Recommended Requirements for a Driving Simulator Visual System

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Introduction:

The information relevant to driving is predominantly visual [1]. Therefore, the visual system is arguably the most critical component of any driving simulator configuration. The characteristics of the visual system determine the range of driving maneuvers that can be realistically trained and evaluated or investigated by researchers. The primary features of a visual system are the size of the screens (or projection surfaces), the width of the field of view (FOV) and the graphic realism, i.e. 1:1 graphic-to-optic ratio vs. compression of the visual scene (similar to a fish-eye lens). These features directly influence the comfort of the driver, the training goals that can be achieved, the risk of negative training, the space required for the driving simulator, the cost of installation and the total cost of the system.

Our purpose in writing this article is to inform users and potential users of driving simulator systems of the importance of matching their training, evaluation and research goals to the appropriate visual system. We propose that driver training, evaluation and research are intrinsically interrelated because driving skills that are trained should also be evaluated and all driving behaviors are subject to research. Therefore, for the sake of brevity we will only refer to driver training goals in relation to the requirements of the simulator's visual system with the understanding that evaluation and research goals are automatically included.

In this article, we describe the minimal requirements of a visual system for driving simulation in terms of its capacity to effectively address the multiple requirements and goals of driver training. We recommend that the minimum specifications for driving simulator visual systems consist of a forward FOV of at least 180 degrees plus rearview mirrors and blind spot displays and a 1:1 graphic-to-optic representation. The recommended visual system will be compared to visual systems of less than 180 degrees, systems without blind spot displays and systems that compress 180 degrees of graphics onto physical displays that are narrower than 180 degrees.

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Screen size

The desired visual FOV and the distance from the eyes to the screen (viewing distance) dictate the size of the screens selected for your visual system. For a given FOV, larger screens allow a greater viewing distance, increasing driver comfort by reducing eyestrain. However, larger screens also increase space requirements and installation costs. Smaller screens allow a shorter viewing distance but can also increase eyestrain for the driver and have been associated with increased symptoms of simulator adaptation syndrome (SAS), like headache, dizziness and nausea.

The 180-degree minimum FOV

The objectives of the driver training scenarios dictate the FOV needed to achieve those objectives. For example, collision statistics report the high frequency of intersection crashes both for novice and aging drivers [2]. This fact highlights the critical importance of training or retraining drivers to have the scanning skills that will systematically reduce their crash risk at those locations. The correct and safe method for crossing intersections is to first scan 90 degrees to the left and right to verify that the way is clear. This training is possible in the 180-degree FOV visual system but is not easily achieved on visual systems with FOVs that are less than 180 degrees, e.g. 150 degrees, or visual systems that compress 180 degrees of graphics into physically narrower screens, e.g. 120 degrees. The reasons for this are explained in more detail in the following sections.

It is also important to note that a FOV of 180 degrees replicates a driver's natural range of central and peripheral vision and improves immersion, the degree to which the external senses of the driver on the simulator are occupied with the driving task vs. any external distraction. Increased immersion is associated with improved learning, transfer and retention.

Blind spot displays

Training drivers to change lanes, to check for cyclists or vehicles approaching from behind before turning and to merge onto expressways requires the ability to verify blind spots. In traffic, to verify his blind spot a driver turns his head to look over his shoulder (sometimes referred to as the *shoulder check*). Some simulators address the training goal of verifying blind spots by using levers or buttons to momentarily flip the blind spot view onto one of the front screens of the simulator. A more realistic solution and one that allows drivers to learn and practice the correct psychomotor coordination and judgments is to place blind spot displays within the driving simulator configuration on either side of the driver, precisely where he needs to look in real life.

Graphic-to-optic representations - 1:1 ratios

A visual system with a 1:1 graphic-to-optic ratio positions objects on the screens in the same locations and at the same angles relative to the driver, as they would appear in the real world. Within a FOV of 180 degrees (see Figure 1), the driver is seated in a central position relative to the three screens and the far edges of the screens on the left (A) and the right (E) form a straight line across the eyes of the driver. The driver's eyes are positioned equidistant from points B, C and D to maintain a constant focal distance across the entire FOV. Points A and E are physically 90 degrees to the left and right, respectively, and images are displayed in precisely the same locations where they would appear in the real world.

As stated above, when a driver in the real world is stopped at an intersection, before proceeding safely he must turn his head almost 90 degrees and look down the crossroads to the left and right in order to detect the presence of pedestrians, cyclists or approaching vehicles. In a driving simulator visual system with 180 degrees of forward view and a 1:1 graphic-to-optic ratio, the driver is able to learn and repeatedly practice the exact same behaviors that he will need in the real world.

