Experimental Verification of Evasive Manoeuvre Assist Controller for Collision Mitigation with Oncoming Vehicles

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Experimental Verification of Evasive Manoeuvre Assist Controller for Collision Mitigation with Oncoming Vehicles

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An evasive manoeuvre assist controller to mitigate the risk of collision with oncoming vehicles while performing evasive manoeuvres has previously been formulated and tested in simulation. In this work, a real-time application of this controller is implemented and used in experiments with a Volvo XC90 hybrid test vehicle. For comparison, manoeuvres are also carried out without the controller but with the driver adopting different speed control strategies. Analysis of the results show that the controller can consistently mitigate collision risk with the oncoming vehicle and while driver control of speed can perform better, it is far less robust and is heavily dependant on the driver skill and performance.

Topics/Advanced Driver Assistant Systems, Driver Behaviors and Assistance

1. INTRODUCTION

One of the most common accident types in the world is the rear-end collision [1]. While many of these can be avoided or mitigated with emergency braking, others need evasive steering [2]. However, development and deployment of steering based driver assist systems are made challenging due to the fact that when performing evasive steering, the vehicle path changes significantly and hence threats along the new potential evasive trajectories need to detected and taken into account as well.

One such major threat that needs to be considered is oncoming vehicles in the adjacent lane. Due to the challenges in detecting the same, particularly before the evasive manoeuvre, when there may not be a clear line of sight to the oncoming vehicle, only a few such assistance systems have been announced by any major OEMs till date [3, 4]. In [5] however, an alternative control strategy is proposed that reduces the collision risk with the oncoming vehicle after or partway through the evasive manoeuvre when a clear line of sight can be established to the oncoming vehicle and detection of the same becomes easier.

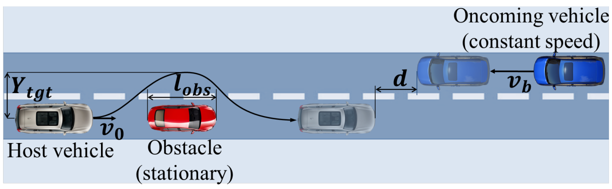

Figure 1: Evasive manoeuvre for avoidance in the presence of oncoming vehicles. The distance margin d, is a measure of the risk of collision with the oncoming vehicle.

Figure 1 shows such a scenario wherein the driver of the host vehicle initiates an evasive manoeuvre to avoid the stationary obstacle while possibly being unaware of the oncoming vehicle. It is assumed that the oncoming vehicle is detected partway through the evasive manoeuvre when the host vehicle front centre clears the obstacle, beyond which the integrated controller assists the driver in reducing the collision risk to the oncoming vehicle. The goal of the integrated controller here is to maximise the distance margin, d to the oncoming vehicle.

It was found in [5] that the control of speed during this manoeuvre could be used to effectively increase the distance margin in this scenario. It was also determined that the need to increase or decrease speed through the manoeuvre was correlated strongly to a *characteristic parameter* that was identified to be $l_{obs}v_b/v_0^2$. Specifically, it was seen that in scenarios with long obstacles and/or bullet vehicles travelling fast relative to the host vehicle (large characteristic parameter), there was a need to speed up and vice-versa.

This work aims to test this hypothesis by controlling speed through this manoeuvre using a closed-loop controller based on the work presented in [5]. Specifically, the longitudinal acceleration controller component from the integrated controller presented in [5] is implemented in a real-time environment and experiments are carried out with the same in a Volvo XC90 test vehicle. Due to limitations in the control interface, the entire integrated controller could not be implemented and instead only the component primarily responsible for reducing collision risk with the oncoming vehicle is implemented. The results from the same are presented and analysed and the performance of the controller evaluated.

2. EXPERIMENTAL SETUP

In this section, the scenario variations, the vehicle setup and the relevant features of the controller are briefly described.

2.1 Scenario setup

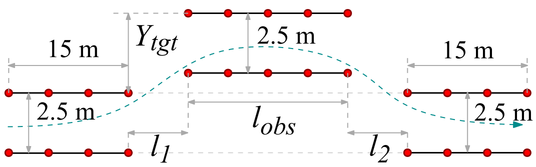

Figure 2: Track layout for the manoeuvre

Table 1: Scenario variations considered for evaluation. Obstacle length (l_{obs}) was 20 m and lateral displacement (Y_{tgt}) was 3 m for all cases.

