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AN ULTRA-LOW-COST MOVING-BASE DRIVING SIMULATOR

T. B. Sheridan, sheridan@mit.edu, fax 617-258-6575
P. W. Young, pwyoung@mit.edu
D. Ngo, davidngo@mit.edu
K. Calef, kmcalef@mit.edu
E. Bachelder, edbach@mit.edu
J. Cooper, cooper@mit.edu

Age Laboratory and Department of Aeronautics and Astronautics, Room 3-354
Massachusetts Institute of Technology
Cambridge, MA 02139
Fax: 617-258-6575
Email: sheridan@mit.edu

ABSTRACT

A novel approach to driving simulation is described, one that potentially overcomes the limitations of both motion fidelity and cost. It has become feasible only because of recent advances in computer-based image generation speed and fidelity and in inertial platform development. Potentially it is both very cheap and very realistic, although there are some obvious restrictions to its use. This is a report on the concept and on initial efforts to implement and demonstrate it.

The test driver in this case drives a real car or truck on a real pavement, but the collision hazards that are presented are computer-generated virtual reality. There are several alternative means to display the scene ahead: closed-circuit video (using a head-mounted or vehicle-mounted display), direct vision through a half-silvered mirror, computer-generated virtual reality, or a combination. Since the driver is controlling a real vehicle the motion is perfectly faithful to actual reality; there is simply no need for any artificial mechanism to produce the motion experience. An inertial measurement unit plus real-time computation are required to make the hazard image faithful to steering and forward velocity and acceleration.

This paper describes the technical options, the technical problems, initial experiments with the concept, and research that needs to be done.

INTRODUCTION

History of Computer-Based Human-on-the-Loop Simulation

Computer-based human-in-the-loop simulation has been used since computers were first available — originally with analog computers and later digital computers. Aviation was the first major application, then nuclear power plants, and more recently automobiles and trucks, trains, spacecraft, military vehicles, and most recently endoscopic surgery (1) . Human-in-the-loop simulation technology in aviation has continually improved since the days of the first flight simulators in the 1940s, to the point where currently the first time a commercial airplane pilots flies a new aircraft is with a full load of passengers. All the airlines make use of realistic flight simulators for training and research. Operators of nuclear power plants routinely use human-in-the-loop simulators for emergency response training and for evaluating new procedures and hardware systems, the simulator in this case being a duplicate of the real control room connected to a large computer rather than the actual nuclear plant. The military services use simulators for all kinds of training in the operation of ships, tanks, aircraft, and command and control centers.

The demand has always been for higher resolution and greater computational speeds, and that is still true today, even with the incredible recent progress in computer-graphics. It can be said that some applications, e.g. automobile driving, put much greater demands on visual display than do others, e.g, nuclear power plants.

Vehicle simulators of all kinds pose the additional need to recreate the cues for the vestibular senses (semicircular canals which sense rotary acceleration, and otolith organs which sense translational acceleration), as well as the muscle and joint sensors which pick up similar motion cues. Generation of a faithful moving base has always been a very expensive item. The hexapod (Stewart platform) devices common in aircraft simulators have posed most of the demand for space in simulator facilities and perhaps half of the capital and maintenance budget. Early driving simulators and the many low-cost PC-based simulators now in use have not been able to justify the cost of the moving base, though in the first author's experience it has long been evident that subjects in such driving simulators tend to oversteer and sometimes experience vertigo because the visual cues are present but the corresponding motion cues are missing.

Fixed-base simulators are most valid for research into cognitive factors of driving where exercise of continuous visual-motor steering skill is the focus, and a more realistic driving experience is not necessary. Only a very few motion-base driving simulators have been built, the first by Daimler in Berlin, another by the University of Iowa, and more recently by several auto manufacturers. However even those simu lators (using conventional hexapods) lack realistic translational acceleration capability beyond low acceleration lane change and braking. The National Advanced Driving Simulator at Iowa City promises to rectify this problem. But it is one of a kind, and the motion capability accounts for by far the greatest share of its 60 million dollar capital cost.

Uses of Driving Simulators

Focusing now on automobile (and other highway vehicle) human-in-the-loop simulation, we consider the uses for which such a simulator has promise:

Research on Driver Response

Highway accidents are clearly one of the principal causes of death and injury in the United States and the world. While improved vehicle and highway technology has made many positive contributions to reducing crash statistics, there are more and more vehicles on the highway driving at ever greater speeds, and an ever greater fraction of drivers are older adults with reduced capabilities for seeing, hearing, anticipating and responding to unexpected or emergency highway situations.

