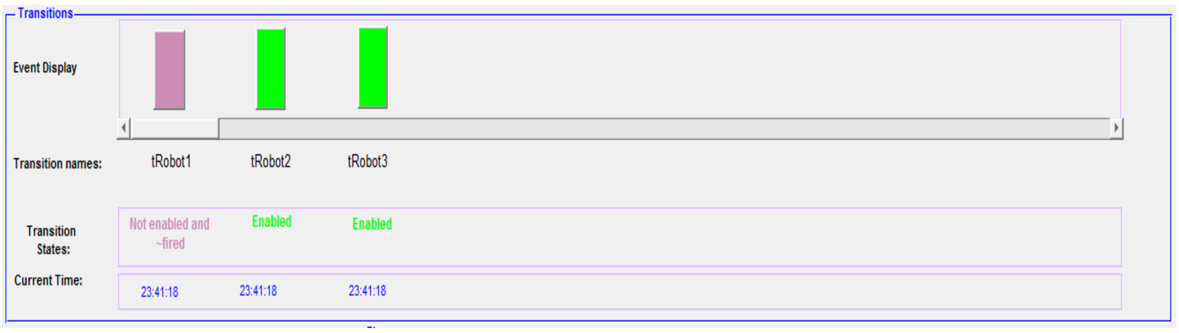


Fig. 49. Transition panel on R-T monitor

The information provided by this panel are; event display or color based animation, associated transition names, Transitions' status and the current time for real-time display. The event display displays the status of every transition in the R-T monitor. Every transition has a display denoted by a rectangle and their status is identified by different colors based on their events. i.e., In a Petri net model, a transition has basic four states, and these are:

a. Enable or not enabled state

In the R-T monitor the enabled transitions are denoted by green rectangle, i.e. whenever a transition fulfils the 'enable' criteria in the precedence matrix in the current simulation loop of GPenSIM, The display rectangle will switch the color to green.

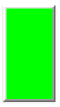


Fig. 50 a transition of R-T monitor on enabled status, Enabled transition

b. Fire or not fired state

Similarly for a transition that is currently firing in the current time and current loop, the rectangle will be switched to red to inform the current status of the transition and it will stay red until the next event comes.

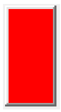


Fig. 51 a transition on firing status

c. Never firing state or dead locked and enable but not firing

This transitional event status display is a little bit different. From the incidence matrix of the Petri net, a transition can fall in to two categories. These are a transition cannot fire in the current loop and a transition is enabled but is not firing in the current loop. This should be observed while we work with real-time simulation. It's because of the fact that we can see the where about of every token and in the preconditions. If a transition fall in this group, the color of the rectangle will switch to cyan for enabled but not firing and light purple for never firing. Here we need to mind that the two events are alike even if the transition is cannot fire in both cases.

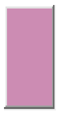


Fig. 52. Never fired transitional event

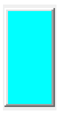


Fig. 53. Enabled but not firing transition

d. Firing complete state

In GPenSIM, after a transition has passed through enabling and firing events, it will be considered as a complete event. So in the R-T monitor, it is denoted by a yellow rectangle as shown in the figure below.

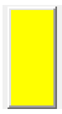
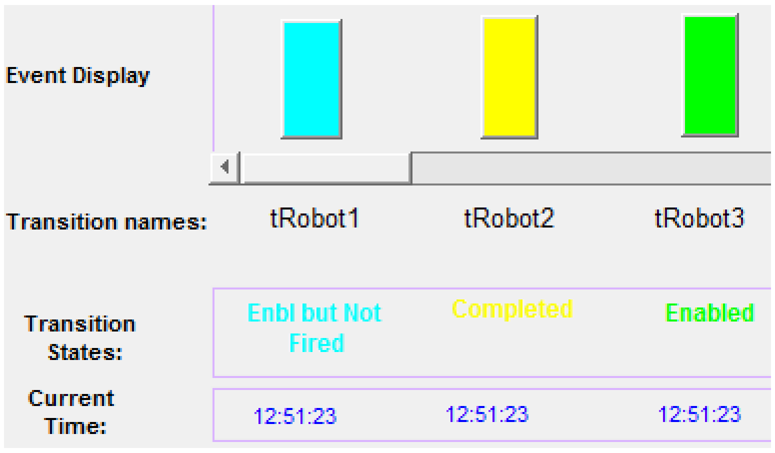


Fig. 54. A Firing complete event

The "Transition panel" also contains information under the rectangles like caption for the name of every transitions named as "Transition name", colored texts based on their status as transition status, and the current time which is in real-time. The need for a color text is that, the events of the transition are as fast as a human eye can't even see it especially in sensor networks. Thus, the good way to keep an eye open is to give extra information about an event and put it to a log file so that the user can revise it at any time.

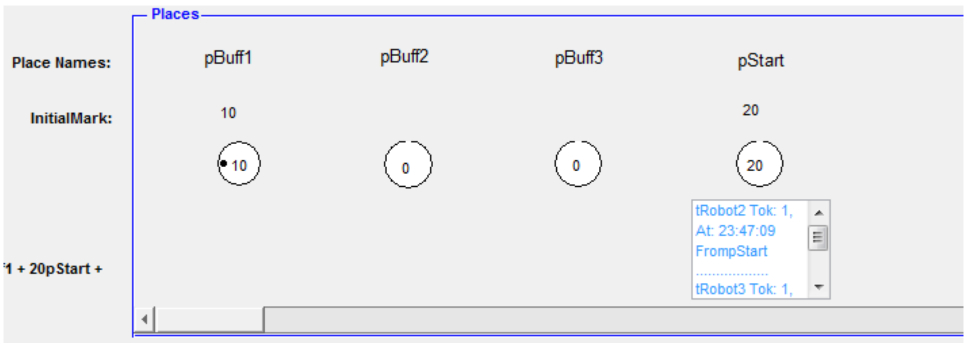

Event Display

Transition names:	tRobot1	tRobot2	tRobot3
Transition States:	Enbl but Not Fired	Completed	Enabled
Current Time:	12:51:23	12:51:23	12:51:23

Fig. 55. Transition names, event status and Current time display

ii. Places panel

A place panel contains a similar to above section i., transition panel, and gives information about the status of the selected real-time places of R-T monitor. Like transitions denoted by a rectangle in "Transition panel", places are also denoted by small circles in this panel, this is also to give extra visibility for places. The following figure shows the place panels in the R-T monitor.


Places

Place Names:	pBuff1	pBuff2	pBuff3	pStart
InitialMark:	10			20
	10	0	0	20

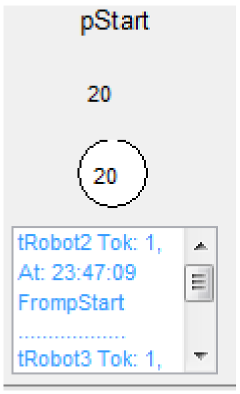
1 + 20pStart +

tRobot2 Tok: 1, At: 23:47:09 FrompStart
....
tRobot3 Tok: 1,

Fig. 56. R-T monitor places

This panel also provides information about the quantity of the tokens, starting from the initial markings up to the final token absorption in every place. When every time a transition fires a token, the R-T monitor also displays the number of tokens mobilized in every places inside the circle.

It has also a textbox to display which transition has taken the token and at what time. Displaying such information is quite feasible especially while we work with some real-time simulation, controlling the movement of tokens gives extra information for the controller. For example while modelling and simulating a building with full of distributed sensor networks, controlling only the events might not be enough. I.e. there might be a need to visualize the movement of every single token in every place.

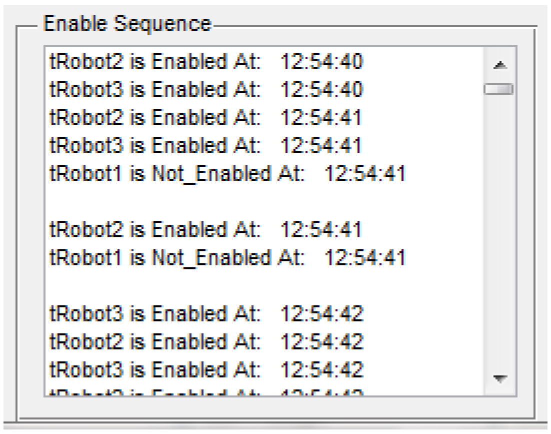


```
tRobot2 Tok: 1,
At: 23:47:09
FrompStart
..................
tRobot3 Tok: 1,
```

Fig. 57. A Single place and full info for R-T monitor.

iii. Enable sequence log.

This GUI panel contains a wide textbox to display the status of the enabled transitions in the entire simulation loop in a sequence fashion. It can also serve as a text log file and it can be exported to another use. Note that this log stores not only the selected R-T monitor transitions but also all the global transitions of the simulation. This helps to give a clear image of the sequence.

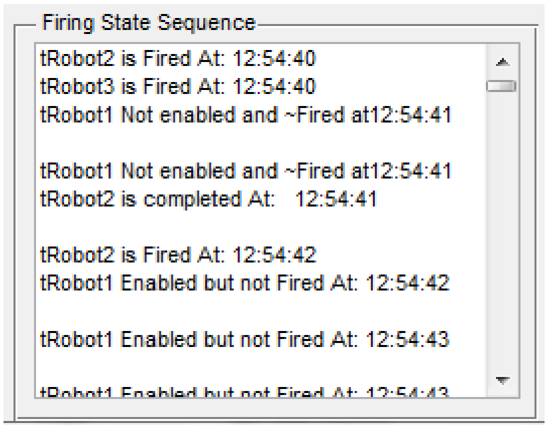


```
tRobot2 is Enabled At:   12:54:40
tRobot3 is Enabled At:   12:54:40
tRobot2 is Enabled At:   12:54:41
tRobot3 is Enabled At:   12:54:41
tRobot1 is Not_Enabled At:   12:54:41

tRobot2 is Enabled At:   12:54:41
tRobot1 is Not_Enabled At:   12:54:41

tRobot3 is Enabled At:   12:54:42
tRobot2 is Enabled At:   12:54:42
tRobot3 is Enabled At:   12:54:42
```

Fig. 58. Enable sequence on R-T monitor screen

iv. Firing sequence log.

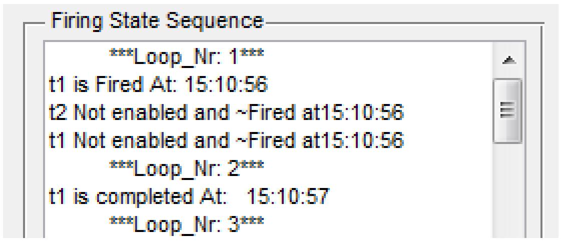
Similar to the enable sequence log, there is also a method called firing sequence log for firing transitions. This again stores the entire firing sequence of the transitions.



```
tRobot2 is Fired At: 12:54:40
tRobot3 is Fired At: 12:54:40
tRobot1 Not enabled and ~Fired at12:54:41

tRobot1 Not enabled and ~Fired at12:54:41
tRobot2 is completed At:   12:54:41

tRobot2 is Fired At: 12:54:42
tRobot1 Enabled but not Fired At: 12:54:42

tRobot1 Enabled but not Fired At: 12:54:43

tRobot1 Enabled but not Fired At: 12:54:43
```

Fig. 59.a Firing sequence on the R-T monitor

The space shows the loop interval and the active transition in every loop. In the GPenSIM main simulation file, if the “global_info.PRINT_LOOP_NUMBER = 1”, the spaces would be replaced with a string with loop number to show the loop interval as shown below.

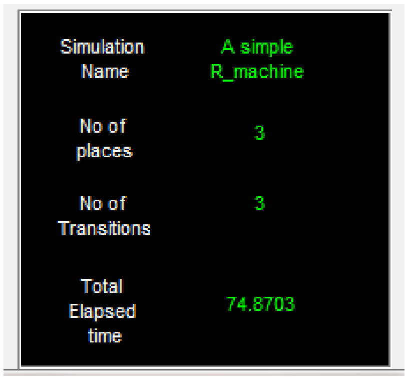


```
        ***Loop_Nr: 1***
t1 is Fired At: 15:10:56
t2 Not enabled and ~Fired at15:10:56
t1 Not enabled and ~Fired at15:10:56
        ***Loop_Nr: 2***
t1 is completed At:   15:10:57
        ***Loop_Nr: 3***
```

Fig. 59.b Firing sequence with loop number

v. Basic info

This GUI panel shows a basic info about the total number of places, transitions, simulation name, and total elapsed time.



Simulation Name	A simple R_machine
No of places	3
No of Transitions	3
Total Elapsed time	74.8703

Fig. 60. Basic info about the Model simulation.

vi. Commands

This is also another panel that contains some commands to control the simulation, this gives the R-T monitor extra capability in controlling the simulation besides displaying the events. For example while we simulate a robot that takes from the CNC machine and put to the buffer, if the user needs some diagnosis, the simulation can be stopped so that the working machines also paused.

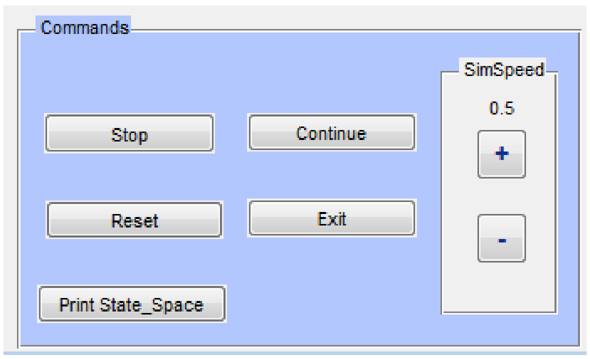


Fig. 61. Control buttons on R-T monitor

While the simulation is pause, there is some added time to the overall elapsed time, this should be handled, otherwise in real-time simulation, delay has a significant factor. Let's denote a delay between two event a and b, as t

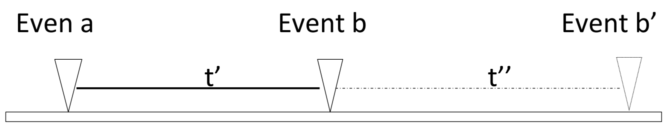


Fig. 62. Event diagram with time

Event b was supposed to happen at t' but due to the delay Δt it ended at t''. The overall elapsed time would be, t' + t'', and the delay is Δt=t''- t'. From this we can conclude that pausing the simulation for longer time will make the Δt to be high. This can lead the system to be less accurate.

Similarly the command panel contains a method to control the speed of the simulation, In GpenSIM, while working with real-time, we can also speed up or delay the firing without losing the real-time but just only adding some delay time, δ.

$\Delta\delta=\delta_f \; - \delta_o$, where f is final time, o is initial time.

The difference between this and the above pause is that the delay time is very small, the maximum 0.25, in speed control so that it won't affect the real-time.

vii. Sequence display of global transition status

The R-T monitor has also an extra display to show the status of the rest of other transitions, this would give a full functionality for the R-T monitor in displaying every event in the entire simulation. For example in the figure below, tRobot3 may be in the in the R-T monitor or not but it is a transition in the entire simulation.

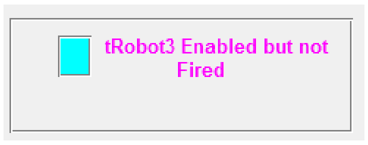


Fig. 63. A small display panel to show the status of all the transitions in the simulation.

Chapter 5

5. Implementation

The R-T display system was implemented using MATLAB software. As it was mentioned in chapter 4, The R-T monitor can be implemented with different kinds of tools like java or other graphical user interface supporting tools like visual studio.net. Note that MATLAB can support and access the packages of java and other languages. But the precise way of implementing this graphics display system, or R-T monitor, for GPenSIM would be using the MATLAB studio. This is due to the fact that GPenSIM by itself runs in a MATLAB platform and also the performance of a MATLAB would decrease while working with an imported graphics data especially for simulation. The previous chapter shows how the basic interface design of R-T monitor is made and what are every single terms in the R-T monitor. Once the system has been designed, the next math is connecting every graphical interface components based on the GPenSIM events. During the simulation process, they should be handling events and giving the interface a real meaning. As discussed above, the MATLAB guide has objects like push button, textboxes, axes and list boxes and their event driven callbacks like **handles**, **hObject** and **eventdata** to export and import information. The implementation has global variables. But the following table shows the most important global variables that carries data throughout the system. There are also other kinds of global variables and they are added in the appendix part of the report.

Global variables	Descriptions	Examples used
`global hn`	It is used to search the hObject in the gui components.	Section 5.1.3
`global PN`	It is a gpesim global struct variable that contains a every information of the Petri net model	Section 5.1.2
`global handles`	It makes the other classes to access the gui event handlers throughout the system.	Section 5.1.2
`global global_info`	This is an important gpensim global variable, its main functionality is to carry information of different cell arrays throughout the system.	Global_info in any main simulation files.
`Global temp1,temp2`	To store the enabling and firing sequences to plot on R-T monitor	

Table. 2. Global variables

5.1 Implementation of R-T monitor.

As it is mentioned in chapter 4, the R-T monitor has two main gui interface forms. The two forms in the R-T monitor are called '**Real_PTtime_select.Fig'** and '**GUI.fig**'. We should recall that the '.fig' extension is a MATLAB figure file extension which contains the layouts of the gui components. Recall that both figure files were designed using a MATLAB GUIDE tool. Every figure file in a MATLAB has a background MATLAB file, *.m. Thus MATLAB keeps two separate files for every MATLAB gui file names with same name but different file extensions. For example for 'Real_PTtime_select' name, there are two kinds of files called 'Real_PTtime_select.m' and the layout 'Real_PTtime_select.fig'. (Note that the two files can be kept on separate directories, but it would be better to keep both of them inside the same directory. A MATLAB file path can detect it wherever the other files. This has been one pro about MATLAB). Both 'GUI' and 'Real_PTtime_Select' runs before the simulation starts. Their main purposes are to prepare a rough sketch i.e. HCI tool to display the simulation status.

The flow chart of R-T system

The flow chart and the algorithm of R-T monitor are shown below. The general overview of the design was shown in the design section.

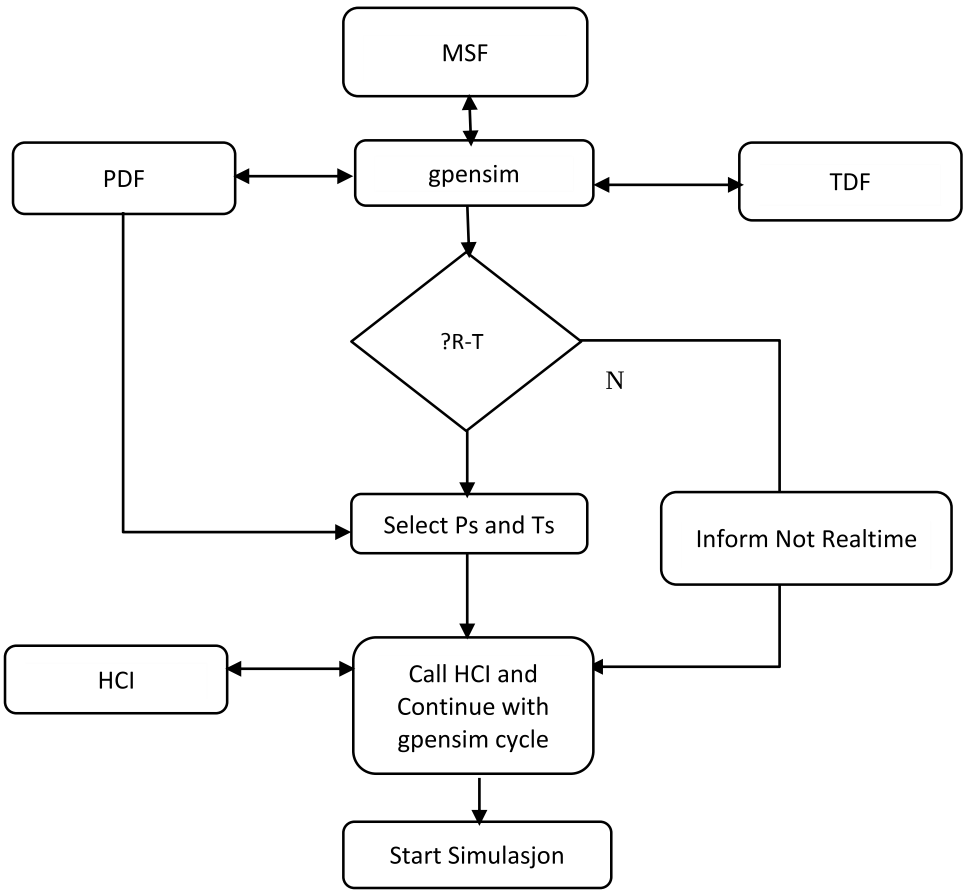


Fig. 64. The flow chart of R-T monitor

In the above flow chart, the HCI tool contains all the gui components and script files of the GUI.m. The rest of the flow is a normal GPenSIM operation.

In addition to the two GUI files, the system has also different classes that help handling the GPenSIM and filling out the information on the GUI. The functions and classes of the R-T monitor, i.e. the GUI components and other files, are added in to the GPenSIM background source code and these are identified by some comments from the original gpensim file. The MATLAB scripts files that are implemented in the R-T display are:

File names	**Description**
Real_PTtime_select.m	See Chapter 4
GUI.m	See Chapter 4
find_GUI_component_places	To search a current source place name where a token has been removed from GUI components.
find_GUI_component_trans	To search a current active transition name from the GUI components.
token_number_ngt.m	This MATLAB file plots the real-time token during the runtime.
fill_GUI_initial_dy.m	This file plots the initial marking of the real-time places at the beginning of the simulation.
gui_painter.m	This MATLAB file has global variables like handles which can directly access the GUI.m and GUI.fig in Order to paint the coloured bars according to the status of the transitions in the current cycle.
enable_AnimNGT.m	This file invokes the file 'gui_painter.m' with associated transition name, current time, and type of colour in order to paint a green bar which is dedicated for enabled states in the R-T monitor.
fire_AnimNGT.m	Similarly this file has a function to invoke the file "gui_painter" with variables like the transition name, current firing time t and colour type in order to plot a red bar for firing transitions.
fire_Complet_AnimNGT.m	This file has also a similar function like the above two. Its purpose is to plot yellow bars for the transitions that have completed firing with the associated firing time t.

hasnotfired_AnimNGT.m	This method calls similarly the “gui_painter” file by passing the current transitions and a flag. The flag is used to differentiate the two states of firing of transitions. I.e. We know that a transition might be enabled but not fired at time t and also there can be a condition where a transition is not enabled and note fired at the current time t.
infoplc.m	This file has function to plot the status of the token flowing. I.e. it will write on the GUI the starting of the token to where the token is absorbed.

Table. 3. Implementation file names of R-T monitor.

5.1.1 Implementation of a user interface to select places and transitions.

This section is about an implementation of a figure file ‘Real_PTtime_select.fig’ in chapter 4. This figure file along with the MATLAB script file is embedded inside a GPenSIM system directory, i.e. the guide layout file with all the graphical user interfaces components “C:\\…\gpensim\timed_pensim\Real_PTtime_select.fig” and also the background script MATLAB file “C:\\...\gpensim\timed_pensim\ Real_PTtime_select.m”. The use and functionality of this MATLAB figure file were clearly described in the previous chapter. The main function of the GUI is:

i. The main function

In MATLAB working environment, the main function name and the file name use the same name. For example in Real_PTtime_select, the main function and the file have the same name. [33]

- The file name is, ‘Real_PTtime_select.m’
- The function name is, function varargout= Real_PTtime_select()

The main function, Real_PTtime_select(), takes two arguments, like any other figure created by GUIDE. These are “varargout” for output and “varargin” for input variable arguments.

Varargout - is a cell array for returning output arguments.

E.g. varargout {1} = handles.output.

Varargin - is also a cell array for passing variables as input arguments.

The main function begins with a series of comments for help documentation about the GUI. I.e. if someone wants to know about the Real_PTtime_select he can just type '>help Real_PTtime_select' on the command window.

The following figure shows the main function that is created by GUIDE to start the GUI layouts.

```
function varargout = Real_PTtime_select(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @Real_PTtime_select_OpeningFcn, ...
                   'gui_OutputFcn',  @Real_PTtime_select_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
```

The '**gui_singleton'** is a variable that is used as a flag to specify if one or more duplicated instances of the gui can exists simultaneously. I.e. it controls how many gui windows we can open at the same time. [32]

If 'gui_singleton' = 1, then there can be only one copy of the figure layout.

If 'gui_singleton' = 0, then there can be more than one simultaneous duplicate of the GUI figure. So in our R-T monitor, the 'gui_singleton' is always 1. I.e. there is no duplicate of the GUI at the same run time.

In addition to a 'gui_singleton' variable, there is also another declared structure variable, this struct contain all the declared variables in a struct form. These are; 'gui_filename', 'gui_singleton', 'gui_OpeningFcn', 'gui_OutputFcn', 'gui_LayoutFcn', 'gui_Callback'. This is automatically created by the GUIDE environment. The purpose is just to store the GUI state in one structure.

```
      gui_State = struct ('gui_Name', mfilename,...
      'gui_Singleton', gui_Singleton,...
      'gui_OpeningFcn', @Real_PTtime_select_OpeningFcn,...
      'gui_OutputFcn', @Real_PTtime_select_OutputFcn,...
      'gui_LayoutFcn', [],...
      'gui_Callback', []);
```

The other variables nargin, It is a MATLAB keyword used to define the number of input arguments for the main function. So the condition

```
if nargin && ischar (varargin{1})
    gui_State.gui_Callback = str2func (varargin{1});
end
```

Checks if there are input arguments i.e. `'varargin {1}'` and the inputs are of character array. If the conditions are fulfilled, then the Callbacks will be populated inside the gui_struct and perform a graphical layout operation.

The results will also be processed using `'nargout'`. Like in the above condition for `'nargin '`, the variable `'nargout'` also checks if there are output arguments. For example if a push button is clicked and the click has handled an event to do something. The result should also be appeared on the graphical user interface. The condition that checks this operation is shown below.

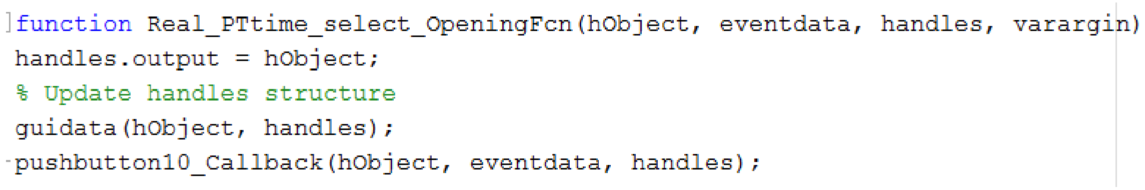
```
if nargout
     [varargout{1:nargout}]= gui_mainfcn(gui_State,
varargin{:});
Else
    gui_mainfcn(gui_State, varargin{:});
end
```

From the above condition, if nargout is true, then the main function calls the other MATLAB function 'gui_mainfcn' and passes the struct gui_state and all of its input arguments (varargin {:}) and returns as an output argument, varargout. If the there is no output, i.e. `nargout` is not true, then the gui_mainfcn will be called but varargout is null.

ii. OpenFcn, OutputFcn and CreateFcn

a. Real_PTtime_select_OpeningFcn

As it is mentioned in the previous chapter, whenever we create a GUI using GUIDE, a MATLAB automatically create different functions with some templates that can be edited. [32] The function 'Real_PTtime_select_*OpeningFcn*' is also a type of function created while designing a 'Real_PTtime_select_*OpeningFcn'* but has been modified to fulfil the conditions of the R-T monitor functionality. This function takes three input arguments of 'hObject', 'handles', 'varargin' and 'eventdata'. The 'hObject' refers to the current component that is doing some activity or event and 'handle' is an event handler of the 'hObject'. The function keeps the object for example pushbutton and put it in to the handles structure as an output.