Parameter	Scn. A	Scn. B	Unit
Host initial velocity (v_0)	55	65	km/h
Bullet vehicle velocity (v_b)	90	110	km/h
1st lane change distance (l_1)	12	16	m
2nd lane change distance (l_2)	[12,14,16]	16	m

Two major variations of the scenario are considered for evaluation, the specifications of which are listed in table 1 and the track layout for the same is shown in fig. 5. Three cases of the first scenario variant called A-12, A-14 and A-16 are also considered wherein the second lane change distance (specified by the number following the 'A') is varied to emulate the effect of a bullet vehicle that is near or far away. All the scenario variations are expected to be benefited from speeding up or maintaining speed. Scenarios where slowing down can be expected to be of benefit are not considered for evaluation due to limitations in the control interface (see section 2.2 more details). No actual oncoming vehicle is used in the experiments, but its presence is assumed and its effect simulated in post-processing.

Apart from the controller assisted manoeuvres, two other driver-only manoeuvres were considered for comparison: a "throttle off" manoeuvre where the driver lifts off the accelerator pedal as soon as the first lane change is initiated and a "Accelerate" manoeuvre where the driver accelerates through the manoeuvre. For the "Accelerate" case, the driver was instructed to accelerate to the extent the driver felt comfortable and confident that they could successfully complete the manoeuvre without knocking over any cones.

Two drivers were used in the tests with different levels of test track experience with respect to performing high dynamic manoeuvres. Driver 1 performed the tests for scenarios A-12, A-14 and B whereas driver 2 performed tests for scenario A-16.

2.2 Vehicle setup and actuators

The test vehicle used is a Volvo XC90 with a hybrid drivetrain that has a 320 hp gasoline engine driving the front axle and a 80 hp electric motor driving the rear axle. The electric motor is powered by a 9.2 kWh battery pack allowing for approximately 30 km of electric range under nominal conditions. The electric range was seen to be a limiting factor for testing duration particularly since the vehicle did not have a drive mode that enabled the battery to be charged with the IC engine during regular driving. Consequently, to ensure the electric drive was available to be used with the controller, for each scenario, the "Ctrl. Rr" case was run first, followed by "Acc" and then finally "Thr. off".

Due to limitations in the interface that was used to apply torques, the following restrictions are observed for the control authority: (1) no access to the brake system, (2) only positive torques could be requested from the drivetrain and (3) torque could be requested from only one actuator (engine or motor) at a time. Additionally, during preliminary testing, it was seen that safety features in the Engine Control Module (ECM) occasionally overrode the drivetrain torque request after a short period when the torque request was very high. After some trial and error, a peak torque request limit of 1500 Nm was used that prevented the torque request from being overridden too early.

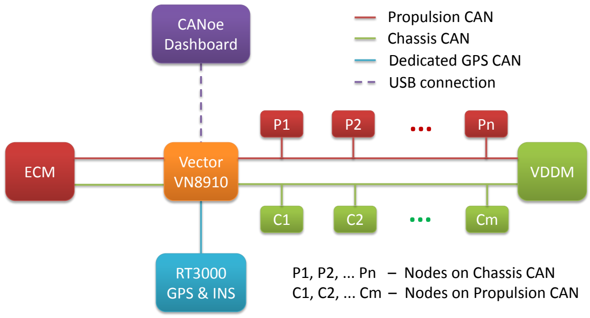

Figure 3: Schematic of the modified CAN network

To be able to request drive torques from the ECM in the first place, the CAN network of the vehicle had to be modified as shown in fig. 3. The propulsion and chassis CAN buses were physically cut immediately after the ECM and the wires routed to a Vector VN8910 experimental computer installed in the trunk of the vehicle where an application forwarded or modified the relevant signals as necessary. An Oxford Technologies RT3000 GPS and inertial system was installed and connected via a private CAN channel to the VN8910. Finally, the application in the VN8910 was controlled with a CANoe dashboard running on a laptop through a USB connection.

