MECHANICAL ENGINEERING

DIMEAS - Innovative electric powertrain controllers based on adaptive digital twins and predictive control for automated and connected vehicles

Funded By	Dipartimento DIMEAS
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Context of the research activity	This PhD project deals with the development of an innovative multi-layer predictive control architecture for next-generation electric, connected and automated vehicles, based on adaptive digital twins. These are simplified models of the considered electric powertrain components, which are progressively adapted based on the condition of the specific vehicle. The digital twins will be based on nonlinear state-space models, as well as computationally efficient neural networks.
	This research is in the framework of the Horizon Europe EFFEREST project, involving industrial and academic participants for the development of innovative energy and thermal management systems for next-generation electric, connected and automated vehicles. The PhD project will use AI-based techniques (e.g., deep reinforcement learning and neural network model predictive control) for the real-time implementation of energy-efficient cruise controllers that account for the previous human / automated driving profiles as well as the current condition of the vehicle components. Moreover, during human driving operation, adaptive drivability maps will be designed and tested to account for the current user's driving profile and facilitate energy-efficient driving behaviours. The activity will involve the integration of the EFFEREST human driver digital twin. Real-time versions of the digital twins of the battery system, traction inverter, electric machine and transmission system will be implemented for predictive health monitoring, based on the outputs from the consortium participants. AI-based predictive health management algorithms (e.g., imposing limitations of the torque/current levels and their rates, according to the specifications) will be developed, to guarantee the completion of the current mission, and then to successfully reach the garage for vehicle maintenance/repair. The algorithms will be assessed through vehicle simulations and software-/hardware-in-the-loop, as well as vehicle experiments, by using the available EFFEREST demonstrators. Year 1 • Literature review on electric powertrain control, adaptive cruise control and path planning/tracking, including consideration of energy efficiency aspects

Objectives	• Literature review on predictive and AI-based control techniques applied to electric powertrain management and adaptive cruise control / automated driving control, with focus on adaptive digital twinning • Preparation and submission of a high-quality review paper (e.g., for Annual Reviews in Control, see the following examples: Model predictive path tracking control for automated road vehicles: A review - ScienceDirect, Preview-based techniques for vehicle suspension control: a state-of-the-art review - ScienceDirect, Anti-jerk controllers for automotive applications: A review - ScienceDirect, Integrated chassis control: Classification, analysis and future trends - ScienceDirect) • Simulation model (e.g., in VSM by AVL) for control system assessment, based on one of the EFFEREST demonstrator vehicles, targeting the baseline vehicle configuration • Experimental assessment of the baseline vehicle, in cooperation with the other consortium participants • Experimental validation of the VSM simulation model • Inclusion of the high-fidelity models of the considered actuators (inverters / electric machines / brake-by-wire / possibly also steering actuation), including actuation dynamics aspects • Toolchain for the development of nonlinear model predictive controllers (ACADO toolkit / ACADOS / CasADi), neural network tools and deep reinforcement learning tools (Matlab, Python) • End of year presentation Year 2 • Set-up of the V2X interface within the vehicle simulation model (preview of road curvature, road irregularities, speed profile, steering profile, yaw rate profile, optionally tyre-road friction factor, as well history of previous use profile of the specific vehicle and the whole fleet) • Digital twins based on artificial intelligence techniques (deep neural networks) • Experimental validation of the resulting digital twins • Neural network model predictive controller for energy-efficient adaptive cruise control and automated driving • Architecture for model adaptation for predictive powertrain control and adaptive cruise control • Simulation-based critical analyses on the resulting: i) energy-efficient adaptive cruise control algorithm; and ii) prediction model adaptation • Preparation of a quartile 1 journal paper on critical analysis i) and a quartile 1 journal paper on critical analysis ii) • End of year 2 presentation Year 3 • Implementation of predictive health management algorithms • Development of deep reinforcement learning (DRL) algorithms for adaptive cruise control • Critical analysis of DRL performance including comparisons with the NNMPCs • Experimental sessions for controller validation on test rigs and at least one EFFEREST demonstrator vehicle • Preparation and submission of a journal paper on DRL and respective critical analysis, and a paper on the experimental validation or predictive health management aspects • Final PhD thesis write-up During the PhD project, at least 6 months will be spent at another company

	or academic institution. In the EFFEREST project framework, funding is available for attending conferences, project meetings, and testing sessions at the facilities of the other industrial and academic participants.

Skills and competencies for the development of the activity	1) Vehicle dynamics and simulation 2) Path tracking control for automated vehicles 3) Matlab-Simulink simulation experience 4) Fundamentals of control theory, including model based control 5) Some experience of model based control applications (e.g., implementation of a linear quadratic regulator) 6) Good oral and written English language skills 7) Good presentation skills 8) Good teamworking capabilities