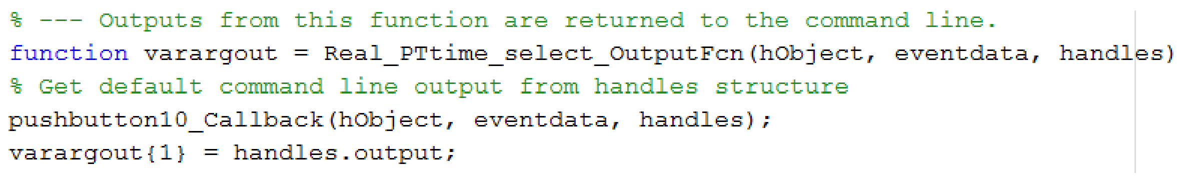
```
function Real_PTtime_select_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
% Update handles structure
guidata(hObject, handles);
pushbutton10_Callback(hObject, eventdata, handles);
```

The variable ‘guidata’ pass the content of the two variables ‘hObject’, ‘handles’. This ‘guidata’ store components like hObject along with their associated events and keep them in a form of structure data type.

This function is called only once in the R-T monitor. As mentioned above, the main purpose of this gui form is to select some places and transitions for displaying and monitoring.

b. Real_PTtime_select_OutputFcn (OutputFcn)

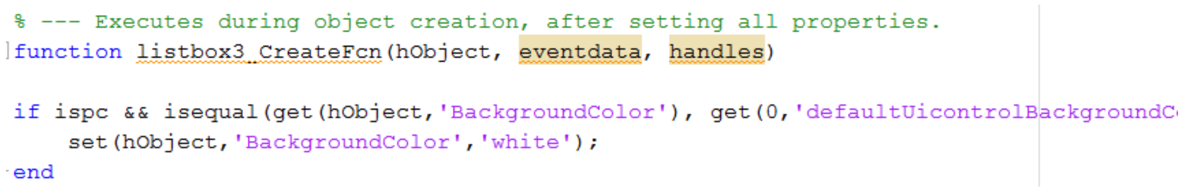
This function returns the output data to the MATLAB command line interpreter after the opening function returns control and before control returns to the command line



```
% --- Outputs from this function are returned to the command line.
function varargout = Real_PTtime_select_OutputFcn(hObject, eventdata, handles)
% Get default command line output from handles structure
pushbutton10_Callback(hObject, eventdata, handles);
varargout{1} = handles.output;
```

c. CreateFcn

This function contains an event that is used to create components like push button, dropdown menu and so on. For example a function to create components for 'listbox1' is named as listbox3_CreateFcn. This built-in MATLAB function automatically creates the ‘edit1’ textbox.



```
% --- Executes during object creation, after setting all properties.
function listbox3_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundC
    set(hObject,'BackgroundColor','white');
end
```

The ‘hObject’ in the above function is used as the newly created event handling object. And the ‘eventdata’ are reserved to the future MATLAB versions.

The variable ‘handles’ contains a structure with event handles and used to pass the newly created object’s event.

The GUIDE always creates components with templates. For example in the above list box, the default is created to be the window’s default background color.

iii. The callback functions

The above functions are just used to make layouts of the gui design, These functions are created by the GUIDE with some templates. To make the layout work the selection, their callback function need to be added. Since there are six buttons in the gui interface, there are six different 'callback' function for each of the buttons. The buttons are:

a. Select Places button
b. Remove places button
c. Select transitions buttons
d. Remove transitions button
e. ok
f. Clear

Both a and c have similar callback functions. Both of them take the selected item from the listed places and transitions from the left side list boxes and store them in to the right side list boxes respectively. At the same time the call back functions in a and c above build a string array that will be the global_info.rt_palces and global_info.rt_transitions. The other function b and d are used to remove unwanted items. The ok button returns to the main GUI display.

5.1.2 Implementation of graphical Display for Real-Time Monitor

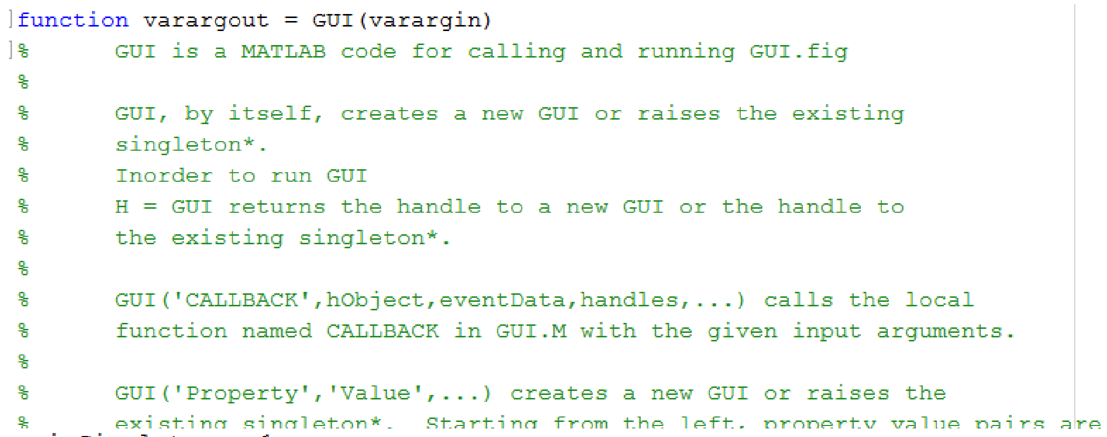
The declaration and initialization parts of the "GUI.fig" are similar to that of the previous section, "Real_PTtime_select" with some extra codes. Similarly this class contains both the layout figure file and the associated MATLAB script file. These both files are embedded inside a GPenSIM system folder, i.e. the guide layout file with all the graphical user interfaces components "C:\\...\gpensim\timed_pensim\GUI.fig" and also the background script MATLAB file "C:\\...\gpensim\timed_pensim\ GUI.m". The GUI.m has also different kinds of functions that plot constantly each event to the gui interface display (GUI.fig).

In the GUI figure of the R-T monitor;

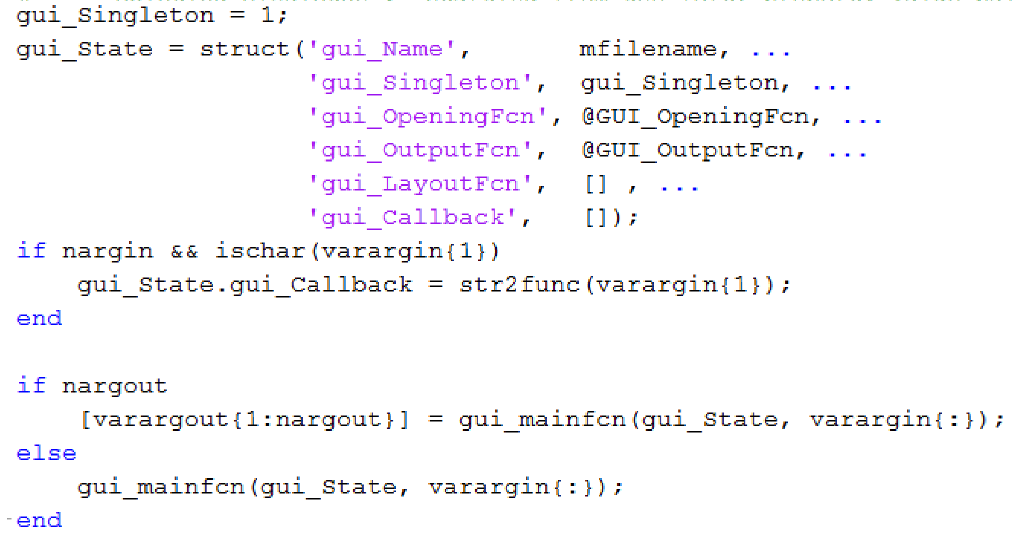
- The file name is called **'GUI.m'**
- The main function is called **'GUI ()'**, It takes and passes an input argument 'varargin' and return an output argument 'varargout'. The prefix name var is associated with the different types of variables in a MATLAB struct cell array form.

i. The main function

Similar to the implementation of 'Real_PTtime_select.m', section 5.1.1, the main function of GUI takes variable arguments and also returns some variable arguments, the main function with its input and output arguments is shown below:



```
function varargout = GUI(varargin)
%      GUI is a MATLAB code for calling and running GUI.fig
%
%      GUI, by itself, creates a new GUI or raises the existing
%      singleton*.
%      Inorder to run GUI
%      H = GUI returns the handle to a new GUI or the handle to
%      the existing singleton*.
%
%      GUI('CALLBACK',hObject,eventData,handles,...) calls the local
%      function named CALLBACK in GUI.M with the given input arguments.
%
%      GUI('Property','Value',...) creates a new GUI or raises the
%      existing singleton*.  Starting from the left, property value pairs are
```



```
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
```

This main function is also created by the MATLAB GUIDE tool as a calling function to call the figure file components. The comments are written for documentation. I.e. it will be served as a help file.

As it can be seen, everything in this main function except the function name is similar to the declaration of 'Real_PTtime_select.m' file. Initially this function was created as a template. i.e. It is a default '**gcf'** control function of the MATLAB GUIDE file that creates the basic layouts [33, 34, 35]. Then it has been edited according to out intension.

ii. OpenFcn, OutputFcn, CreateFcn

All of the three functions have a similar structure as that of the previous section. This are again initialized by the MATLAB GUIDE tool and edited according to the aim of the R-T monitor. The Opening function that has been called by the main function is shown below. This function is used to import and work event data. The keyword guidata accepts variables of the object or components called hObject and the event handler handles. The function will invoke another function that is called a start function by passing variables of the input arguments 'hObject', 'eventdata' and 'handles'. Those variables will call the function that starts the plotting and painting.

```
function GUI_OpeningFcn(hObject, eventdata, handles, varargin)
global cnt;
cnt=0;
handles.output = hObject;
guidata(hObject, handles);
startCode(hObject, eventdata, handles);
```

Similarly to the previous one, the output function would also be initialized automatically by the GUIDE. The main objective to prepare an output argument called 'varargout' that is used by the main function. The following code snippet shows the GUI_OutputFcn. Note that GUI is the name of the R-T monitor in the thesis.

```
function varargout = GUI_OutputFcn(hObject, eventdata, handles)
global global_info;
% global hn;
% global a;
varargout{1} = handles.output;
```

The varargout {1} refers to the number of event handles that would be returned as an output argument.

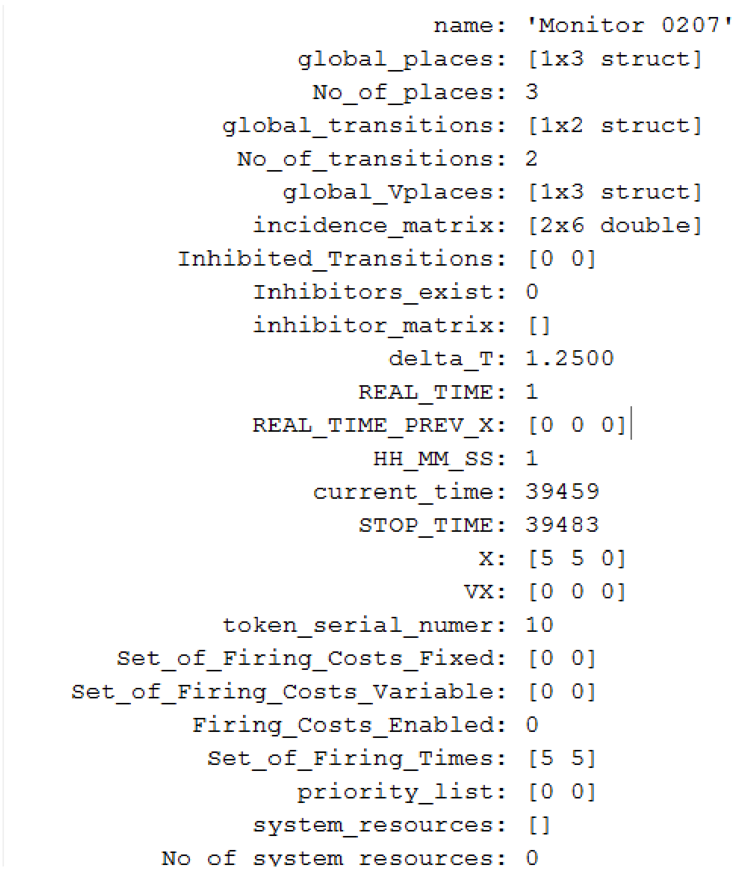
The 'createFcn', as mentioned in the previous section, is a function that creates the entire layout for every 'gui' component.

iii. Start The graphical user interface and plot the basic layouts

The function 'GUI_OpeningFcn', from the above section, invokes a function called 'startCode' which starts plotting a small circle for places and a bar for transition. Here not that the places and transitions are the selected places and transition from the overall places and transitions for a Real-Time displaying purpose. The function to do such condition is shown below.

```
function startCode(hObject, eventdata, handles)
global PN; % to acces the PN structure and informations from the Gpensim
global global_info;% is used to pass and acces the global variables
global gp_pause; % is used to pause the whole system to create a delay
gp_pause=0.5;% initilize to 0.5 second
```

In the above code snippet, the global variables are used as a bridge to import a gpensim run time components. Note that In MATLAB GUIDE the global variables should be declared inside every function unlike other programming language where global variables are declared on the top the class. [37]. in this implementation, the "global_info" is used to pass global variables. GPenSIM stores every component in a structure called PN. This PN contains information about the Petri net model. For example for figure 1 in the chapter 2, the PN struct variable contains a structure that is shown in in the next figure.



```
                      name: 'Monitor 0207'
             global_places: [1x3 struct]
               No_of_places: 3
        global_transitions: [1x2 struct]
          No_of_transitions: 2
            global_Vplaces: [1x3 struct]
          incidence_matrix: [2x6 double]
     Inhibited_Transitions: [0 0]
          Inhibitors_exist: 0
          inhibitor_matrix: []
                   delta_T: 1.2500
                 REAL_TIME: 1
          REAL_TIME_PREV_X: [0 0 0]
                  HH_MM_SS: 1
              current_time: 39459
                 STOP_TIME: 39483
                         X: [5 5 0]
                        VX: [0 0 0]
        token_serial_numer: 10
   Set_of_Firing_Costs_Fixed: [0 0]
Set_of_Firing_Costs_Variable: [0 0]
       Firing_Costs_Enabled: 0
        Set_of_Firing_Times: [5 5]
             priority_list: [0 0]
          system_resources: []
     No of system resources: 0
```

The above figure is a PN structure for a petri net model that has three places and two transitions. The structure value contains information like name, number of places, global places, and set of firing times, system resources and so on. For example the name of the simulation is denoted as PN.name, it contains the name of the simulation. Similarly it contains the global transition and places and these are denoted as 'PN.global_transitions' and PN.global_places. Note that both of them contain a matrix structure. For example if we have three places, the PN.global places will be: PN.global_places: [1x3 struct] and it will return the name of the places, the total number of tokens in that places and the token bank, a place where tokens are absorbed and stored. The [1x3 struct] for the above structure give a result in the command window as:

```
1x3 struct array with fields:
    name
    tokens
    token_bank
```

The next step is to organize the global variables as below before moving towards to plotting. Here the GUI accepts both the Real-Time and the non-real-time simulation. This condition is checked as

- If it is not a real-time, i.e. if we are using a simulated time, the places and transitions are by default extracted from the global PN variable. Simply we don't have places and transition that are selected for real-time display purpose. I.e. 'Real_PTtime_select' didn't run in the gpensim. The values are
    - PN.global_places
    - PN.global_transitions
- If it is in real-time, i.e. we have places and transition that are selected on run time from the 'Real_PTtime_select' interface. These values are named as:
    - global_info.rt_monitor_places and
    - global_info.rt_monitor_trans

```
if not(PN.REAL_TIME), % not real time, but work anyway
    disp('Not real time...')
    set(handles.text84,'String','NOT REAL TIME(SIMULATED CLOCK)')
    No_trans=PN.No_of_transitions;
    No_places=PN.No_of_places;
    global_info.rt_monitor_places = PN.global_places;
    global_info.rt_monitor_trans = PN.global_transitions;
else % if it is in realtime, take the global variable
     %from the Real_PTselect
    set(handles.text84,'String','REAL TIME')
    if ~isempty(global_info.rt_monitor_places) &&...
            ~isempty(global_info.rt_monitor_trans)
        No_trans=length(global_info.rt_monitor_trans);
        No_places=length(global_info.rt_monitor_places);
    else
        disp(['There is not places and transitions',...
            'selected for the realtime please select']);
        return;% there is nothing selected so...
               %return to the gpensim normal
    end
end
```

After calling the global values and check whether they are the member of the real-time or not. The next step is to pass each of those values to the MATLAB gui plotter to plot the circles and bars.

a. To display the status of places

For the places, the plotting is done as in the following code snippet. It shows the calling of the MATLAB 'axes' and 'Edit' gui components for every places in that cell array. The 'axes', which are MATLAB gui components, are used to plot small circles to illustrate the places and the edit boxes are used to put the name of the associated place that we need to plot. Remember that the names are extracted from the global places.

The function uses a MATLAB built in function called ‘eval’ in order to invoke the callback for the edit and ‘CreateFcn’ for axes. The ‘eval’ is an easy and fast MATLAB built in function used to run a given value.

```
for j=1:No_places
    try
        res=strcat('axes',num2str(j),'_CreateFcn(hObject, eventdata, handles);');
        res2=strcat('edit',num2str(j+2),'_Callback(hObject, eventdata, handles);');
        eval(res);eval(res2);
    catch err
         disp(err);
        break;
    end
end
```

The MATLAB string builder produces the two strings, for example for the first iteration in the loop, the ‘strcat’ yields,

```
 'axes',num2str(j),'_CreateFcn(hObject, eventdata, handles);'
   Gives: 'axes1_CreateFcn(hObject, eventdata, handles);'
 'edit',num2str(j+2),'_Callback(hObject, eventdata, handles);'
   Gives: 'edit3_Callback(hObject, eventdata, handles);'
```

Hence the ‘eval’ evaluates the above two strings, which has a meaning in the MATLAB GUIDE.

After evaluating the strings, or calling the callbacks, the MATLAB gui starts running the string.

– The functions that plot a small circle using axes are shown below.

MATLAB has different techniques to plot circles. The usual approach is using a rectangle command by changing the curve as [1, 1] which the MATLAB compiler knows this is a circle. CenterX, CenterY is the center of the axes,

```
function axes1_CreateFcn(hObject, eventdata, handles)
radius = 2;
centerX = 5;
centerY = 7;
% To draw a circle using rectangle in matlab
rectangle('Position',[centerX - radius, centerY - ...
                      radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;% make the axis same as the given dimention
```

– The function that writes place named just below the circles is shown below

```
function edit3_Callback(~, ~, handles)
global global_info;
global PN;
set(handles.uipanel20,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text68,'String',PN.global_places(1).name);
else
    set(handles.text68,'String',global_info.rt_monitor_places(1));
end
```

Since we have two kinds of simulation, this check whether the simulation is in real-time or not. The main purpose of this function is to plot place names. The command, set (handles…, 'Visible', 'on'), makes the initially invisible components visible during the run time. This is because of the fact that when the R-T monitor was designed using the designer tool, GUIDE, the components were made to be invisible and let the simulation makes them visible whenever they are needed.

b. To display the status of transitions

Similarly for the transition, a pushbutton is used to serve as a bar to represent the selected transitions. Again here the 'eval' function is used to run the built string using 'strcat' with the associated place. For example if we want to plot the first place, p1, the for loop produces a string as

```
'pushbutton1_Callback (hObject, eventdata, handles);
```

The eval will run this callback by passing the three basic variables.

```
for i=1:No_trans
    try
        m=strcat('pushbutton',num2str(i),'_Callback(hObject, eventdata, handles);');
        eval(m);
    catch err
        disp(err); break;
    end
end
```

The 'eval' runs the string and calls the callback function to plot or prepare the rectangular bar. The string that was built on the above code and called by the 'eval', starts running the following code in order to prepare a bar for the transitions to be plotted on the GUI during the simulation. The code runs for every transition in the R-T monitor.

```
function pushbutton1_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton1,'Visible','on'); % make the bar visible
if not(PN.REAL_TIME),
    set(handles.text1,'String',PN.global_places(1).name);
else
    set(handles.text1,'String',global_info.rt_monitor_trans(1));
end
```

The above code clearly shows if the simulation is in real-time, the name will be taken from 'PN.global_places' struct variable. Every buttons were made invisible at first. Whenever Their 'Callback' is called; they will be visible and ready for color plotting.

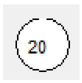
5.1.3 Other implementations of R-T monitor

The above two implementations, i.e. in section 5.1.1 and 5.1.2, are just used to select the Real-Time places and transitions and to prepare a graphical user interface to show the whole Simulation process for human, or they are used as a front end to communicate the user with the background GPenSIM libraries. The main issue is not to design a graphical user interface, rather it is to extract the basic information from the Petri net during the simulation process and plot those values graphically and enable the user to control the simulation accordingly. This is in other word; the statement of our problem is resolved. The codes that do this activity, i.e. those that connect the GUI components with the gpensim were roughly described in the table 2. In this section, we will try to look them deeply here.

i. Plot Number of Tokens on R-T monitor

As described shortly in table 2, the function 'token_number_ngt' is used to plot the number of tokens on every selected places during the gpensim runtime. The MATLAB file that do this activity is called **token_number_ngt.m.** And the associated function that passes arguments is called 'token_number_ngt ()'. This file is also embedded inside a gpensim system folder and contains a method to call the gui event handler and plot the number of tokens inside the small circles on the GUI. The file is stored in a gpensim folder as; C:\gpensim\05-Print_and_Plot\ token_number_ngt.m.

The extracted token numbers will be sent to the GUI, on the gui design view it will be displayed as.



This gpensim calling function of this file is called 'markings_string'. The use of the marking_string in gpensim is to identify the markings with a range of the matrix indices.

[25] This function takes two input arguments, these are the markings and the range of the incidence matrix named as ‘range_of_indices’.

```
function [markings_str] = markings_string (markings, range_of_indices)
```

Converts token vectors (markings) into a display string, e.g. [0 1 0 3] becomes 'p2 + 3p4'.

```
if tokens,
    if eq(tokens, 1),
        tokens_nr_str = ''; % no need to print '1' before
    else
        tokens_nr_str = int2str(tokens);
    end;
    markings_str = [markings_str, tokens_nr_str, ...
        PN.global_places(i).name, ' + '];
end; % if tokens,
```

The above condition checks if there are tokens in the gpenism matrix, if there are any, it will build the string ‘**markings_str**’ which contains the number of tokens in every places at time t. Now one the tokens are extracted, the next step is to display those tokens on the graphical interface. This is done by the **token_numner_ngt.m** file and it is invoked by passing variable as shown below.

```
%%%%NGT
if PN.REAL_TIME,
    token_number_ngt(curr_Place,int2str(tokens),markings_str);
end
%%%%NGT
end; % for i = 1:Ps,
```

In the above code, the **curr_Place** is the place that is currently holding the current tokens. Tokens are the current tokens in every places and the **marking_str** is the string that has a format to display on the command window.

'p1+ p2 + 3p4' for Matrix [1 1 0 3].

The function **‘token_number_ngt’** takes those variables and start putting the number of tokens in every place, i.e. circles in the GUI. The first step is to find the current place on the GUI by calling the function ‘**find_GUI_component_places**’ and then it starts putting those values.

```
function [] = token_number_ngt(curr_Place, tokens, markings_str)
global handles;
global global_info;
s=find_GUI_component_places(curr_Place);
%%%% To print the number of tokens in each places
if ismember(curr_Place,global_info.rt_monitor_places),
   if strcmp(s,'text68'),
       set(handles.text95,'String',tokens);
   elseif strcmp(s,'text69'),
       set(handles.text89,'String',tokens);
```

The set command put the tokens of the places in to the gui using the global handles.

ii. find_GUI_component_places.m

This MATLAB file is used to look after the place where the currently fired token has been taken from. I.e. it displays the source of the current token that has been stored into the virtual token bank. This function checks both for real-time and non-real-time components. If the simulation is in real-time, the place is checked from the cell array of the real-time, from the one that we have selected at the beginning.

```
function [s]=find_GUI_component_places(curr_source_name)
```

This function takes the current source place and returns its associated GUI member. This function is invoked by the **'fill_GUI_initial_dy.m'** and **'token_number_ngt.m'**.

```
len=length(global_info.rt_monitor_places);
if PN.REAL_TIME,
    for j=1:len
        if strcmp(curr_source_name,global_info.rt_monitor_places(j)),
            curr_source_name=global_info.rt_monitor_places(j);
            myobj = findobj(hn,'String',global_info.rt_monitor_places(j));
            if isempty(myobj),disp('cant get it');return; end
            myobj2=get(myobj);
            s = myobj2.Tag(~isspace(myobj2.Tag));
        end
    end
```

The above cone snippet is taken from the MATLAB file and its purpose is to find the place component in the GUI.

iii. Plot the initial markings on the GUI

According to chapter 2, the main simulation file of a gpensim contains the initial dynamics of the system modules. Thus it would be better to show the initial dynamics also on the real monitor screen. Its purpose is to show the comparison of token from their initial state throughout their simulation process. Note that the previous one is used to plot the quantity of tokens in every place as the simulation is on progress. This would give a big picture. I.e. the user doesn't need to recheck the initial dynamics as on the run time. The implemented script file that does this activity is called **fill_GUI_initial_dy.m.**

```
function fill_GUI_initial_dy(initial_dynamics)
global hn;
global PN;
global handles;
global global_info;

Ps = PN.No_of_places;
X0 = zeros(1, Ps);  % initially
```

X0 is used to put the initial markings in a cell array.

The function, ‘fill_GUI_initial_dy’ takes the initial dynamics of the gpensim as an input argument and plots it on the main gui by searching their appropriate place name on the gui interface. The MATLAB function that searches an object on the gui is shown below.

```
imarkings = initial_dynamics.m0;
if iscell(imarkings),  % sources = {'p1',1, 'p2', 3, ...}}
    no_of_sources = length(imarkings)/2; % number of places
    % extracting places
```

‘imarkings’ returns the initial marking of the MSF. Then from the ‘imarkings’, the code below extracts the number of token at the starting point.

The place will be searched on the GUI using the **‘find_GUI_component_places’** function and returns the place id on the GUI.

Once the searched object matched the one from the global real-time places i.e. the value of s is found in the above code snippet, the initial markings would be inserted into on the textbox that is found on the GUI.

```
for i = 1:no_of_sources,
 curr_source_name = imarkings{2*i -1};
 source_nr = check_valid_place(curr_source_name);
 initial_tokens = imarkings{2*i};
 X0(source_nr) = initial_tokens;
     if strcmp(s,'place_pos_nr_1'),
        set(handles.text77,'String',num2str(X0(source_nr)));
     elseif strcmp(s,'place_pos_nr_2'),
        set(handles.text78,'String',num2str(X0(source_nr)));
```

The above loop iterates for every places whose initial markings are declared in the main simulation file. For example, suppose we have 5 places and the initial marking is declared as dyn.m0 = {‘p1’, 10,’p2’, 10,’p4’, 20}, where ‘p3’ and ‘p5’ doesn’t have an initial marking, the loop skips those places that doesn’t have an initial marking even if they are components of the real-time simulation.

iv. Color plotter on R-T monitor

This file contains methods that frequently call the GUI eventdata handlers during the simulation process for plotting the status of the selected transitions. This MATLAB file is called from the three files i.e. v, vi, vii, and viii of the file sections below. All of them passes similar variables but with different kinds of information including the colour types to plot on the GUI. This is a way how the R-T monitor differentiates the status of every transition.

