Complex Embedded Automotive Control Systems
CEMACS

DaimlerChrysler
SINTEF
Glasgow University
Hamilton Institute
Lund University

PUBLIC
ACTIVITY REPORT WORKPART 3
DELIVERABLE D3

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Executive Summary

This is the activity report of workpart 3 *Controller Design* of the CEMACS project (deliverable D3). It covers the first 6 months of activities towards Milestone 1.

The focus of Workpart 3 is on the theory and methods of controller design with the aim to adapt these to the applicational needs of the project. Most project partners have been active in this workpart during the reporting period. This can be summarised as follows: SINTEF has worked on WP3.2 and WP3.4, Glasgow University has been active on WP3.1, the Hamilton Institute has contributed to WP3.2 and 3.4, while Lund University has worked on WP3.1–3.4. Details of the activities are given in this report.

During the reporting period, the activities were targeted towards formulating the controller design problems and possible approaches. The techniques reviewed will form the theoretical and methodological basis for the design process.

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Contents

1 Activities towards Milestone 1

The expected results for Milestone 1 are to formulate problems and possible solutions, and to lay out the theoretical and methodological basis of the design process. The workpackage is divided into four parts according to four complementary techniques. The activities for each part are reported below for each project partner.

1.1 WP 3.1: Classical Multivariable Control Analysis and Design

Glasgow University: In line with the overall structure of the workplan, work package WP3.1 on Classical Multivariable Control Analysis and Design takes a bottom-up approach where representative automotive applications are taken as a starting point for Control Design Activity. In the case of Glasgow University, this focusses on the Collision Avoidance problem using steer-by-wire of WP1.2. The adopted analysis and design methodology is Individual Channel Analysis and Design (ICAD) [1, 2].

The application of ICAD to the integrated control of large complex systems, in particular aerospace (helicopter and fixed wing) control [3, 4], has shown that the technique is suitable approac in the face of higher levels of systems integration (flight control systems, engines, utilities), stronger cross-coupling, many more inputs/outputs (control surfaces), actuator redundancy; and not least, more demanding performance requirements in the form of tighter control (manoeuvreability). These are precisely the control design issues that define the Collision Avoidance problem of WP1.2, especially the need for tighter (high-bandwidth) control.

Of the various design issues arising from these control requirements, initial efforts within WP 3.1 are directed towards exploring the following issues:

1. Which system outputs are best controlled by which system inputs? Develop systematic methods for assigning input-output pairs based upon multivariable structure elucidated by ICAD;

2. Issues of redundancy in actuators and actuator failure compensation.

The helicopter ICAD application [3] is of interest to issue 1 in that it demonstrated that while it was possible to use ICAD to design a suitable multivariable controller for a given choice of system input-output pairs, control difficulties were considerable reduced through a subsequent different choice of input-output pairs. In effect, the appropriate assignment of system input-output pairs is intimately related to the best multivariable structure of the individual control channels. Often, as in the helicopter case, the best ICAD assignment of input-output pairs accords with accepted industrial practice. Initial efforts to explore this are within the context of collision avoidance of WP1.2, starting with vehicle lateral dynamics later integrated with longitudinal dynamics.

Lund University: Several aspects in control of multivariable systems are addressed. A central theoretical issue is decentralization. This is important in car dynamics, because the fast loops need to operate locally, while coordination and parameter estimation can work on a slower time scale. We work on decentralized solutions in state observers and observer based feedback. We also study how experiences from industrial success of PID control can be transfered to a multi-variable setting.

1.2 WP 3.2: Hybrid Control Systems

SINTEF: The objective of this work has been to establish novel hydrid control design methods, and qualify recently developed advanced hydrid control methods for application in automotive applications. Recently developed numerical methods for multi- parametric nonlinear programming has been tested on an automotive yaw stabilization problem, providing similar functionality as ESP (electronic stability program). The method gives an explicit characterization and representation of the optimal solution. It has been tested in simulation case studies and the results show that this systematic model-based nonlinear constrained optimal control strategy can provide excellent performance, and robustness to unmodelled dynamics, changes in road friction characteristics, actuator constraints, and safety constraints. The method is implementable on fixed-point embedded computers using a few hundred aritmetic operations per sample. The implementation makes use of a pre-computed binary search tree data structure that can be verified, and the main challenge is to minimize the need for embedded computer memory. The method is promising for handling of complex, nonlinear and dynamic constraints when coordinating a set of automotive brake and steering actuators [5].

Hamilton Institute: Quadratic stability of systems with constraints and quadratic stability of switched systems with uncertain parameters are investigated. We have started to look at the *Multiple-model adaptive control* paradigm for application to automotive control problems. Initially we will focus on the vehicle rollover problem using differential braking. This work will be used to seed a theoretical work programme that will examine the approach more closely and verify its suitability for our applications.

Lund University: For hybrid control systems, we work on verification of safety properties and optimization of switch strategies. In both cases, methods from discrete automata are generalized to work for a general class of hybrid systems.

1.3 WP 3.3: Multivariable Control Systems with time delay

Lund: This research are has a long history in Lund. Our most recent publication in Automatica a few months ago was devoted to frequency domain criteria for robustness to time-varying delays [6].

1.4 WP 3.4: Nonlinear and adaptive control

SINTEF: In many nonlinear control applications the essential nonlinearities may be highly uncertain. In such cases the use of nonparametric nonlinear models such as Gaussian Process models does not require prior knowledge of the model structure. In the first place Gaussian Process models give an estimate of the nonlinear model with a given variance, but also a direct estimate of the linearized model with corresponding variance is available. This may be used in the nonlinear hybrid controller development based on multiple linearized models. An application to wheel slip control illustrates controller development based on a nonparametric model of the unknown and uncertain friction nonlinearity [7].

Control allocation deals with the mapping of a commanded control force or moment to a redundant set of actuators that are subject to constraints on their operation. In automotive vehicles, the brakes, steering and suspension all have an effect on the lateral dynamics of the vehicle and can be used for steering,lateral stabilization and rollover prevention. A recently developed general nonlinear control allocation strategy, that is well founded in Lyapunov stability theory, has been extended to the adaptive case in order to also handle uncertainty in the actuator forces. In automotive systems this may be due to uncertain mass (distribution) and more importantly uncertain tyre/road friction characteristics. Theoretical results regarding stability and convergence of the adaptive closed loop system has been developed. Further work will be to develop stronger theoretical properties, investigate numerical implementation aspects that are highly relevant in embedded automotive systems, and quality the technology for automotive applications [8].

Hamilton Institute: The Hamilton Institute is studying stability problems that arise in switched linear systems where the switching law is a function of the system state. Such problems arise in a variety of control design problems. Initial work has focused on deriving spectral conditions for strict positive realness, and on deriving necessary and sufficient conditions for a quadratic Lyapunov function, for a class of non-linear systems.

Lund University: Synthesis methods for nonlinear control are developed based on classical ideas of dynamic programming in a modern computational setting based on convex optimization.

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