A better understanding of the limitations of all drivers, especially older drivers, is needed, together with means to design within these limitations to make driving safer. This problem is exacerbated by:

(1) the increased attentional demands imposed on the driver by cell telephones, navigation systems, and the myriad of other devices being added to vehicles, often by third party vendors and without interface integration with manufacturer-supplied devices;
(2) ever-increasing highway congestion and the resulting driver stress;
(3) the flood of new drugs coming on to the market which may affect driver alertness; and
(4) dependence on highway vehicles for commuting, shopping and daily living, and the associated frustration and loss of personal self-worth by older drivers when they are restricted from driving.

Researching driver behavior in emergencies by examination of real accidents has limited yield because every accident is unique to some extent, determining causation is difficult, and controlled experimental research is inherently not possible for real accidents. Human-in-the-loop driving simulators enable the driver to experience emergency situations where his/her responses can be measured in controlled experiments without exposing the driver to actual risk. Driving simulation is therefore becoming more and more attractive as an alternative to making inferences from accident data — provided it is realistic enough that results in the simulator can be shown to translate to the actual highway.

Driver Training and Evaluation

Mostly driver training is conducted in class rooms and in actual automobiles being driven in real traffic. That is fine for normal driving, but seldom exposes trainees to sudden or unexpected hazards. Some schools for professional drivers include special pavement areas for learning to control out of skids. If some means were available to allow driver trainees to experience collision hazards, bad visibility, etc. without actual exposure to risk

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it could be a very useful part of training. Older or incapacitated drivers undergo such tests for licensing evaluation or self evaluation. Unfortunately current fixed-base driving simulators are inadequate (mostly because motion cues are lacking) and moving-base simulators are currently far too expensive.

Vehicle Evaluation for Development

Vehicle manufacturers, secondary suppliers and car/truck fleet owners usually perform developmental tests in actual vehicles, but this is limited to experiences not involving collision hazards. Some use is made of moving base simulators, but the cost is great, especially the cost of measuring and modeling the vehicle equations of motion, and programming these as well as reconfiguring the simulator to represent the type of vehicle in question. The question again is: can means be found to use actual vehicles but at the same time confront the test driver with hazards which appear real but actually pose no risk?

PROPOSED SIMULATION APPROACH

The proposed new approach is to use virtual reality for the collision hazard stimuli in an actual vehicle being driven by the test subject. Until this approach is well proven such a simulator requires that the driving be done on a pavement where there is no danger of actual collision. (Large parking lots, unused aircraft runways and little-used stretches of roadway can safely serve for transient maneuver tests.) A vehicle with dual controls and a second driver may be necessary to assure the test driver of his or her safety. In general no virtual hazards should be presented which incite violent steering or braking maneuvers sufficient to overturn the test vehicle or otherwise endanger its driver(s). Alternatively, limits on steering and braking actuation can be imposed.

There are several ways to render the visual scene:

(1) *The outside scene is a real-time color television picture with computer-generated hazards superposed.* This can be displayed through a head-mounted display from a camera looking co-linear to the driver's view point (attached directly to the head-mount, Figure 1), or using a vehicle-mounted display from a vehicle-mounted camera. One major advantage of the head-mounted display approach is that the driver can turn his or her head sideways to look for vehicles overtaking or oncoming at intersections, or look up at traffic lights or down at panel instruments. A conventional video mixer is used to superpose a computer-generated hazard to the forward scene, for example another vehicle or a pedestrian or an animal on a collision course with the driven test vehicle.

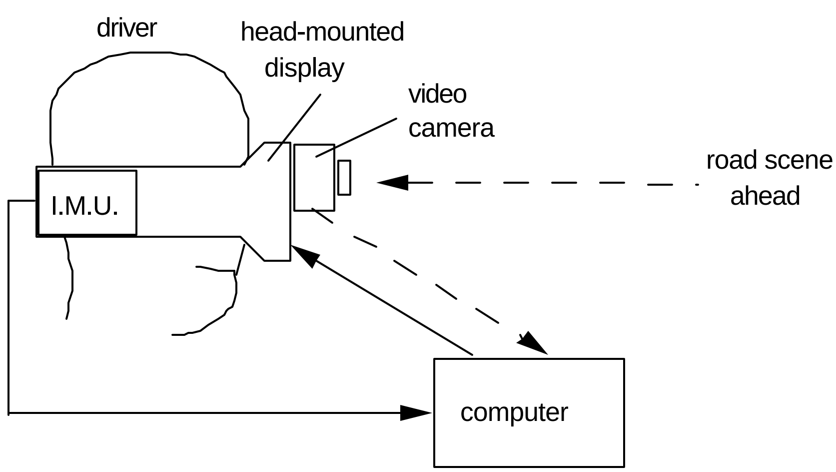

Figure 1. Head-mounted display of video road scene with earth-referenced hazard image superposed.