The 'gui_painter' function is shown below. The script file that does this activity is called **gui_painter.m.**

```
function[] = gui_painter(t1,t_btncolr,textT_str,textT_colr,str)
global PN;
global handles;
global global_info;
```

The calling function passes the arguments as follow for enable transition.

```
gui_painter(t1,'g','Enabled','g',str1);
```

Where t1 is the index of the current transition from the enabled transitions set, 'g' is a property in MATLAB for green color, and the function takes five input arguments.

args	Description	Input variables
t1	T1 is an index that selects the current transition from the global cell array.	.t1
t_btncolr	Color for the current active transition and plotted on the GUI.	'g' 'r' 'c' 'y'
textT_str	Name of the current active transition and written on the GUI.	'Enabled' 'Fired'
textT_colr	Color for the name of the current active transition.	'g' 'r' 'c' 'y'
Str	Status in text forms and used to give information in text. i.e. fired, enabled and so on	Str1,str2,str3

Table. 4. Variable that pass arguments to the painter

The variable 's_trans' is the current transition that is on processing at real-time t. then search the transition on the GUI and plot the appropriate info.

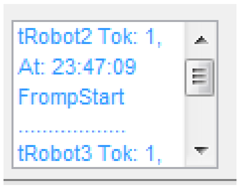
```
s_trans = find_GUI_component_trans(t1);
if ~isempty(s_trans),
    disp(s_trans)
    if strcmp(s_trans,'trans_info_txt'),
        set(handles.trans_info_txt1','String',string_HH_MM_SS(current_time()));
        set(handles.gui_bar1,'BackgroundColor', t_btncolr);
        set(handles.trans_info_txt11,'String',textT_str);
        set(handles.trans_info_txt11,'ForegroundColor', textT_colr);
    elseif strcmp(s_trans,'trans_info_txt2'),
        set(handles.trans_info_txt2','String',string_HH_MM_SS(current_time()));
        set(handles.gui_bar2,'BackgroundColor', t_btncolr);
        set(handles.trans_info_txt22,'String',textT_str);
        set(handles.trans_info_txt22,'ForegroundColor', textT_colr);
```

The strings with a single quotation in the above code snippet shows the names of the text boxes in the GUI designer and the ‘gui_bar’s are the bars designed on the designer of the MATLAB GUIDE to illustrate transitions and plot the color using series of ‘set’ commands as shown above. As it is shown on chapter four, the transitions are designed using a push button as a bar and their name on a text box. So what actually this function do is that; it searches the name of the transition, which is denoted by a pushbutton and the name with a text field, and plot colors using a set command with the appropriate properties.

v. Display real-time activities of places on R-T monitor

```
function []=infoplc(plI,transition,tokens_to_be_consumed)
```

This file has a function that do a similar function to that of the one which writes the tokens I every places but this one adds features that tell at what time is the token fired and which transition is responsible for it. It gives the output like this on the GUI. The MATLAB script file that does this activity is called **infoplc.m.**



```
tRobot2 Tok: 1,
At: 23:47:09
FrompStart
.................
tRobot3 Tok: 1,
```

vi. Start Firing for an enabled transition

The function that starts the firing of an enabled transition in GPenSIM is called **Firing_strat.m.** The next four steps, vii viii ix and x, introduces a method to plot the status of every transitions by calling the above file ‘gui_painter.m’. All of them are called from a ‘/gpensim/13-firing/firing_start.m’ file system folder. To describe their functionality we need to discuss about the firing_start.m file and its functions.

```
function [EIP]= firing_start(EIP)
```

This function is called from a gpensim file where the simulation starts, the variable EIP is a gpensim system file that is used for creating queue Q for events in progress no that EIP is initially 0 as there is no events in Q.

```
if any(PN.Enabled_Transitions),
   [EIP] = firing_start(EIP);
end
```

The firing start is an important gpensim system function, it has a lot of operations like resource management of tokens along with firing. But for the R-T monitor, the focus would be limited to only extracting he enabled transitions from the incident array.

vii. enable_AnimNGT.m

The name, 'enable_AnimNGT', is given after the term 'animation for an enabled' event of a transition from the project view as it performs the color plotting as a kind of animator. If there are any enabled transitions at time t, then it changes the color of the rectangular bars on the GUI to a green color by calling the function of 'gui_painter'.

In a Petri net model, there can be more than one enabled transition at a time t during a simulation process and gpensim puts all those enabled transition into a one dimensional Matrix, Array. For example if we have four transition, t1 t2 t3 and t4, in the model. Then gpensim puts all those values in an incidence matrix form as shown below.

PN.Enabled_Transitions: [0 1 1 0]

1:- Enable, i.e. p2 and p3 are enabled at time t

0:- Not enabled, i.e. p1 and p4 are not enabled at time t

From the above: say the current time t is: at 13:35:25 or 48917, then it can be described as At: 13:35:25 or 48917

```
48917        0        1        1        0
```

As the simulation goes, i.e. at Δt, the sequences of the enabled transition will be stored in a cell array and it will also been putted on the text box on the GUI. The value will be at: 13:35:25 or 48917, suppose the firing time is 1 second.

```
48917        0        1        1        0
48918        0        1        1        1
48919        1        1        0        1
```

PN is a global structure, as it was described in section 5.1.2, in gpensim that carries all the information about the Petri net model and the status and information of the Petri net model will be stored in a structure that contains matrix array and values are stored inside the PN structure.

In the same simulation cycle, the gpensim will call the ‘enable_AnimNGT’ file from the gpensim main file, i.e. gpensim. To do so the following functions calls this variable.

```
if any(PN.Enabled_Transitions),
    enable_AnimNGT();
   [EIP] = firing_start(EIP);
end
```

From the above code, the condition checks whether there are any enabled transitions in the current simulation cycle. And if so all the enabled transitions will be plotted green at the same time on the GUI until one of them fires. I.e. the one that fired automatically be turned to red by the fire animator.

We have discussed that in the cell array, values that are numbered one are enabled and what the ‘enableAnim’ function do is that it takes the index of those values that have one in the cell array and check if they are selected on the R-T monitor at the beginning. After checking those values it will call the ‘gui_painter.m’. The steps are shown below.

- It gets the index of values that are one in the cell array. E.g. [1 0 1 1 1]. This is the enabled transitions.

```
enbl_trans=PN.Enabled_Transitions;%   [0 1 1]
for i=1:length(enbl_trans)
    if eq(enbl_trans(i),1),
        curr_trans=PN.global_transitions(i).name;
        t1=i;
```

- Checks whether the transition exists in the cell array and if it is not a member it returns to the normal simulation system.

```
if PN.REAL_TIME,
   if ~ismember(curr_trans ,global_info.rt_monitor_trans),
        disp(['At ', rt_clock_string(), ' '...
          ,PN.global_transitions(t1).name,...
          ' is Enaled but not member of RT monitor ...']);
        disp('--RETURN ON RT_DISPLAY--');
        return;
   end
end
```

If the transition is enabled and found in the real-time array, then the ‘gui_painter’ will be called with a method.

```
gui_painter(t1,'g','Enabled','g',str1);
```

‘Str1’ is a global variable that records the status of the transition along with the current real-time that the transition is in an enabled state.

viii. fire_AnimNGT.m

This function has a method to call the gui painter in order to paint a red-bar on the GUI interface to illustrate that the current transition is on a fire-state.

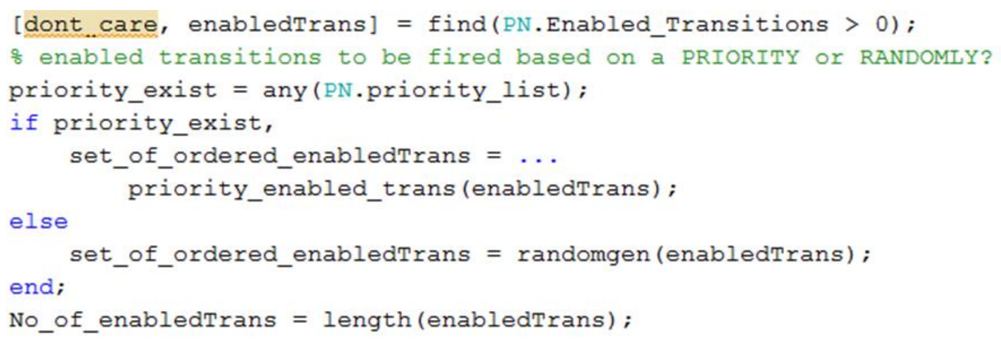
According to a Petri net theory,

Only an enabled transition can fire [11], and also by adding the GPenSIM TDF formalism, i.e. only a transition that is enabled and fulfils the precondition rule can fire. Thus like the enabled plotter, this function takes values from the gpensim variable PN, and call the gui plotter function in order to plot the red-bar on the main interface.

To call the 'fire_AnimNGT' from the 'firing_start.m' gpesim file, we need to pass the index of the current active transition. The variable used here is called t and the following two code snippets shows this action

```
function [EIP] = firing_start (EIP)
```

Inside the '**firing_start'** function, the next step, i.e. to plot a red bar on the GUI for a fired transition, we need get those enabled transitions. The method to extract enabled transitions is performed using a MATLAB keyword called "find".



```
[dont_care, enabledTrans] = find(PN.Enabled_Transitions > 0);
% enabled transitions to be fired based on a PRIORITY or RANDOMLY?
priority_exist = any(PN.priority_list);
if priority_exist,
    set_of_ordered_enabledTrans = ...
        priority_enabled_trans(enabledTrans);
else
    set_of_ordered_enabledTrans = randomgen(enabledTrans);
end;
No_of_enabledTrans = length(enabledTrans);
```

From the above code, the 'find' function returns all the items from the above Matrix, PN.Enabled_Transtions, with a value of 1. We should note that the find looks only for the transitions in current loop. Hence only one dimension is checked at time t Based on their priority i.e. t1, t2, t3, t4 or randomly, the transitions. The transitions would be sorted according to their priority or randomness.

GPenSIM provides sorting mechanism using two functions called "priority_enabled_trans" and "randomgen". The first function sorts out enabled transitions in descending order of their priority. And the other tool is used to order the enabled transitions randomly using a function called "randomgen". [25]

All of the transitions that are enabled are now sorted in a single cell array known as 'set_of_ordered_enabledTrans'. Then the next step is letting the transition that fulfils the pre-conditions to fire and on the other hand plotting calling the plotter to make the associated bar on the GUI red.

```
for i = 1:No_of_enabledTrans, % check events one by one
    t1 = set_of_ordered_enabledTrans(i);
    if not(PN.REAL_TIME),
        pause(1); % make some delay to reduce the speed for
        %simulated time
    end;
```

From the above code we can clearly see that ‘t1’ is the index of the current enabled transitions.

```
if and(PN.Enabled_Transitions(t1),...  % enabled & notcurrently firing
        ~(PN.Firing_Transitions(t1))),
```

Once the condition satisfied, i.e. transition (t1) is enabled but not currently firing, the next step is to check it on the precondition.

```
 [fcs, new_color, override, selected_tokens, additonal_cost]= ...
     firing_preconditions(t1);
```

The variable FCS returns the precondition result from the calling function, ‘**firing_precondion**’.

```
 if fcs, % firing conditions satisfied, let the transition fire
     PN.Firing_Transitions(t1) = 1;  %
     disp(['At ', num2str(current_time()), ' '...
         ,PN.global_transitions(t1).name, ' is fired ...']);
     %%% NGT
     fire_AnimNGT(t1);
```

The ‘fire_AnimNGT.m’ do a similar function to that of the ‘enable_AnimNGT’ but here the code takes ‘t1’ as the current firing transition state and is only used to plot red-bar on the GUI. The current transition can be accessed as follow.

```
curr_trans = PN.global_transitions (t1).name;
```

The function then called the ‘gui_painted’ in order to plot a red-bar on the GUI.

```
gui_painter(t1,'r','Fired','r',str2);
```

Str2 is a global value. Like that of ‘str1’ for enabled transitions, it records the status of the current firing transition as a string along with the current time.

```
str2=[PN.global_transitions(t1).name,' is Fired At: '];
```

```
temp=sprintf([temp,str2,num2str(current_time()),10]);
```

The value 10 is used to set a margin to record values on a newline. The ‘sprintf’ is the MATLAB keyword used to build string in a formatted way.

ix. fire_Complet_AnimNGT.m

After a transition is fired, it would be great to show the firing completion after some firing time t, this makes the HCI model more meaning full. Since GPenSIM has methods to show that the completion of the firing and store that statistics in its log file recorder. In the R-T monitor, the ‘fire_Complete_AnimNGT’ is called from the gpensim file for completing a firing called ‘firing_complete’ the following code shows the calling function for the ‘firing_compelte’.

```
if (EIP_not_empty),
    %NGT: *********************************************
    [LOG, colormap, EIP, number_of_completions] = ...
        firing_complete(LOG, colormap, EIP, FTS_index);
    %NGT: *********************************************
end;
```

The ‘firing_complete’ is gpensim built in file and takes all the basic information about a transition along with log file the color map for colored Petri net and the ‘EIP’ and the FTS_index. In a single simulation cycle, there might be more than transition that has completed firing, thus these are identified in gpensim as a top event. I.e. gpensim takes the transition that is on the top of the ‘EIP’. top_event = EIP (1). Then the transition that has completed firing is returned as ‘completing_tran = top_event.event’.

The function that calls the R-T plotter is shown below.

```
while and(EIP_not_empty, time_to_fire),
    top_event = EIP(1);
    time_to_fire = le(top_event.completion_time, PN.current_time);
    if (time_to_fire),
        [log_record, colormap_record] = ...
            firing_complete_one(top_event, FTS_index);
        %%% NGT :
        completing_tran = top_event.event;
        fire_Complet_AnimNGT(completing_tran);
        %%%End NGT
        LOG = [LOG; log_record]; %recording of events for tracing back
        colormap = [colormap colormap_record];
        EIP = EIP(2:end);
        no_of_completions = no_of_completions + 1;
    end;
    EIP_not_empty = ~isempty(EIP);
end;
```

The ‘fire_Complete_AnimNGT’ perform similar function to that of the ‘fire_AnimNGT’ but here the transition is not extracted from the global PN. Rather it is the transition which is on the top of the event queue that is taken for plotting on the R-T monitor.

As mentioned in chapter 4, on the gui, the bar that tells the status of the current completed transition is denoted by a yellow color. Thus the painter is called by.

```
gui_painter(completing_tran,'y','Completed','y',str3);
```

Str3 is an array of strings that records those transitions that has completed firing.

```
str3=[curr_trans,' is completed At:    '];
temp=sprintf([temp,str3,num2str(current_time()),10]);
```

x. hasnotfired_AnimNGT.m

Referring chapter 4, section 4.3.2, and this function takes two event of a transition, these are:-

- A transition is enabled but not fired
- A transition is not enabled and not fired

Both plotting are taken place in this file. They are identified using a flag. i.e. 1 and 0. If 0 it is the first condition and the color would be 'cyan' and if it is 1 the color would be light purple.

The function is called from a 'start_firing.m' which similar to the plotting for a 'firing' condition in Section viii.

To check the two conditions;

- For a transition not enabled but not fired

  ```
  if and(~PN.Enabled_Transitions(t1),...
          ~(PN.Firing_Transitions(t1))),
      hasnotfired_AnimNGT(t1,1);
  end
  ```

  The above condition checks the status of the PN and if both conditions are not satisfied, the plotter function 'hasnotfired_AnimNGT' with a flag value of 1 will be called.

- For a transition enabled and not fired

  This function is a continuation of the 'if' condition of the 'fire_AnimNGT'. As it is mentioned on section 'x' above, considering an enabled transition and the preconditions, the precondition checker function returns the firing condition satisfied, 'FCS' value. If this condition is satisfied the 'firing_AnimNGT' is called. Otherwise the 'hasnotfired_AnimNGT' will be called with a flag value '0' to tell the plotter that the event is 'enabled' but can't fire, i.e. it will plot a cyan color.

  ```
  hasnotfired_AnimNGT(t1,0);
  ```

  This function also calls a 'gui_painter' in order to paint the cyan color on the R-T monitor display.

5.2 Implementation of gpensim code for the real-time models

This implementation section describes short descriptions about the implementation of the real-time DEDS using a gpensim for model that are designed on chapter 3.

5.2.1 Implementation of R-T simulation in Industrial application

As discussed in chapter3, one application of real-time simulation is in industrial area. For the example discussed above, the gpensim code for a model that uses areal-time is given below.

1. **PDF**

   The PDF file define the static Petri net structure (or graph) of a module. The png return the basic structural information about the PN model.

```
function[png] = production_def()
png.PN_name = 'A Simple Petri Net definition';
png.set_of_Ps = {'pInout_Buff', 'pOutput_Buffer', 'pOutPut1', 'pOutput2', ...
                  'pOutput3'};
png.set_of_Ts = {'tAssemble','tInPut','tProduction_line1','tProduction_line2'...
                 ,'tProductionline3'};
png.set_of_As = {'pInout_Buff' ,'tProduction_line1' ,1 ,'pInout_Buff' ...
     ,'tProduction_line2' ,1 ,'pInout_Buff' ,'tProductionline3' ,1 ...
     ,'pOutPut1' ,'tAssemble' ,1 ,'pOutput2' ,'tAssemble' ,1 ,'pOutput3'...
     ,'tAssemble' ,1 ,'tAssemble' ,'pOutput_Buffer' ,1 ,'tInPut' ,'pInout_Buff' ...
     ,1 ,'tProduction_line1' ,'pOutPut1' ,1 ,'tProduction_line2' ,'pOutput2' ...
     ,1 ,'tProductionline3' ,'pOutput3' ,1};
```

   As the name shows, the model is about a simple workshop machine that takes input from the Input area and puts in different buffer locations.

2. **MSF**

   The main simulation file contains declaration of the simulation and color PN components. Assume we have color distribution as shown below

```
global_info.PRINT_LOOP_NUMBER = 1;
global_info.STOP_AT = current_clock(3) + [inf inf inf];
global_info.REAL_TIME = 1;
global_info.cr = {'1','2','3','4'}; % color rotation
```

   ‘1’ – is for raw material one for the production line

   ‘2’ – is for raw material two for the production line

   ‘3’ – is for raw material three for the production line

   ‘4’ – is for raw material four for the production line

   Now every transition will select the color combination and put to the assembler. These are done by the TDF files.

   The simulation will run a life time. But every detail runs under real-time notion.

```
global_info.cr_index = 0; % init rotation index = 0
```

The variable cr_index is used for color rotation among tokens. The index makes the colors to rotate so that the input buffer makes a random choice of tokens.

3. TDF

It has been designed a three kinds of transitional definition files to let the system has a preconditions before firing. From the definition of gpensim, when a transition fire, it inherits colors of all input tokens; thus new tokens deposited into output places would have all the colors inherited from the input tokens. To prevent inheritance of tokens, gpensim provides a method called overriding. The three pre conditions in this model are

- ‘tInPut_pre’: This TDF file has a method to rotate colors and put them in to the input buffer so that the three transitions can access the color tokens. The code snippet shows the function that does this activity.

```
function [fire, transition] = tInPut_PRE (transition)
global global_info;
if strcmp(transition.name, 'tInPut'),
     index = mod(global_info.cr_index, 4)+1;
     global_info.cr_index = global_info.cr_index + 1;
     transition.new_color = global_info.cr(index);
     fire = 1;
     return;
end;
```

The function produces new colors at the transition is enabled and ready to fire.

- ‘COMMON_PRE’: This function is used as common pre condition for the threetransitions,'tProduction_line1','tProduction_line2', and,'tProductionline3'. Production line 1 takes input raw material colored by, ‘1’,’2’, and ‘4’ and use all of them. Similarly production line 2 takes input raw material colored by ‘2’ and ‘3’ and use one of them as an input at time t. and the last one uses only input colored by ‘3’.
- ‘tAssemble_pre’:

  This transition fires as long as all the above three transitions fire and the output places are not empty.

5.2.2 Implementation of R-T simulation in door security using gpensim

The implementation includes three PDF file, one MSF and common pre condition for transitions. This section has a similar implementation to that of the section 5.2.3, door alarm model with NXT. Except that there is *no NXT* device in this section. Only the source code will be provided in the appendix section. But roughly it contains.

1. PDF file for each module.

   The implementation was made by using a modular approach of gpensim.

   The modules are:

   - Door_def.m
   - Alarm_model_def.m
   - Key_padmodel_def.m

   The PDF codes are found in the design section or in the appendix.

2. MSF file

   The main simulation file contains global variables to pass global parameters. The following code show the global variables in this model.

```
global_info.STOP_AT = current_clock(3) + [1 1 20]; % stop
1:1:20
global_info.passwords=['A' 'B' 'C'];
global_info.deltaT=0;
global_info.readIn=0;
png =
petrinetgraph({'door_def','alarm_model_def','key_padmodel
_def'});
```

3. TDF file

   There are two pre and two post conditions. These are:

   - COMMON_PRE.m: A common pre-condition for some transitions.
   - COMMON_POST.m: A common post-condition of some transitions.
   - tEntry_pre: A pre-condition of an event to arm the alarm.
   - tRinging_post: The post condition to let the alarm ring.

5.2.3 Implementation of R-T door alarm system using NXT

The implementation of this model contains methods. The complete code is available on Appendix c.

1. **PDF**

   The model has two PDF file, thus we use a modular approach. The pdf of both models were described in the design part, section 3.3.1, of the R-T door alarm model.

2. **MSF**

   The main simulation file contains the global variable declarations, for example it defines whether the system is in real-time or not, and the elapsed real-time, and the passwords. Besides; the **init_Alarm_NXT** initializes the NXT intelligent Brick. The firing time of the detection transition is set to be 5 and the rests are 1.

```
clear all; clc;
global global_info;
global_info.REAL_TIME = 1;     % This is a Real-Time run
global_info.STOP_AT = current_clock(3) + [0 0 20]; % stop after 2
global_info.passwords=['A' 'B' 'C'];
global_info.resetCMD = 1000;
init_ALARM_NXT(); % initialize NXT
png = petrinetgraph({'alarm_def','doorModule_def'});
dyn.m0 = {'pArrive',1,'pEnd',1,'pCode',1};
dyn.ft = {'tDetect',5, 'allothers', 1};
pni = initialdynamics(png, dyn);
%disp('System is ready ...');
sim = gpensim(pni);
close_Alarm_NXT(); % Never forget to clean up after your work!!!
```

It is advisable to close all the NXT ports and setting after the simulation is completes, this helps the MATLAB to save more memory by removing the catches.

– **init_Alarm_NXT:**

This part contains the basic initializations of the NXT and the sensor nodes by connecting the NXT with the Bluetooth port of the PC.

```
function [] = init_TL_NXT()
% initialize traffic lights and switches in NXT
global global_info;
% initialize global variables
global_info.NORMAL_CYCLE = false;
% initializ NXT
warning('off', 'MATLAB:RWTHMindstormsNXT:noEmbeddedMotorControl');
COM_CloseNXT all;
hNXT = COM_OpenNXT('bluetooth.ini');% look for USB devices
COM_SetDefaultNXT(hNXT);     % sets global default handle
```

Then also assign the ports as shown below.

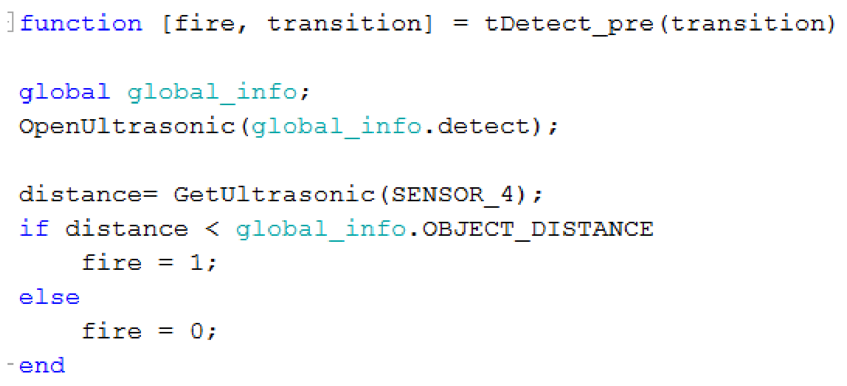
```
global_info.NXT_handle = hNXT;
global_info.detect = SENSOR_4;
global_info.RESTART_BUTTON = SENSOR_1;
global_info .OBJECT_DISTANCE = 20;
```

From the above code snippet, it can be shown as the sensor port 4 is used to connect the ultrasonic sensor. Similarly the sensor port 1 is used for restart button that is used to switch of the ringing signal. Similarly the objects can be detected at a distance of 20 cm. the distance is small due to the sensing capability of the ultrasonic sensor of the NXT device.

3. TDF

– **tDetect_pre**

This pre file has a method to read the ultrasonic value and set fire if the object is detected.

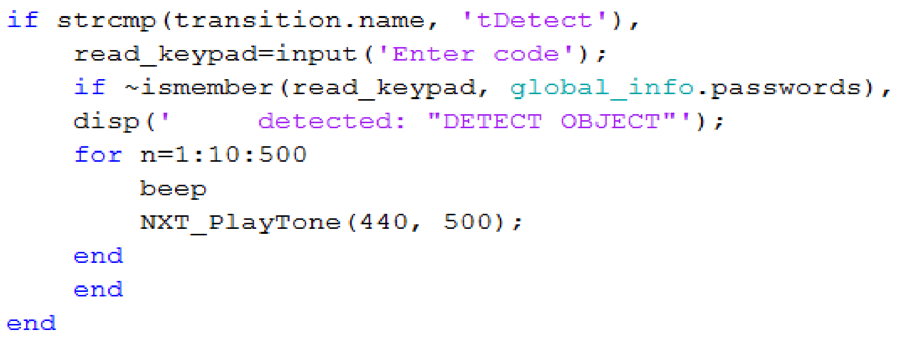


```
function [fire, transition] = tDetect_pre(transition)

global global_info;
OpenUltrasonic(global_info.detect);

distance= GetUltrasonic(SENSOR_4);
if distance < global_info.OBJECT_DISTANCE
    fire = 1;
else
    fire = 0;
end
```

From the above code, the 'OpenUltrasonic' function detects the object from the sensor_4 which is the source port for the ultrasonic sensor node. If the object is detected in a given interval, then it will fire.

– **tDetect_post**

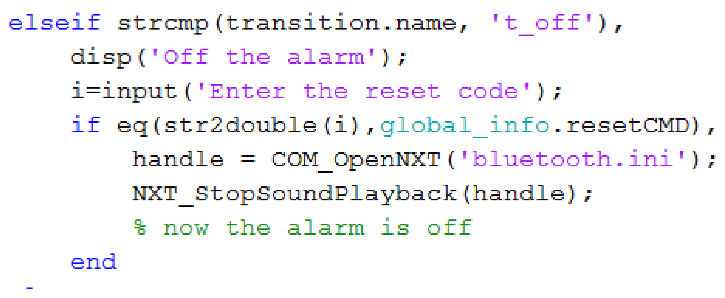
The post condition function lets the alarm to be triggered if the person doesn't enter the appropriate code within a given time.



```
if strcmp(transition.name, 'tDetect'),
    read_keypad=input('Enter code');
    if ~ismember(read_keypad, global_info.passwords),
    disp('      detected: "DETECT OBJECT"');
    for n=1:10:500
        beep
        NXT_PlayTone(440, 500);
    end
    end
end
```

– **COMMON_PRE**

The common precondition is set to be same for some transitions, they fire as far as they are enabled. This function also has a condition to turn of the ringing alarm if the user entered the correct code.



```
elseif strcmp(transition.name, 't_off'),
    disp('Off the alarm');
    i=input('Enter the reset code');
    if eq(str2double(i),global_info.resetCMD),
        handle = COM_OpenNXT('bluetooth.ini');
        NXT_StopSoundPlayback(handle);
        % now the alarm is off
    end
```

5.2.4 Implementation of R-T City Traffic light system using NXT [39]

The implementation for traffic signal has different function. Some of them are adapted from the discrete event dynamics system course but with some changes.