2.3 Control design

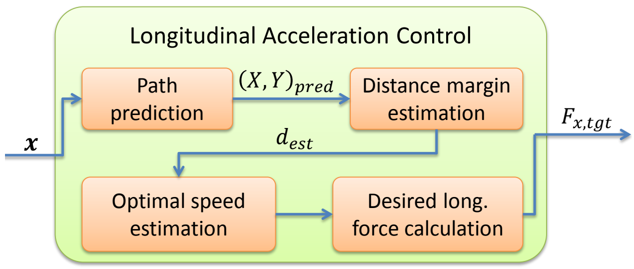

Figure 4: Structure of the longitudinal acceleration controller

The controller implemented here is based on the integrated controller outlined in [5]. However, since the brake system was inaccessible, only the longitudinal acceleration control part is implemented. The longitudinal force request is then limited based on actuator capabilities and simply applied to the rear axle. Distributing to both axles was made difficult by the fact that torques could be requested from only axle at a time. While control of front axle only was initially attempted, it was seen that the response of the IC engine was inconsistent and perceived as uncomfortable by the driver and the occupants and was hence abandoned after a few runs.

The specific CAN signals that were needed to be manipulated in order to request drivetrain torque were determined based on a preliminary analysis of the CAN database files followed by trial and error during exploratory tests. These relevant signals included not only torque request signals,

