THE INTEGRATION OF A DESIGN TOOL AND A SCHEDULABILITY ANALYSIS TOOL FOR REAL-TIME

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ABSTRACT

In real time systems, the important point is the scheduling analysis of system. It means providing the responses to all events (external or internal) fast and fairly in the system. Therefore, the design of the software must consider timing predictability and dependability. In order to provide predictable design, an integration approach which integrates design modeling Techniques and Schedulability Analysis Techniques should be considered. This synthesis analysis allows us to detect error at an early stage of development and unfeasible real time architectures. Furthermore, it prevents from design mistakes and accelerates development schedules. This integration also allows the developer to verify the real time performance of the design at early phase before proceeding to coding phase. As a result, aim of this paper is to show the integration approach which allows the developer to verify the real time performance of the design at early phase before coding phase. In this paper, Rhapsody design tool and RapidRMA for Rhapsody scheduling tool are used to perform designing and scheduling of real-time system respectively. Also an autonomous mobile robot (AMR) is used as a case study.

Keywords: Integration, UML-SPT, Rhapsody, RapidRMA for Rhapsody

1 INTRODUCTION

Real-Time software systems consist of several tasks and concurrent processes; each task should communicate and synchronize with each other and with their environments. These structures are very complex. Due to the need of processing concurrent inputs from many sources in real time systems, simultaneous and real time events are unpredictable. Real time system structure is highly expected to prove the response of concurrent tasks fairly and fast. Real-Time software is part of safety and mission in critical systems that require high dependability and timeliness during system operations.

In real time systems, the important point is the scheduling analysis of system. It means providing the response to all events (external or internal) fast and fairly in the system. For this particular propose, it is required to integrate Unified Modeling Language (UML) model with scheduling analysis. In addition, there are several benefits of this integration [1]. Firstly, this synthesis analysis provides automatic timing analysis as opposed to manual inspection of timing properties due to use of tools [2]. Secondly, it allows the designers to catch the timing fault of design in early phase. In addition, it is capable of estimating the impact of different architectures and software allocations on the timing performance before the system is completed. Finally, it hides complexities of schedulability analysis of real time system and composite coding phase from the designer. It helps the designer focus more on the design phase instead of implementation or testing phase [3].

The importance of real time systems design increases rapidly due to the complexities of real time systems structure. The UML is the Object-Oriented Method language for all software and it is widely used due to its extensibility mechanism, stereotypes, tag values and profiles. Besides, another important feature of UML is that it has object paradigm which support to cope with software complexity effectively. [4] UML-SPT profile was produced by OMG to capture timeliness, performance, and schedulability properties of real time systems.

Rate Monotonic Analysis (RMA) schedulability technique is a basic algorithm that assigns the priorities according to the RM algorithm meaning that tasks with shorter periods get higher priorities. [5]

Scheduling analysis can be done easier by using a suitable scheduling tool. It helps engineers apply the scheduling analysis easier. RapidRMA for
Rhapsody is a tool that was produced by Tri-Pacific software Inc. [8].

RapidRMA is very useful tool for users designing the system. Users can use RapidRMA to coordinate the tasks and to adjust the tasks parameters. Users also can choose the best scheduling algorithm technique because scheduling algorithm can be easily changed in the model. By using RapidRMA tool, users can predict ahead of time whether or not system will meet its requirements timing. One of big advantages of RapidRMA tool is to predict, reliably, if sets of tasks will be scheduled under all possible circumstances.

An autonomous Mobile Robot system must be capable of traversing a field, performing given jobs, sensing of its environment and wisely reacting to it. Predicting and analysis of timing play important roles for reliable mobile systems as foremost requirements. The real time computing theories, scheduling algorithms can be used in developing robotics applications in order to have more reliable robot systems, guaranteed a stable behavior and predictable performance.[11]

The aim of this paper is to illustrate how to integrate RapidRMA tool and Rhapsody UML-SPT design tool and its benefits for real time system designers. This paper also shows how to design a predictable mobile robot real-time system by using this integration. The layout of this paper is as following: Section 2 discussed UML-SPT design model and Rhapsody design tool. Rate Monotonic Analysis (RMA) and RapidRMA schedulability analysis tool were discussed in Section 3. The autonomous mobile robot (AMR) controller was discussed in Section 4. Section 5 has discussion and finally Section 6 concluded the overall of this paper.