The functions are listed below:

1. **The PDF** file: we have three modules, thus we have three different kinds of PDF files.

   These are:

   - traffic_NXT_def (PDF for Normal cycle)
   - pedes_def (PDF for Pedestrian crossing)

   It contains a PDF file for a pedestrian crossing model.

   - emergency_def (PDF for emergency blinking)

2. **MSF** : Similarly the msf file is denoted as

   - traffic_NXT

   The MSF is similar to the above section’s main simulation file, except the names of some variables.

   Since there are three modules, the calling function of the PDF files is shown below

```
png = petrinetgraph({'pedes_def', 'emergency_def', ...
    'traffic_control_NXT_def'});
```

   And also the initial dynamics are declared as shown below

```
dyn.m0 = {'pR',1};
dyn.ft = {'tR_ON',5, 'tRY',2, 'tG',5, ...
    'tY',2, 'tPEDES_BEEP',1, 'tEM_Y_ON',1, 'tEM_Y_OFF',1, 'allothers', 0.1};
```

   The firing times of the transitions differ from each other. For example the firing time of red,’tR_ON’, light is on for five seconds.

3. **The TDF files,**

   – **COMMON_PRE (COMMON TDF)**

   This ‘common precondition’ of the transitions checks whether the current enabled transition the enabled transition in gpensim structure, PN, by using a MATLAB string comparison method and send command to the NXT device to turn on the appropriate light.

```
if strcmp(transition.name, 'tR_ON'),
    disp('      ON: "RED"');
    SwitchLamp(global_info.lightRED, 'on');

elseif strcmp(transition.name, 'tRY'),
    disp('      ON: "RED", "YELLOW"');
    SwitchLamp(global_info.lightRED, 'on');
    SwitchLamp(global_info.lightYELLOW, 'on');
```

The above code is the first two if close blocks just added to show how the lights are enabled to be on.

Similarly in this common precondition file, the conditions for a pedestrian are checked and let the NXT ‘beep’ sound to be triggered. Note that the pedestrian is on as the pedestrian crossing button is pressed. In this model the touch button is used to do so.

```
if strcmp(transition.name, 'tPEDES_BEEP'),
disp('      ON: "pedes beep"');
NXT_PlayTone(440, 500);
```

The pedestrian transition fires for some amount of time then returns to the normal simulation cycle. This is done by decrementing the count by 1 as shown below.

```
if strcmp(transition.name, 'tPEDES_CYCLE'),
if not(global_info.PEDES_CYCLE_COUNT),
    fire = 0;
    return;
else
    global_info.PEDES_CYCLE_COUNT = ...
        global_info.PEDES_CYCLE_COUNT - 1;
end;
```

– **COMMON_POST (COMMON TDF)**

  The common post condition release the resources after transitions fires, in this case the post condition turns off the lights on the NXT devices.

```
if strcmp(transition.name, 'tR_OFF'),
    disp('      OFF: "RED"');
    SwitchLamp(global_info.lightRED, 'off');

elseif strcmp(transition.name, 'tRY'),
    disp('      OFF: "RED", "YELLOW"');
    SwitchLamp(global_info.lightRED, 'off');
    SwitchLamp(global_info.lightYELLOW, 'off');
```

– **tEM_BUTTON (Specific TDF)**

  The emergency blinking turns continuously the yellow light on and off for a given cycle. This button runs whenever the emergency button is pressed.

```
EM_BUTTON = global_info.EMERGENCY_BUTTON;
 OpenSwitch(EM_BUTTON);
 switchState = GetSwitch(EM_BUTTON);
 CloseSensor(EM_BUTTON);

if (switchState), % RESTART BUTTON not pressed
    fire = 1;
global_info.EMERGENCY_CYCLE = true;
global_info.NORMAL_CYCLE = false;
```

- The other function is the restart button; it is not included in the implementation to reduce redundancy. It is used to restart the normal cycle. It is a reset button done by using a touch sensor.

4. NXT functions that are used to interact the NXT intelligent Brick device with GPenSIM are:

- **init_TL_NXT (Special file for NXT functions)**

```
global_info.NXT_handle = hNXT;
global_info.lightRED = MOTOR_A;
global_info.lightYELLOW = MOTOR_B;
global_info.lightGREEN = MOTOR_C;
global_info.RESTART_BUTTON = SENSOR_1;
global_info.PEDES_BUTTON = SENSOR_2;
global_info.EMERGENCY_BUTTON = SENSOR_3;
global_info.NORMAL_CYCLE = false;
global_info.PEDES_CYCLE = false;
global_info.PEDES_CYCLE_COUNT = 5;
global_info.EMERGENCY_CYCLE = false;
                     function [] = init_TL_NXT()
```

This MATLAB file initialize light sensors, touch sensors and the motor ports in the NXT. The NXT devise has three inputs and four output ports and one USB port. To connect the NXT with the MATLAB, we need to install the toolbox for NXT devices called RWTH toolbox. [38] This function connects with the PC through a USB port and a Bluetooth port. The Bluetooth port is opened using the following function.

```
hNXT = COM_OpenNXT('bluetooth.ini');
```

'bluetooth.ini' has a configuration files for assigning a port as shown below.

```
[Bluetooth]
NXT-Name=NXT
NXT-MAC=00165302F0DD
Channel=3
BaudRate=9600
DataBits=8
Stop its=1
SendSendPause=5
SendReceivePause=25
Timeout=2
```

Then the 'hNXT' port file is set as a default communication port for the brick.

```
COM_SetDefaultNXT(hNXT)
```

GPenSIM interacts with the NXT intelligent Brick using global variables. Every ports are declared into the global_info variable.

Chapter 6

6. Experimentation and Analysis

This chapter show some test result of the implementations in chapter 5. This part includes a test result of simulating models in chapter 3 using R-T monitor. This would give a brief explanation about the objective of the project.

6.1 Experimentation for R-T simulation in section 5.2

6.1.1 Test results for R-T simulation in Industrial application.

The model for this section was deeply described on the implementation section 5.2.1. As it was described on the design section, the first step before the simulation starts were to select the real-time components i.e. selected places and transitions. The screen shot of the operation below shows the progress of selection of places and transitions that is intended to be displayed on the R-T monitor.

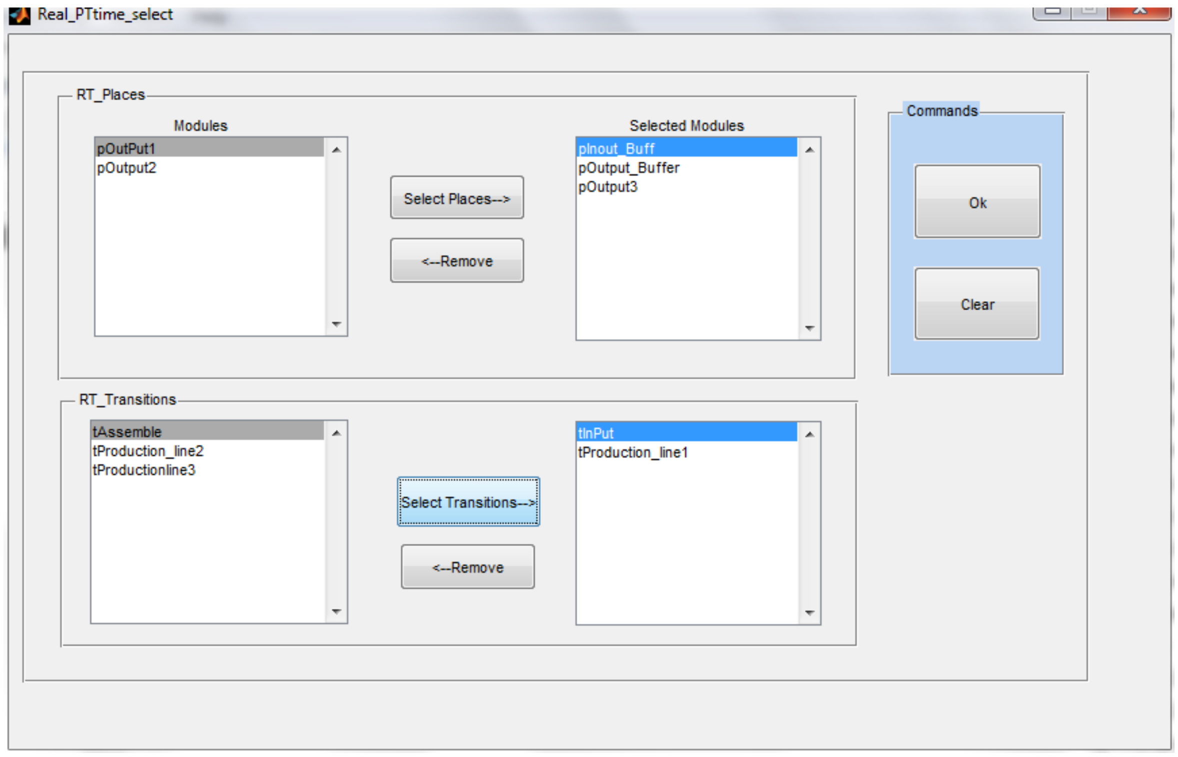


Fig. 65. Test result picture of the R-T component select window

Until the user select places and transitions, the gpensim wait for a response of the ok button. Once the ok button is clicked, the simulation will resume by displaying the R-T monitor. Since there are few places and transition, the whole components can be selected and are displayed as shown below.

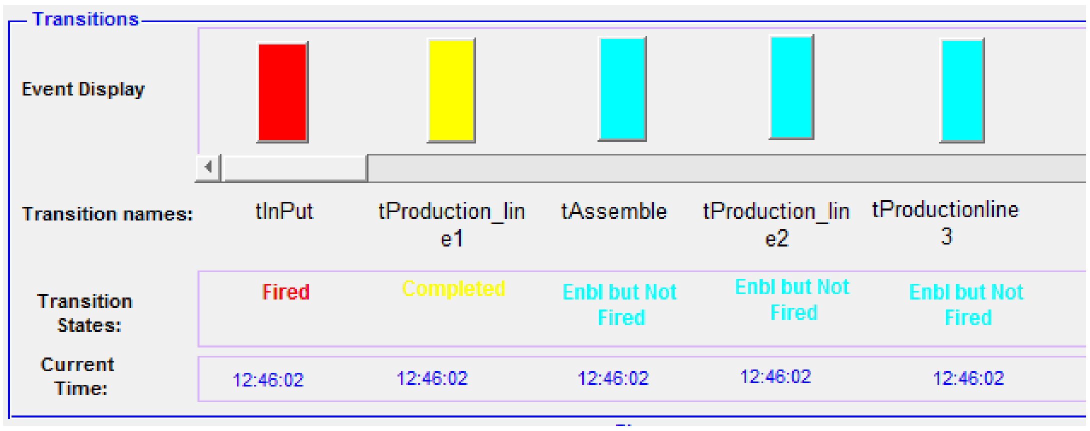


Fig. 66. Test result of status of transitions in the running simulation of production line model

As we can see from the above figure, i.e. the transition panel, the event of the transitions is clearly described using a color plotting. Whenever the 'tInput' of the P-N model fires, the event handler let the associated name 'tInput' handler to be red. Similarly the plotting continues for all of the selected transitions. As it is in real-time, the time that the event takes place is also displayed using **'hh-mm-ss'** format.

Similarly for the selected places, the place panel gives the following figure at some time t

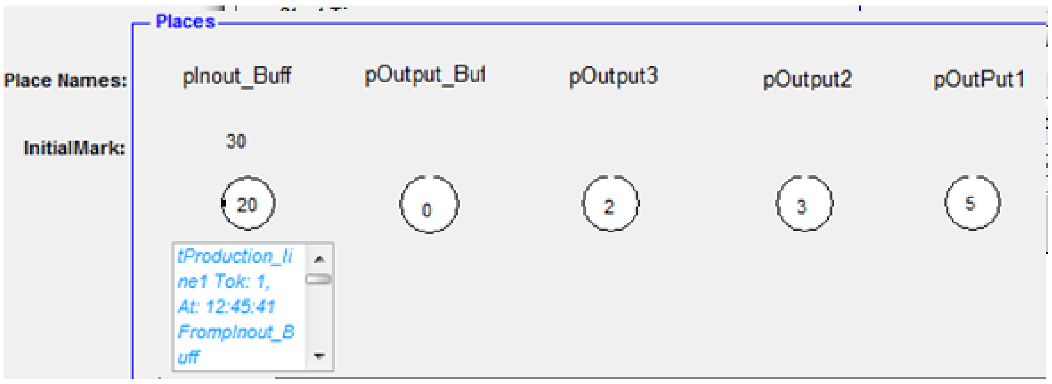
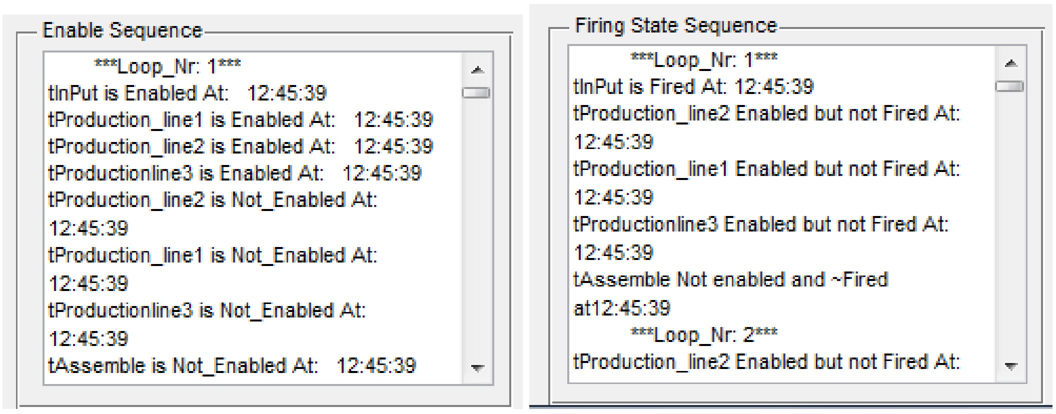


Fig. 67. Test result of status of places in the running simulation of production line model

Suppose that we have initial marking of 30 in a place 'pInput_Buff' for the production feeder. The event handlers plot this value under the place name. As the simulation processes and token are moved from one place to another, the plotter will put the number of token under the plotter to the associated places.



```
Enable Sequence
        ***Loop_Nr: 1***
tInPut is Enabled At:   12:45:39
tProduction_line1 is Enabled At:   12:45:39
tProduction_line2 is Enabled At:   12:45:39
tProductionline3 is Enabled At:   12:45:39
tProduction_line2 is Not_Enabled At:
12:45:39
tProduction_line1 is Not_Enabled At:
12:45:39
tProductionline3 is Not_Enabled At:
12:45:39
tAssemble is Not_Enabled At:   12:45:39
```

```
Firing State Sequence
        ***Loop_Nr: 1***
tInPut is Fired At: 12:45:39
tProduction_line2 Enabled but not Fired At:
12:45:39
tProduction_line1 Enabled but not Fired At:
12:45:39
tProductionline3 Enabled but not Fired At:
12:45:39
tAssemble Not enabled and ~Fired
at12:45:39
        ***Loop_Nr: 2***
tProduction_line2 Enabled but not Fired At:
```

Fig. 68. Test result of enable and firing sequence of the production line in R-T monitor

The above two windows shows the enabling and the firing sequence of the model in ASCII code. This gives extra information about the simulation process.

Similar along with the graphical display, the result can also be analyzed using graphical plotting as it is done on the normal gpensim output.

The plot result of the above system gives the following result

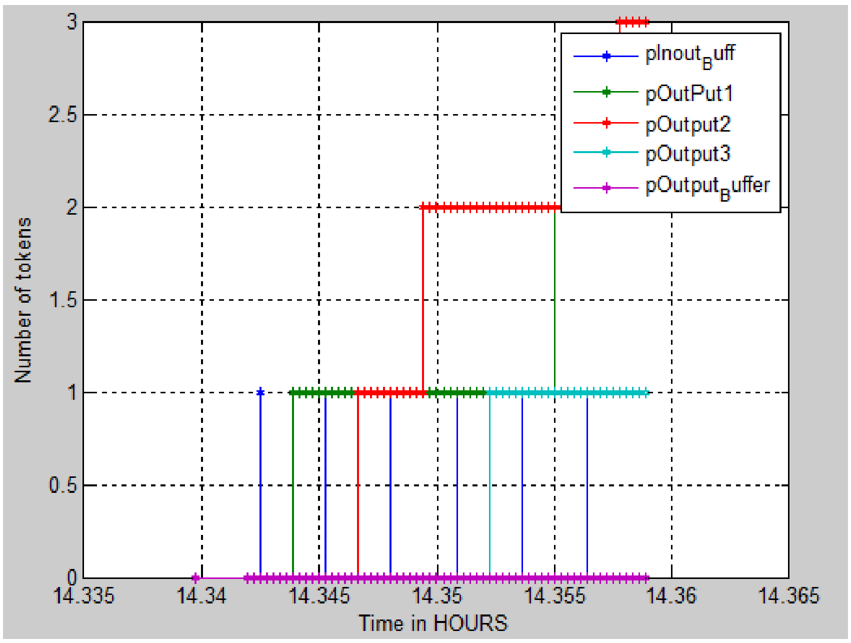


Fig. 69. Number of tokens vs time plot result

From the above plot, Number of tokens versus real-time; we can see the flow of the simulation operation. From the legend we can see which color shows for which place. GPenSIM provides a method to plot the simulation result as shown above.

Similarly using the control button, the simulation can be controlled like it can be stopped and continued and even abort the simulation. And also the speed of the simulation can be controlled using the buttons as shown below.

6.1.2 Test results For NXT door alarm model

As it is mentioned on the implementation section, the system uses two sensors, i.e. the ultrasonic sensor to detect an object approaching the door and also a touch sensor to reset the system. The picture below shows the live result of the sensor nodes as the gpensim is running with the new R-T monitor and display system implemented in this thesis.

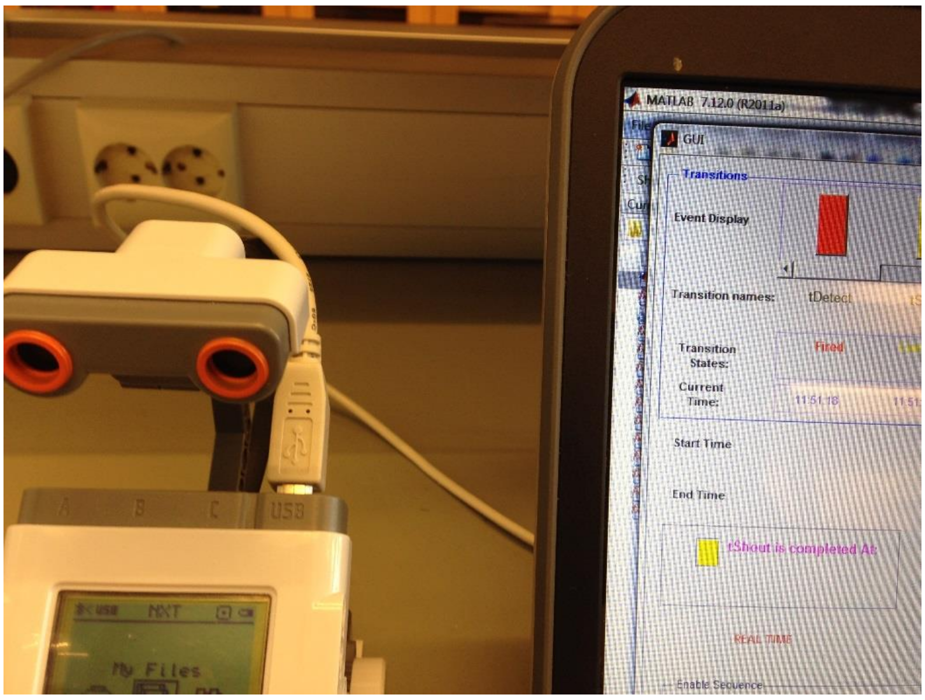


Fig. 70. Picture taken during the process of the ultrasonic door alarm model

The above figure was taken during the running time of the door alarm system. Similar to the other simulations on this section, it starts by running the form to select the real components, places and transitions, in this thesis sense.

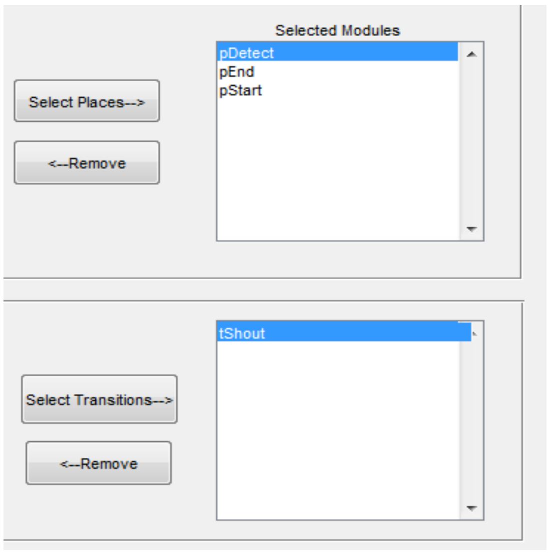


Fig. 71. Select R-T components for Door alarm model

After selecting the components, the next step is plotting on R-T. The transition panel for two selected transition is shown below.

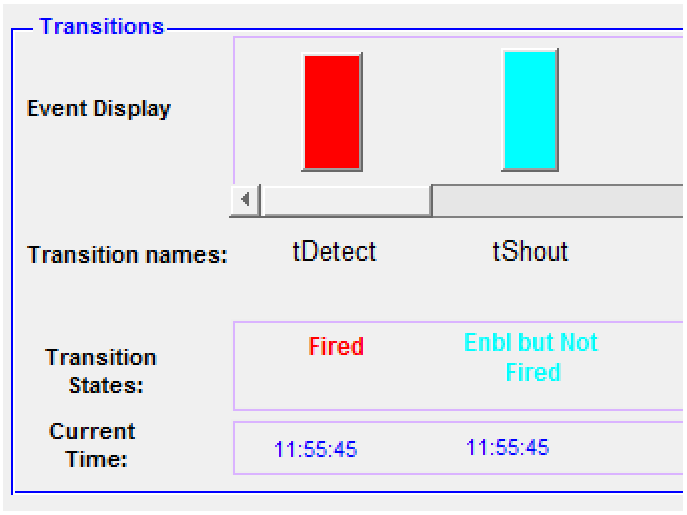


Fig. 72. Transitional panel of the R-T monitor for door alarm shows the Sensor detects

The analysis can be shown in the following table.

Transition name	**Event Display**	**Transition status**	**Current time (hh:mm:ss)**
tDetect	Red bar	Fired	11:55:45
tShout	Cyan bar	Enabled but not fired	11:55:45

Table. 5. Analysis of the transition 'tDetect' on the door alarm model using NXT

After some time t and different cycle, the transition states are changed to different terms, and this can be shown as.

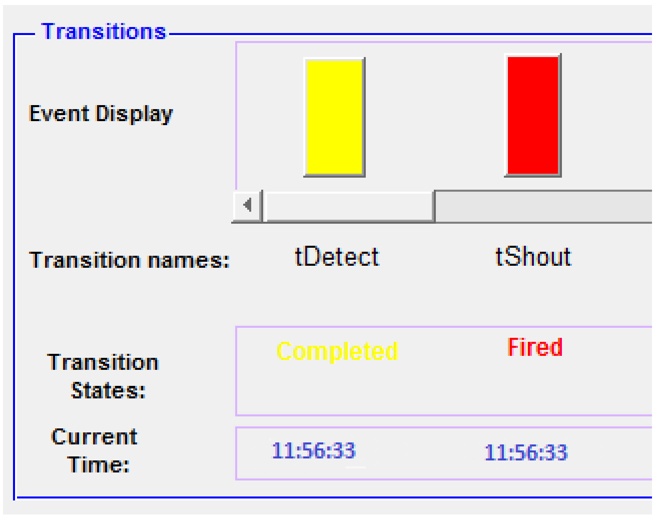


Fig. 73.The alarm is triggered as the input code mismatches

The status described as:

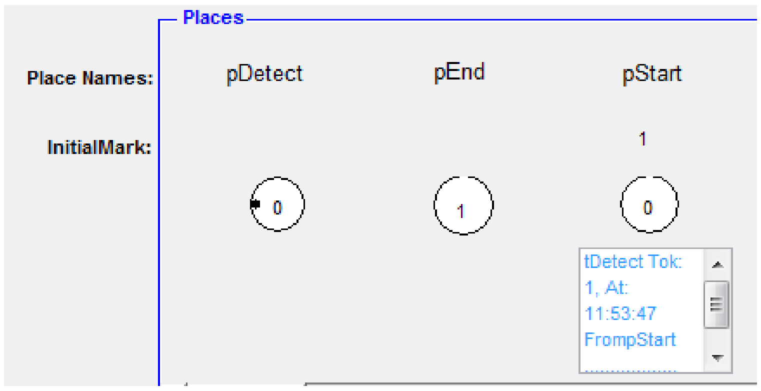
Transition name	Event Display	Transition status	Current time (hh:mm:ss)
tDetect	Yellow display	Complete	11:56:33
tShout	Red display	Fired	11:56:33

Table. 6. Analysis of the transition 'tShout' on the door alarm model using NXT

From the above table, the R-T monitor status completely changed in to different status. The previous time was 11:55:45 and the current time is 11:56:33. We can clearly observe the system has detected an object at time t0 and so tDetect fire at t0 and complete its firing at t1. From the above pic the user doesn't enter the password correctly and hence the NXT trigger the alarm signal and shout at t1. The input password is inserted in the MATLAB command window as shown below.

```
Enter code

At 42681 tShout is fired ...
tShout
At 42683 tShout is completed.
```

Similarly tokens can be displayed on the place panel of the R-T monitor. The display show the result below.



tDetect Tok:
1, At:
11:53:47
FrompStart

Fig. 74. Status of tokens in the selected places

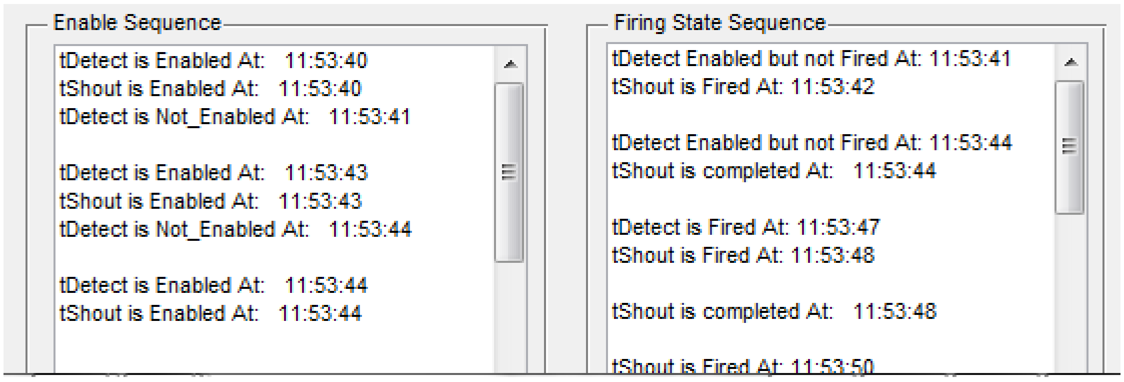
The above figure shows the initial marking of the tokens and their status during the simulation process. The box shows the place pStart has initial marking at time 11:53:47 and by scrolling down, it is possible to see the status of the token gaming on every simulation cycle.