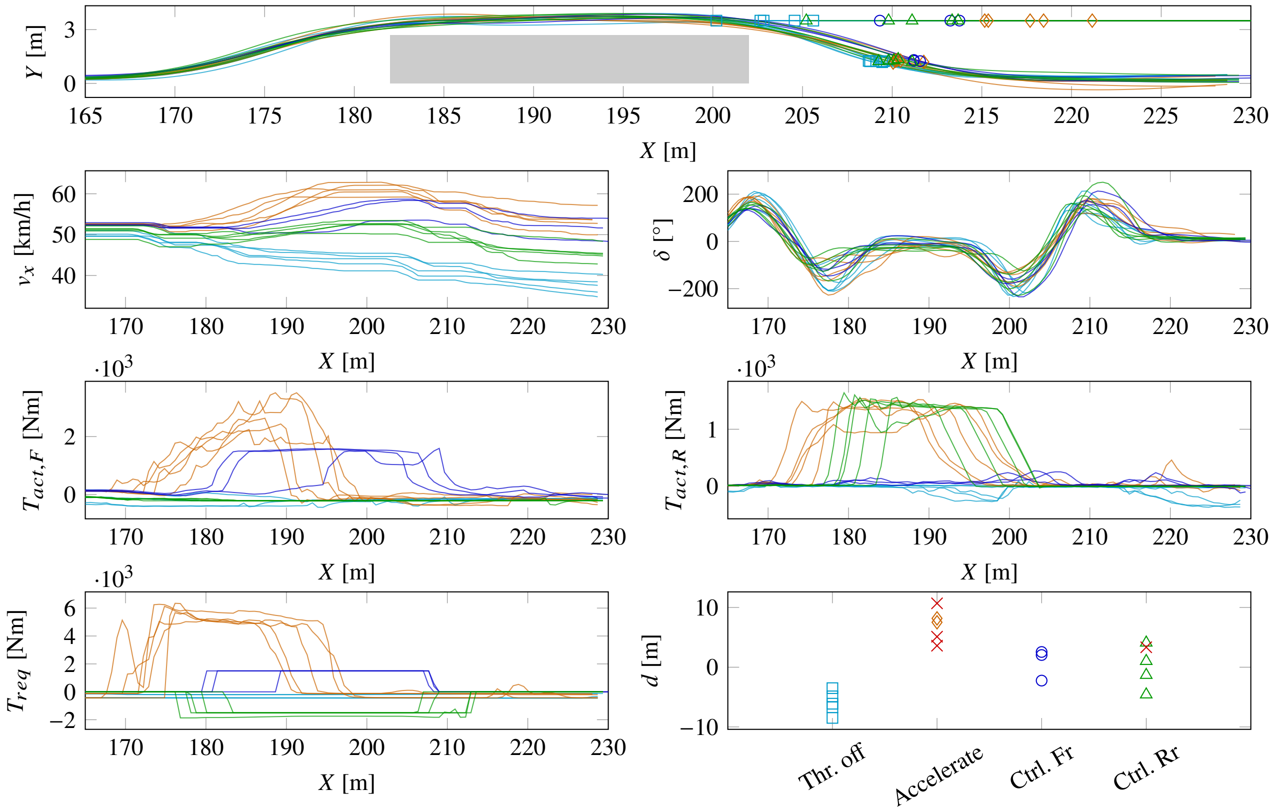

Figure 5: Paths, velocity, steering wheel angle, actual and requested torques and distance margin plots from scenario A-12. The horizontal lines at the top right portion of the path plots show the trajectories and the final positions of the bullet vehicles as the corresponding host vehicles return to the original lane. In the torque request plots, for the cases of "Ctrl. Fr" and "Ctrl. Rr", positive and negative values indicate torque request for the engine and the motor respectively from the controller. For the other cases, the torque request is the driver requested torque from the accelerator pedal position. In the distance margin plots, × represents a failed run (hitting one or more cones).

but also other related safety signals, checksums, update bits, etc. An application was implemented in Vector CANoe that modified the relevant signals and forwarded all other signals unchanged. The Autosar end-to-end protection and calculation of checksum and update bits for the modified signals were managed by CANoe itself using a vehicle platform specific interaction layer. The controller itself was implemented in MATLAB/Simulink, compiled to a Functional Mockup Unit (FMU)[1] and was then imported into CANoe using its Functional Mock-up Interface (FMI) tool.

The structure of the longitudinal acceleration controller is shown in fig. 4. First, the controller predicts a nominal path that the vehicle *could* take assuming simplified dynamics. Since the steering - which arguably has the largest influence on the vehicle path - is controlled by the driver, the exact path the vehicle will take cannot be predicted by the controller. Furthermore, since there is no attempt to follow the predicted path, a simplified path prediction is sufficient for our purpose. The controller assumes a constant global longitudinal speed and a "bang-bang" lateral acceleration profile while performing the path prediction. This path is then used to estimate the distance margin to the oncoming vehicle. While constant speed is assumed for the oncoming vehicle in this estimation, the formulation can easily be extended to incorporate accelerations for the oncoming vehicle. An optimisation is then carried to find an optimal longitudinal speed that maximises the distance margin to the oncoming vehicle. A longitudinal force is then determined such that when applied to the vehicle would result in it achieving the optimal speed halfway through the manoeuvre. More details about this controller can be found in [5].

Note that while this controller is functionally the same as its counterpart presented in [5], it has been adapted to enable operation in a real-time environment. Primarily, the optimisation component has been rewritten from scratch to manually find the optima instead of using Matlab's built-in optimisation functions which are not real-time ready. To maintain performance, the optimisation routine uses a simple gradient descent search using the previous optima as an initial guess, performs step size adaptation based on gradient and enforces a hard iteration limit for the optimisation among other techniques.

3. EXPERIMENTAL RESULTS

Figure 5 shows the results of runs with driver 1 in the A-12 scenario. As can be seen, significant distance margin improvements can be achieved with the help of the longitudinal acceleration controller. While the electric machine was expected to perform better due to its quicker response, it is observed instead that the IC engine just as well. The cause for this can be seen from the requested and actual torque plots, wherein the rear axle torque is cut-off early by the ECM. Whereas on the front axle, even though the response is much slower, the torque is delivered for the

[1]An FMI toolbox for Simulink package is available for free from Dassault systems.

