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CONFORM – A visualization tool and method to classify driving styles in context of highly automated driving

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Abstract

The paper introduces the method and tool CONFORM (Conflict regocnition by image processing methods). CONFORM will be integrated as a driver model into the ibeo test vehicle during the project phase of EU–project HoliDes. The aim of CONFORM is to support the system designer to properly parameterize the default behavior of a highly automated vehicle to guarantee a high system acceptance. Thereby CONFORM addresses intra and inter individual differences in the driving behavior. CONFORM measures the difference between the default system behavior and the natural driving behavior of a human driver situation-dependent to determine the necessity of an adaptation. Based on a driving simulator study the paper describes how CONFORM is able to visualize and to cluster certain driving patterns/styles in a vehicle following/vehicle approaching scenario. We use the study results to derive recommendations for the design of the system behavior of highly automated vehicles.

1 Introduction

OEMs and suppliers recently announced their goal to roll out the first highly automated vehicles in 2025 [1]. Highly automated vehicles will be smart. They will be able to control the lateral and longitudinal motion of the vehicle. Therefore highly automated vehicles allocate a new role to the driver. The driver only has to monitor the system and is allowed to be inattentive for instance while writing emails [3]. This new role requires the drivers' willingness to hand over control to the vehicle. A central point to enhance this willingness is to ensure a high acceptance of the system behavior by the driver. Therefore, system designers typically adjust the system behavior to an average driver based on their knowledge from driving studies. Nevertheless studies also unveil a variance in natural driving behavior among drivers [2-9]. Thus we will deal with situations where the default behavior of the highly automated vehicle differs from the expectation of the current driver.

One existing approach to overcome this issue is the adaptation of the system behavior to different driver types. In the literature [2-9] similar categories of driver types were found which we summarized into four categories: A normal/moderate driver, a sporty/dynamic driver, an aggressive driver, a calm/conservative/comfort-oriented driver. However, the literature review also reveals a wide range of definitions. Especially the considered parameters depend on the author and the driving task addressed by the system. That's why we prefer the term driving style rather than driver type since "style" is more related to the performance of a certain driving task in a specific situation whereas "type" alludes to a stable personality trait. We will use the term "driving style" as a linguistic description of observable patterns of parameter sets related to the maneuver and trajectory planning level. Of course the above mentioned categories sporty, normal, comfort-oriented, aggressive can be a foundation for the description of driving style patterns. These situation/context specific patterns will not only enable the system designer to configure the default behavior properly. In cases of observed discrepancies between driver and system behavior they allow an appropriate adaptation of the system behavior. Our contribution will introduce a method and tool called CONFORM which addresses these two issues.

2 CONFORM

Overall CONFORM is a tool and method for a system designer to:

1. Visualize, measure, analyze the discrepancy between driver and system behavior
2. Identify system parameters for an adaptation
3. Visualize and cluster inter and intra individual differences in the driving behavior

CONFORM is an upgrade of our method presented in [10] and is currently supported through the EU-Project HoliDes. During the project phase we will integrate CONFORM as driver model into the ibeo test vehicle. The ibeo test vehicle will have a highly automated driving mode. The goal of CONFORM will be to adapt the system to certain driving styles situation-dependently by adapting the preference of maneuvers and their trajectory. CONFORM therefore consists of three modules: a situation classifier to adapt to the situation, a memory to adapt to the natural driver behavior and a conflict analyzer to recognize the urgency for an adaptation. Fig 1 illustrates the applied structure of CONFORM in the HoliDes project.