Place names	Initial marking	Current total tokens status
pStart	1	0
pDetect	0	0
pEnd	0	1

Table. 7. Analysis of the tokens and places on the door alarm model using NXT

From the above table, it can be observed that tokens are removed from pStart as the NXT detected an object and Fired and token are stored in the end place.

The R-T monitor has also a method to display the status of the simulation by denoting it as enable and firing sequences. The figure below shows this operation.


Enable Sequence

```
tDetect is Enabled At:   11:53:40
tShout is Enabled At:   11:53:40
tDetect is Not_Enabled At:   11:53:41

tDetect is Enabled At:   11:53:43
tShout is Enabled At:   11:53:43
tDetect is Not_Enabled At:   11:53:44

tDetect is Enabled At:   11:53:44
tShout is Enabled At:   11:53:44
```

Firing State Sequence

```
tDetect Enabled but not Fired At: 11:53:41
tShout is Fired At: 11:53:42

tDetect Enabled but not Fired At: 11:53:44
tShout is completed At:   11:53:44

tDetect is Fired At: 11:53:47
tShout is Fired At: 11:53:48

tShout is completed At:   11:53:48

tShout is Fired At: 11:53:50
```

Fig. 75. Sequence of enable and firing

There are also other tools on the R-T monitor. This are again enhanced tools help to control the simulation process. The panel that contains this is:

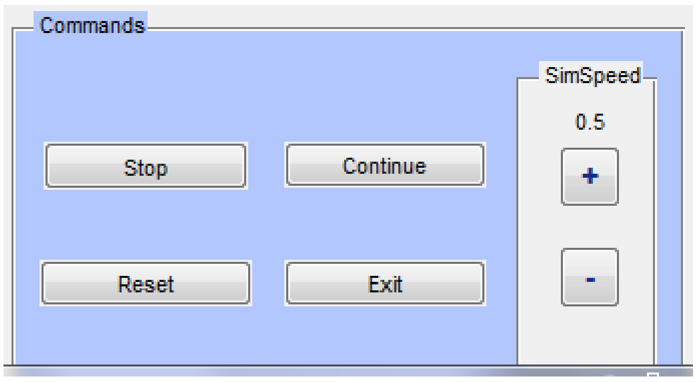
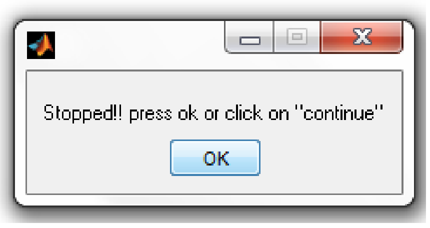


Fig. 76. Control panel

0.5 shows the speed interval in second. The other buttons were clearly described in chapter 4. Whenever a user click on the stop button, the simulation stops until the continue button is pressed or the ok button from the pop up massage box is clicked. The message box that informs the user to do so is looks like below.

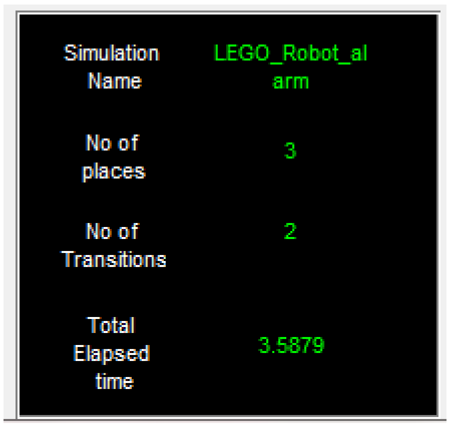


Stopped!! press ok or click on "continue"

OK

Fig. 77. Message box that appears when the stop button clicked

- The R-T monitor also provides a text display on the main display to inform about the total number of place, the transition names and total elapsed time. This is shown in a black box.



Simulation Name	LEGO_Robot_alarm
No of places	3
No of Transitions	2
Total Elapsed time	3.5879

Fig. 78. General information about the simulation

The simulation name is retrieved from the PN.name and also the number of places from PN.No_of_places and PN.No_of_transtions. The total elapsed time show, the total simulation time.

The plot analysis from gpensim gives a result as shown below. This also gives extra information about the status of the simulation.

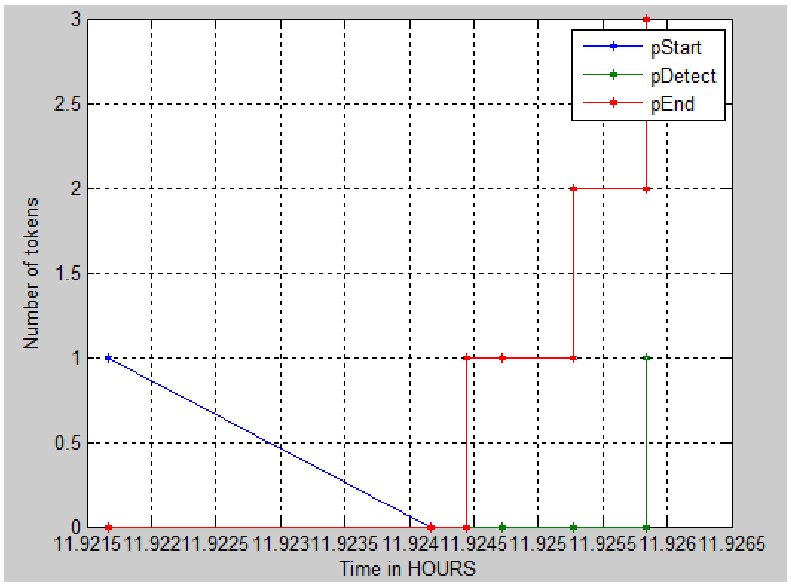


Fig. 79. plot result for Door alarm model

From the above plot and the legends, we can see that the token from ***pStart*** declined as they are fired by the transition, ***tDetect***. The tokens in tDetect are fired only once in the given time and it goes up and stop at time t. And finally the number of tokens in the ***pEnd*** increase as the token gaming stores the tokens inside this place.

6.1.3 Test results for traffic light system

The traffic light model uses three light outputs and three input touch sensors for NXT model. The following picture was taken during operation.

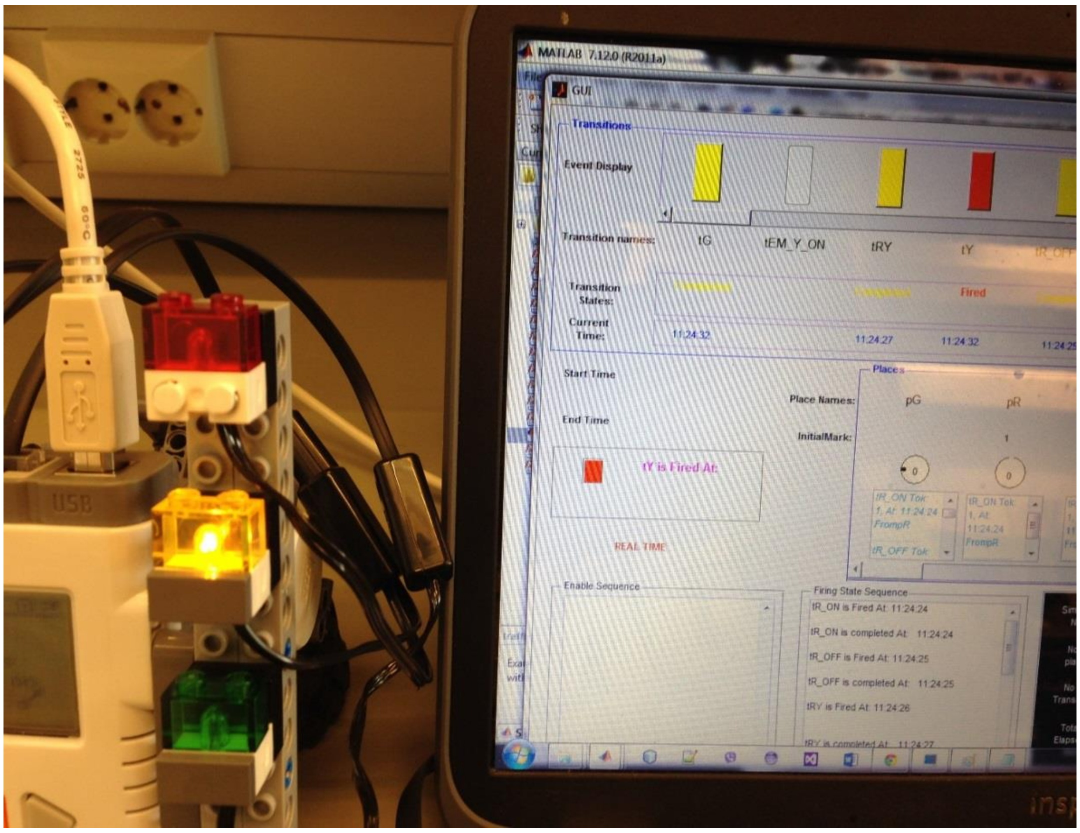
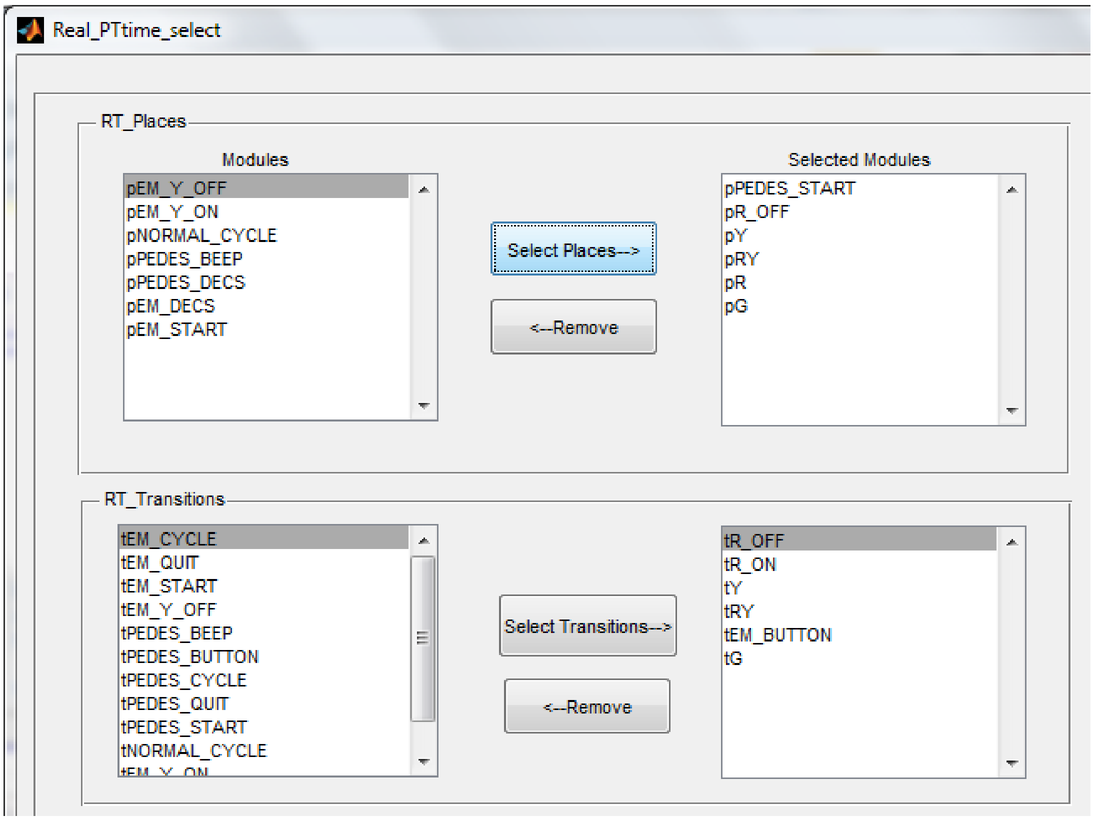


Fig. 80. A picture taken during the simulation process of the traffic light model

Again this simulation runs by letting the user to select the real-time components. When the simulation starts at MSF, A graphical display will appear and the user can select the places and transitions to be displayed on the R-T display. The R-T monitor skips the rest of places and transitions that are not selected and inform it on the command window as shown below.

```
At 11:13:40 tPEDES_BUTTON is Enaled but not member of R-T monitor ...
--RETURN ON R-T_DISPLAY--
   ON: "RED"
At 40411 tR_ON is fired ...
At 11:13:40 tR_ON is Fired but not member of R-T monitor ...
```

The form that is used to select places and transition for the traffic light system is shown below. This has also been clearly described in chapter 4.


Real_PTtime_select

RT_Places

Modules
```
pEM_Y_OFF
pEM_Y_ON
pNORMAL_CYCLE
pPEDES_BEEP
pPEDES_DECS
pEM_DECS
pEM_START
```

Selected Modules
```
pPEDES_START
pR_OFF
pY
pRY
pR
pG
```

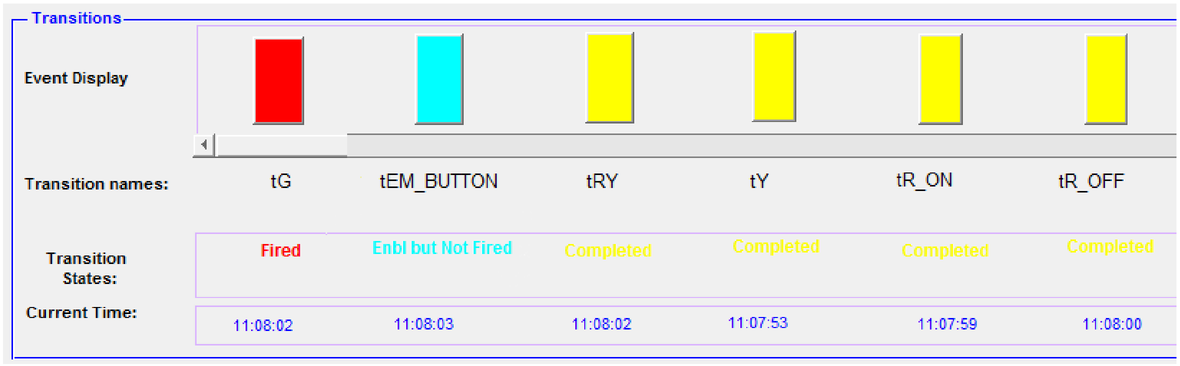
RT_Transitions
```
tEM_CYCLE
tEM_QUIT
tEM_START
tEM_Y_OFF
tPEDES_BEEP
tPEDES_BUTTON
tPEDES_CYCLE
tPEDES_QUIT
tPEDES_START
tNORMAL_CYCLE
tEM_Y_ON
```

```
tR_OFF
tR_ON
tY
tRY
tEM_BUTTON
tG
```

Fig. 81. Select R-T components for Traffic model

- The ASCII dump files of the gpensim results are shown below. For comparison it is displayed below.

The selected transitions and places from the above form will be displayed on the R-T monitor. The transitions panel on the monitor is shown below.


Transitions

Event Display	🟥	🟦	🟨	🟨	🟨	🟨
Transition names:	tG	tEM_BUTTON	tRY	tY	tR_ON	tR_OFF
Transition States:	Fired	Enbl but Not Fired	Completed	Completed	Completed	Completed
Current Time:	11:08:02	11:08:03	11:08:02	11:07:53	11:07:59	11:08:00

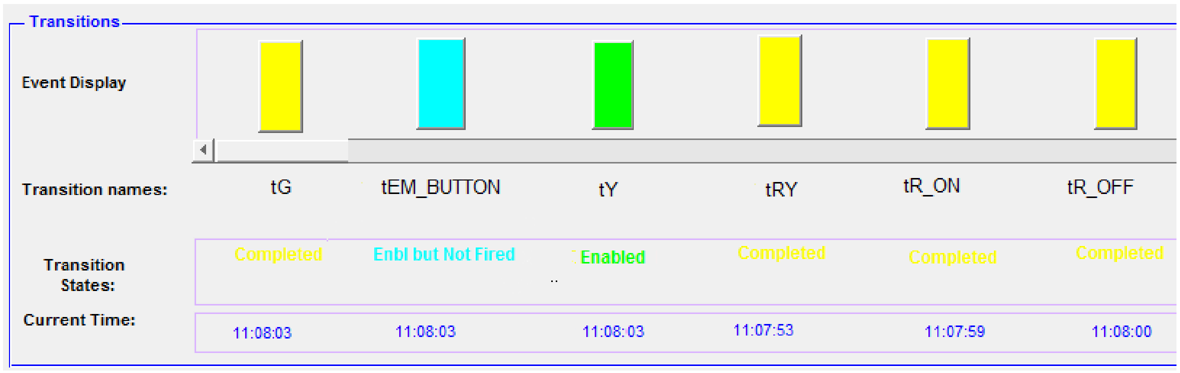
Fig. 82. Transitional panel that shows the Green light is on; on the Traffic light model

From the above figure, it can be seen the status of every selected transition during the simulation process. As mentioned in the design section, the rectangles along with the texts below frequently change based on the simulation status. The table below clearly shows the status of the simulation during one cycle.

Transition names	Event Display	Transition Status	Current Time (t)	Description
tG	Red display	Fired	11:08:02	Green light is on at t
tEM_BUTTON	Cyan	Enabled but not firing	11:08:02	Emergency button ready to fire at t.
tRY	Yellow	Completed	11:08:02	Red to yellow has completed at t
tY	Yellow	Completed	11:07:53	Yellow light has completed t-delta t
tR_ON	Yellow	Completed	11:07:59	Red light on status finished
tR_OFF	Yellow	Completed	11:08:00	Red light is off

Table. 8. Analysis of the selected transitions of the traffic light model at time t.

Once after the one cycle has finished its operation, the next step is getting into another cycle. Conventionally the traffic light after green light is the yellow light to tell caution about the red light for the traffic flow in that direction. The tG releases its resource to tY. This can be illustrated on the R-T monitor as shown below.



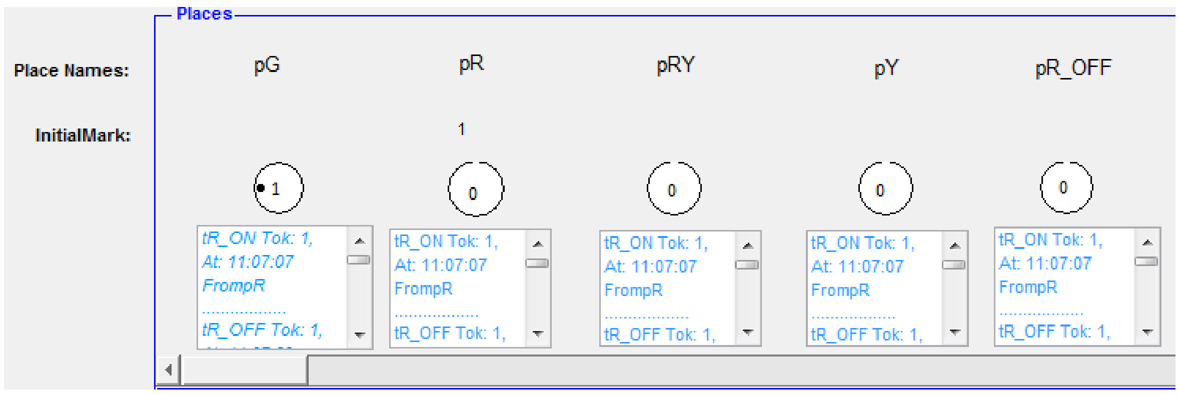
Transition names:	tG	tEM_BUTTON	tY	tRY	tR_ON	tR_OFF
Transition States:	Completed	Enbl but Not Fired	Enabled	Completed	Completed	Completed
Current Time:	11:08:03	11:08:03	11:08:03	11:07:53	11:07:59	11:08:00

Fig. 83. Transitional display panel, Green light is one, yellow is enabled

It can be observed that tY is immediately enabled after tG has completed firing at the current time which is 11:08:03.

N.B. This plotting process continues for every cycle until the simulation is terminated.

Similarly here, it is possible to see the status of the number of tokens in every place on the same monitor as discussed in chapter 4. The place panel that does this is shown below



Places

Place Names: pG pR pRY pY pR_OFF

InitialMark: 1

```
pG: 1    tR_ON Tok: 1, At: 11:07:07 FrompR ................ tR_OFF Tok: 1,
pR: 0    tR_ON Tok: 1, At: 11:07:07 FrompR ................ tR_OFF Tok: 1,
pRY: 0   tR_ON Tok: 1, At: 11:07:07 FrompR ................ tR_OFF Tok: 1,
pY: 0    tR_ON Tok: 1, At: 11:07:07 FrompR ................ tR_OFF Tok: 1,
pR_OFF: 0 tR_ON Tok: 1, At: 11:07:07 FrompR ................ tR_OFF Tok: 1,
```

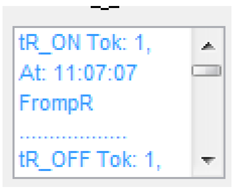
Fig. 84. Status of number of token on a selected places

To illustrate this, see the following table.

Place names	**Initial marking**	**Current total tokens status**	**Description**
pG	0	1	A place for green light
pR	1	0	A place for red light
pRY	0	0	A place for red and yellow lights
pY	0	0	A place for yellow light
pR_OFF	0	0	A pace for red light off

Table. 9. Analysis of the selected places and tokens of the traffic light model at time t.

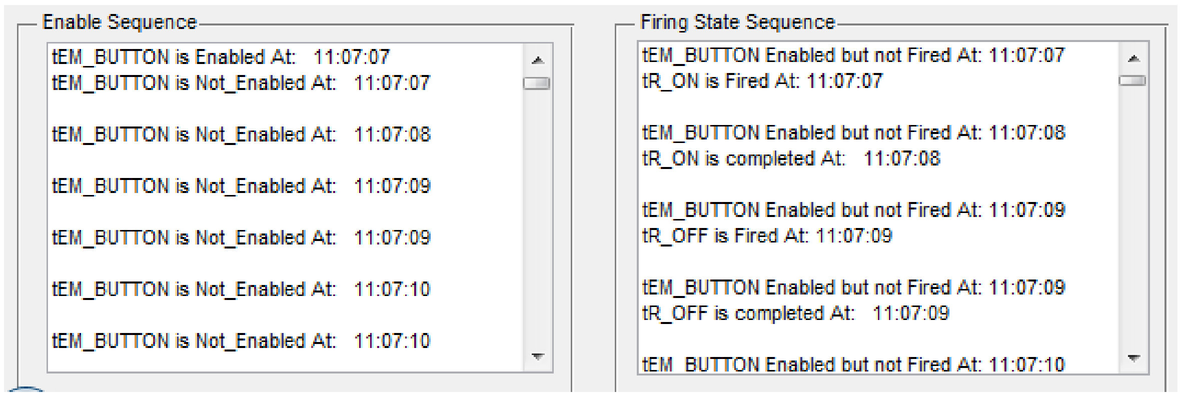
The status of the number of tokens is also displayed inside a small box which is found straight below the small circles on the R-T monitor. For example for the places tR_OFF the series of each token gaming is shown below. tR_ON takes 1 token from pR at 11:07:07. These are discussed in detail in chapter 4.



```
tR_ON Tok: 1,
At: 11:07:07
FrompR
.................
tR_OFF Tok: 1,
```

Fig. 89. Display to show the token gaming

- Like all the simulations the enable and firing sequence can also be displayed on the big boxes on the R-T monitor. The two panel for the traffic light system gives following result.


```
Enable Sequence
tEM_BUTTON is Enabled At:   11:07:07
tEM_BUTTON is Not_Enabled At:   11:07:07

tEM_BUTTON is Not_Enabled At:   11:07:08

tEM_BUTTON is Not_Enabled At:   11:07:09

tEM_BUTTON is Not_Enabled At:   11:07:09

tEM_BUTTON is Not_Enabled At:   11:07:10

tEM_BUTTON is Not_Enabled At:   11:07:10
```

```
Firing State Sequence
tEM_BUTTON Enabled but not Fired At: 11:07:07
tR_ON is Fired At: 11:07:07

tEM_BUTTON Enabled but not Fired At: 11:07:08
tR_ON is completed At:   11:07:08

tEM_BUTTON Enabled but not Fired At: 11:07:09
tR_OFF is Fired At: 11:07:09

tEM_BUTTON Enabled but not Fired At: 11:07:09
tR_OFF is completed At:   11:07:09

tEM_BUTTON Enabled but not Fired At: 11:07:10
```

Fig. 85. Enable and Firing sequence for traffic model

Note that to get the current status of the simulation, the scroll button must be used. This stores and displays the results in a text format. This helps us to analyze the reachability and other P-N analysis.

- The state diagram for the simulation result is shown below. GpenSIM stores its result as a dump file and display its result on the MATLAB command window. As it is discussed on the statement of problems, this dump file to large and not show results live during the simulation process. The following shows a state space result of the traffic light system.

```
======= State Diagram =======
**    Time: 11:13:31   **
 pR + pR + pR + pR +
 State:0 (Initial State): pR
At start ....
At time: 11:13:31,  Enabled transitions are:    tEM_BUTTON
tPEDES_BUTTON   tRESTART_BUTTON   tR_ON
At time: 11:13:31,  Firing transitions are:     tR_ON
**    Time: 11:13:40   **
State: 1
Fired Transition: tR_ON
pR_OFF + pR_OFF +
Current State: pR_OFF
Virtual tokens: (no tokens)
Right after new state-1 ....
At time: 11:13:41,  Enabled transitions are:    tEM_BUTTON
tPEDES_BUTTON   tRESTART_BUTTON   tR_OFF
At time: 11:13:41,  Firing transitions are:     tR_OFF
**    Time: 11:13:42   **
State: 2
Fired Transition: tR_OFF
pRY + pRY + pRY +
Current State: pRY
Virtual tokens: (no tokens)
Right after new state-2 ....
At time: 11:13:43,  Enabled transitions are:    tEM_BUTTON
tPEDES_BUTTON   tRESTART_BUTTON   tRY
At time: 11:13:43,  Firing transitions are:     tRY
**    Time: 11:13:45   **
```

```
State: 3
Fired Transition: tRY
pG + pG + pG + pG + pG +pG + pG + pG + pG +
 Current State: pG
Virtual tokens: (no tokens)
Right after new state-3 ....
At time: 11:13:45,  Enabled transitions are:    tEM_BUTTON   tG
tPEDES_BUTTON   tRESTART_BUTTON
At time: 11:13:45,  Firing transitions are:     tG
.
.
.
Right after new state-25 ....
At time: 11:14:58,  Enabled transitions are:    tEM_BUTTON
tPEDES_BUTTON   tRESTART_BUTTON   tR_ON
At time: 11:14:58,  Firing transitions are:
```

The above code continues until the 25 state space diagrams [25]. Here only some lines are displayed due to the lengthiness of the result. The plot result is for the above code is shown below.

- The plot using gpensim is shown below. From the plot, it is possible to analyze the simulation result.