2 UML-SPT AND RHAPSODY TOOL

The important feature of UML-SPT is the timeliness properties among different tools such as UML modeling tools and schedulability analysis tools. In addition, this profile does not invent any new technique; it just gathers all that has been done to capture about timeliness and other properties. [9] Moreover, this profile does not break the standard semantics of UML.

This profile also aims to define some concepts for real time applications. These concepts compose three things, which are the stereotypes, tags, and constraints. Figure 1 illustrates us the structure of UML-SPT Profile. The main advantage of this profile is it provides to standardize idioms design patterns common in a particular domain. However the UML-SPT profile only provides the annotation timing and performance characteristics of the GRM sub profiles and performance analysis sub profile.

![Image](https://via.placeholder.com/150)

Figure 1. The structure of UML-SPT Profile [10]

GRM (General Resource Model) is the primary package which contains the basic concepts of real time systems. Moreover, GRM model is built on a classic client server model. The client requests services to be performed by the servers. [10] GRM can be divided into three parts of sub profiles as below:

i. RTResource modeling consists of general concepts of the real time systems such as, events, actions, response, scenario, execution engine and so on.

ii. RTConcurrency modeling includes about concurrency modeling of actions, responses, and shareable resources.

iii. RTTime modeling contains time-related mechanism for schedulability analysis. Indeed this modeling is a framework which uses most of some elements such as clocks, and timers to send triggers at a specified interval. [10]

Second main package is analysis model which provides sub packages for different kinds of analytical method.

i. S-profile for schedulability analysis defines the stereotypes, tags, and constraints for common of schedulability analysis. In addition, this sub profile ensures a framework to analyze the schedulability of real time situations.

ii. P-profile defines common performance analysis methods.
Rhapsody is a visual design environment that helps to design, analyze and build real time and embedded systems. [8] It is a design tool that can be used to design the system using UML. Rhapsody was produced by I-Logix Company; this tool involves in diagrams such as use case, object model, state chart, sequences, and component diagrams. Moreover, the intended behavior of the system can be analyzed earlier in the development cycle by generating code from UML and SysML diagrams and testing the application as it is created.

3 RATE MONOTONIC ANALYSIS (RMA) AND RAPIDRMA TOOL

Rate Monotonic Analysis has been first discussed by Serlin in 1972 and then been padded by Liu and Layland in 1973. Rate monotonic analysis (RMA) is based on the use of a priority pre-emptive task scheduling policy. It uses mathematical technique to evaluate a set of tasks in guiding the engineers to particularize, understand, analyze and anticipate the behaviors in real-time system [5] [6]. In RMA, the task with the shortest period has the higher priority to be executed first. Liu and Layland theory stated that a set of independent tasks that are scheduled by rate monotonic algorithm will always meet their deadlines if,

\[ U_n = \sum_{i=1}^{n} \frac{C_i}{T_i} \leq n \left(2^{\frac{1}{n}} - 1\right). \]  

Where \(C_i\) is the ith task’s computation time, \(T_i\) is the ith task’s period and \(U_n\) is the utilization bound for n task. Consequently, any periodic task set is schedulable by RMA When \(n\) is equal to 2, \(U_n\) equal to 0.828. It approaches \(\ln2\) (0.693), shown by the dashed line, for large \(n\). Consequently, any set of periodic tasks are scheduled by RMA if the tasks’ combined utilization is less than 69%. [10]

The worst case utilization bound in the theorem is assumed to be tight in the sense that there exist some infeasible task sets with utilization arbitrarily close to \(n \left(2^{1/n} - 1\right)\).If tasks’ relative deadline (Di) equal to their respective periods (Ti) and the tasks are periodic, independent, preemptable then RMA scheduling algorithm can schedule tasks up to 100% utilization.

The usual problem in RMA is that the arrangements of priority for each task are not suitable, where a task that should be the higher priority has to wait for a resource being used by a task with lower priority.

In RapidRMA as shown Figure 2, tasks can be quickly created and modified, also tasks priorities can be changed easily. By using RapidRMA users can easily change the tasks parameters and then quickly see the result of system timing analysis. Also they can see easily blocking problems and other problems of resources graphically. Moreover, they can find non repeatable timing problems and nonschedulable tasks that cause many schedule delays. In addition, users can look not only at an isolated task set on a specific processor, but also at entire embedded systems and networks with end-to-end analysis capabilities. In the real time systems, there are many aperiodic tasks such as hardware interrupts which occur at an unpredictable time. By using RapidRMA, these aperiodic events are handled by using relevant devices which are called periodic servers. A periodic server is assigned to each aperiodic task to execute them.