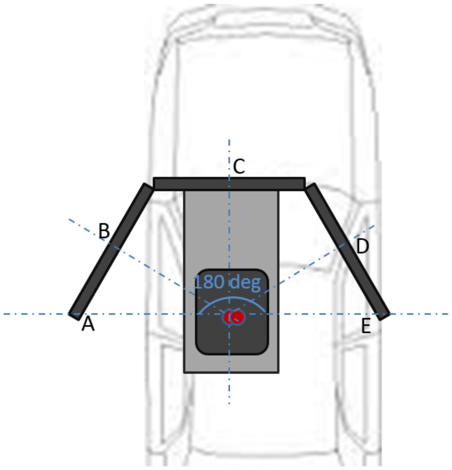

Figure 1: Representation of a 180-degree FOV

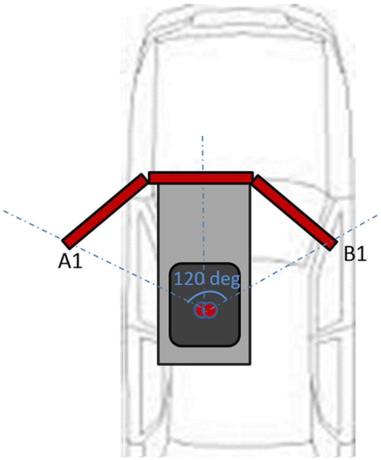

Figure 2: Representation of a compressed visual system displaying 180 degrees of graphic information in an optical (physical) FOV of 120 degrees

Compressed visual representations

A compressed representation displays the same images as a 1:1 graphic-to-optic system but does so on a system of screens physically narrower than 180 degrees (compare Figure 2 to Figure 1). The advantage of compressed visuals is that they allow the use of smaller screens and shorter viewing distances. The disadvantage of the compressed visuals is that they distort the representation of reality.

Differences in driver training between 1:1 graphic-to-optics and compressed visuals

In the following example (see Figure 3), the driver, represented by the red circle, is preparing to turn left at a busy intersection. The driver must remain vigilant because of the presence of the oncoming truck (black rectangle) and a pedestrian (blue stick figure) who is about to enter the crosswalk that intersects the driver's intended turning path.

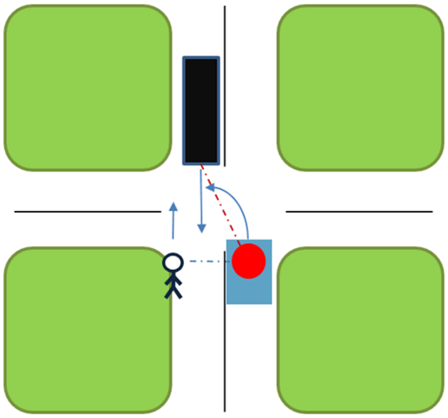

Figure 3: Driver planning a left turn

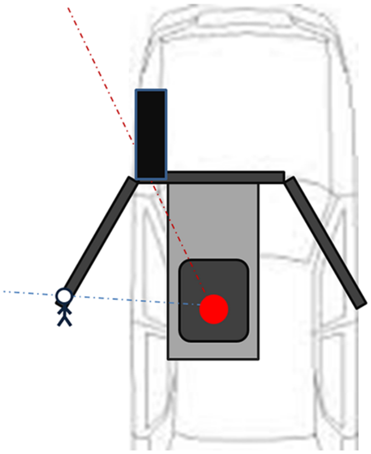

Figure 4: Graphic representation of Figure 3 left turn on a 1:1 visual system

In Figure 4, the dashed red and blue lines reproduce the locations on the simulator screens where the driver needs to look to monitor the progress of the truck and the pedestrian presented in Figure 3. As we can see, in the 1:1 visual system, the images appear at the exact same optic angles on the screen as they would on the real road. In this case, the pedestrian appears at a 90-degree angle to the driver in line with the driver's left shoulder just is he would in real traffic.

Figure 5 compares how the pedestrian and truck from Figure 3 are represented with compressed graphics on a physical 120-degree system of visual displays vs. a 180-degree 1:1 visual system. The pedestrian preparing to cross the street will appear at point P in the 1:1 visual system and at point P1 in the compressed visual system. A similar error occurs for the position of the truck when we compare C and C1. We can observe that the compressed visual system creates a visual distortion, an error in the placement of objects that increases incrementally and reaches its maximum at the extreme end of our visual field. The more the visual system is compressed, e.g. 180 degrees of FOV on screens that are physically only 90-degrees wide, the greater the error.

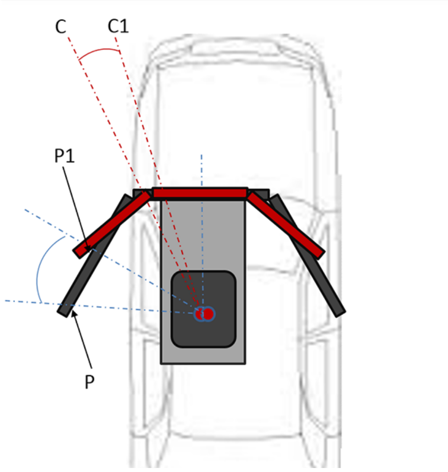

Figure 5: Images from a 180-degree FOV, 1:1 visual system vs. 180-degree graphical FOV compressed within 120 degrees of visual display.

