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Design OptiMisation for efficient electric vehicles based on a USer-centric approach

DOMUS – Deliverable Report

D2.3 Results of Virtual Assessment of Novel Cabin Designs

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1. Publishable Summary

Electric Vehicles (EVs) call for a radical redesign of the thermal comfort system in two ways:

- First, traditional Internal Combustion Engine (ICE) vehicles make use of heat from the engine for heating (although this is sometimes augmented with other heaters) and rotational torque from the engine to run the Air Conditioning (AC) compressor. EVs, on the other hand, have dedicated systems for heating and cooling that are not dependent on the speed or temperature of the engine and therefore can be designed more efficiently.
- Second, energy wasted by a vehicle in heating or cooling is of lower significance for ICE vehicles whereas current EVs vehicles have a much smaller driving range and thus the cost of waste is higher.

The thermal aspects of the vehicle cabin have evolved slowly and in a piecemeal fashion. Changes to the thermal comfort system have been piecemeal in the sense that it is straightforward to introduce a new feature, such as heated seating, but difficult to integrate the control of that new feature into the existing logic. A further issue with car climate systems is that they aim to control air temperature rather than comfort. However, thermal comfort actually depends on many other factors in addition to air temperature. It is readily apparent that a system that aims to control air temperature cannot reasonably also control heated surfaces. The fault here lies in trying to control the wrong thing. A more appropriate control target is some form of thermal comfort metric that incorporates both air temperature and radiant effects. Identifying such a comfort metric was the subject of DOMUS deliverable D1.3 [Gentner et al., 2020].

Through integrating control of multiple comfort systems, this work aims to substantially reduce the energy consumption of the combined system.

Previous research has shown there are opportunities for energy savings from integrated control. For example, passengers were thermally neutral with a lower air temperature when the seat heating was on than when it was not [Zhang et al., 2007]. This work uses machine learning to devise control logic that maximises a combination of holistic comfort, energy, and safety according to the assessment framework (D1.2 [Brusey et al., 2018]) and holistic comfort model (D1.3 [Gentner et al., 2020]). Furthermore, optimisation is used to select the best possible set of DOMUS features (such as, windshield heating, radiant panels, and so forth) to obtain the best assessment framework result. While the optimisation is performed virtually, the simulation is also validated and cross-checked with the real cabin using Climatic Wind Tunnel (CWT) trials.

1.1. Task Objectives

In the description of Work Package (WP) 2 in the Grant Agreement, the following objectives are given:

- Radical redesign of EV cabin with understanding of driver comfort perceptions, technological innovations (WPs 2–5), and vehicle level performance optimisation.
- Virtual development process for cabin redesign and multidimensional optimisation.
- Measure impact of cabin redesign and advanced efficiency increasing interventions on vehicle efficiency, range, comfort, and safety via comparison to baseline.

- Development and application of an approach to simplify the virtual assessment of comfort and efficiency and perform optimisation work.

1.2. Methods

This work builds on D1.5 [Brusey and Rostagno, 2020] to build three ultra-fast simulators for the Heating, Ventiliation, and Air Conditioning (HVAC) system, Design Variant Zero (or base Fiat 500e) (DV0), and Design Variant One (DOMUS-enhanced vehicle) (DV1).

Open AI Gym library is used together with Proximal Policy Optimisation (PPO) to learn a control policy that optimises for energy consumption and safety, while ensuring reasonable comfort.

Bayesian optimisation using Gaussian Processes is used to search for an optimum configuration.

1.3. Results

1.3.1. Integrated simulator

Simulator accuracy for the three simulators is given in Table 4.1 and Table 4.2 for the one-step and multi-step average prediction accuracy. The worst case one-step prediction accuracy is around $8 \times 10^{-3}\,\%$ of the range of possible values, while the worst case multi-step average prediction accuracy is around 1.70 %. The best performing simulator is DV1 and this probably reflects the large amount of varied data made available from Computational Fluid Dynamics (CFD) simulations. This also indicates that significant accuracy improvement should be possible for all simulators given more data.

The individual simulators take around 700 µs to compute each simulated second, which is a 1400-fold performance improvement over typical Zero Dimensional (0D) simulators, which can take around 1 s per simulated second.

1.3.2. RL controller performance

The aim of the development of the Reinforcement Learning (RL) controller is to outperform hand-coded approaches and to optimise according to the Assessment Framework (AF) as presented in Brusey et al. [2018]. The results, which are summarised below, indicate that the controller does broadly achieve this aim although there may still be some room for further improvement. Briefly, the RL controller gives a comfortable and safe environment for a greater percentage of the time while using significantly less energy. The AF is a combined metric that considers comfort, safety, and energy in proportions established at the start of the project with a higher value being better.

	Comfort %	Energy	AF	Safety %
DV0-SH	84.8 %	2390 W	−1.82	17.1 %
DV1-RL	95.7 %	748 W	−0.0484	99.7 %
DV1-SH	92.2 %	3780 W	−1.69	24.1 %

The RL controller not only outperforms the hand-coded one but also integrates control for components that are not usually controlled automatically, including heated seats, heated windows, the smart outlet, and radiant panels. While this performance improvement is yet to be replicated in the car, it is very promising and suggests this approach is likely to enable significant energy savings while maintaining or improving on comfort and safety.

1.3.3. Cabin optimisation results

The aim of the cabin optimisation approach is to select the set of cabin features that provide optimal performance. It was not possible to include all novel Design OptiMisation for efficient electric vehicles based on a USer-centric approach (DOMUS) features in the feature set due to restrictions in the simulator. However, the results were able to indicate a set of possible configurations, including one that only includes the smart vent and window heating, that provide the best AF performance. Notably, some configurations, such as including all features except the radiant panels, were considerably worse. Overall, the range of improvement possible from cabin optimisation is small and a larger improvement is provided by optimising the control logic.