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How Does Task Scheduling Affect Engine Control Performance?

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Abstract—**The timing behavior of engine control applications has been analyzed in several papers, whose results allow verifying the system schedulability under different schedulers and assumptions. However, the characterization of the scheduling problem suffers from several inaccuracies, the most important one being probably the hard deadline assumption. In fact, in engine control, a few deadline misses are often well tolerated and the objective of the scheduling is not necessarily to meet all deadlines, but rather maximizing the engine performance. This requires evaluating the impact of the scheduler, which is much more complex, since it does not refer to timing properties in isolation, but is related to the functional behavior and overload management. The open problem addressed here is to understand how scheduling decisions affect the engine performance. A possible approach to address such a problem is through a suitable tool chain that integrates a scheduling simulation framework with an engine model for estimating the impact of a scheduling policy on engine performance.**

I. Introduction

Engine control systems require actions that need to be performed at specific angular rotations of the crankshaft, in addition to other regular periodic activities. As a consequence, a typical engine control application consists of time-driven periodic tasks with fixed periods, typically between a few milliseconds and 100 ms (see [1], page 152), and angular tasks triggered at specific crankshaft angles. The activation rate of such angular tasks hence varies with the engine speed (variable-rate tasks). For example, for engines where the speed varies from 500 to 6500 revolutions per minute (RPM), the interarrival times of the angular tasks range from about 10 to 120 ms (assuming a single activation per cycle).

To prevent overload conditions at high engine speed, such angular tasks are implemented in such a way to decrease their computational requirements for increasing speeds [2], hence they are referred to as adaptive variable-rate (AVR) tasks. In particular, they are implemented as a set of operational modes, each characterized by a set of functions operating within a given speed range.

Analyzing the schedulability of tasks sets consisting of both periodic and AVR tasks is a difficult problem that has been addressed by several authors under various simplifying assumptions, under both fixed priority scheduling [3]–[5] and Earliest Deadline First (EDF) [6]–[8].

All the papers considered above, however, focused on analyzing the schedulability of task sets consisting of periodic and AVR tasks, without any concern on engine performance.

A performance-driven design approach has been addressed in [9] for finding the transition speeds that trigger the mode changes of an AVR task.

The challenging open problem addressed here is to understand how scheduling decisions may affect engine performance, in terms of power, fuel consumption, and pollution. Solving this problem requires the integration of different crucial components, including a realistic engine model, schedulability analysis, control algorithms, and a simulation environment that accounts for the delays introduced by the operating system.

II. Open problems

The analysis of engine control applications is an interesting and challenging problem. Not only the scheduling problem is relatively new and complex (due to the presence of AVR tasks), but the application is characterized by multiple performance criteria (power, emissions, fuel consumption, noise) and deadline misses are clearly tolerated by the control logic. In addition, when studying the impact of time delays on the performance, details on the functional and code implementation of the controls cannot be avoided. Depending on them, a deadline miss can result in skipping an actuation, or performing an actuation with old data, or even with incomplete and approximate information available.

The impact of all these issues on the performance criteria of the engine is far from obvious. Likely, most of the computational models and their corresponding real-time analyses that are available today, fail in accounting for all the parameters that affect the engine performance.

Similarly, the performance indices that are more affected by scheduling issues are to date, and to the best of our knowledge, unknown.

Finally, further complications arise when considering the adaptive behavior of engine control tasks. As discussed in Section I, to avoid overload conditions, AVR tasks perform a mode-change among a set of possible control implementations. As the engine speed increases, AVR tasks switch to simplified (or even different) control implementations with a reduced computational demand. The switch happens at given *transition speeds*. This determines a trade-off between system schedulability (or in general, response-times and deadline miss ratio) and the resulting performance of the engine. The design problem of transition speeds has been investigated in [9] under hard real-time schedulability constraints. Alternative approaches based on extended analyses to cope with temporary overaload conditions are still not explored.

III. Proposed approach and outstanding issues

To solve the problem of how to evaluate the impact of deadline miss and scheduling delays on the performance of the CPS system there are several possible approaches. One possibility is to attempt a functional characterization of the dependency of the performance function(s) from the temporal parameters. For some simple control systems this is possible, but for realistic CPS the task soon becomes prohibitively difficult because of several reasons, including the need to satisfy multiple performance criteria and the difficulty in finding analytical models for the impact of late task executions on other tasks (this is why several papers of this type restrict the analysis to scheduling with time isolation).

Fuel injection is a prototypical case in this sense for the reasons discussed in the previous section.

We are attempting a first analysis of these issues by building a sample experimental framework. The envisioned approach for the evaluation of the impact of scheduling policies is based on a cosimulation framework that, following the principles of CPS system analysis, includes a set of models:

- A model of the engine and the combustion process in it (the physical system or plant)
- A model of the engine controls
- A model of the task configuration and the scheduling

The system is based on the Simulink toolset and leverages the T-Res environment for the simulation of the task scheduling. For the development of the engine model we leveraged information from several sources, including engine models for the steady state and event-based models as described in [1] and other empirical models found online. The engine controls are currently extremely simple and only contains a simple analytical formula that computes the angle of injection and the injection time that is defined by a calibration table.

The T-Res simulation framework is described in [10]. For the purpose of this project we extended the task model block and the timing information associated with the task to allow for the modeling of the AVR behavior. The task block in T-Res includes a signal for the explicit activation in case of event-triggered tasks, and this signal is used to define the activation of the task in correspondence to defined position of the engine crankshaft. In addition, the block has been extended to include another imput that refers to a generic *mode*. This input can be used for multiple purposes and defines in general a different execution time behavior for a finite and enumerated set of conditions. In our case, the mode index is provided from a simple block that looks at the engine rotation speeds and, based on the speed range, defines the execution time that the task requires.

Currently, within the assumptions of our model, the simulation is able to show how the scheduling delays result in errors in the angle/duration of the injection actuation (as shown in Figure 1, which aims at showing that adaptation of the task WCET for higher rates is indeed required to reduce the errors). However, we are still not able to express how a more complex implementation (WCET) also translates into a possible more accurate control law.

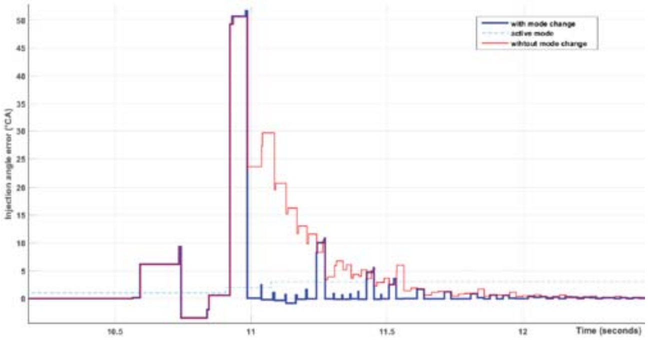

Figure 1. Angle error with scheduling delays with and without adaptation in the task execution times.

Future directions: While the framework and the approach are quite general, it is not clear what amount of work is reusable and if the problem can be partitioned in such a way that the timing problem can be separated from the functional analysis. In this case, the simulations with the model of the system and the controls could be used to derive a formulation of the dependency of the performance(s) with respect to the timing parameters (and select the relevant parameters). The performance function(s) could then be used to evaluate the scheduling solutions.

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