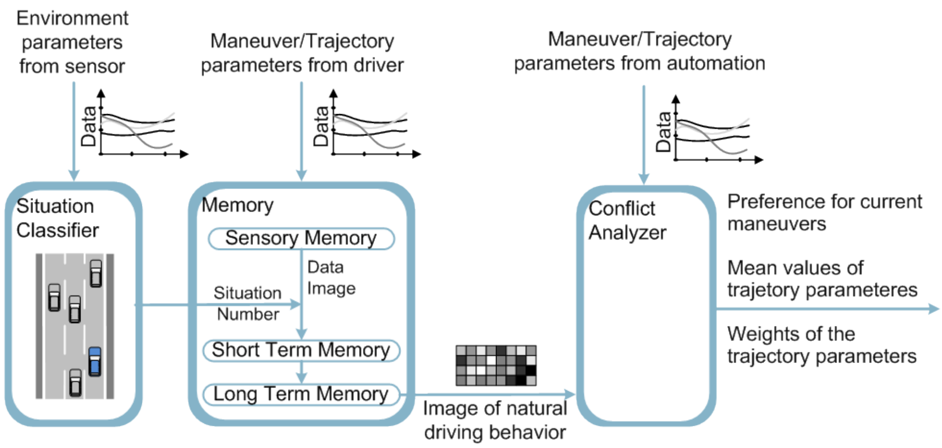


Figure 1: Structure of CONFORM in the HoliDes project

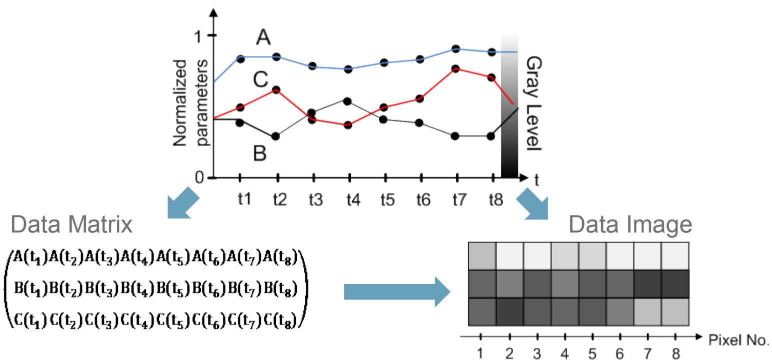


Figure 2: Derivation of a data image

The basic ideas of CONFORM are already mentioned and explained in [10]. Nevertheless we will briefly recall them. CONFORM uses the classification of the situation to divide the data stream into data stream snippets. Fig. 2 shows such a data stream snippet. CONFORM represents discrete multivariate time series of the data stream snippet not as a matrix. CONFORM rather applies a gray level mapping to transform the time series in to a data image, as illustrated in fig. 2. Since a situation can occurs more than once, CONFORM organizes the data images situation-dependently through memory cells based on a design metaphor namely the human memory. A memory cell in CONFORM (as shown in fig. 3 and

5) is a part of the memory storage in the short or long term memory which assigns a stack of collected data images to a classified situation. From this stack of data images CONFORM calculates a median image (see fig. 3). This median image represents the natural driving behavior in a given situation. CONFORM uses the median image for the comparison with the system behavior image of the automation. The result is an offset image. CONFORM further analyzes this offset image by image processing method to obtain to a value to describe the discrepancy between driver and system behavior. The result is called the conflict potential and shows the urgency of an adaptation. As mentioned CONFORM is not only a method, it is also a tool. Therefore we realized a GUI. The GUI is shown in fig. 3. The GUI visualizes the current memory, the current offset image and the current conflict potential. Additionally, for each cell it visualizes the median image and its development over the time. Thus the GUI visualizes the inter-individual difference of the driving behavior. The visualization of the memory and the median image covers the possibility to visualize and cluster intra-individual differences of the driving behavior into driving style clusters. These clusters will be used to define situation-dependently different ranges for the control variables of the highly automated with regard to the different driving style clusters. For the longitudinal control such variables are for example time headway, braking response time or max. deceleration.

