The Apparent Vertical Filter Concept – Effects of Driving on a Slope

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***Abstract** - Motion cueing in driving simulators is an important issue and still needs to be improved with respect to simulation quality. The constraints resulting from a limited space envelope impede the provision of accelerations that match those observed in a car identically. For example translational accelerations cannot be provided directly and need to be transformed to angular attitudes or scaled down depending on their characteristics. Current motion drive algorithms like the classic washout filter algorithm are using sets of high- and low-pass filters in combination with gain factors to answer this problem. But those filtering methods do not distinguish between the causes of accelerations with respect to the driving maneuvers. The Apparent Vertical Filter developed by the German Aerospace Center provides a different approach to this problem. The current paper gives an overview of how the problem of unwanted forces could be approached within a number of idealized maneuvers. The filter principle will be demonstrated for driving on a lateral slope. In contrast, the constraints of current filter methods will be discussed utilizing a classic washout filter as an example. Furthermore it gives an overview of how the apparent vertical filter deals with the problem and how it is structured. Finally, the responses of the two filter methods to a set of car model data are compared.*

All current motion drive algorithms including the classical washout filter algorithm (CWA) use methods to represent side forces due to car roll attitudes. As discussed in the full paper it is impossible to ideally represent those forces by using a CWA. A novel approach to tackle this problem is the Apparent Vertical Filter (AVF).

To understand the nature of the response of motion drive algorithms one can think of a set of idealized maneuvers representing the longitudinal, lateral, and vertical specific forces a driver senses. From aviation simulation amongst others a set of lateral maneuvers is known. One particular example is a straight flight with a constant roll attitude which can be found in steady-heading sideslip maneuvers. This case corresponds with driving a car on a lateral slope that is subject to this paper.

Driving on a slope within this context therefore describes a pure lateral maneuver (Figure 1). The initial state of the car is an un-accelerated and straight drive. By driving onto a slope a roll attitude is induced in a way that lateral side forces can be observed. After reaching the full roll attitude 3 seconds later the car will drive straight on the slope. Consequently, after starting the maneuver, a lateral side force is felt by the driver.

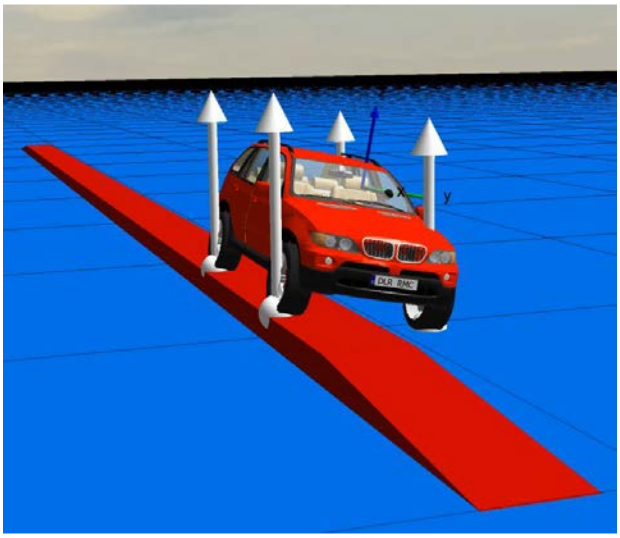

Figure 1: Modelled Car Driving on a lateral slope

The corresponding input signals for this maneuver may be idealized in a way shown by Figure 2. The roll rate is 10°/s for 3 seconds and zero again for the rest of the maneuver. The specific lateral side force is therefore a sine function, the vertical specific force a cosine function of the roll angle.

Figure 2 also shows the response of a classical washout filter algorithm in dark blue. The first graph shows the roll attitude and roll rate of the car. The second graph shows the lateral specific force of the idealized maneuver and the force felt in the cabin of the simulator. It is easy to see that a side force observed by the driver in the simulator is different from that in the modelled car. As a consequence, this side force could lead to a misunderstanding of the current state of the car and to a false reaction of the driver. The last graph shows that the vertical specific force acts accordingly.