(2) *The outside scene is completely computer-generated.* Again, either a head-mounted or vehicle-mounted display can be used. Because computer-generated realism of a full view is difficult to achieve with conventional PC speeds this approach might work best for night-time driving where the number of continuously refreshed pixels comprises only a fraction of the visual scene. In all other respects it is the same as (1).

(3) *The viewed outside scene is real, with the hazard added through a "head-up" display (half-silvered mirror).* This configuration is shown in Figure 2. Such a "head-up" display is common in military fighter aircraft, and more recently has been introduced to the Cadillac automobile as part of an optional night-vision system. Again nighttime or dusk driving might be easiest for the purpose of superposing the collision hazard objects on the otherwise realistic scene, but in this case for a different reason. Speed in computer-generation of pixels would not be the problem, since the hazard would normally be but a small part of the total visual scene. The problem in daytime would be matching the illumination level of the hazard to that of the parts of the visual scene that are directly seen through the half-silvered mirror. At night any mismatch might be less obvious.

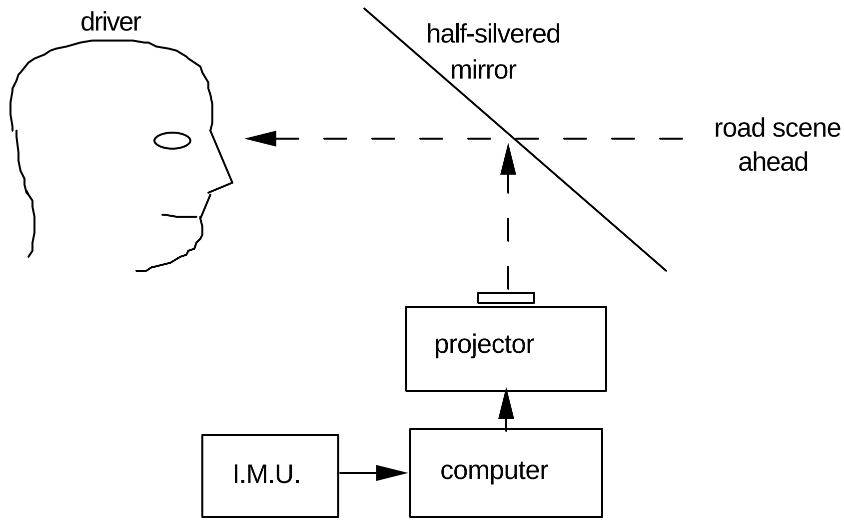

Figure 2. Road scene viewed directly though half-silvered mirror with earth-referenced hazard-image superposed

A critical element in all of the above schemes is the computation of the size and lateral position of the hazard to be rendered on the display screen. As the test vehicle moves forward the perceived size (retinal angle) of any object on the road ahead will increase. As the test vehicle turns the lateral (angular) displacement relative to the vehicle will change. Thus the size and lateral position on the driver's display must be continuously recomputed, based on measured changes in vehicle forward and lateral position as well as yaw angle. Fortunately, while measurement of these changes has heretofore been an extremely expensive proposition, current inertial measurement devices have come down in price and size. Now they are at the point where accelerations can be measured using low-cost devices and integrated to provide sufficiently accurate translational and angular position information over a period of a number of seconds (all that is necessary for a transient encounter with a highway hazard).

In the case of a display fixed relative to the vehicle any lateral or vertical head motion will cause the perceived hazard to move in the opposite direction. This problem can be fixed by head tracking (e.g., with pivoted arm connecting head and vehicle roof and having rotary sensors, or with an electromagnetic device such as the Polhemus tracker). Or, more simply, one can just constrain the head position.

In the case of the head mounted display the abovementioned parallax problem does not appear, since the display moves with the head. In this case the inertial measurement unit would be attached directly to the head (mounted display) so that it accounts for both head motion relative to the vehicle and vehicle motion relative to the roadway. Both video cameras and inertial measurement units are now quite small, such that when added to a helmet or head-mount their added weight is hardly noticed.

INITIAL EXPERIMENTS

Initial trials are in progress. A first crude test sought only to get a subjective sense of what it is like to drive an actual car while viewing the road ahead through a head-mounted display. A Virtual Research VR4 head-mounted display (2) was worn by the test subject (the first author), with a miniature S-video camera attached to the front looking approximately co-linear with his line of sight. He slowly maneuvered his own automobile from his home driveway and down his neighborhood street. The most serious problem encountered was that in this first test the camera lens was very wide angle, so that while the viewed image covered more of the visual scene than was necessary, the angular position feedback was inadequate for safe driving.