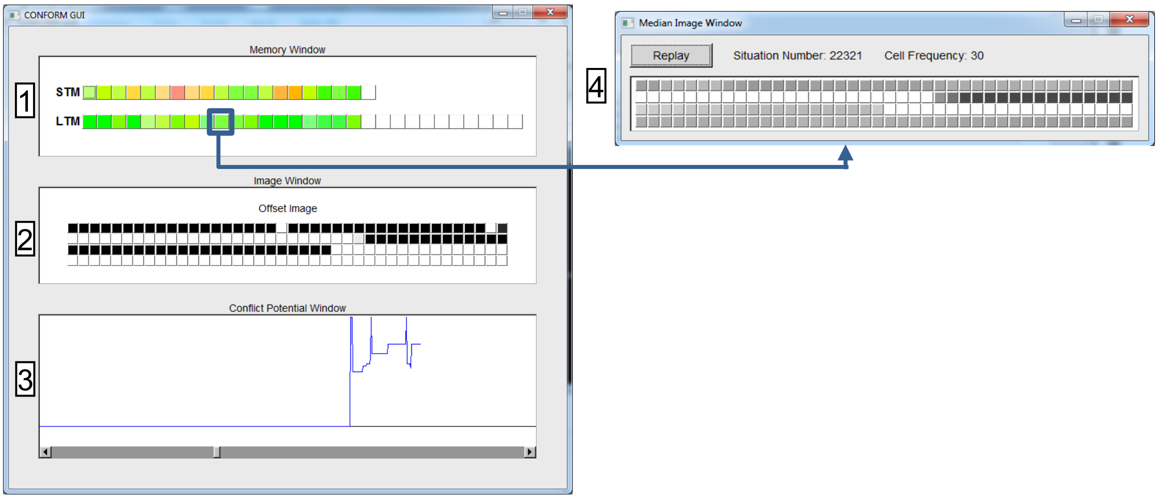


Figure 3: CONFORM GUI: (1) current memory structure, (2) current offset image, (3) current conflict potential, (4) exemplary median image for one situation/memory cell

3 Visualization and Classification of driving styles

In the first step we consider the distribution of situations in the memory and their potential criticality. For the recognition of patterns we color less critical situation green to yellow and more critical situations orange to red (see fig. 5). We calculate the potential criticality of the situation based on a prediction (t = 3s) and the following equation:

$$pred.rel.\ distance = \left(rel.distance + (0.5 * a_{Lead} * 3^2 + 3 * v_{Lead})\right) - 3 * v_{Ego} \in [-40,20]$$

Additionally we came to the conclusion to limit the value to a range between -40m and 20m. We use the hsv color model and a color interval from red (0°) to green (120°). For that reason a value of around zero is mapped onto a color between yellow and green (80°), since it is the boundary between collision and no collision. For a first evaluation of our approach we focused on vehicle approaching maneuvers. We conducted a study in the dynamic driving simulator at DLR with 14 participants (11 male, 3 female, average age: 28.9, age range: 19-44). The scenario was a 10 min drive on a highway. The traffic density was high to avoid lane changes and the lead vehicle executed a couple braking maneuvers as shown in fig. 4. This scenario was the input for CONFORM to learn the driving behavior of each participant.

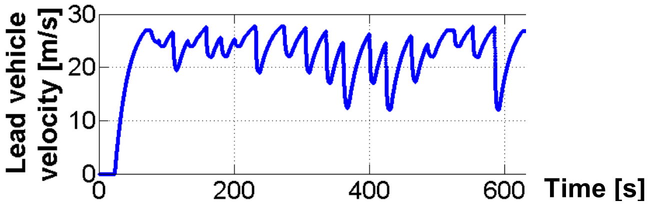


Figure 4: Velocity profile of the lead vehicle

3.1 Results

We used our approach described in [10] to classify the situations. We found out that all participants showed a different memory structure and thus differing driving behaviors. Nevertheless when we looked closer at the memory structure it was possible to describe four different clusters/driving styles. Two of them are illustrated in fig. 5.

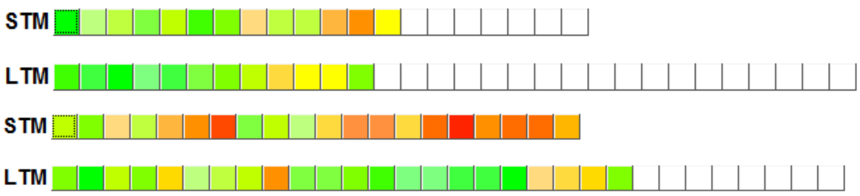


Figure 5: Visualization of two exemplary memory structures: The top shows a careful driving style (less critical situations in STM/LTM), at the bottom is a risky driving style (larger number of critical situations in STM/LTM).

Cluster A1 (4 participants): Large number of critical situations in STM/LTM. Those drivers prefer a more risky driving style in general.

Cluster B1 (3 participants): Larger number of critical situations in STM but few in LTM. Those drivers tend to a safe driving style but still have phases when they drive risky.

Cluster C1 (3 participants): Only few critical situations in STM/LTM. Those drivers focus on a safe driving style.

Cluster D1 (4 participants): Barely any critical situations in STM/LTM. Those drivers have a really careful driving style in general.

Table :1 Visualization of the median images clusters for two different situations. The median image shows the steering angle pos**.** (1st row), brake pedal pos**.** (2nd row), accel. throttle pos. (3rd row), lat. deviation (4th row). Each pixel per column represents a 100ms timestemp.