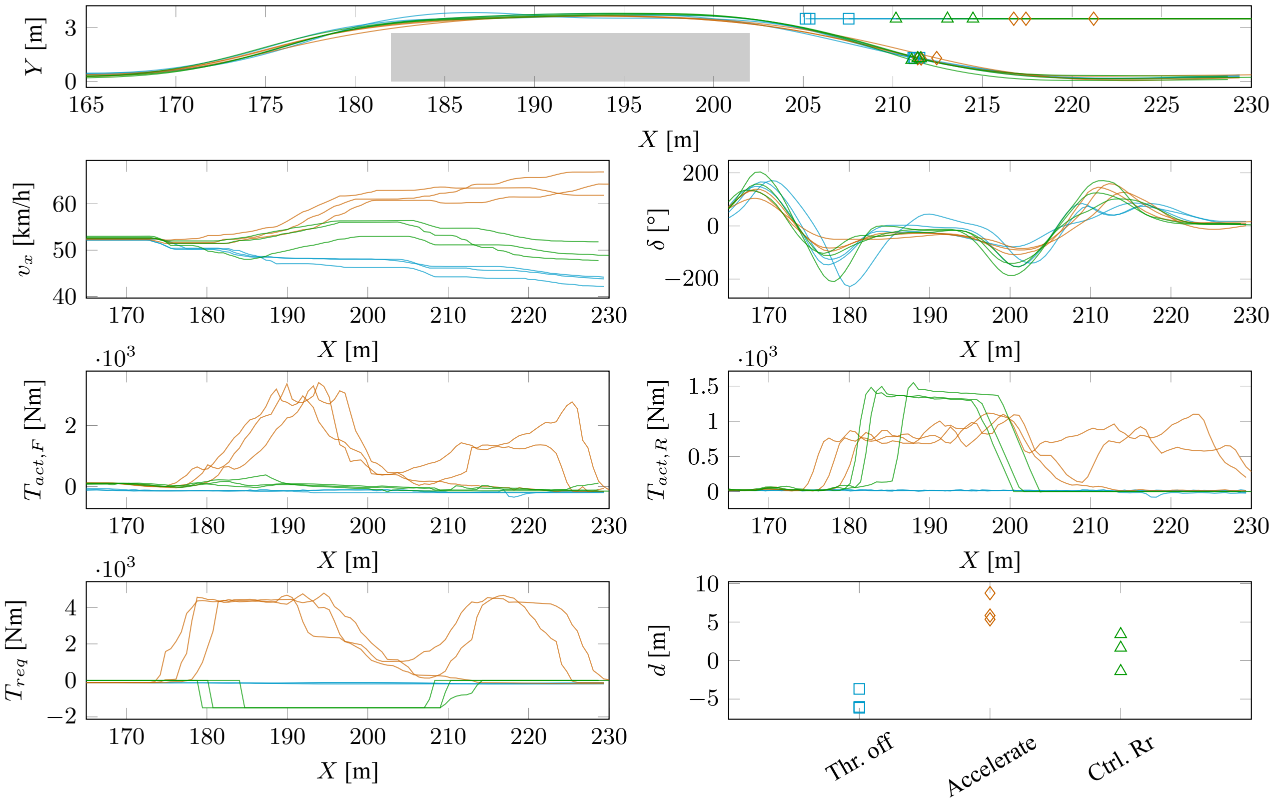

Figure 6: Paths, velocity, steering wheel angle, actual and requested torques and distance margin plots from scenario A-14. The horizontal lines at the top right portion of the path plots show the trajectories and the final positions of the bullet vehicles as the corresponding host vehicles return to the original lane. In the torque request plots, for the case of "Ctrl. Rr", negative values indicate torque request for the motor. For the other cases, the torque request is the driver requested torque from the accelerator pedal position. In the distance margin plots, × represents a failed run (hitting one or more cones).

entire duration of the request. However, as mentioned, the IC engine response was perceived to be uncomfortable by the occupants and hence IC engine control was abandoned.

While driver acceleration performs even better than the controller, the cause for the same can be seen easily from the torque plots: the torque delivered on the front axle alone is more than twice the torque magnitude requested by the controller. Furthermore, since the driver is aware of the oncoming vehicle in advance, the driver's torque request starts much earlier than the controller which has to wait until an oncoming vehicle is detected.

Comparing the "Acc" case to that of "Ctrl. Rr" also highlights another fact: it is far more difficult to complete the manoeuvre successfully when the driver needs to control the steering in addition to the longitudinal dynamics as opposed to letting the controller manage the same. It is also worth keeping in mind that, as mentioned, the "Ctrl. Rr" cases are the ones that are run first for each scenario. Consequently, these runs can be expected to have a higher number of failed runs and larger variation as the driver gets accustomed to the new track layout.

Figure 6 shows the results of the runs with driver 1 in scenario A-14. Once again, significant and consistent increases in distance margin is seen with the controller over the case of "throttle off" while driver acceleration is seen to be the best. No failed runs are recorded in this scenario. This is partly due to the driver getting used to the manoeuvre after the runs of scenario A-12 and partly due to the scenario being less challenging with the longer lane change distance. Once again, it can be seen that when the driver accelerates, the torque request begins significantly earlier than with the controller and the delivered torque on the front axle alone is larger than the torque request from the controller.