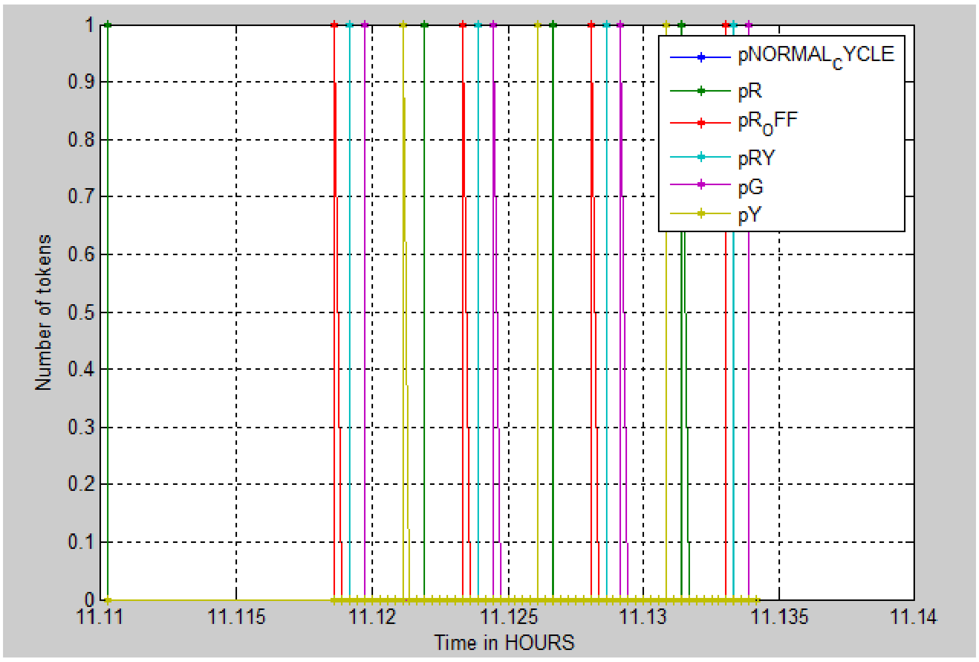


Fig. 86. Plot result of the simulation for traffic light model

 Since we have only one token in the initial mark, from the plotting it can be noticed that the number of tokens falls between 0 and 1. As the simulation time goes, the number of token in every places shows a onetime up and down.

Chapter 7

7. Discussion and conclusion

7.1 Discussion

The need for simulation and modelling is unquestionable. Different areas apply simulation and modelling for different purposes. For example some companies prefer to use simulation and modelling in order to keep the quality of their products at a small cost. They model and simulate every single unit before performing the real physical implementation. As it is mentioned in chapter two; systems can either be static or dynamic. Dynamic systems with a discrete event flow has become an easy way to model systems. This ensures more concurrency and optimization. Since Petri nets provides concurrency, parallelism and synchronization, [11] they became more popular tool to model DEDS. Having both the DEDS and P-N, any kind of system can be modeled. Once we have the model, the next step is to simulate it. The simulation in DEDS is performed based on their events. Events are key terms in DEDS, every single action is encountered as an event. Especially monitoring those events in a real time needs more caution. It is very important to pay more attention for a real-time simulation. In a non-real-time simulation, the analysis can be performed at the end of the simulation. But in real-time simulation it is impractical to analyze the simulation at the end of simulation as we can't get back the already passed time. GPenSIM can perfectly simulate the DEDS that are modeled using a Petri net tool. But GPenSIM doesn't provide a way to display and control the simulation progress visually. The newly implemented R-T displaying tool provides GPenSIM to have a tool that serve as an HCI to display the status of the real-time simulation and even provides a way to control the status of the running simulation. Previously; GPenSIM used to store the simulation result in ASCII dump file and print only the states of the simulation, using 'print_state_space' function, at the end of the simulation. The R-T monitor is integrated inside gpensim so that all the gpensim operations can be interpreted in to the R-T monitor. The R-T monitor displays the operation live without showing the background GPenSIM operation.

In addition to developing R-T monitor for displaying the status of a real-time simulation, it has also been developed different kinds of real life models. The models were created to test the R-T monitor and to illustrate the real-time simulation of DEDS. The systems that were modeled are; production line on real-time and colored P-N, room security using keypad, door alarm using NXT ultrasonic sensor, and the traffic light system using NXT. These modeled were designed to resemble the actual system and their event to be monitored on real-time basis. Modeling a system is not an easy task; it needs a deep knowledge of the developing tools and real life model. Especially working with NXT intelligent Bricks needs a deep understanding of the MATLAB environment and functionality of the NXT microcontroller.

All the models were created based on the real life dynamic systems whose events rely on real- time. The models are constructed to examine the behavior of real life systems using a Petri net theory and to test the R-T monitor. The models are not designed to be too large so that anyone can easily understand them. Simulation of a large Petri net model is intrinsically a difficult task, partly because of the fact that many elements have to be processed in large number of cycles. The best way to simulate those large models is that the models should be designed in a modular approach, by dividing the large model in to smaller sub models.

Some drawbacks

The newly implemented tool can display the status of any kind of P-N model developed by gpensim. Even if it can do so, it has also some drawback and needs further improvements. Some of the drawbacks are.

- Speed of plotting: - even though developing a gui using MATLAB is a prior option for gpensim. Due to some cons of the MATLAB GUIDE, the result shows some small delay in plotting but which is not significant for small models. This is because of the fact that MATLAB GUIDE is developed for some simple GUI application not for working with simulation and modelling of larger systems. In simulation and modelling large amount of data can be processed at a small time interval. For example if we work with 12 transitions and the firing time of each is very small, the GUIDE 'findobj' searches for all of the transition in one cycle and on the gpensim might start the next cycle before the gui components are finished searched for plotting. Thus the system shows some slowdowns. This happens due to the object searcher tool.

- Delay time to select transitions and places: - while we select places and transitions, we might spend a lot of time where the NXT sensors might not tolerate.

7.2 Further Improvement

The System can be further extended. Anyone who is interested can extend the system to be more intelligent and even can add more control features. It is possible to implement a monitor that not only displaying the status of the transition and places but also can work as a decision maker tool and can even add some conditions like supervisory control and fuzzy logics. For example in distributed sensor network, it is possible to implement a method

that makes decision based on the gpensim formalism. The system can also be implemented to be integrated with other tools. Even it is possible to implement a tool that can run on mobiles and the user can easily control the simulation on mobile devices.
Also the drawbacks can be corrected and the system can be re implemented to be a fault-tolerant system.

7.3 Conclusion

GPenSIM is a power full tool to model any kind of DEDS. By adding tools like an HCI system, a gpensim can be extended to perform more excellent tasks; like displaying the status of the simulation. Generally in this thesis, it has been seen that the discrete event of the dynamic systems can be modeled using Petri nets and can be simulated on real-time using GPenSIM and their simulation status can be displayed on a newly implemented R-T monitor. It has been successfully developed a user friendly tool that helps to display and control the status of a real-time simulation of discrete event dynamic systems. The newly implemented tool was also successfully tested as shown in the chapter 6, test results. I believe this tool can be used in real life applications of GPenSIM.

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Appendix A

Install GpenSIM and configure NXT

A.1 Install GPenSIM and R-T monitor tool

1. Download 'GPenSIM' zipped file from the author's website. The web address: http://www.davidrajuh.net/gpensim/

   Note that the website also provides a handy user manual for building a Petri net model.

2. Unzip the file in to the hard drive of the PC.

3. To add the newly implemented R-T monitor tool, it has to be embedded inside a GPenSIM file. The tool needs a manual integration. I.e. we need to copy and paste the files one by one. The following table shows the files and their associated directory inside GPenSIM. The directories can be different; it depends on the directory of the unzipped folder location.

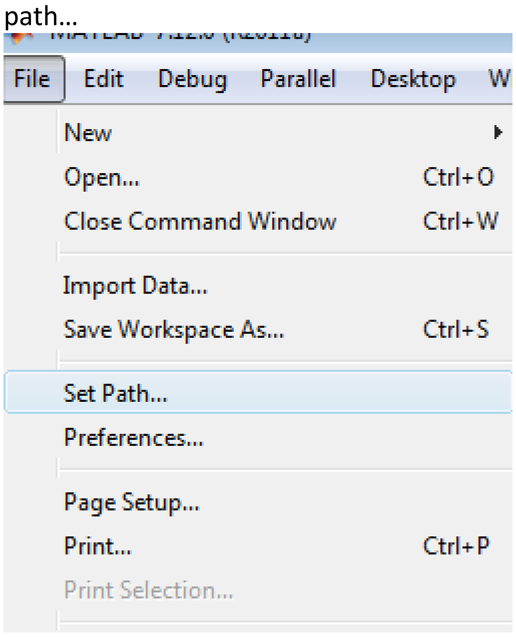
R-T-Monitor Files	GPenSIM directory
Real_PTtime_select.m	C:\...\gpensim\12-timed_pensim\ Real_PTtime_select.m
GUI.m	C:\...\gpensim\12-timed_pensim\ GUI.m
gpensim.m	*C:\...\ gpensim\12-timed_pensim\gpensim.m
find_GUI_component_places	C:\...\gpensim\12-timed_pensim\ find_GUI_component_places.m
find_GUI_component_trans	C:\...\ gpensim\13-firing\ find_GUI_component_trans.m
token_number_ngt.m	C:\...\gpensim\05-Print_and_Plot\ token_number_ngt.m
markings_string.m	*C:\...\ gpensim\05-Print_and_Plot\ markings_string.m
fill_GUI_initial_dy.m	C:\...\gpensim\12-timed_pensim\ fill_GUI_initial_dy.m
gui_painter.m	C:\...\gpensim\ 13-firing\ gui_painter.m
enable_AnimNGT.m	C:\...\gpensim\ 13-firing\ enable_AnimNGT.m
fire_AnimNGT.m	C:\...\gpensim\ 13-firing fire_AnimNGT.m
fire_Complet_AnimNGT.m	C:\...\gpensim\ 13-firing\ fire_Complet_AnimNGT.m
hasnotfired_AnimNGT.m	C:\...\gpensim\ 13-firing\ hasnotfired_AnimNGT.m
firing_start	*C:\...\gpensim\ 13-firing\ firing_start.m
Infoplc.m	C:\...\gpensim\16-token-gaming\infoplc.m
consume_tokens.m	*C:\ ...\gpensim\16-token-gaming\ consume_tokens.m

Table 10. How to add the R-T monitor to the existing gpensim file.

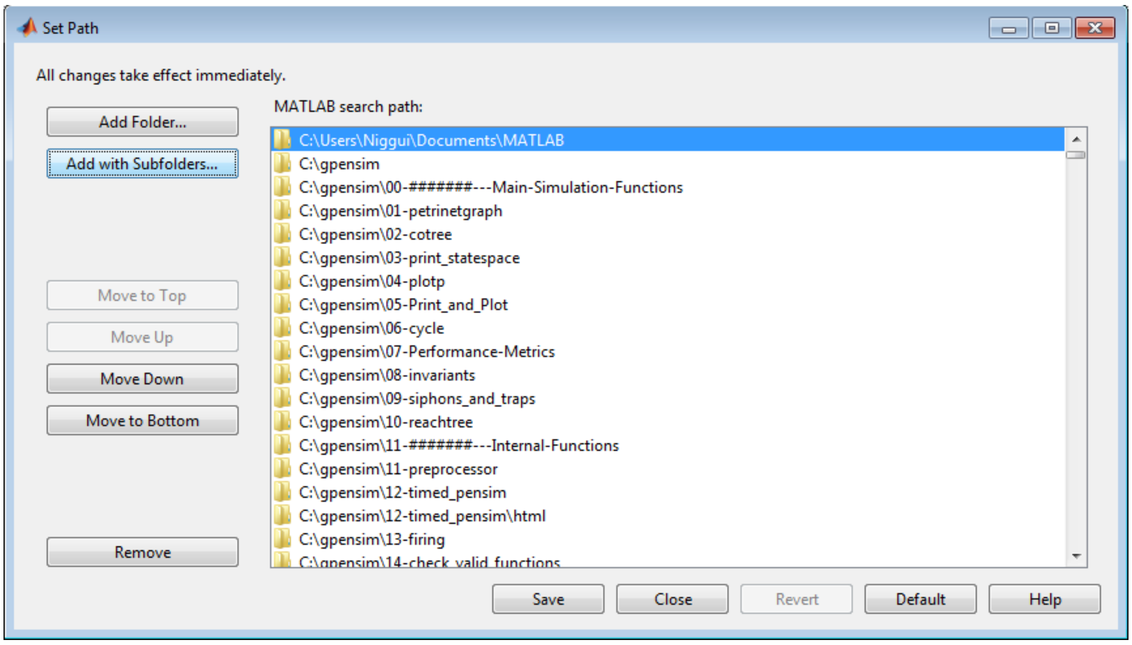
The files with directory '*' sign are the original files of gpensim files where the R-T-monitor files are integrated in. i.e. there are calling methods inside these files.

4. Open MATLAB in administrator mode, and set the path as shown below.

=> Go to: File -> set path...



5. On the new pop up dialog window, click add with sub folders.



All changes take effect immediately.

MATLAB search path:

```
C:\Users\Niggui\Documents\MATLAB
C:\gpensim
C:\gpensim\00-#######---Main-Simulation-Functions
C:\gpensim\01-petrinetgraph
C:\gpensim\02-cotree
C:\gpensim\03-print_statespace
C:\gpensim\04-plotp
C:\gpensim\05-Print_and_Plot
C:\gpensim\06-cycle
C:\gpensim\07-Performance-Metrics
C:\gpensim\08-invariants
C:\gpensim\09-siphons_and_traps
C:\gpensim\10-reachtree
C:\gpensim\11-#######---Internal-Functions
C:\gpensim\11-preprocessor
C:\gpensim\12-timed_pensim
C:\gpensim\12-timed_pensim\html
C:\gpensim\13-firing
C:\gpensim\14-check_valid_functions
```

A new browser window will pop up then browse the unzipped gpensim file and select the file and save it and close the window.

Or using a MATLAB Command

>> Addpath/home/user/MATLAB/unzipped gpensim file. And press enter

5. To check whether the path is set or not, type gpensim on the Matlab command window and enter.

A.2 Operation in GPenSIM.

The author's website of GpenSIM provides an instruction how to develop a Petri Net model using GPenSIM. The instructions were clearly discussed on the GPenSIM part. The simple way to use GpenSIM

1. Open new MATLAB script file
2. Start by creating Petri net Definition file, PDF. Then save the file with suffix '_def' at the end of the file name. For example, production_def.m
3. After creating the PDF file, open new MATLAB script file and start creating the transitional definition file for the intended transition. The transitional definition files contain the 'post' and 'pre' conditions. If two or more transitions have same pre and post event, create a common TDF file by the name 'COMMON_PRE' and 'COMMON_POST'.
4. After Creating the TDF files, the next step is creating a main simulation file, MSF.

A.3 How to set up the NXT device

The NXT device doesn't usually work on windows 7 service pack1, but in this thesis it has been used service pack 2 and works fine.

To install the NXT device, we need to download and install the RWTH Toolbox in the MATLAB Environment. The steps to do so are.

1. Download the version of the toolbox, (v4.08-JUN-2013 is used in this setup),
2. Extract the zipped file in to the hard drive. (Preferred into MATLAB toolbox folder inside the MATLAB installed folder).
3. Now similar to the steps in appendix section A.1, Open MATLAB in administrator mode and go to the file menu.
4. Under file menu point to set path button; => File -> set path…
5. In a similar way to that of section A.1, a window will pop up. Click on 'add with subfolder' and browse the RWTH toolbox save and close the window.

   When the above steps are done, the NXT toolbox environment should be added to the MATLAB toolbox directory.

A.4 How to connect the NXT device with the windows 7

The primary connection of the NXT device is to connect it using the USB cable. This is used to setup the device and let is to prepare for a Bluetooth connection. The steps to setup the NXT with USB and Bluetooth follow the following instruction.

1. Download the **Fantom Driver** from the web at.

   http://www.lego.com/en-us/mindstorms/downloads/software/ddsoftwaredownload/

Note that there are different kinds of Fantom Driver for different platforms, so it must be downloaded to the appropriate one. In this set up, it has been downloaded for Windows 7, 64 bit.

2. Extract the zipped folder. Then open the folder with two options, one for Mac devices and one for windows. Since the setup of this project is done on windows, open for windows. Follow the instruction to install the driver.
3. Finally the NXT device is successfully integrated with PC.
4. After the driver is installed, the next step is to update the NXT firmware. Because the NXT device firmware should always be updated before a Bluetooth connection is setup. To update the firmware.
    - Turn on the NXT by holding the on/off orange Button.
    - Press the left arrow button until the ***setting*** icon on the NXT display is shown. Then select this setting icon with the orange button.
    - Again push the left arrow until the ***NXT version*** is shown. Select this icon by using the orange button.
    - Now the version will be shown.
    - The newer firmware version can be downloaded from the http://www.lego.com/en-us/mindstorms/downloads/software/nxt-firmware/
    - Again download the utility tool, ***NeXT Tools***, to access the NXT device from a PC. It can be downloading from the website. http://bricxcc.sourceforge.net/utilities.html
    - Now connect the NXT with the PC using a usb 2.0 cable.
    - Open the NeXT tools and a small window with port option will appear. Select usb from a dropdown menu and press ok.
    - Choose Download firmware from the menu.
    - Wait for some minutes, until the firmware is updated.

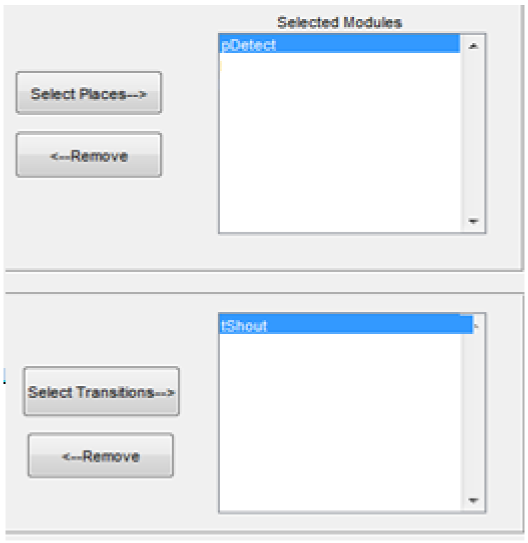
- Now turn on the NXT brick, and browse to the setting using the left arrow button. Inside that setting there is a Bluetooth icon, open the icon and press the orange button to connect to the PC. N.B the PC's Bluetooth device should be visible so that the NXT can locate the Bluetooth signal.

Appendix B

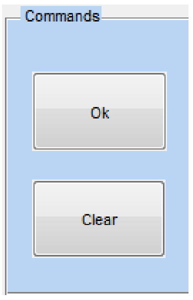
User manual for the R-T monitor

To use the R-T monitor, read chapter 4 well or follow the following instructions steps.

1. Run MSF. The one that has been created using GPenSIM instruction.
2. A new window will appear if GpenSIM is running on real-time. The window requests the user to select the places and transitions from the overall transitions and places. It is the file with name 'Real_PTtime_select.m' in this newly implemented R-T tool. The tools also provide a button to remove the unwanted but selected items.



3. After selecting places and transition, click on the ok button to start the simulation or clear to clear the selected fields. If there are no selected items



4. Now the real components are selected, the R-T window will appear.
   The R-T monitor integrates with the running GPenSIM and starts plotting the status of the simulation.
5. The R-T monitor has also tools to control the simulation. This includes controlling the simulation speed, stop the simulation, and continue the simulation.

Appendix C

C.1 Source codes for R-T monitor

Real_PTtime_select.m

```
function varargout = Real_PTtime_select(varargin)
% REAL_PTTIME_SELECT MATLAB code for Real_PTtime_select.fig
%      REAL_PTTIME_SELECT, by itself, creates a new REAL_PTTIME_SELECT or raises the existing
%      singleton*.
%
%      H = REAL_PTTIME_SELECT returns the handle to a new REAL_PTTIME_SELECT or the handle to
%      the existing singleton*.
%
%      REAL_PTTIME_SELECT ('CALLBACK',hObject,eventData,handles,...) calls the local
%      function named CALLBACK in REAL_PTTIME_SELECT.M with the given input arguments.
%
%      REAL_PTTIME_SELECT ('Property','Value',...) creates a new REAL_PTTIME_SELECT or raises the
%      existing singleton*.  Starting from the left, property value pairs are
%      applied to the GUI before Real_PTtime_select_OpeningFcn gets called.  An
%      unrecognized property name or invalid value makes property application
%      stop.  All inputs are passed to Real_PTtime_select_OpeningFcn via varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%

% Edit the above text to modify the response to help Real_PTtime_select
% Last Modified by GUIDE v2.5 30-May-2014 15:35:08
% Begin initialization code - DO NOT EDIT(it might disorder the layouts)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @Real_PTtime_select_OpeningFcn, ...
                   'gui_OutputFcn',  @Real_PTtime_select_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
   gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
   [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
   gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before Real_PTtime_select is made visible.
function Real_PTtime_select_OpeningFcn(hObject, eventdata, handles, varargin)
```

```
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);
pushbutton10_Callback(hObject, eventdata, handles);

% --- Outputs from this function are returned to the command line.
function varargout = Real_PTtime_select_OutputFcn(hObject, eventdata, handles)
% Get default command line output from handles structure
pushbutton10_Callback(hObject, eventdata, handles);
varargout{1} = handles.output;
% --- Executes on button press in pushbutton3.
function pushbutton3_Callback(hObject, eventdata, handles)
% --- Executes on selection change in listbox3.
function listbox3_Callback(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function listbox3_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

% --- Executes on selection change in listbox4.
function listbox4_Callback(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function listbox4_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
global newmenu_Trans;
currentItems_t = get(handles.listbox3, 'String');
list_entryT = cellstr(currentItems_t);
index_selected_t = get(handles.listbox3,'value');
choice_listbox3 = list_entryT(index_selected_t);
listitems=get(handles.listbox4,'String');
   newmenu_Trans = [listitems;choice_listbox3];
set(handles.listbox4,'String', newmenu_Trans);
set(handles.listbox3, 'Value', []);
newItems_t = currentItems_t;
newItems_t(index_selected_t) = [];
set(handles.listbox3, 'String', newItems_t);
if ~isempty(newItems_t)
   if length(newItems_t) >= 1
      set(handles.listbox3, 'Value', 1);
   end
end
% --- Executes on selection change in listbox5.
function listbox5_Callback(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function listbox5_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end
```

```
% --- Executes on selection change in listbox6.
function listbox6_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function listbox6_CreateFcn(hObject, eventdata, handles)
% Hint: listbox controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press to select R-T places.
function pushbutton5_Callback(hObject, eventdata, handles)
global newmenu; %store the values in cellarray string.
currentItems = get(handles.listbox5, 'String'); %Accuse from the right side list
list_entry = cellstr(currentItems);
index_selected = get(handles.listbox5,'value'); % get the list index
choice_listbox5 = list_entry(index_selected);
    newmenu = [newmenu,choice_listbox5]; % build the R-T places cell array
set(handles.listbox6,'String', newmenu);
% put on the right side list box(selected items)
set(handles.listbox5, 'Value', []); % remove the selected item from the left listbox
newItems = currentItems;
newItems(index_selected) = []; % a MATLAB method to remove a cell array item
set(handles.listbox5, 'String', newItems);
if ~isempty(newItems)
    if length(newItems) >= 1
        set(handles.listbox5, 'Value', 1);
        % always put at the top to eliminate duplicate
    end
end

% --- Executes on button press to remove unwanted selected places from the right listbox.
function pushbutton6_Callback(hObject, eventdata, handles)
global new_remove_menu;
global newmenu;
newmenu=[];
currentItems2 = get(handles.listbox6, 'String');
list_entry = cellstr(currentItems2);
index_selected = get(handles.listbox6,'value');
choice_lstbox2 = list_entry(index_selected);
curl2=get(handles.listbox5,'String');
    new_remove_menu = [curl2;choice_lstbox2];
set(handles.listbox5,'String', new_remove_menu);
set(handles.listbox6, 'Value', []);
newItems = currentItems2;
newItems(index_selected) = [];
set(handles.listbox6, 'String', newItems);
if ~isempty(newItems)
    if length(newItems) >= 1
        set(handles.listbox6, 'Value', 1);
    end
end
% --- Executes on button press in pushbutton7.
function pushbutton7_Callback(hObject, eventdata, handles)
```

```
% --- Executes on ok button pressed.
function pushbutton8_Callback(hObject, eventdata, handles)
global newmenu; % stores the places
global newmenu_Trans;%stores the transtions
global global_info; % stores global variable everywhere
global hn;
% global_info.rt_monitor_places = {'pStart','pBuff2','pBuff1','pBuff3'};
% global_info.rt_monitor_trans = {'tRobot1','tRobot2','tRobot3'};
lst1=get(handles.listbox6,'String'); % to check places
lst2=get(handles.listbox4,'String'); % to check transtions
if ~isempty(lst1) && ~isempty(lst2),
   global_info.rt_monitor_places=newmenu; % copy the cell array to global R-T places
   global_info.rt_monitor_trans=newmenu_Trans;% copy the cell array to global R-T trans
   set(handles.text3,'String','Please wait..');
   close(Real_PTtime_select); % close the window
else
   msgbox('please select transtion and places from the left lists...');
end

% --- Executes on clear button press in pushbutton9.
function pushbutton9_Callback(hObject, eventdata, handles)
% clear items
set(handles.listbox4,'String',[]);
set(handles.listbox6,'String',[]);
% --- Executes on button press in pushbutton10.
function pushbutton10_Callback(hObject, eventdata, handles)
global PN;
my_list1 = PN.global_places;% load global places from GPenSIM
my_list2=PN.global_transitions;% load global trans from GPenSIM
% convert to cell array to put into list box for places
pics_cell1 = cell(numel(my_list1),1);
for j=1:numel(my_list1) % for places
   pics_cell1{j} = my_list1(j).name;
end
%put into the list box
set(handles.listbox5,'String',pics_cell1);
% convert to cell array to put into list box for transitions
pics_cell2 = cell(numel(my_list2),1);
for k=1:numel(my_list2)
   pics_cell2{k} = my_list2(k).name;
end
set(handles.listbox3,'String',pics_cell2);


% --- Executes on select transtions to the R-T transtions.
function pushbutton11_Callback(hObject, eventdata, handles)
global new_remove_menuTs; % stor all the ne
global newmenu;
newmenu=[];
currentItems22 = get(handles.listbox4, 'String');
list_entry = cellstr(currentItems22);
index_selected = get(handles.listbox4,'value');
choice_lstbox2 = list_entry(index_selected);
curl2=get(handles.listbox3,'String');
   new_remove_menuTs = [curl2;choice_lstbox2];
set(handles.listbox3,'String', new_remove_menuTs);
set(handles.listbox4, 'Value', []);
newItems = currentItems22;
newItems(index_selected) = [];
set(handles.listbox4, 'String', newItems);
if ~isempty(newItems)
    if length(newItems) >= 1
        set(handles.listbox4, 'Value', 1);
    end
end
```