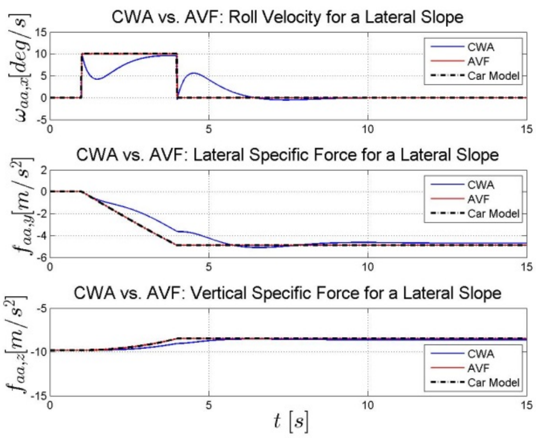

Figure 2: Classical Washout vs. Apparent Vertical Filter response

The main idea of the apparent vertical filter is to represent specific forces in the simulator with respect to the perceived apparent vertical angle rather than the correct quantity. In the words of engineering mechanics: "the orientation of the force vector should be correct as far as possible, while the length of the vector is to be adapted to the technical constraints of the motion system." This is achieved by comparing the current angular attitude with the current specific forces felt in the car. It should be noted that any translational acceleration and any change of angular attitude leads to a change of the cued apparent vertical different from gravity. As a consequence the two specific forces and angular attitudes can be expressed as a change of the apparent vertical angle.

Figure 2 furthermore shows the reaction of the AVF to the input signal due to an idealized lateral slope ride in red. It is easy to see that the side forces in the simulator are of the same magnitude like the input signals. The roll rate as well as the vertical specific force, again, shows no differences concerning the input signal. These are remarkable differences to the results found for a CWA.

After having shown the response of the AVF and CWA for a lateral slope, both filter responses to the outputs of a car simulation model will be demonstrated. Again, driving on a lateral slope is the reference maneuver for comparing the response. Figure 3 shows the input signals and the filter response for both filtering methods. While the first graph shows the force magnitude, i.e. the length of the force vector, represented in the simulator, the second graph presents the apparent vertical angle or the orientation of the force vector. Again, the input signals are colored in dashed black, the AVF response is shown red and that of the CWA is presented in dark blue.

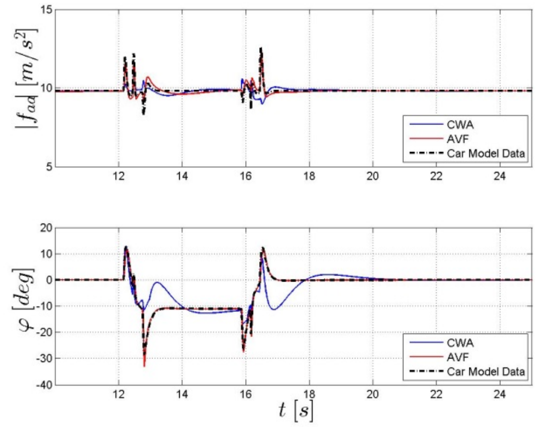

Figure 3: Classical Washout vs. Apparent Vertical Filter response

It is interesting to see how both filter methods react to this signal. Please note that both filter parameters are set to equivalent break-frequencies and damping coefficients. The gain of all input signals is 1 and no physiological limitation is set. While the magnitude of the simulated specific force is similar for both filter methods one can observe noticeable differences in the lower graph. While the AVF is able to follow the change of the apparent vertical angle, the CWA suffers from doing the same. This behavior is coherent to the results of the idealized drive on a lateral slope and therefore it can be seen as an inherent disadvantage of the CWA.

The example of a lateral slope drive maneuver shows major differences in the motion system response between using a classical washout filter algorithm and an apparent vertical filter. Due to its inherent design the CWA is hardly able to represent a roll rate during the whole maneuver which is similar to that of the car.

The AVF on the other hand is able to roll the simulator cabin in the same way the car does, and to present identical g-forces for this maneuver. Of course this behavior is constrained by the space envelope limiting the roll attitude achievable by the simulator cabin.

It could be shown that for both tests the AVF shows an almost perfect match of the apparent vertical comparing the input specific forces with the specific forces felt in the simulator.