Design Automation for Automotive Cyber-Physical Systems

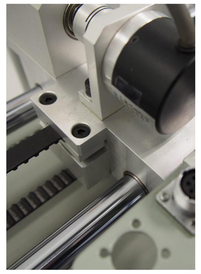
PI: Samarjit Chakraborty (UNC) **Co-PIs: James Anderson (UNC), Parasara Sridhar Duggirala (UNC), Khaja Shazzad (GM)**

Graduate Students: Prateek Ganguli, Clara Hobbs and Shengjie Xu (B. Ghosh graduated in 2023, now faculty at University of Alabama)

Motivation

- Methods for incorporating implementation artifacts like delays, numerical errors, and side-effects introduced by software have been studied in the control technology literature (e.g., starting with Computer-Controlled Systems by Åström and Wittenmark)
- But modern automotive electrical/electronic (E/E) architectures have hundreds of electronic control units (ECUs) connected by a complex communication architecture with buses like CAN, FlexRay, LIN and automotive Ethernet
- Such highly distributed and heterogeneous architectures offer *many* different controller implementation options

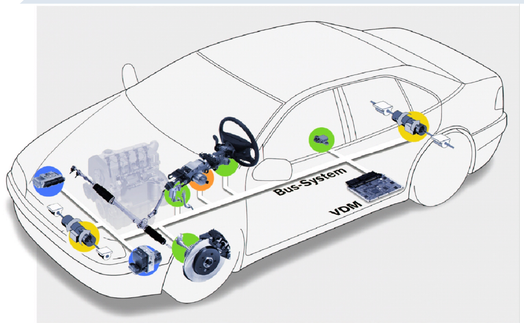
Variety of Control Software



Distributed E/E Architecture

Different Communication Buses

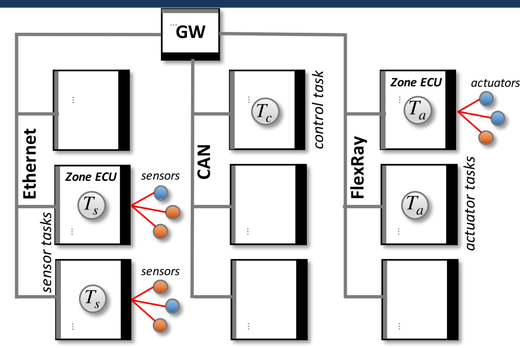
Modern Automotive Hardware/Software Architectures



Driving Problem

Basic problem: How to implement feedback controllers on distributed embedded systems?

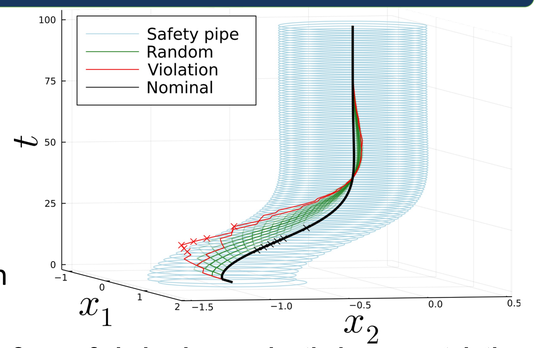
- Modern cars are equipped with a variety of sensors such as cameras, radars and lidars, which involve computationally expensive processing
- There are many ways in which such processing may be organized or structured, each associated with different delays or timing behaviors
- How can we automatically explore these different implementation options and the associated modifications to the controllers? What kind of tool support is necessary to support this design flow and control/architecture co-design?



Heterogeneous Automotive Architecture

Recent Results

- Methods for safety-driven co-synthesis of controllers under timing uncertainties
- Neural network sizing and GPU partitioning for autonomous systems
- Statistical hypothesis testing to check safety of controller implementations in the presence of timing uncertainties
- SMT-based control safety checking under timing uncertainties and its scalability
- Using combinations of model checking and fuzzing for test case generation
- Extension of dynamics-aware schedule synthesis to the industrial automation domain
- Cell balancing techniques to reduce battery aging in electric vehicles



Safe & unsafe behaviors under timing uncertainties

Highlights

- Shengjie Xu offered summer internship at General Motors in 2024 & 2025
- Clara Hobbs completed summer internships at GM in 2021 & 2022
- Research contract from General Motors to study timing analysis of service-oriented automotive architectures
- Timing analysis tool developed with GM Research & Development being transferred to GM Engineering for use in Software Defined Vehicles project
- Bineet Ghosh graduated and joined University of Alabama as tenure track Assistant Professor in 2023
- Chakraborty & Duggirala gave tutorials at VLSI Design 2024 & ESWeek 2024 and invited talks on the work from this project at CPS Week 2024, BU, UCSC
- Broadening participation: mentoring undergraduate students (multiple refereed conference publications involving undergraduate students)

Selected Recent Publications

- Yeolekar et al., “Repairing Control Safety Violations via Scheduler Patch Synthesis,” ICCPS 2025
- Zhu et al., “Controllers for Edge-Cloud Cyber-Physical Sys.,” COMSNETS 2025
- Capogrosso et al., “LO-SC: Locally-only Split Computing for Accurate Deep Learning on Edge Devices,” VLSI Design 2025
- Hobbs et al., “Quantitative Safety-Driven Co-Synthesis of Cyber-Physical System Implementations,” ICCPS 2024
- Xu et al. “Neural Architecture Sizing for Autonomous Systems,” ICCPS 2024
- Ghosh et al., “Statistical Verification of Autonomous System Controllers Under Timing Uncertainties,” Real-Time Systems Journal, Springer, 2024
- Capogrosso et al., “MTL-Split: Multi-Task Learning for Edge Devices using Split Computing,” DAC 2024

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