CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 OVERVIEW

In this Chapter, an insight of the research work done along with major contributions as explained in this thesis and the future scope of this research work are provided. For this purpose, a complete review of the thesis Chapter wise is initially provided in Section 7.2. The details of the roadmap executed in regard to the completion of the research work are provided in Section 7.3. The details of the major contributions made in this research work are presented in Section 7.4. Finally the future scope in regard to this research work is emphasized in Section 7.5.

7.2 REVIEW OF THESIS

As explained through the earlier Chapters, the purpose of this thesis is to study techniques to achieve Fault Diagnosis and Identification (FDI) using estimation procedures, and to identify conditions for imparting Fault Tolerant Control (FTC) schemes on systems. The systems are broadly classified into discrete, continuous and hybrid systems and the studies are focussed to achieve combined FDI and FTC on the systems, individually.

For this purpose in this research work, typical systems classified as Discrete Event Dynamic Systems (DEDSs), Continuous Event Systems (CESs), and Hybrid Event Systems (HESs) are analyzed by modeling the systems using discrete, continuous,
and hybrid Petri nets, individually. After successful modeling and analysis of the models developed in the Petri net environment through numerical and graphical approaches, fault diagnosis procedures and fault tolerant schemes are proposed and applied to various benchmark systems, and are simulated. For this purpose, structural properties of Petri nets such as reachability, observability, and controllability are utilized and based on the Literature study done, algorithms to achieve combined FDI and FTC on the benchmark systems are proposed along with the numerical results.

Next, this is followed with the application of proposed techniques on real-time system data collected from petroleum refinery and on typical sequential processes, such as bottle-filling plant, and sewage treatment process to achieve FDI and FTC. The systems models developed earlier are then considered to be a Markovian process, and based on the Markovian process, various performance measures are evaluated to check the correctness of the models developed. For this purpose, the conditions for model checking are formulated based on the constraint information available, and analytical results are obtained.

In order to explain the research work done, the thesis was broadly classified into seven chapters. In Chapter 1, an overview of the need to develop the research along with the problem statement and objectives of the research work carried out, and the expected outcome was explained. In Chapter 2, the theoretical concepts of Petri net modeling along with the details of observability and controllability properties which motivated in building this research work was covered. In Chapter 3, a total description of the systems considered for study under research work along with the modeling capabilities and analysis was provided. Estimation based techniques to achieve fault diagnosis and identification, and fault tolerant control in typical benchmark systems considered was explained in detail in Chapter 4. Chapter 5
covered a detailed description of FDI and FTC achieved in real-time case studies considered for research work. Chapter 6 covered the results and discussions along with performance evaluation for model checking in regard to the systems considered.

### 7.3 RESEARCH WORK ROADMAP

The details of the roadmap followed in regard to the completion of this research work in shown in Table 7.1.

<table>
<thead>
<tr>
<th>Stages</th>
<th>Content</th>
<th>Details</th>
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<tbody>
<tr>
<td>1</td>
<td>Literature survey</td>
<td>Collection of various reference papers along with materials for carrying out the research work was done</td>
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| 2      | Study and analysis of the systems | This work included the following:  
1. Detailed study of basics and applications of Petri nets for modeling of systems.  
2. Study and analysis of the system models developed under various conditions.  
3. Simulation of the above analysis |
| 3      | Implementation of FDI and FTC    | Software based implementation of proposed FDI and FTC on system models developed in earlier stage was done initially.  
This is followed by application of the techniques to achieve FDI and FTC in real-time system data collected. |
| 4      | Performance evaluation           | Evaluation of performance measures applicable for the system models developed for model checking was done with graphical and analytical results. |
7.4 MAJOR CONTRIBUTIONS MADE IN THIS RESEARCH WORK

The major contributions made in the proposed research work are as follows:

1. Algorithm for visualized representation of flow of tokens in the modeled control structure developed in Petri net environment shows the real-time working of the systems considered in this research work. Graphical results comprising performance indices provide a detailed description of the system performance.

2. Here, fault diagnosis based on event occurrences have been carried out using Petri net models as compared to state occurrences dealt with state model approaches.

3. Here, the proposed algorithm is based on the individual and combined effects of sensor and actuator failures modeled as place and transition failures.

4. In order to achieve FDI in a hybrid system, the proposed method is based on considering the continuous part, rather than the discrete part.

5. The proposed algorithm to achieve FTC is based on individual and multiple faults.

6. Simulation results are obtained to diagnose faults and impart tolerant control when the output is both observable and unobservable.

7. An account of various performance measures along with their values has been evaluated which is useful in studying the system performance.
7.5 FUTURE SCOPE

In this research work, some considerations with respect to modeling of systems in Petri net environment are made, such as (1) the initial marking of the system model is known (2) the faults that are identified and diagnosed occur one at a time only. Hence, by suitable modifications and improvements, such as real-time system identification and multiple FDI and FTC techniques, the research work can be enhanced.

Moreover, the performance measures evaluated in this research work are highly useful for checking the correctness of the systems models developed. With suitable improvements, various other qualitative based analysis of a Petri net model can be performed. As discussed in Chapter 4, in order to achieve FDI and FTC, the concepts of observability, reachability and controllability of Petri nets are utilized which are based on the behavioural properties of Petri nets. Likewise, based on the structural properties such as concurrency, liveness, safety, deadlock etc. [26], various other analyses such as scheduling, reliability analysis, safety analysis, HAZard and OPerability (HAZOP) analysis, etc. can be performed which form the future scope in regard to the enhancement of this research work.