Figure 2. Shows RapidRMA interface

4 THE INTEGRATION WITH AMR SYSTEM CASE STUDY

In this paper, as mentioned earlier that an AMR case study was used to provide the integration. Figure 3 illustrates the steps of the integration. As seen in Figure 3, previously case study is designed by using Rhapsody design tool based on UML-SPT design model. During design time, the designer should determine the real time requirements of the system such as, worse case execution times, priorities of the tasks and so on.

Determining of timing requirements definitely takes an important role for real-time systems. If designers do not take into account the timing requirements at the design phase, then they
might encounter with difficulties after completion of the system.

To do integration with AMR case study, those steps mentioned will be followed. First of all, functional requirements of AMR case study will be determined and drawn in Object Model diagrams. This diagram specifies the structure and static relationship of the classes in the system. Secondly, all states will be drawn in the statechart diagram which shows the sequence of the states. Finally, sequences diagram of AMR case study will be drawn. This diagram is a graphical view of a scenario that shows an object interaction in a time-based sequence.

After completion of designing phase, RapidRMA for Rhapsody tool is used to perform schedulability analysis of the system. In this context, rhapsody tool enables to transfer the real-time requirements mentioned to the RapidRMA tool by using some middle forms. It is very useful feature for designer because they do not take much effort to transfer the real-time requirements to the RapidRMA tool. Figure 4 shows one of the middle forms which is called Run Analysis Dialog Form offered by Rhapsody in order to transfer real-time requirements of the system.

The middle form which is seen in Figure 4 is obtained within the Rhapsody design tool and used to determine which scheduling analysis will be used. Moreover, the designers can choose whether there is a thread or not in the system and assign thread counts manually. In addition, this middle form also allows the designers to set the priorities of each task.

Another middle form is depicted in Figure 5. This form is very important to fulfill the schedulability analysis of the system because it is used to map the system requirements by using tags and values. Designers can select the tasks of the system on the left –side of the form and assign each task to the schedulability analysis by selecting tag and assigning a value. However, RapidRMA just focuses on the timing properties on the system. Because of that, designer cannot assign all system values to the schedulability analysis tagged value. They should consider the timing values for performing system schedulability. After filling the middle forms with timing values to transfer to the RapidRMA tool, schedulability analysis will be automatically performed by RapidRMA tool.

After some given information on the integration, the chosen case study of Autonomous Mobile Robot (AMR) will be explained. The goal of the robot software is to control the movement of the robot in finding a passage and exiting through the passage while avoiding obstacles. In order to move the robot and achieve the robot’s goal, the software needs to control the motor at each robot
drive wheels, monitor the environments and navigate the robot. The embedded controller monitors its environment by using four infrared proximity sensors. The robot can be moved forward, reverse, turn left and turn right. The robot moves at constant speed during straight movement and this speed will be changed during turning movement.

There are seven tasks derived from the Autonomous Robot System (AMR) system and all tasks are listed in Table 1. \textit{Wcet} is obtained as worst case execution times for each task after execution of schedulability analysis of the system. Table 1 also includes \textit{Period} column that shows period for each task. The \textit{Period} and \textit{Wcet} are used for each task in the table as input for RMA analysis of timing properties. Another column shows priorities of the AMR tasks. If designers use Fixed Priority analysis like RMA, DMA so on, these priorities are assumed by designers. The tasks are ordered from highest to lowest priority in the table.

<table>
<thead>
<tr>
<th>Task</th>
<th>Wcet (C)</th>
<th>Period (T)</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorctrl_left</td>
<td>6</td>
<td>10</td>
<td>1 (highest)</td>
</tr>
<tr>
<td>Motorctrl_right</td>
<td>6</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Subsumption</td>
<td>10</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Avoid</td>
<td>9</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>Stop</td>
<td>10</td>
<td>20</td>
<td>4 (lowest)</td>
</tr>
</tbody>
</table>

After completion of the execution, a message box will appear to confirm whether the system is schedulable or not.