For a second experiment a conventional Sony camcorder with an S-video output was used for its camera. The whole camcorder was taped to the subject's head-mounted display with duct tape. In this case the subject found driving much more natural, even though the resolution of the picture was not high. The fact of a normal lens made the angular position feedback quite satisfactory. The field of view was obviously reduced from the wide-angle test but seemed to be no problem. Because the camera was attached to the head-mounted display the subject was able to move his head to look for oncoming cars at intersections. The subject easily accomplished a slow speed drive around the neighborhood block (avoiding parked cars, etc.) and back into the subject's home driveway without once "cheating" by removing the head-mounted display.

These simple experiments strongly suggest that the concept is workable and safe, at least for initial low speed tests in a restricted area . Further, the VR4 is a relatively antiquated head-mounted display. Newer head-mounted displays and camera s (the pair should be matched) can be used subsequently to provide higher quality images with respect both to pixel resolution and field of view.

Experiments in the laboratory have also been conducted on a test table with two versions of the Crossbow Technology inertial measurement unit (3) . Two inch and one inch cubed units both appear to have sufficient accuracy, precision and stability for the anticipated need to provide a ground-reference for computer-generated hazard images, as well as being small and light enough for head mounting.

RESEARCH ISSUES IN NEED OF STUDY

Simulator Development / Construction

Our plan is to construct a prototype simulator around a dual control but otherwise conventional automobile. It will be rigged to accommodate either: (1) a standard high-resolution 30 deg FOV VGA head-mounted display, (2) an exchangeable full or half-silvered mirror capable of allowing a video or computer-generated image for an approximately 30 degree-wide forward view of the forward scene as described above. (The computer/ video projector in this case can easily be mounted on the vehicle roof.) This should provide a sufficiently wide field of view for initial evaluation of the technique in all three scene generation modes. At a later time a wider field-of-view simulator could allow virtual hazards to be presented in peripheral vision, or in the rear view mirror, or out a side window, etc.

No sound cues are contemplated for the initial simulator development, though these could easily be added at a later time, using loudspeakers at four quadrants to provide virtual sounds corresponding to objects moving relative to the test vehicle.

Independent and dependent variables for evaluation

All three projection modes described above would be evaluated. In each mode a range of obstacles would appear at different distances, demanding different response times and braking/steering intensities and different degrees of visibility (based on both size and brightness/contrast) and under both day and night conditions. Other independent variables might be distractions such as windshield wipers operating on wet windshield, use of a cell phone, etc. Experimental subjects would include both young and older drivers. Thus the <u>independent</u> variables are:

(1) head-mounted display versus fixed display (fixed to vehicle)
(2) display mode for the forward view of the road (closed-circuit video, half-silvered mirror or computer-generation)

(3) distance at which obstacle first appears
(4) size and motion of obstacle
(5) brightness or contrast of obstacle with background
(6) day vs. night environmental conditions
(7) in vehicle distractions
(8) age of driver subject (over 65 and university students).
(9) Other factors such as driver skill, driver vision, and driver self-confidence would be noted but not systematically controlled.

Each subject would serve as his or her own control and experience multiple scenarios with variables 1-8 spread across the scenarios and counterbalanced with respect to the order for different subjects.

The <u>dependent</u> variables would include:
(1) degree and mode of obstacle avoidance, either by braking or steering
(2) subjective scale of event realism
(3) anecdotal comments by experimental observer (second driver) or test driver (subject)

The experimental design should adapt to a multifactorial ANOVA in terms of both avoidance distance and subjective rating for realism. One experimental control might be the performance of the same maneuvers in an already available Systems Technology fixed-base simulator in the MIT Age Lab.

CONCLUSIONS

A new approach to human-in-the-loop driving simulation is presented, where the test vehicle is an actual automobile or truck driven by the human driver, but where collision hazards are computer-generated virtual reality superposed on the display of the road scene ahead. The road scene may be a closed circuit video image (presented through either a head-mounted or a vehicle-mounted display), a direct view through a half-silvered mirror, or a computer-generated picture. In all cases an inertial measurement unit must be used to provide ground-based coordinates with respect to which the hazard is programmed to move in a realistic way.

Preliminary experiments driving with a video image viewed through a head-mounted display suggest that the camera lens should be normal (not wide angle) and that standard video and VGA resolution are minimally sufficient.

This approach could find usefulness in driver training, in human factors research, or in testing the handling qualities of new vehicles. The major advantage is the ability to provide true motion cues without the large capital and maintenance costs of an artificial mechanism for generating those motion cues. Further, there is no need to measure, model and program the dynamic equations of motion of the vehicle, since they are reproduced perfectly by whatever actual vehicle is used.

Current limitations are roughly the same as those of all driving simulators: resolution field of view and realism of the displayed scenario, especially that of the hazard. For the immediate future use of such a simulator on populated and trafficked roads is not recommended.

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