Figure 7 shows the results of the runs with driver 2 in scenario A-16. Driver 2 had less experience driving high dynamic manoeuvres and consequently, the results look significantly different compared to those from scenarios A-12 and A-14. First, it can be seen that there is a lot more variation in the results and also more failed runs. Specifically, large variation can be seen in the path and the steering wheel angle plots, particularly in the "Ctrl. Rr" cases which, as mentioned, are the cases that are run first. More interestingly, for this driver, the "Accelerate" case performs worse than "Ctrl. Rr". The cause for the same can be inferred from the torque request plots, wherein it can be seen that the driver starts acceleration quite late after nearly completing the first lane change. This is a lot later compared to the controller and also compared to the runs in scenarios A-12 and A-14. The driver also stops accelerating before the second lane change in many cases. This behaviour can be attributed to the driver's inexperience and comfort level in performing such on-limit manoeuvres wherein the driver avoids high levels of combined longitudinal and lateral acceleration. The combination of a relatively short driver torque request and the slow response of the engine results in a brief pulse of actual engine delivered torque. Overall, for this driver and

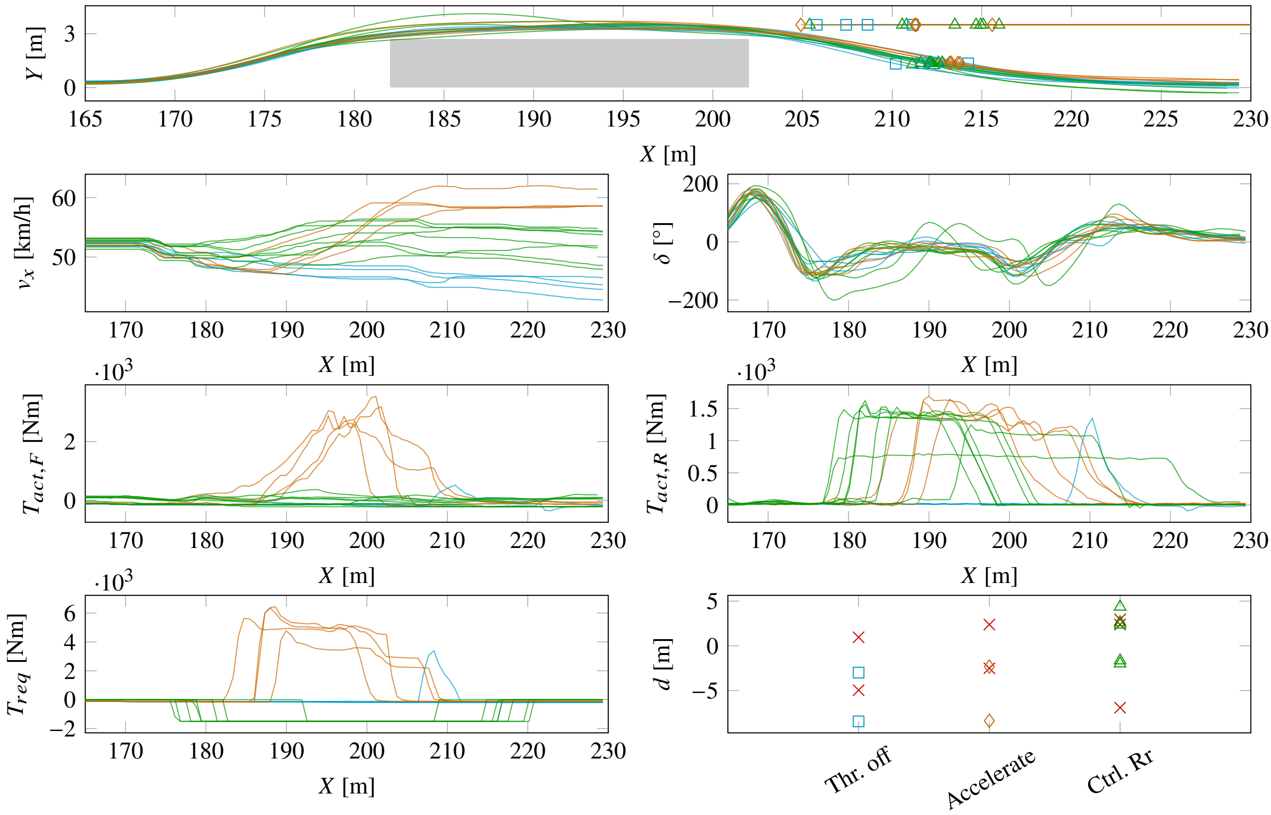

Figure 7: Paths, velocity, steering wheel angle, actual and requested torques and distance margin plots from scenario A-16. The horizontal lines at the top right portion of the path plots show the trajectories and the final positions of the bullet vehicles as the corresponding host vehicles return to the original lane. In the torque request plots, for the case of "Ctrl. Rr", negative values indicate torque request for the motor. For the other cases, the torque request is the driver requested torque from the accelerator pedal position. In the distance margin plots, × represents a failed run (hitting one or more cones).

scenario, the "Ctrl. Rr" performs the best with the "Acc" case performing slightly worse.

Figure 8 shows the results of the runs with driver 1 in scenario B which involves higher speeds and was perceived to be more challenging. Consequently, despite the driver being habituated to the manoeuvre by now, a higher number of failed runs are seen. Particularly, higher number of failed runs are seen in the "Acc" case despite which the improvements in the distance margins are not as pronounced as in the other scenarios. Once again, it can be seen that the driver torque request starts much earlier and is also much higher compared to the controller torque request and that the controller torque request is cut off prematurely.

