Timing Analyzing for Systems with Execution Dependencies between Tasks

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ABSTRACT

In this paper, a novel approach to timing analysis of complex real-time systems with intricate execution dependencies between tasks, such as asynchronous message-passing and globally shared state variables, is presented. By applying the method to a model taken from a real robotic control system, we show the benefit, in terms of reduced pessimism, when compared to a combination of standard static WCET analysis and Response-Time Analysis.

Categories and Subject Descriptors

C.3 [**Special-purpose and application-based system**]: Real-time and embedded systems; D.2.4 [**Software/program verification**]: Model checking; D.4.1 [**Process management**]: Scheduling; D.4.4 [**Communications management**]: Message sending

General Terms

Verification

Keywords

response-time analysis, parametric worst-case execution-time estimates on tasks, complex real-time systems, TIMES

1. INTRODUCTION

To date, there are many embedded real-time software systems, where the adhering tasks exhibit strong temporal dependencies, e.g. asynchronous message-passing and globally shared state variables, which vary the execution time of the tasks radically. One problem when maintaining such complex systems can be timing-related errors, and one approach to avoid these errors is to use schedulability analysis methods, such as Response-Time Analysis (RTA) [1]. Nevertheless, RTA (and other schedulability analysis techniques), although providing the prediction about timing behavior of execution in worst-case scenarios, rely on the existence of a fixed Worst-Case Execution-Time (WCET) of the tasks. Correspondingly, the quality of the analysis is directly correlated to the quality of the WCET estimates. Unfortunately, the WCET of tasks obtained by static WCET analysis techniques may not easily be bounded if the analysis assumes each task is independent of the others. An example is where the execution time of two tasks may vary depending on the status of queues they use to share data. A WCET dependent on external context is often referred to as a parametric WCET. Sometimes a pessimistic WCET bound can be calculated based on maximum queue lengths, and in other cases the WCET is completely unbounded until the behavior of dependent tasks is known.

In this paper, we present a novel approach to tackle this issue by using parametric WCET estimates on tasks and TIMES [6] (a timed model checking tool). In the evaluation work, we show that the proposed approach can find the exact value of WCET and WCRT of tasks in the model, yielding much less pessimistic results compared with the static WCET analysis using native assumption (introduced in Section 3.2) and basic RTA in [2].

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2. MODELING OF COMPLEX REAL-TIME SYSTEMS

Practically, the system model with intricate task execution dependencies as mentioned previously is described by a modeling language used in RTSSim [3]. For the purpose of this work, it is sufficient to know that RTSSim employs a hierarchical model to specify the system structure consisting of a number of *tasks*. Moreover, each task is composed of a number of *jobs* and RTOS services invoked by e.g., message passing. Each job in an RTSSim task is represented by the modeling primitive *execute*, e.g., `execute(tcb, 100, 10)` means the adhering task will consume 10 model-time units with 100 percent possibility. For a full definition of the language refer to [4].

3. EXPERIMENTAL EVALUATION

The evaluation model contains a First-In-First-Out (FIFO) buffer IOQ with queue size 13 and three periodic, non-blocking tasks executed on a single processor under Fixed-Priority Preemptive Scheduling (FPPS), i.e., ENV_IO, IO and CTRL task with the parameters shown in Table 1 (the lower numbered priority is more significant). The ENV_IO task is an environmental task which generates 2 external events that are stored in the global variable `nofEvents`. The complex tasks' temporal dependencies between the IO and CTRL tasks are dependent on the input-dependent data placed in the IOQ queue and the GSSV `gstate1_ctrl` which vary tasks' execution times radically. For the sake of space, more details of the model can be found in [5].

Table 1: Tasks and task parameters for the evaluation model.

Task	*Priority*	*Period*	*Parameter*
ENV_IO	0	200	No
IO	3	500	`k`
CTRL	4	1000	`i, j`

3.1 Parametric WCET Representation of Tasks

For the IO task, its parametric WCET estimate can be expressed as follows:

$$C^p_{IO} = C^p_{io,v} = m_{sio} \times C^{sendMsg} \qquad (1)$$

For the CTRL task, its parametric WCET representation can be expressed as follows:

$$C^p_{CTRL} = m_{rctrl} \times C^{recvMsg} + Sel(Val(gssv1\_ctrl), C_{gssv1\_ctrl}) \qquad (2)$$

After filling up Equation 1 and Equation 2 with parameters `k`, `i` and `j` specified in the model, the new parametric WCET representation of the IO and CTRL tasks are as follows:

$$C^p_{IO} = C^p_{io,v} = k \times C^{sendMsg} \qquad (3)$$

$$C^p_{CTRL} = i \times C^{recvMsg} + 2 + j \times C(10) \qquad (4)$$

3.2 Basic RTA

With the purpose of performing safe analysis, covering the system model worst-case behavior when runtime information is missing, the annotation to, e.g., `ioevent` and `gstate1_ctrl` are given by naive assumption (NA), that is, the maximum queue length (i.e., 13) and the maximum of the variable (i.e., 1). Once the value of parameters is obtained, the WCET of tasks can be calculated and plugged into the response-time computation formula in basic RTA, in a position to obtain the value of WCRT of tasks on focus.

3.3 Results Comparison

Looking at Table 2, concerning the CTRL task, the value of parameter `i` obtained by TIMES i.e., 10 is 23% (i.e., $(13-10)/13\times100\%$) less pessimistic than 13 given by NA in terms of maximum queue length. Moreover, the value of parameter `j` obtained by TIMES i.e., 0 is 100% (i.e., $(1-0)/1\times100\%$) less pessimistic compared with the value assumed by NA, i.e., the maximum value of the variable. Next, concerning the WCET of the CTRL task, the results using the value of parameters obtained by using TIMES i.e., 42.1% (i.e., $(38-22)/38\times100\%$) less pessimistic compared with the one derived from static WCET analysis using NA, as showed in Table 3. Regarding the WCRT of the CTRL task, the result given by TIMES reduces the pessimism, 32% (i.e., $(50-34)/50\times100\%$) compared with basic RTA, obviously.

Table 2: The upper bound of parameters in the evaluation model determined by different analyses.

Parameter	*Static WCET analysis using NA*	*TIMES*
i	13	10
j	1	0
k	6	6

Table 3: The results obtained by TIMES and basic RTA using static WCET analysis using NA.

WCET/WCRT	*Basic RTA using static WCET analysis with NA*	*TIMES*
WCET(IO)	12	12
WCET(CTRL)	38	22
WCRT(CTRL)	50	34

4. CONCLUSIONS

In this paper we present a novel approach to timing analysis of complex real-time systems, i.e., a combination of using parametric WCET of tasks and a model checker TIMES. By applying the method to a model inspired by a real robotic control system shows the benefit, in terms of reduced pessimism, over static WCET analysis using native assumption, e.g., maximum queue size and maxima of the variables, and basic RTA.

5. ADDITIONAL AUTHORS

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