MOTION SYSTEMS AND VISUAL DISPLAYS

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Driving is an instinctive, almost automatic process in which the driver interacts with the vehicle by a process of **motion interaction or "feel"** in response to road conditions or his/her actions on the controls. The visual information which the driver receives is used to set overall objectives and not as part of the instantaneous process of control. That is to say, the driver will look ahead to see where he intends to go and maintain a precautionary awareness of his surroundings: but vehicle control is a different process. The driver will use visual information for planning: body sensations from the seat and the steering wheel are used for the actual driving task.

It therefore follows that driving simulators must include the tactile and motion cues because they form part of the instinctive response which the experienced driver needs to learn. The steering wheel, the gear lever and the control pedals have to feel exactly right: tactile and motion cues must be applied to the body in accurate synchronism with the visual displays.

In fact, there is a strong interdependency between the motion system and the visual displays to which I should like to draw your attention.

THE IDEAL SYSTEM

For realistic driver training it is important that the driver believes that he has an all round view. He needs to be able to move his head to see the correct view as he would in a real vehicle, to be able to see what is happening behind him in his overhead and wing mirrors and to perceive peripheral events in a view which is generally forward looking.

One way to achieve this is to use a model of the vehicle cab surrounded by video screens to the front, side and rear. Ideally, the screens will be at a significant distance from the vehicle cab so that there is a strong differential focus between the control instruments on the dash board, the extreme edges of the car and the more distant view of the road ahead. This can be achieved with six or more overhead projectors and a series of large screens surrounding the vehicle to front side and rear. Unfortunately, the complete simulator installation then has a significant size, weight and inertia, so that if the whole system is mounted on a motion base the motion system has to be large, powerful and inevitably very expensive.

You will appreciate that there are other difficulties of construction in that the screens and the projector mounting have to be strongly constructed so as to resist the forces caused by the motion base. The foundations of the system must be substantial and the size of the room in which this large moving object has to be located is that of a large hall. The Daimler-Benz simulator in Munich is a well known example of such a system.

COST REDUCTIONS

It is possible to reduce the cost of the motion base by replacing the six-axis system by a three-axis system. This is because sway (side acceleration) can be represented by a roll motion which is not perceived by the occupant. In the same way surge (acceleration along the direction of travel) can be represented by a pitch angle and yaw-rate (speed of spin rotation) can be represented by a combination of pitch and roll motions.

To reduce the size and cost of the motion system the weight and inertia of the structure may be decreased by using a series of TV screens in place of the vehicle windows. However the number of computing channels is increased because there are more TV screens than there would be projectors for a cinema screen system. To bring the number of computing channels to a realistic number it is possible to reduce to (say) five the number of forward TV channels, using (say) three other channels for the rear view system and eliminating the side view displays.

FIXED DISPLAYS - MOVING VEHICLE

There is, however, a strong preference for the visual displays to be at a significant distance from the perceived edges of the vehicle; the experience that one looks out of a glass windscreen onto a world which is at a distance from the edge of the car is a very strong one. If TV screens are used they have to use optical enhancements which put the image at infinity: projectors and display screens are preferred. Another form of simulator has therefore been devised in which the screens and their projectors remain fixed and only the simulated vehicle is fitted to a motion base.

The problem with this idea is that the "virtual motion" effect is strongly dependent on the assumption that the simulator occupant does not know what his real motion actually is. In an enclosed capsule, for example, it is impossible to tell whether the capsule is pitched or rolled; so that when the appropriate motion cue is applied it is felt as a surge or sway acceleration. In the same way lateral acceleration such as heave is perceived to continue for longer than it actually does, because the "virtual view" shows the continuing action whilst the real movement is gently brought to a halt.
Although the simulator may be mounted in a darkened room there is always sufficient light reflected from the screen to show where the floor and ceiling are; thus the occupant of the simulator knows which way is "up". Of course, if the pitch or roll motion ever becomes too extreme the sight line of the occupant will actually include the edges of the projector screen, thus breaking the illusion completely. Fixed screen simulator systems therefore use motion bases which only move through small angles - typically plus or minus five degrees in pitch and roll.