![Figure 6. UML-SPT object model diagram of AMR](image)

![Figure 7. UML-SPT sequence diagram of AMR](image)

![Figure 8. Run Analysis Diagram in RapidRMA for Rhapsody tool](image)
If the system is schedulable, users can see the Timing Model Table as shown in Figure 9 which is created depending on the middle forms as filled. In addition, this table involves the columns which consist of task name, priority, and worst case execution time cells etc. in this table. Timing model table also shows whether each task has met its deadline or not and the results of scheduling of the system based on chosen scheduling policy. Those cells in the table are filled by the incoming results after execution of scheduling analysis.

Users can particularly see global priority, local priority, completion time, whether the task schedulable or not for each task. In addition, users can also see the schedulable results and the total utilization rate of the system.

The table also shows the result of the fields mentioned above. In our instance result of the utilization rate after execution is (0.8). This result shows that the system is schedulable because as mentioned before that RMA schedulability analysis algorithm has $U_n$ utilization bound for n task.

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**Figure 9: Timing Model Table in RapidRMA for**

**Figure 10: Timing Analyze Table in RapidRMA for Rhapsody**
To analyze the system there is a graph provided by RapidRMA tool for Rhapsody as shown in Figure 10. After execution of the scheduling analysis, users will have the results of scheduling analysis of the system. Schedule Graph is obtained in Rhapsody sequence diagram and shows worst case timeline of the all tasks (Wcet). Schedule graph for the set of AMR controller is shown in Figure 10. In this graph, users can see timeline of the worst-case of the tasks or any resources on a selected node.

According to given priorities to the task, Motorctrl_left task has a higher priority than others and it will be the first executed task as seen in Figure 10. Consequently, every job in Motorctrl_left task will be scheduled and executed as soon as it is released.

5 DISCUSSION

The design of the real-time system must consider timing predictability and dependability. We have proposed the integration a schedulability tool and a design tool to obtain predictability design for real time system. RapidRMA tool for rhapsody design is used to do schedulability analysis based on RMA methodology. In this section, we have discussed our integration approach that consists of three main points. 1-) usability of tools 2-) providing all schedulability circumstances 3-) feedback of information during integration process.

With respect to the usability of tools, design and schedulability tool, makes design and analyze quite easy. In real, designers of real time system should cope with detail of the system such nonfunctional requirements like timing, predictability so on. design tools must provide simple and understandable features to make design easily for designers. Rhapsody and RapidRMA for rhapsody tools make design and schedulability analysis of the system easy for designers.

Our second point is whether RapidRMA tool supports all schedulability circumstances or not. Unfortuantely, designer can choose just two schedulability policies to perform schedulability analysis of the system which are RMA and DMA. These are not enough if designers want to use dynamic priority algorithms such as EDF (Earliest Deadline First), LST (Least-Slack Time First) to schedule the system, they cannot choose them in the RapidRMA tool. This is a lack of the tool for designers.

Finally, with related to the last point in our approach that is feedback of information, as mentioned, the steps of integration have been shown in Figure 3. These integration tools should ensure the feedback of information for each step during design and analyze of the system. According to our experience, we have truly obtained the feedback of information by using RapidRMA tool and Rhapsody tool together. This is very important issue that is if designer cannot catch any error or warning while system execution, they cannot complete the design smoothly. Commercial tools should provide the feedback of information fast and truly for designers.

6 CONCLUSION

This paper presents the integration of the selected scheduling analysis tool and design tool in order to obtain predictable design for an autonomous mobile robot system. The tool selected is RapidRMA for Rhapsody scheduling tool and Rhapsody design tool. TeleLogic Company has produced RapidRMA for Rhapsody tool which integrated RapidRMA scheduling analysis tool in the Rhapsody design tools based on UML-SPT design model. This integration allows users to easily fulfill the design and scheduling of the system within one Rhapsody design tool. With respect to the latter issue, designers can focus directly on the system design. Moreover by using those tools, designers can detect error at an early stage of development and unfeasible real time architectures. This integration allows the developer to verify the real time requirements of the design. According to our experience of using RapidRMA for Rhapsody commercial tool, the scheduling analysis can be performed very easily by real-time system’s designers.

In the future work, we will use RapidRMA for Rose RT tool and Rose RT design tool based on UML-RT design model. RapidRMA for Rose RT scheduling tool also has been produced by TeleLogic Company. After using both scheduling tools we will evaluate their facilities for real-time system’s designers.

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