GUI.m

```
function varargout = GUI(varargin)
%     GUI is a MATLAB code for calling and running GUI.fig
%     The GUI is designed and created by Nigussie Girma as realtime display
%     and monitor for GPenSIM.
%     The GUi is embedded inside a GPenSIM
%     A GPenSIM is a general petrinet simulator
%     ------------------------§§§----------------------------
%
%     GUI, by itself, creates a new GUI or raises the existing
%     singleton*.
%     In order to run GUI
%     H = GUI returns the handle to a new GUI or the handle to
%     the existing singleton*.
%
%     GUI ('CALLBACK', hObject, eventdata, handles...) calls the local
%     function named CALLBACK in GUI.M with the given input arguments.
%
%     GUI ('Property', 'Value',) creates a new GUI or raises the
%     existing singleton*.  Starting from the left, property value pairs are
%     applied to the GUI before GUI_OpeningFcn gets called.  An
%     unrecognized property name or invalid value makes property application
%     stop.  All inputs are passed to GUI_OpeningFcn via varargin.
%
%     *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%     instance to run (singleton)".
%     To use this tool, one should have a knowledge of Petri net and
%     GPenSIM in addition to Matlab GUIDE
% See also: GUIDE, GUIDATA, GUIHANDLES, gpensim, Petrinet

% Last Modified by GUIDE v2.5 13-Apr-2014 17:55:59
% Begin initialization code -
% CAUTION: !!! DO NOT EDIT The code before reading the readme file!!!
%                   -----------§§§----------------
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @GUI_OpeningFcn, ...
                   'gui_OutputFcn',  @GUI_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end
```

```
if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
% --- Executes just before GUI is made visible.
function GUI_OpeningFcn(hObject, eventdata, handles, varargin)
global cnt;
cnt=0;
% global global_info; % user data

handles.output = hObject;
guidata(hObject, handles);
% set(gcf, 'Units', 'normalized', 'Position', [0, 0, 1, 1])
% get(gcf, 'Position')   % >> 0 0 1.0 0.9154

pushbutton14_Callback(hObject, eventdata, handles);

function varargout = GUI_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;
% varargout{2} = handles.uipanel11;

%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Main Start%%%%%%%%%%%%%%%%%%%%%%
%function Start_button_Callback(hObject, eventdata, handles)
function pushbutton14_Callback(hObject, eventdata, handles)
global PN;
global global_info;%
global gp_pause;
gp_pause=0.5;
if not(PN.REAL_TIME),
    disp('Not real-time...')
    set(handles.text84,'String','NOT REAL TIME(STOCHASTIC TIME)')
    No_trans=PN.No_of_transitions;
    No_places=PN.No_of_places;

    global_info.rt_monitor_places = PN.global_places;
    global_info.rt_monitor_trans = PN.global_transitions;
else
    set(handles.text84,'String','REAL TIME')
    if ~isempty(global_info.rt_monitor_places) && ~isempty(global_info.rt_monitor_trans)
        No_trans=length(global_info.rt_monitor_trans);%PN.No_of_transitions;
        No_places=length(global_info.rt_monitor_places);%PN.No_of_places;
    else
        disp('Please choose the display places and trans in The main simulatio file')
        return;
    end
end
set(handles.text75,'String',num2str(gp_pause));
set(handles.text40,'String',No_places);
set(handles.text41,'String',No_trans);
if No_places > 7,
    No_places=7;
end
for j=1:No_places
```

```
   try
      res=strcat('axes',num2str(j),'_CreateFcn(hObject, eventdata, handles);');
      res2=strcat('edit',num2str(j+2),'_Callback(hObject, eventdata, handles);');
      eval(res);eval(res2);
   catch err
       disp(err);
      break;
   end
end
if No_trans > 10,
   No_trans=10;
end
for i=1:No_trans
  try
   m=strcat('pushbutton',num2str(i),'_Callback(hObject, eventdata, handles);');
   eval(m);
  catch err
   disp(err); break;
  end
end
%%%%%%% button (transition)handlers
function pushbutton1_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton1,'Visible','on');
if not(PN.REAL_TIME),
   set(handles.text1,'String',global_info.rt_monitor_trans(1).name);
else
   set(handles.text1,'String',global_info.rt_monitor_trans(1));
end

function pushbutton2_Callback(hObject, eventdata, handles)
global global_info;%
global PN;
set(handles.pushbutton2,'Visible','on');
if not(PN.REAL_TIME),
   set(handles.text2,'String',global_info.rt_monitor_trans(2).name)
else
   set(handles.text2,'String',global_info.rt_monitor_trans(2))
end

% --- Executes on button press in pushbutton14.
function pushbutton3_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton3,'Visible','on');
if not(PN.REAL_TIME),
   set(handles.text21,'String',global_info.rt_monitor_trans(3).name)
else
   set(handles.text21,'String',global_info.rt_monitor_trans(3))
end

% --- Executes on button press in pushbutton4.
function pushbutton4_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton4,'Visible','on');
```

```
if not(PN.REAL_TIME),
    set(handles.text22,'String',global_info.rt_monitor_trans(4).name)
else
    set(handles.text22,'String',global_info.rt_monitor_trans(4))
end

function pushbutton5_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton5,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text16,'String',global_info.rt_monitor_trans(5).name)
else
    set(handles.text16,'String',global_info.rt_monitor_trans(5))
end


% --- Executes on button press in pushbutton18.
function pushbutton6_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton6,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text17,'String',global_info.rt_monitor_trans(6).name)
else
    set(handles.text17,'String',global_info.rt_monitor_trans(6))
end

% --- Executes on button press in pushbutton7.
function pushbutton7_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton7,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text18,'String',global_info.rt_monitor_trans(7).name)
else
    set(handles.text18,'String',global_info.rt_monitor_trans(7))
end

% --- Executes on button press in pushbutton8.
function pushbutton8_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton8,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text19,'String',global_info.rt_monitor_trans(8).name)
else
    set(handles.text19,'String',global_info.rt_monitor_trans(8))
end

% --- Executes on button press in pushbutton9.
function pushbutton9_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton9,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text20,'String',global_info.rt_monitor_trans(9).name)
```

```
else
    set(handles.text20,'String',global_info.rt_monitor_trans(9))
end

% --- Executes on button press in pushbutton10.
function pushbutton10_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.pushbutton10,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text23,'String',global_info.rt_monitor_trans(10).name)
else
    set(handles.text23,'String',global_info.rt_monitor_trans(10))
end

function pushbutton15_Callback(hObject, eventdata, handles)% For stop button
global h2
h2=msgbox('Stopped!! press ok or click on "continue" ');
uiwait(h2);

% --- Executes on button press in resetbtn.
function resetbtn_Callback(hObject, eventdata, handles)
global gp_pause;
if(gp_pause > 0)
    gp_pause=gp_pause+0.1;
    set(handles.text75,'String',num2str(gp_pause));
else
    gp_pause=0.2;
    set(handles.text75,'String',num2str(gp_pause));
    set(handles.text75,'String','Min speed');
end
% --- Executes on button press in pushbutton18.
function pushbutton18_Callback(hObject, eventdata, handles)

close(GUI);
clear all;clc;

% --- Executes on button press in pushbutton7.
function pushbutton11_Callback(hObject, eventdata, handles)
global h2;
uiresume(GUI);
close(h2)

function circle2()
% to add tokens we should be able to draw some small circles.
% let use a small dots
radius = 0.25;
centerX = 3.5;
centerY = 7;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','k');


function del_circles()
global y;
global n;
global j;
clear j;
radius = 0.25;
centerX = 5+y;
centerY = 7-n;
j=rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[0,0],...
    'FaceColor','w','LineWidth',0.00001);


function circle()
global y;
global n;
global  cnt;
randcolor=[rand(1) rand(1) rand(1)];
% for i=1:2
    radius = 0.3;
    x=rand(1);
    y=x;
centerX = 5+x;
    m=rand(1)-rand(1);
    n=m;
centerY = 7-m;
cnt=cnt+1;

rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor',randcolor,'LineWidth',1);

% --- Executes during object creation, after setting all properties.


function axes1_CreateFcn(hObject, eventdata, handles)
global y;
global n;
global j;

radius = 2;
centerX = 5;
centerY = 7;
%j=hObject;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;
circle2();

% --- Executes during object creation, after setting all properties.
function axes2_CreateFcn(hObject, eventdata, handles)
global PN;
radius = 2;
centerX = 5;
centerY = 7;

rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
```

```
axis equal;

% --- Executes during object creation, after setting all properties.

function edit1_Callback(hObject, eventdata, handles)

% Hints: get(hObject,'String') returns contents of edit1 as text
%        str2double(get(hObject,'String')) returns contents of edit1 as a double

% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)

%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function edit2_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit2_CreateFcn(hObject, eventdata, handles)
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
% --- Executes during object creation, after setting all properties.
function uipanel14_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function uipanel15_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text13_CreateFcn(hObject, eventdata, handles)

% --- Executes when user attempts to close figure1.
function figure1_CloseRequestFcn(hObject, eventdata, handles)
delete(hObject);

function edit3_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.uipanel20,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text68,'String',PN.global_places(1).name);
else
    set(handles.text68,'String',global_info.rt_monitor_places(1));
end
% --- Executes during object creation, after setting all properties.
function edit3_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit4_Callback(hObject, eventdata, handles)
global global_info;
global PN;
```

```
set(handles.uipanel24,'Visible','on');
if not(PN.REAL_TIME),
   set(handles.text69,'String',PN.global_places(2).name);
else
   set(handles.text69,'String',global_info.rt_monitor_places(2));
end


% --- Executes during object creation, after setting all properties.
function edit4_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end


function edit5_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.uipanel25,'Visible','on');
if not(PN.REAL_TIME),
   set(handles.text70,'String',PN.global_places(3).name);
else
   set(handles.text70,'String',global_info.rt_monitor_places(3));
end

% --- Executes during object creation, after setting all properties.
function edit5_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit6_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.uipanel26,'Visible','on');
if not(PN.REAL_TIME),
   set(handles.text71,'String',PN.global_places(4).name);
else
   set(handles.text71,'String',global_info.rt_monitor_places(4));
end

% --- Executes during object creation, after setting all properties.
function edit6_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit7_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.uipanel27,'Visible','on');
if not(PN.REAL_TIME),
   set(handles.text72,'String',PN.global_places(5).name);
else
```

```
    set(handles.text72,'String',global_info.rt_monitor_places(5));
end


% --- Executes during object creation, after setting all properties.
function edit7_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit8_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.uipanel28,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text73,'String',PN.global_places(6).name);
else
    set(handles.text73,'String',global_info.rt_monitor_places(6));
end

% --- Executes during object creation, after setting all properties.
function edit8_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit9_Callback(hObject, eventdata, handles)
global global_info;
global PN;
set(handles.uipanel29,'Visible','on');
if not(PN.REAL_TIME),
    set(handles.text74,'String',PN.global_places(7).name);
else
    set(handles.text74,'String',global_info.rt_monitor_places(7));
end

% --- Executes during object creation, after setting all properties.
function edit9_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit9 (see GCBO)
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes during object deletion, before destroying properties.
function axes1_DeleteFcn(hObject, eventdata, handles)
ax = gca();
cla(ax)%,'reset');

% --- Executes during object deletion, before destroying properties.
function axes7_DeleteFcn(hObject, eventdata, handles)
ax = gca();
cla(ax)%,'reset');

% --- Executes on slider movement.
function slider1_Callback(hObject, eventdata, handles)
```

```
                    sliderMin=get(hObject,'Min');
                    sliderMax=get(hObject,'Max');
                    dummy=get(hObject,'Value');
                    s=dummy/(sliderMax-sliderMin);
                    dummy=get(handles.uipanel30,'position');
                    frameWidth=dummy(3);
 set(handles.uipanel30,'position',[0.1+frameWidth*s 0.071 frameWidth 0.78]);

% --- Executes during object creation, after setting all properties.
function slider1_CreateFcn(hObject, eventdata, handles)

% Hint: slider controls usually have a light gray background.
if isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor',[.9 .9 .9]);
end


% --- Executes on slider movement.
function slider2_Callback(hObject, eventdata, handles)
% Hints: get(hObject,'Value') returns position of slider
%        get(hObject,'Min') and get(hObject,'Max') to determine range of slider

% --- Executes during object creation, after setting all properties.
function slider2_CreateFcn(hObject, eventdata, handles)
% Hint: slider controls usually have a light gray background.
if isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor',[.9 .9 .9]);
end

function edit10_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit10_CreateFcn(hObject, eventdata, handles)

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit11_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit11_CreateFcn(hObject, eventdata, handles)
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit12_Callback(hObject, eventdata, handles)


% --- Executes during object creation, after setting all properties.
function edit12_CreateFcn(hObject, eventdata, handles)

% Hint: edit controls usually have a white background on Windows.
%      See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit17_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit17_CreateFcn(hObject, eventdata, handles)
% Hint: edit controls usually have a white background on Windows.
%      See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit16_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit16_CreateFcn(hObject, eventdata, handles)

% Hint: edit controls usually have a white background on Windows.
%      See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit15_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit15_CreateFcn(hObject, eventdata, handles)

% Hint: edit controls usually have a white background on Windows.
%      See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit14_Callback(hObject, eventdata, handles)
% Hints: get(hObject,'String') returns contents of edit14 as text
%       str2double(get(hObject,'String')) returns contents of edit14 as a double


% --- Executes during object creation, after setting all properties.
function edit14_CreateFcn(hObject, eventdata, handles)

% Hint: edit controls usually have a white background on Windows.
%      See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
   set(hObject,'BackgroundColor','white');
end

function edit13_Callback(hObject, eventdata, handles)

% Hints: get(hObject,'String') returns contents of edit13 as text
% str2double(get(hObject,'String')) returns contents of edit13 as a double

% --- Executes during object creation, after setting all properties.
```

```
function edit13_CreateFcn(hObject, eventdata, handles)

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'), get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in pushbutton20.
function pushbutton20_Callback(hObject, eventdata, handles)
global gp_pause;
if(gp_pause > 0)
    gp_pause=gp_pause-0.1;
    set(handles.text75,'String',num2str(gp_pause));
else
    set(handles.text75,'String',num2str(gp_pause));
    set(handles.text75,'String','Max speed');
    gp_pause=0.1;
end

% --- Executes during object creation, after setting all properties.
function text68_CreateFcn(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function text69_CreateFcn(hObject, eventdata, handles)

% set(handles.edit4,'BackgroundColor', get(0,'DefaultUicontrolBackgroundColor'));
% --- Executes during object creation, after setting all properties.
function text70_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text71_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text72_CreateFcn(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function text73_CreateFcn(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function text74_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text1_CreateFcn(hObject, eventdata, handles)
% --- If Enable == 'on', executes on mouse press in 5 pixel border.
% --- Otherwise, executes on mouse press in 5 pixel border or over resetbtn.
function resetbtn_ButtonDownFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function axes3_CreateFcn(hObject, eventdata, handles)
radius = 2;
centerX = 5;
centerY = 7;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;

 % circle();

% --- Executes during object creation, after setting all properties.
```

```
function axes4_CreateFcn(hObject, eventdata, handles)
radius = 2;
centerX = 5;
centerY = 7;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;

% Hint: place code in OpeningFcn to populate axes4

% --- Executes during object creation, after setting all properties.
function axes5_CreateFcn(hObject, eventdata, handles)
radius = 2;
centerX = 5;
centerY = 7;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;

% Hint: place code in OpeningFcn to populate axes5
% --- Executes during object creation, after setting all properties.
function axes6_CreateFcn(hObject, eventdata, handles)
radius = 2;
centerX = 5;
centerY = 7;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;

% Hint: place code in OpeningFcn to populate axes6

% --- Executes during object creation, after setting all properties.
function axes7_CreateFcn(hObject, eventdata, handles)
radius = 2;
centerX = 5;
centerY = 7;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;

% --- Executes during object creation, after setting all properties.
function axes15_CreateFcn(hObject, eventdata, handles)
radius = 2;
centerX = 5;
centerY = 7;
rectangle('Position',[centerX - radius, centerY - radius, radius*2, radius*2],...
    'Curvature',[1,1],...
    'FaceColor','w');
axis equal;
% --- Executes during object creation, after setting all properties.
function uipanel1_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text3_CreateFcn(hObject, eventdata, handles)
```

```
% --- Executes during object creation, after setting all properties.
function text4_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text5_CreateFcn(hObject, eventdata, handles)
% --- Executes during object creation, after setting all properties.
function text6_CreateFcn(hObject, eventdata, handles)
% --- Executes on button press in pushbutton19.
function pushbutton19_Callback(hObject, eventdata, handles)
global gp_pause;
if(gp_pause > 0)
gp_pause=gp_pause+0.1;
set(handles.text75,'String',num2str(gp_pause));
else
   gp_pause=0.1;
set(handles.text75,'String',num2str(gp_pause));
end
```

gpensim.m

```
if (nargin==0), gpensim_ver; return; end;

global PN;
global handles;
global hn;
global temp;
global temp2;
global IDy_store;
PN = pni;    % pni is the global PetriNet structure with ini dyn.
global global_info;
global gp_pause;
global hPT;

% initialize all the variables
   if PN.REAL_TIME,
      hPT=Real_PTtime_select; % GUI to select real_time monitor elements
                        %, i.e. places and transitions
      uiwait(hPT)
   end
t = cputime;
[Ts,EIP,LOG, colormap,Enabled_Trans_SET,Firing_Trans_SET,SIM_COMPLETE,Loop_Nr, ETS_index,
FTS_index] = ...
         gpensim_init_all();
% ---NGT:
% Prepare the monitor here GUI
disp('-----------GUI---------- Start here')
close(findobj('type','figure','name','GUI'));
if ~isempty(GUI),
   close(GUI);
end
tic;
hn=GUI;
handles=guidata(hn);
```

```
count=0;
   if not(PN.REAL_TIME),
      disp('Simulation will be paused for 1 sec');
      disp(' It is not real-time, please select global places and transitions as real-time monitoring')
   end;
fill_GUI_initial_dy(IDy_store);
set(handles.text75,'String',num2str(gp_pause));
if eq(str2double(gp_pause),0), gp_pause=1; end
% ---End NGT
disp('%%%%%%%%%%%%%%%%%%%%%%%%%%%%  MAIN LOOP
%%%%%%%%%%%%%%%%%%%%%%%%%%%%')
pause on;
while ~(SIM_COMPLETE),
   Loop_Nr = Loop_Nr + 1;
   %NGT: ************************************************          1
   if global_info.PRINT_LOOP_NUMBER,
   disp(['Loop: ',int2str(Loop_Nr),'  Time: ',num2str(PN.current_time)]);
   %%%%% Put loop to gui
      temp2=sprintf([temp2,'       ***Loop_Nr: ',int2str(Loop_Nr),'***',10]);
      if ~isempty(temp2),
         set(handles.edit1,'String',temp2);
      end
      temp=sprintf([temp,'         ***Loop_Nr: ',int2str(Loop_Nr),'***',10]);
      if ~isempty(temp),
         set(handles.edit2,'String',temp);
      end
   else
        if ~isempty(temp2),
           temp2=sprintf([temp2,10]);
           set(handles.edit1,'String',temp2);
        end
        if ~isempty(temp),
           temp=sprintf([temp,10]);
           set(handles.edit2,'String',temp);
        end
   end;
   %End NGT: ********************************************          1
   for i = 1:Ts, PN.Enabled_Transitions(i) = enabled_transition(i); end;
   %start NGT: ************************************************          2
   if(~isempty(PN.name)),
      set(handles.text39,'String',PN.name);
   end
   len=length(PN.Enabled_Transitions);
   count=count+1;
    if any(PN.Enabled_Transitions),
       enable_AnimNGT();
       [EIP] = firing_start(EIP);
    end
   end; %while ~(SIM_COMPLETE)
% Finally, pack results
pack_sim_results(Enabled_Trans_SET, Firing_Trans_SET, LOG, colormap);
sim_results = PN;
%%%NGT
distime=rt_clock_string();
set(handles.text67,'String',distime);
e = cputime-t;
toc;
```

```
set(handles.text42,'String',num2str(toc));% elapsed time
```

find_GUI_component_places.m

```
function [s]=find_GUI_component_places(curr_source_name)
global global_info;
global hn;
global PN;
if ~ismember(curr_source_name,global_info.rt_monitor_places),...
      s=''; disp(' ');return;
end
len=length(global_info.rt_monitor_places);
if PN.REAL_TIME,
   for j=1:len
      if strcmp(curr_source_name,global_info.rt_monitor_places(j)),
         %curr_source_name=global_info.rt_monitor_places(j);
         myobj = findobj(hn,'String',global_info.rt_monitor_places(j));
         if isempty(myobj),disp('cant get it');return; end
         myobj2=get(myobj);
         s = myobj2.Tag(~isspace(myobj2.Tag));
      end
   end
else
   disp('Not R-T')
   for j=1:len
      if strcmp(curr_source_name,global_info.rt_monitor_places(j).name),
         %curr_source_name=global_info.rt_monitor_places(j).name;
         myobj = findobj(hn,'String',global_info.rt_monitor_places(j).name);
         if isempty(myobj),disp('cant get it');return; end
         myobj2=get(myobj);
         s = myobj2.Tag(~isspace(myobj2.Tag));
      end
   end

end
```

token_number_ngt.m

```
function [] = token_number_ngt(curr_Place, tokens, markings_str)
global handles;
global global_info;

s=find_GUI_component_places(curr_Place);
if ~isempty(s),
   %%%% To print the number of tokens in each places
if ismember(curr_Place,global_info.rt_monitor_places),
  if strcmp(s,'text68'),
     set(handles.text95,'String',tokens);
  elseif strcmp(s,'text69'),
     set(handles.text89,'String',tokens);
  elseif strcmp(s,'text70'),
     set(handles.text90,'String',tokens);
  elseif strcmp(s,'text71'),
     set(handles.text91,'String',tokens);
  elseif strcmp(s,'text72'),
    set(handles.text92,'String',tokens);
  elseif strcmp(s,'text73'),
    set(handles.text93,'String',tokens);
  elseif strcmp(s,'text74'),
    set(handles.text94,'String',tokens);
  end
end
set(handles.print_state_space,'String',markings_str);
end
```

markings_string.m

```
for i = start_pi:stop_pi,
  tokens = markings(i);
  curr_Place = PN.global_places(i).name;
  if tokens,
    if eq(tokens, 1),
      tokens_nr_str = ''; % no need to print '1' before
    else
      tokens_nr_str = int2str(tokens);
    end;
    markings_str = [markings_str, tokens_nr_str, ...
      PN.global_places(i).name, ' + '];
  end; % if tokens,
  disp(markings_str)
  set(handles.print_state_space,'String',markings_str);
%%%%NGT
if PN.REAL_TIME,
  token_number_ngt(curr_Place,int2str(tokens),markings_str);
end
%%%%NGT
end; % for i = 1:Ps,
```

fill_GUI_initial_dy.m

```
function fill_GUI_initial_dy(initial_dynamics)
global hn;
global PN;
global handles;
global global_info;

Ps = PN.No_of_places;
X0 = zeros(1, Ps);  % initially
if not(isfield(initial_dynamics, 'm0')), % initial_markings
  warning('initial markings: NOT given ...'); disp(' ');
else
  imarkings = initial_dynamics.m0;
  if iscell(imarkings),  % sources = {'p1',1, 'p2', 3, ...}}
    no_of_sources = length(imarkings)/2; % number of places
    % extracting places
    for i = 1:no_of_sources,
      curr_source_name = imarkings{2*i -1};
      source_nr = check_valid_place(curr_source_name);
      initial_tokens = imarkings{2*i};
      X0(source_nr) = initial_tokens;
      %%%% NGT
```

```
          if ismember(curr_source_name,global_info.rt_monitor_places),
          s=find_GUI_component_places(curr_source_name);
         if ~isempty(s),
             if strcmp(s,'text68'),
               set(handles.text77,'String',num2str(X0(source_nr)));
             elseif strcmp(s,'text69'),
               set(handles.text78,'String',num2str(X0(source_nr)));
             elseif strcmp(s,'text70'),
               set(handles.text79,'String',num2str(X0(source_nr)));
             elseif strcmp(s,'text71'),
               set(handles.text80,'String',num2str(X0(source_nr)));
             elseif strcmp(s,'text72'),
                set(handles.text81,'String',num2str(X0(source_nr)));
             elseif strcmp(s,'text73'),
               set(handles.text82,'String',num2str(X0(source_nr)));
             elseif strcmp(s,'text74'),
               set(handles.text83,'String',num2str(X0(source_nr)));
             end
         end
%
          end
          %%%%%End NGT
      end;
   else  % sources is a vector: imarkings = [1 3 0 0 1]
      if ne(length(imarkings), Ps),
         error('initial marking must be same length as number of places');
      end;
      X0 = imarkings;
   end;
end;
```

gui_painter.m

```
function[] = gui_painter(t1,t_btncolr,textT_str,textT_colr,str)
% global PN;
global handles;
%global global_info;
s_trans = find_GUI_component_trans(t1);
if ~isempty(s_trans),
   if strcmp(s_trans,'text1'),
      set(handles.text44','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton1,'BackgroundColor', t_btncolr);
      set(handles.text47,'String',textT_str);
      set(handles.text47,'ForegroundColor', textT_colr);
   elseif strcmp(s_trans,'text2'),
      set(handles.text45','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton2,'BackgroundColor', t_btncolr);
      set(handles.text48,'String',textT_str);
      set(handles.text48,'ForegroundColor', textT_colr);
   elseif strcmp(s_trans,'text21'),
      set(handles.text46','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton3,'BackgroundColor', t_btncolr);
      set(handles.text49,'String',textT_str);
      set(handles.text49,'ForegroundColor', textT_colr);
   elseif strcmp(s_trans,'text22'),
      set(handles.text57','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton4,'BackgroundColor', t_btncolr);
      set(handles.text50,'String',textT_str);
      set(handles.text50,'ForegroundColor', textT_colr);
   elseif strcmp(s_trans,'text16'),
      set(handles.text58','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton5,'BackgroundColor', t_btncolr);
      set(handles.text51,'String',textT_str);
      set(handles.text51,'ForegroundColor', textT_colr);
   elseif strcmp(s_trans,'text17'),
      set(handles.text59','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton6,'BackgroundColor', t_btncolr);
      set(handles.text52,'String',textT_str);
      set(handles.text52,'ForegroundColor', textT_colr);

   elseif strcmp(s_trans,'text18'),
      set(handles.text60','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton7,'BackgroundColor', t_btncolr);
      set(handles.text53,'String',textT_str);
      set(handles.text53,'ForegroundColor', textT_colr);

   elseif strcmp(s_trans,'text19'),
      set(handles.text60','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton8,'BackgroundColor', t_btncolr);
      set(handles.text54,'String',textT_str);
      set(handles.text54,'ForegroundColor', textT_colr);

   elseif strcmp(s_trans,'text20'),
      set(handles.text61','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton9,'BackgroundColor', t_btncolr);
      set(handles.text55,'String',textT_str);
      set(handles.text55,'ForegroundColor', textT_colr);

   elseif strcmp(s_trans,'text23'),
      set(handles.text62','String',string_HH_MM_SS(current_time()));
      set(handles.pushbutton10,'BackgroundColor', t_btncolr);
      set(handles.text56,'String',textT_str);
      set(handles.text56,'ForegroundColor', textT_colr);
   end
   set(handles.uipanel1, 'BackgroundColor', t_btncolr); % for the small window
   set(handles.text13,'String', str);

   %pause(0.2)
end
```