It will be understood that even for a small angular displacement it is necessary to maintain the sight line of the visual horizon in the same relationship to the vehicle occupant as it would be if the occupant, vehicle and screen all moved together. If the motion system pitches forward, for example, the picture must move down the screen or else the simulator occupant will know that the simulator has pitched forward. This does not mean that the projector has to move; merely that the computer graphics must cause the picture to be redrawn with the horizon at a different vertical height, or at a different angle if a roll motion takes place. Such visual tricks are effective for only a second or so, because in a non-enclosed environment the brain, given time to think about it, soon perceives that the screen horizon is not locked to the "real" visual horizon (floor or ceiling line). The effect of the subterfuge is lost if the screen horizon is not quickly restored to normal.

It is also important to note that the simple idea of using a mirror on the motion platform to deflect the image onto the screen is actually counter-effective because the laws of optics say that the angle through which the image moves is twice the angle through which the mirror moves; this means that the movements of the motion platform would be exaggerated instead of compensated.

Some thought and observation will also show that rapid motions of the simulator, produced by simulated road surface variations for example, should not be fed into the optical system. We are all used to feeling motion in a vehicle whilst we observe surroundings which we know to be fixed: our head and eye stabilisation system and the workings of the brain compensate for the rapid variations of the vehicle position. Thus a visual display showing the rest of the world away from the vehicle is not expected to move and looks incorrect if it does so. A simulator which uses onset cues of vehicle motion in relation to a fixed visual display is quite effective.

Rotation about a vertical axis ("yaw") becomes important to the motion cueing system when the screen is fixed. We are used to relating our sensations of motion to our movements across what we know to be a "fixed" environment. In a simulator representing a fast turn or a spin this means that the initial yaw onset should be physically represented; meanwhile the visual image on the screen must begin to move in the opposite direction to that in which the simulated vehicle is supposed to be turning. To represent a sustained turn, or perhaps an uncontrolled spin, a rotating pitch and roll motion (yaw-rate representation) and a synchronised tilt in the optical horizon are also acceptable.

The motion system of a fixed screen simulator must produce accelerations in six axes.

FIXED DISPLAYS - FIXED VEHICLE - MOVING SEAT

It might at first be thought to be impossible to move the seat of a vehicle to any real extent without disturbing the driver's interface to his controls.

However a study of body accelerations in a road vehicle will show that we are used to feeling movements in relation to the seat - or seat motion in relation to us. When we turn left our body moves slightly to the right across the seat and visa-versa. When we brake we move slightly forward and when we accelerate we move slightly back. When we turn at speed our body rolls slightly on the seat surface and there is a continuous up and down motion which generally represents changes in our interface to the road surface. It is therefore possible to represent these motions by moving the seat a small distance in the opposite direction to that in which we would move if the seat were fixed to the floor of a real vehicle. For example a braking motion - in which we would be thrown forward - can be represented by moving the seat, complete with seat belt, suddenly backwards a centimetre or so, producing precisely the same sensation. Similarly, a manoeuvre which would throw our body slightly to the right can be synchronised with a motion cue which moves the seat and seat belt slightly to the left.

Another strong source of motion sensation in a vehicle is produced by the varying tensions of the muscles in the arms which link the body with the steering wheel and in the legs which link the body to the foot control pedals. When braking, for instance, the limbs brace to prevent the torso being flung forward against the steering wheel, and when cornering at speed the limbs are used to keep the body upright against the centrifugal forces which tend to throw it left or right.

These forces may be represented in a simulator by tilting motions of the seat; pitching forwards to represent braking, pitching backwards to represent acceleration and rolling left or right to represent the centrifugal forces. These small tilting motions of the seat - in the same direction as the body would be thrown - can be applied at the same time as the small lateral motions in the opposite direction. In this way convincing motion cues can be generated from motion of a driver training seat alone, the vehicle and the visual display screens remaining stationary throughout.

SUMMARY

Visual displays and motion systems are interdependent. Motion can be applied to the whole simulator, to the vehicle or to the seat - or to a combination of these.

It is now possible to construct driver training simulators with a convincing "feel" and at reasonable cost, removing the strongest obstacle to customer acceptance of the product.