Figure 9 shows the pareto front for steering effort (measured as the L-4 norm of the steering rate) versus distance margins achieved by the different control strategies. Also shown are second order fits for each case and a 50 % error estimates around these fits. As expected, "Ctrl. Rr" performs consistently better than "Thr. off" and while "Acc" can be better in some cases (medium to large steering effort), it can also be seen that it involves much higher variation and can be inconsistent. Note that due to drivers of different levels of experience being used for testing different scenarios, a typical pareto front shape is not seen. However, from the collective results, it can be concluded that the "Ctrl. Rr" performs consistently and robustly better whereas while "Acc" can perform better under some conditions, there is a high degree of uncertainty associated with it.

4. CONCLUSIONS

A closed-loop controller from [5] that controls speed through an avoidance manoeuvre in order to mitigate the risk of collision with oncoming vehicles is implemented and tested in a Volvo XC90 hybrid test vehicle. The aim of the experiment was to test the hypothesis presented in [5] regarding the need to control speed depending on the scenario parameters in order to reduce the oncoming vehicle collision risk.

Two drivers with different levels of test track experience are used in two main scenarios (with 3 sub-cases for one of the scenarios) and apart from the controller, two driver managed speed control strategies are evaluated. The results show that the controller can robustly and consistently increase distance margin in the evaluated scenarios over a case of the driver lifting off of the accelerator pedal during the manoeuvre. They also show that while driver acceleration can perform better, it is far less robust and depends heavily on the driver skill and performance. Significantly more failed runs were recorded with driver acceleration indicating that it is a challenging task for the driver and the controller can help improve driver performance here by taking over the longitudinal control task and reducing the workload for the driver. Overall, the presented results show that appropriate control of speed through the manoeuvre based on the scenario parameters can effectively increase the distance margin and thereby