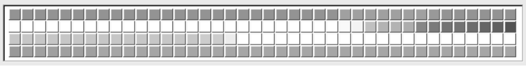
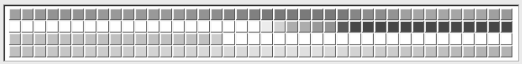
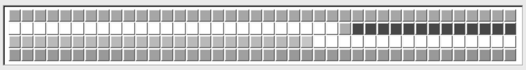
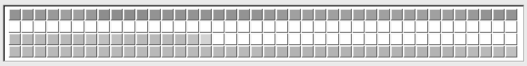
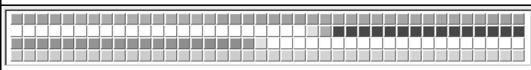
Less critical Situation (green colored cell): Rel. distance >25m, <50m, ego vel. around 20 m/s, rel. vel. around zero, lead vehicle brakes (-2m/s²) with a brake duration >3 sec	**More critical Situation (orange colored cell):** Rel. distance >15m,<25m, ego velocity <22m/s,> 18m/s; rel. velocity around -6 m/s, lead vehicle brakes (-2m/s²) with a brake duration between 2-3 sec
A2	A3
	
B2	B3
	
C2	C3
	
D2	D3
	

Table 1 illustrates data images [10] and recognized patterns for a less critical situation and a more critical situation. Based on the data images we get a better understanding of the actual driver behavior in the classified situation. Data images allow us to visualize the variance in the behavior. In other words, data images help us to configure the system behavior and can give us a hint on how well an implemented average behavior would perform. Based on the data images of the less critical situation we see different strategies to decelerate the vehicle. Moreover we see that all participants show a similar behavior on the steering wheel and lateral position. All together we found the following driving styles:

Cluster A2 (2 participants): Late and smooth braking

Cluster B2 (4 participants): Early and smooth braking

Cluster C2 (3 participants): Same as B2 but stronger braking

Cluster D2 (5 participants): Smooth release of the accel. throttle and no braking

With regard to the more critical situation we see the same behavior for all participants: no movement of the steering wheel, lateral position in the middle of the lane and release of the accelerator throttle to brake the vehicle with slightly differences in the response time (up to 500ms). Therefore it is justifiable to combine the images into the following clusters:

Cluster A3 (3 participants): Very late release of the accelerator throttle

Cluster B3 (3 participants): Late release of the accelerator throttle

Cluster C3 (5 participants): Normal release of the accelerator throttle

Cluster D3 (1 participant): Early release of the accelerator throttle

All together we see that CONFORM allows to cluster the vehicle following/approaching behavior of drivers into different driving styles dependent on the situation. This allows us to conclude some recommendations for the longitudinal control of the highly automated vehicle. In general the description of an average behavior for the longitudinal control of a highly automated vehicle which suits all drivers seems challenging because of the variation among the driving styles. It seems a more feasible approach to adapt the behavior to the above mentioned driving styles dependent on the current situation/scenario. For a vehicle-following scenario we would adapt the time headway to the lead vehicle with regard to the driving styles described in (A1-D1). For instance for a driver with a riskier driving style (A1) we would choose a small time headway (thw). For a driver with a careful driving style (D1) we would choose a large thw. For the vehicle approaching scenario in less critical situations (which should be the standard scenario for highly automated driving) we would adapt the deceleration strategy according to driving styles defined in A2-D2. In case of a hazard situation, such as a vehicle cutting-in the lane or a suddenly braking lead vehicle, we would at least adapt the warning time strategies dependent on the driving styles A3-D3.

4 Conclusion & Outlook

The paper addressed the issue for a system designer to properly parameterize the default behavior of a highly automated vehicle to guarantee a high system acceptance. We addressed the difference in the system behavior and the natural driving behavior as one reason of the issue. Motivated by this idea we discussed the possibility to adapt the behavior of the highly automated vehicle to inter- and intra-individual driving styles. For that reason CONFORM estimates the necessity of an adaptation by measuring the discrepancy between driver and system behavior in a first step. If an adaptation is necessary CONFORM is able in to recognize certain driving styles for an adaptation. A driving simulator study confirmed the ability of CONFORM to cluster driving styles dependent on the situation into different categories. In the next development phase we will further investigate natural driving behavior on highways with a focus on the classification of driving styles in lateral direction, i.e. lane change maneuvers. Therefore simulator studies are planned. Moreover we will investigate drivers' expectations of highly automated vehicles. A very important question to be answered is: Do drivers really expect that a highly automated vehicle drives as they do, or do they in general expect something such as a safe driving chauffeur?

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