enable_AnimNGT.m

```
function []=enable_AnimNGT()
global PN;
global str1;
global temp2;
global handles;
global global_info;
global prev_trans;
enbl_trans=PN.Enabled_Transitions;%  [0 1 1]
for i=1:length(enbl_trans)
```

```
  if eq(enbl_trans(i),1),
     curr_trans=PN.global_transitions(i).name;
     t1=i;
     disp(curr_trans)
     a= current_time();
     if PN.REAL_TIME,
        if ~ismember(curr_trans ,global_info.rt_monitor_trans),
           disp(['At ', rt_clock_string(), ' '...
              ,PN.global_transitions(t1).name,...
              ' is Enaled but not member of R-T monitor ...']);
           disp('--RETURN ON R-T_DISPLAY--');
           return;
        end
     end
     if eq(a,current_time()) && strcmp(curr_trans,prev_trans);
        disp('????curr_trans,prev_trans are equal'),return;
     end
     if PN.REAL_TIME,
        temp2=sprintf([temp2,PN.global_transitions(t1).name...
           ,' is Enabled At:   ',rt_clock_string(),10]);%
     else
        temp2=sprintf([temp2,PN.global_transitions(t1).name...
           ,' is Enabled At:   ',num2str(current_time()),10]);%
     end

     if ~isempty(temp2),
        set(handles.edit1,'String',temp2);
     end
     disp(['At ', num2str(current_time()), ' ',PN.global_transitions(t1).name, ' is enabled ....']);
     str1=[PN.global_transitions(t1).name,' is enabled'];
     gui_painter(t1,'g','Enabled','g',str1);
     prev_trans=curr_trans;
  end
end
```

fire_AnimNGT.m

```
function []=fire_AnimNGT(t1)
global PN;
global str2;
global temp;
global handles;
global global_info;

curr_trans = PN.global_transitions(t1).name;
%curr_Place =PN.global_places(i).name;
if PN.REAL_TIME,
  if ~ismember(curr_trans,global_info.rt_monitor_trans),
     disp(['At ', rt_clock_string(), ' ',PN.global_transitions(t1).name,...
        ' is Fired but not member of R-T monitor ...']);
     disp('--RETURN ON R-T_DISPLAY--');
     return;
  end
end
if PN.REAL_TIME,
  str2=[PN.global_transitions(t1).name,' is Fired At: '];
  temp=sprintf([temp,str2,rt_clock_string(),10]);
  %temp=temp(~isspace(temp));
  if ~isempty(temp),
     set(handles.edit2,'String',temp);
  end
else
  str2=[PN.global_transitions(t1).name,' is Fired At: '];
  temp=sprintf([temp,str2,num2str(current_time()),10]);
  set(handles.edit2,'String',temp);
end
%%%% Call painter here
gui_painter(t1,'r','Fired','r',str2);
```

fire_Complet_AnimNGT.m

```
function []=fire_Complet_AnimNGT(completing_tran)
global PN;
global temp;
global handles;
global global_info;

curr_trans=PN.global_transitions(completing_tran).name;
if PN.REAL_TIME,
  if ~ismember(curr_trans ,global_info.rt_monitor_trans),
     disp(['At ', rt_clock_string(), ' ',curr_trans,...
        ' is Comleted but not member of R-T monitor ...']);
     disp('--RETURN ON R-T_DISPLAY--');
     return;
  end
  str3=[curr_trans,' is completed At:   '];
  temp=sprintf([temp,str3,rt_clock_string(),10]);

else
  str3=[curr_trans,' is completed At:   '];
  temp=sprintf([temp,str3,num2str(current_time()),10]);
end
set(handles.edit2,'String',temp);
gui_painter(completing_tran,'y','Completed','y',str3);

disp(['At ', num2str(current_time()), ' ', ...
  curr_trans, ' is completed. ']);
disp(' ' );
```

hasnotfired_AnimNGT.m

```
function []=hasnotfired_AnimNGT(t1,f)
global PN;
global str2;
global temp2;
global temp;
global handles;
global global_info;

curr_trans = PN.global_transitions(t1).name;
%curr_Place =PN.global_places(i).name;
if PN.REAL_TIME,
   if ~ismember(curr_trans,global_info.rt_monitor_trans),
      return;
   end
   temp2=sprintf([temp2,PN.global_transitions(t1).name...
   ,' is Not_Enabled At:   ',rt_clock_string(),10]);%
if ~isempty(temp2),
   set(handles.edit1,'String',temp2);
end
end

if(f==0),% for not fired
   str2=[PN.global_transitions(t1).name,' Enabled but not Fired At: '];
   if PN.REAL_TIME,
      temp=sprintf([temp,str2,rt_clock_string(),10]);
   else
      temp=sprintf([temp,str2,num2str(current_time()),10]);
   end
   set(handles.edit2,'String',temp);
   gui_painter(t1,'c','Enbl but Not Fired','c',str2);

else % for never fired

   str2=[PN.global_transitions(t1).name,' Not enabled and ~Fired at'];
   if PN.REAL_TIME,
      temp=sprintf([temp,str2,rt_clock_string(),10]);
   else
      temp=sprintf([temp,str2,num2str(current_time()),10]);
   end
   set(handles.edit2,'String',temp);
   gui_painter(t1,[0.8 0.55 0.7],'Not enabled and ~fired',[0.8 0.55 0.7],str2);
end
```

firing_start

```
function [EIP]= firing_start(EIP)

% *
% *
% GPenSIM firing_start.m
% *
% *
%

global PN;

Rs = PN.No_of_system_resources;
[dont_care, enabledTrans] = find(PN.Enabled_Transitions > 0);
% enabled transitions to be fired based on a PRIORITY or RANDOMLY?
priority_exist = any(PN.priority_list);
if priority_exist,
   set_of_ordered_enabledTrans = ...
      priority_enabled_trans(enabledTrans);
else
   set_of_ordered_enabledTrans = randomgen(enabledTrans);
end;
No_of_enabledTrans = length(enabledTrans);
%%%%%%%%NGT end continue..
```

```
for i = 1:No_of_enabledTrans, % check events one by one
   t1 = set_of_ordered_enabledTrans(i);
   if not(PN.REAL_TIME),
       pause(1); % make some delay to reduce the speed for
       %simulated time
      disp('Sim paused')
      disp(' not Real_Time')
   end;
   disp(' ');
   if and(~PN.Enabled_Transitions(t1),...  % not enabled & firing
         ~(PN.Firing_Transitions(t1))),
      hasnotfired_AnimNGT(t1,1);
   end
%%%%%%%%%%%%%%%%%%%%
   if and(PN.Enabled_Transitions(t1),...  % enabled & notcurrently firing
         ~(PN.Firing_Transitions(t1))),

      [fcs, new_color, override, selected_tokens, additonal_cost]= ...
         firing_preconditions(t1);
      if fcs, % firing conditions satisfied, let the transition fire
         PN.Firing_Transitions(t1) = 1;  %
         disp(['At ', num2str(current_time()), ' '...
            ,PN.global_transitions(t1).name, ' is fired ...']);
         %%% NGT
         fire_AnimNGT(t1);
         %%%End NGT

         [delta_X,output_place,inherited_color,inherited_costs]= ...
            consume_tokens(t1, selected_tokens);

         % assign any resources reserved by t1
         resource_usage_cost = 0;
         if (Rs), [resource_usage_cost] = resource_assign(t1); end;
         [output_token_cost] = cost_of_output_token(t1,additonal_cost,...
                          resource_usage_cost,inherited_costs);
         % create new event to be put in Queue
         new_event_in_Q = create_new_event_in_Q(t1, ...
            delta_X, output_place);

         if (override), colorset = new_color;
         else colorset = union(new_color,inherited_color);
         end;
         if ischar(colorset), colorset = {colorset}; end;
         new_event_in_Q.add_color = colorset;
         new_event_in_Q.add_cost  = output_token_cost;
         EIP = add_to_events_queue(new_event_in_Q, EIP); % addto Queue

         % Update list of enabled trans after token removal
         for j = 1:No_of_enabledTrans, %check events one by one
            t2 = set_of_ordered_enabledTrans(j);
         PN.Enabled_Transitions(t2)=enabled_transition(t2);
         %recheck
         end;

      else % if firing conditions are NOT satisified
         %%% NGT START
         hasnotfired_AnimNGT(t1,0);
```

```
          %%% NGT END
          % cancel any resource reservations by the transition
          if (Rs), resource_unreserve(t1); end; %
       end; % if fcs,
   end; %if enabled_transition

end; %for t = 1:

%%% for non enabled trans
 [dont_care2, notenabledTrans] = find(PN.Enabled_Transitions <= 0);
 set_of_ordered_nenabledTrans = randomgen(notenabledTrans);
 No_of_nonenabledTrans = length(notenabledTrans);
 for k = 1:No_of_nonenabledTrans, % check events one by one
    t = set_of_ordered_nenabledTrans(k);
    hasnotfired_AnimNGT(t,1);
 end
```

Infoplc.m

```
function []=infoplc(pll,transition,tokens_to_be_consumed)
%infoplc(i,PN.global_transitions(transition).name,tokens_to_be_consumed);
global PN;
global handles;
global tem_pl;
global global_info;
curr_trans = PN.global_transitions(transition).name;
curr_Place = PN.global_places(pll).name;

s_infoplcs=find_GUI_component_places(curr_Place);

if ~isempty(s_infoplcs),
%     s_infoplcs='';disp(' ')
%     return;
% end
if PN.REAL_TIME,
if ismember(curr_Place,global_info.rt_monitor_places)...
      && ismember(curr_trans,global_info.rt_monitor_trans),
   tem0=[];%
   for i=1:length(global_info.rt_monitor_places)
      comp=global_info.rt_monitor_places(i);
      for j=1:length(PN.global_places)
         if strcmp(comp,PN.global_places(j).name),
            tem0=[tem0;PN.X(j)];
         end
      end
   end
disp(' ')
a=1;
while(a <= length(global_info.rt_monitor_places)),
   switch a;
      case 1;set(handles.text95,'String',num2str(tem0(1)));
      case 2;set(handles.text89,'String',num2str(tem0(2)));
      case 3;set(handles.text90,'String',num2str(tem0(3)));
      case 4;set(handles.text91,'String',num2str(tem0(4)));
      case 5;set(handles.text92,'String',num2str(tem0(5)));
      case 6;set(handles.text93,'String',num2str(tem0(6)));
      case 7;set(handles.text94,'String',num2str(tem0(7)));
   end
a=a+1;
end
   if strcmp(s_infoplcs,'text68'),
      tem_pl=sprintf([tem_pl,curr_trans,' Tok: ',num2str(tokens_to_be_consumed)...
         ,', At: ',num2str(rt_clock_string()),' From'...
         ,curr_Place,10]);
      tem_pl=sprintf([tem_pl,'.................',10]);
      set(handles.edit11,'String',tem_pl);
      set(handles.edit11,'Visible','on');

  elseif strcmp(s_infoplcs,'text69'),
      tem_pl=sprintf([tem_pl,curr_trans,' Tok: ',num2str(tokens_to_be_consumed)...
         ,', At: ',num2str(rt_clock_string()),' From'...
         ,curr_Place,10]);
      tem_pl=sprintf([tem_pl,'.................',10]);
      set(handles.edit12,'String',tem_pl);
      set(handles.edit12,'Visible','on');

  elseif strcmp(s_infoplcs,'text70'),
      tem_pl=sprintf([tem_pl,curr_trans,' Tok: ',num2str(tokens_to_be_consumed)...
         ,', At: ',num2str(rt_clock_string()),' From'...
         ,curr_Place,10]);
      tem_pl=sprintf([tem_pl,'.................',10]);
      set(handles.edit13,'String',tem_pl);
      set(handles.edit13,'Visible','on');
  elseif strcmp(s_infoplcs,'text71'),
      tem_pl=sprintf([tem_pl,curr_trans,' Tok: ',num2str(tokens_to_be_consumed)...
         ,', At: ',num2str(rt_clock_string()),' From'...
         ,curr_Place,10]);
      tem_pl=sprintf([tem_pl,'.................',10]);
      set(handles.edit14,'String',tem_pl);
      set(handles.edit14,'Visible','on');
  elseif strcmp(s_infoplcs,'text72'),
      tem_pl=sprintf([tem_pl,curr_trans,' Tok: ',num2str(tokens_to_be_consumed)...
         ,', At: ',num2str(rt_clock_string()),' From'...
         ,curr_Place,10]);
      tem_pl=sprintf([tem_pl,'.................',10]);
      set(handles.edit15,'String',tem_pl);
      set(handles.edit15,'Visible','on');
  elseif strcmp(s_infoplcs,'text73'),
      tem_pl=sprintf([tem_pl,curr_trans,' Tok: ',num2str(tokens_to_be_consumed)...
         ,', At: ',num2str(rt_clock_string()),' From'...
         ,curr_Place,10]);
      tem_pl=sprintf([tem_pl,'.................',10]);
      set(handles.edit16,'String',tem_pl);
      set(handles.edit16,'Visible','on');
  elseif strcmp(s_infoplcs,'text74'),
      tem_pl=sprintf([tem_pl,curr_trans,' Tok: ',num2str(tokens_to_be_consumed)...
         ,', At: ',num2str(rt_clock_string()),' From'...
         ,curr_Place,10]);
      tem_pl=sprintf([tem_pl,'.................',10]);
      set(handles.edit17,'String',tem_pl);
      set(handles.edit17,'Visible','on');
  end
end
end
```

```
end
```

consume_tokens.m

Note that the blue highlight is the original source code of the GpenSIM consume_tokens.m

```
function [delta_X,index_OP,inherited_color_set,inherited_costs] = ...
      consume_tokens (transition, selected_tokID)

global PN;

Ps = PN.No_of_places;
A =  PN.incidence_matrix;

%token removals from input place
input_weigths = A(transition,1:Ps); %extracting the weight of input arcs
% disp('input_weigths');
% disp(input_weigths)

inherited_color_set = {};
inherited_costs = 0;

% Move input tokens into Virtual places as "virtual tokens"
PN.X  = PN.X  - input_weigths;   % take tokens from input places ...
PN.VX = PN.VX + input_weigths; %   and push into Virtual places

PN.global_transitions(transition).absorbed_tokens = input_weigths;

for i = 1:Ps,
   tokens_to_be_consumed = input_weigths(i);
%     disp('tokens_to_be_consumed');disp(tokens_to_be_consumed)
   if (tokens_to_be_consumed),
            % %%%%%%% NGT %%%%%%%
      % display the following
      % transiton = transiton,
      % place = i,
      % number of tokens = tokens_to_be_consumed
      % time = PN.current_time
      % %%%%%%% NGT %%%%%%%
      [inherited_color_from_pi, inherited_costs_pi, selected_tokID] = ...
         consume_token_in_place_i ...
         (i, tokens_to_be_consumed, selected_tokID);
      % inherit colors and costs from different places
      inherited_color_set = union(inherited_color_set, ...
         inherited_color_from_pi);
      inherited_costs = inherited_costs + inherited_costs_pi;
      %disp('inherited_costs');disp(inherited_costs);
      %NGT infoplc.m called here
      infoplc(i,transition,tokens_to_be_consumed);

   end;
end;
```

C.2 gpensim codes for the R-T system models

i. Source code for production line

MSF.m

```
% the main file to run simulation

clear all;clc;
global global_info;
global_info.PRINT_LOOP_NUMBER = 1;
global_info.STOP_AT = current_clock(3) + [0 0 30];
global_info.REAL_TIME = 1;
global_info.cr = {'1','2','3','4'}; % color rotation
global_info.cr_index = 0; % init rotation index = 0
png = petrinetgraph('production_def');
% dyn.m0 = {'pOutPut1',1,'pOutput2',1,...
%                'pOutput3',1};
dyn.ft = {'tInPut',2,'allothers',1};
pni = initialdynamics(png, dyn);
print_system_info(pni);
sim = gpensim(pni);
print_statespace(sim);
plotp(sim, { 'pInout_Buff','pOutPut1', 'pOutput2', ...
                'pOutput3','pOutput_Buffer'});
grid on;
```

production_def.m

```
function[png] = production_def()
png.PN_name = 'A Simple Petri Net definition';
png.set_of_Ps = {'pInout_Buff', 'pOutput_Buffer', 'pOutPut1', 'pOutput2', ...
                'pOutput3'};
png.set_of_Ts = {'tAssemble','tInPut','tProduction_line1','tProduction_line2'...
               ,'tProductionline3'};
png.set_of_As = {'pInout_Buff' ,'tProduction_line1' ,1 ,'pInout_Buff' ...
   ,'tProduction_line2' ,1 ,'pInout_Buff' ,'tProductionline3' ,1 ...
   ,'pOutPut1' ,'tAssemble' ,1 ,'pOutput2' ,'tAssemble' ,1 ,'pOutput3'...
   ,'tAssemble' ,1 ,'tAssemble' ,'pOutput_Buffer' ,1 ,'tInPut' ,'pInout_Buff' ...
   ,1 ,'tProduction_line1' ,'pOutPut1' ,1 ,'tProduction_line2' ,'pOutput2' ...
   ,1 ,'tProductionline3' ,'pOutput3' ,1};
```

tInout_pre.m

```
function [fire, transition] = tInPut_pre (transition)

global global_info;

if strcmp(transition.name, 'tInPut'),
   index = mod(global_info.cr_index, 4)+1;
   global_info.cr_index = global_info.cr_index + 1;
   transition.new_color = global_info.cr(index);
   fire = 1;
   return;
end;
```

tAssembly_pre.m

```
function [fire, transition] = tAssemble_pre (transition)

if strcmp(transition.name, 'tAssemble'),
   fire = 1;
```

```
else
   disp('Wait until other lines finish their task')
   fire=0;
end;
```

COMMON_PRE.m

```
function [fire, transition] = COMMON_PRE (transition)

if strcmp(transition.name, 'tProduction_line1'),
   tokID1 = select_token_with_colors('pInout_Buff',1,'1');
   tokID2 = select_token_with_colors('pInout_Buff',1,'2');
   transition.selected_tokens = [tokID1 tokID2];
   fire = any(transition.selected_tokens);
elseif strcmp(transition.name, 'tProduction_line2'),
   tokID1 = select_token_with_colors('pInout_Buff',1,'2');
   tokID2 = select_token_with_colors('pInout_Buff',1,'3');
   transition.selected_tokens = [tokID1 tokID2];
   fire = any(transition.selected_tokens);
elseif strcmp(transition.name, 'tProductionline3'),
   tokID1 = select_token_with_colors('pInout_Buff',1,'4');
   transition.selected_tokens = tokID1;
   fire = tokID1;
else
   fire = 1;
end;
```

ii. Source code for room security model

Door_def.m

```
% S door model of the alarm system
function [png]=door_def()

png.PN_name='Door_alarm_model';
png.set_of_Ps={'pDoor_Close','pDoor_OPen','pDoor_was_Opened'};
png.set_of_Ts={'tClose','tOpen','t_Check_open','tWO','tWC'};
png.set_of_As={'pDoor_Close','tOpen',1,'pDoor_Open','t_Check_open',1,...
   'pDoor_was_Opened','tWC',1,'pDoor_OPen','tClose',1,...
   'tOpen','pDoor_Open',1,'tClose','pDoor_Close',1,'t_Check_open',...
   'pDoor_was_Opened',1,'tWO','pDoor_Open',1,'tWC','pDoor_Close',1};
```

Alarm_model_def.m

```
% An alarm model
function [png]= alarm_model_def()

% Alarm_system_model
png.PN_name='Alarm_system_model';
png.set_of_Ps={'pDisarmed','pArmed','pRing'};
png.set_of_Ts={'tDetect','t_a_off','tOff','tRinging'};
png.set_of_As={'pDisarmed','tDetect',1,'pArmed','tRinging',1,...
   'pRing','tOff',1,'tDetect','pArmed',1,'tRinging','pRing',1,...
   'tOff','pDisarmed',1,'t_a_off','pDisarmed',1};
```

Key_padmodel_def.m

```
% a Key pad model for key combination
function [png]=key_padmodel_def()
% A PN model for key pad
png.PN_name='a PN model for key pad';
png.set_of_Ps={'pBuffer','pEntry_entered','pExit_entered'};
png.set_of_Ts={'tEntry','tExit'};
png.set_of_As={'pBuffer','tEntry',1,'pBuffer','tExit',1,...
  'tEntry','pEntry_entered',1,'tExit','pExit_entered',1};
```

Room_sec_MSF.m

```
clear all; clc;
global global_info;
global_info.REAL_TIME = 1;   % This is a Real-Time run
global_info.STOP_AT = current_clock(3) + [1 1 20]; % stop 1:1:20
global_info.passwords=['A' 'B' 'C'];
global_info.deltaT=0;
global_info.readIn=0;
png = petrinetgraph({'door_def','alarm_model_def','key_padmodel_def'});
dyn.m0 = {'pDoor_Close',5,'pBuffer',5,'pDisarmed',1};
dyn.ft = {'tDetect',5, 'allothers', 1};
pni = initialdynamics(png, dyn);
disp('System is ready ...');
sim = gpensim(pni);
plotp(sim,{'pStart','pDetect','pEnd'});
```

COMMON_PRE.m

```
function [fire, transition] = COMMON_PRE(transition)
global global_info;

if strcmp(transition.name,'tOpen')&&...
    strcmp(transition.name,'tExit')
  if strcmp(transition.name,'tDetect'), % tDetect is enabled since there
    %are tokens in pDisarmed and pExit_entered
    deltat1=current_time();
    readIn=input('Enter the combination code');
    deltat2=current_time();
    deltaT=deltat2-deltat1;
    if deltaT < 60,
      if ismember(readIn,global_info.passwords),
        fire=1;
      end
    else
      fire=0;
    end
  end
end
```

COMMON_POST.m

```
function [] = COMMON_POST(transition)
if strcmp(transition.name,'t_a_off') || ...
        strcmp(transition.name,'tOFF'),
    beep off;
end
```

tEntry_pre.m

```
function [fire, transition] = tEntry_pre(transition)
global global_info;
%readIn
if ismember (global_info.readIn,global_info.passwords),
  fire=global_info.deltaT < 60; % disarm the alarm
end
```

tRinging_post.m

```
function [] = tRinging_post(transition)
% Trigger the alarm
beep on;
```

iii. Source code door alarm model

alarm_def.m

```
function[png] = alarm_def ()
png.PN_name = 'LEGO_Robot_alarm';
png.set_of_Ps = {'pStart','pRestart','pAlarm','pDetect','pEnd','pCodes',...
   'pNotMatch','pRinging','pEnd'};
png.set_of_Ts = {'t_Start_btn','tOn','tDetect','tCheck','tShout','tOff'};
png. set_of_As = {'pStart','t_Start_btn',1,'t_Start_btn','pRestart',1,...
   'pRestart','tOn',1,'tOn','pAlarm',1,'pAlarm','tDetect',1,'tDetect','pDetect',1,...
   'pDetect','tCheck',1,'pCodes','tCheck',1,'tCheck','pNotMatch',1,'pNotMatch',...
   'tShout',1,'tShout','pRinging',1,'pRinging','tOff',1,'tOff','pEnd',1,...
   'pEnd','t_Start_btn',1};
```

doorModule_def.m

```
function [png] = doorModule_def()
png.PN_name='Door_alrm_model';
png.set_of_Ps={'pArrive','pDoor','pDetect','pGrant','pInside','pNot_alarm_on'};
png.set_of_Ts={'tArrive','tNo_alarm_set','tEnter_in','tEnter','tCheck','tDetect'};
png.set_of_As={'pArrive','tArrive',1,'pDoor','tNo_alarm_set',1,...
   'pDoor','tDetect',1,'pDetect','tCheck',1,'pGrant','tEnter',...
   1,'pNot_alarm_on','tEnter',1,'tArrive','pDoor',1,'tDetect','pDetect',...
   1,'tCheck','pGrant',1,'tEnter_in','pInside',1};
```

Alarm_control_NXT.m

```
clear all; clc;
global global_info;
global_info.REAL_TIME = 1;    % This is a Real-Time run
global_info.STOP_AT = current_clock(3) + [0 0 20]; % stop after 2 mins
global_info.passwords=['A' 'B' 'C'];
global_info.resetCMD = 1000;
init_ALARM_NXT(); % initialize NXT
png = petrinetgraph({'alarm_def','doorModule_def'});
dyn.m0 = {'pArrive',1,'pEnd',1,'pCode',1};
dyn.ft = {'tDetect',5, 'allothers', 1};
pni = initialdynamics(png, dyn);
%disp('System is ready ...');
sim = gpensim(pni);
close_Alarm_NXT(); % Never forget to clean up after your work!!!
plotp(sim,{'pStart','pDetect','pEnd'});
```

init_ALARM_NXT.m

```
function [] = init_ALARM_NXT()
% initialize alarm and ultrasonic in NXT
global global_info;
% initialize global variables
global_info.NORMAL_CYCLE = false;
% initializ NXT
warning('off', 'MATLAB:RWTHMindstormsNXT:noEmbeddedMotorControl');
COM_CloseNXT all;
hNXT = COM_OpenNXT('bluetooth.ini');% look for USB devices
COM_SetDefaultNXT(hNXT);    % sets global default handle
global_info.NXT_handle = hNXT;
global_info.detect = SENSOR_4;
global_info.RESTART_BUTTON = SENSOR_1;
global_info .OBJECT_DISTANCE = 20;

NXT_PlayTone(440, 500);
```

Close_alarm_NXT

```
function [] = close_Alarm_NXT()

COM_CloseNXT('all');
```

tDetect_pre.m

```
function [fire, transition] = tDetect_pre(transition)

global global_info;
OpenUltrasonic(global_info.detect);

distance= GetUltrasonic(SENSOR_4);
if distance < global_info.OBJECT_DISTANCE
   fire = 1;
else
   fire = 0;
end
CloseSensor(SENSOR_4);
```

tDetect_post.m

```
function [] = tDetect_post(transition)
disp('Object detected');
```

COMMON_PRE.m

```
function [fire, transition] = COMMON_PRE(transition)
global global_info;
if strcmp(transition.name, 'tNo_alarm_set'),
   disp('No Alarm: the entrance if free');
elseif strcmp(transition.name, 'tEnter_in'),
   disp('Inside house');
elseif strcmp(transition.name, 'tEnter'),
   disp('The Person is clear the alarm and check line');
elseif strcmp(transition.name, 't_off'),
   disp('Off the alarm');
```

```
    i=input('Enter the reset code');
    if eq(str2double(i),global_info.resetCMD),
        handle = COM_OpenNXT('bluetooth.ini');
        NXT_StopSoundPlayback(handle);
        % now the alarm is off
    end
else
   disp('the alarm is set... continue')
end;
fire = 1;
```

tCheck_pre.m

```
function [fire, transition] = tCheck_pre(transition)
global global_info;
% pause(1);
read_keypad=input('Enter code');
if ~ismember(read_keypad, global_info.passwords),
    disp('     detected: "DETECT OBJECT"');
    for n=1:10:500
        beep
        NXT_PlayTone(440, 500);
        NXT_PlaySoundFile('Woops.rso', 0);

    end
    fire =0;
else
    fire=1;
end
```

t_Start_btn_pre.m

```
function [fire, transition] = t_Start_btn_pre(transition)
global global_info;
res_btn = global_info.RESTART_BUTTON;
% check for RESTART BUTTON press
OpenSwitch(res_btn);
switchState = GetSwitch(res_btn);
CloseSensor(res_btn);
if (switchState), % RESTART BUTTON is pressed
    fire = 1;

else
    fire = 0;
end;
```

t_start_btn_post.m

```
function [] = t_Start_btn_post(transition)
global global_info;
disp('RESTARTING ....');
handle = COM_OpenNXT('bluetooth.ini');
NXT_StopSoundPlayback(handle);
```

Hardware_NXT.m

```
function   [] = Hardware_NXT(command_str)
% function [] = Hardware_NXT(command_str)

switch lower(command_str)
   case {'initialize','init'}
      init_TL_NXT(); %  switches in NXT

   case {'close', 'clear'}
      close_TL_NXT(); % Never forget to clean up after your work!!!
   case 'nearest'
      disp('Method is nearest')
   otherwise
      disp('Unknown method.')
end;
```

iv. Source code for traffic light model

The complete source code for traffic light system is available at. [39]