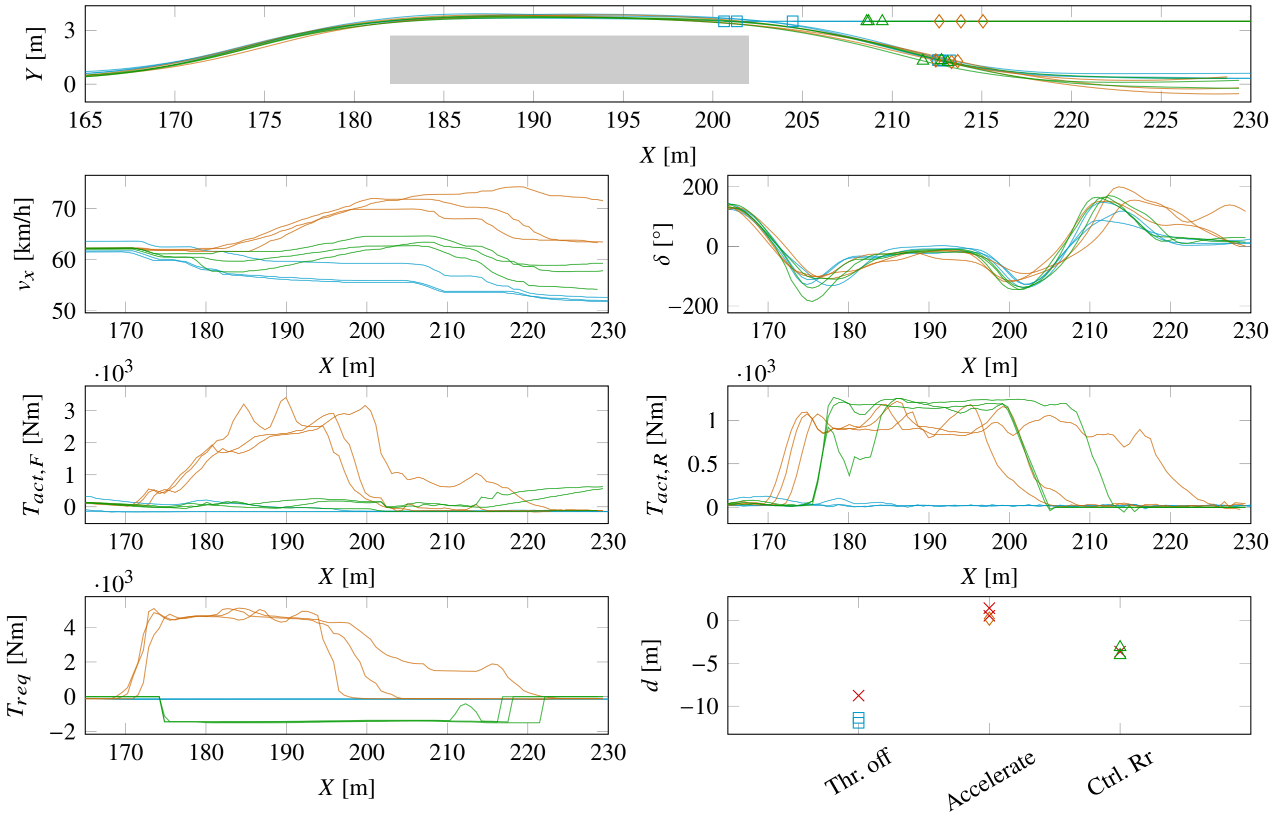

Figure 8: Paths, velocity, steering wheel angle, actual and requested torques and distance margin plots from scenario B. The horizontal lines at the top right portion of the path plots show the trajectories and the final positions of the bullet vehicles as the corresponding host vehicles return to the original lane. In the torque request plots, for the case of "Ctrl. Rr", negative values indicate torque request for the motor. For the other cases, the torque request is the driver requested torque from the accelerator pedal position. In the distance margin plots, × represents a failed run (hitting one or more cones).

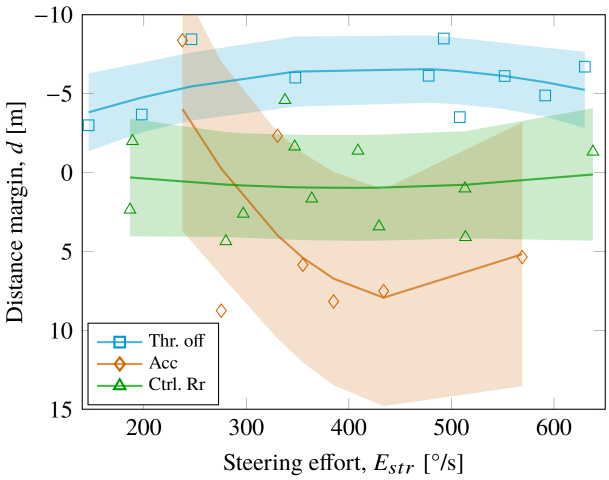

Figure 9: Pareto front for steering effort vs distance margin (markers) and a second order fit (solid line) for each case with a 50 % error estimate (shaded area). For clarity, the "Ctrl. Fr" cases and the failed runs are not shown.

reduce the oncoming vehicle collision risk in this scenario.

5. ACKNOWLEDGEMENTS

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