Imagine yourself in the driver's seat and compare the amount of head turning required to see the pedestrian in a 180-degree FOV. 1:1 ratio simulator to the amount of head turning required to see the pedestrian in a compressed visual system. The brain of the driver, especially an inexperienced, novice, will learn to scan intersections according to the physical parameters of the driving simulator in which he is driving.

Positive and negative driver training

The goal of all driver training delivered on the road or on driving simulators is to achieve a positive transfer of the desired skills to real driving situations. The key phrase here is *positive transfer*. First, if there is no transfer of skills, then the training has not been successful and the investment of time and money by all parties has been wasted. If there is a transfer to real driving situations, it needs to be positive in order for drivers to correctly perform the driving skills needed to systematically reduce their crash risk.

Unfortunately, it is possible for drivers to learn negative habits both on the road and in driving simulators. Negative habits or negative transfer is the unintentional development of incorrect psychomotor reflexes, sometimes called muscle memory, which could produce dangerous mistakes. For example, if drivers are permitted to drive without buckling their seat belts, they learn that this is an acceptable behavior and they will be more likely to repeat it. If, on the other hand, they learn to buckle their seat belt each time they sit behind the steering wheel of a car or a simulator, this behavior is more likely to become an automatism or habit that becomes increasingly easier to repeat.

The same logic applies to driving maneuvers. Consider that a significant proportion of crashes occur at intersections.

> "At intersections, the driver [is required] to scan left, and right looking for potential hazards and checking for traffic. In this case, a 180-degree forward field of view would be ideal to safely negotiate the intersection." [3, p. 14-11]

There is a risk in training a novice driver to scan intersections by turning his head only 60 degrees to the left and right (i.e. the physical limit imposed by a 120-degree FOV screen driving simulator) because in real traffic he may repeat this exact same behavior and may not look for or notice a vehicle approaching from a 90-degree angle (i.e. a vehicle that could be seen in a 180-degree FOV, 1:1 graphics-to-optics driving simulator). Evaluating experienced or aging drivers for their intersection behavior is also complicated by a limited or compressed FOV because it is impossible to detect if those drivers correctly scan their intersections. [2]

The same challenges arise for lane changes, merges, or turns where blind spot verifications are required for safety. If a learner driver repeatedly makes lane changes or turns or merges onto expressways without first verifying the appropriate blind spot, there is a risk that these driving behaviors will become habits that are reinforced and strengthened each time they are repeated and which may go unnoticed and uncorrected while driving in real traffic. Evaluating the blind spot verifications of experienced or aging drivers is also complicated by the lack of actual blind spot monitors.

Table 1 summarizes the driving skills that can be trained effectively on different visual systems. Driving skills that only require a limited forward view can be trained on driving simulators with narrow FOVs. However, for any driving skill that requires awareness of traffic approaching at 90-degree angles at intersections or verifications of blind spot areas, i.e. lane changes, turns and expressway merges, visual systems with 180-degree FOV screens plus blind spots and 1:1 graphic-to-optic ratios are recommended.

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[2] Drivers involved in intersection crashes often report they "looked but did not see" the other vehicle. One potential explanation is that these drivers may not have looked far enough to the left or right to see the approaching vehicle in time. Training and evaluating the critical safety skill of correct scanning is difficult to accomplish on a compressed visual system.

Table 1. Suitability of different visual systems to evaluate a normal range of driving skills

Driving skills	**180-degree FOV screens with 1:1 graphic-to-optic ratio plus blind spots**	**120-degree FOV screens with graphic compression of 180 degrees and no blind spots**
Speed control	Yes	Yes *
Brake reactions	Yes	Yes
Lane keeping	Yes	Yes
Turns at Y intersections	Yes	Yes
Proceeding straight through intersections	Yes	No
Lane changes (with shoulder checks)	Yes	No
Turns (with shoulder checks)	Yes	No
Expressway merges (with shoulder checks)	Yes	No

***** Speed perception decreases as field of view narrows [4]

Conclusion

Learning theory [5, 6] suggests that transfer of learning depends upon the presence and correct location of elements in the learning situation that are identical to those same elements in the transfer situation. Driving simulators provide safe learning situations and have great potential to help drivers acquire skills that will help keep them safe in the transfer situation, i.e. the real road. Behaviors that are learned and deliberately practiced until they are performed smoothly with little or no conscious thought in the driving simulator will be repeated in exactly the same way and performed automatically (habitually) on the road. Visual systems that compress a 180-degree FOV into a physically narrower visual display are suitable for training a limited range of driving skills. However, it appears that the majority of driving skills, particularly those skills associated with reducing the risk of involvement in intersection crashes, require the use of a driving simulator with a minimum visual system consisting of no less than a 180-degree forward FOV plus rearview mirrors and blind spot displays and a 1:1 graphic-to-optic representation.

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