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The Future of Driving Simulation

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Abstract

The Past to Present. The simulation of the driving experience has been used for both research and most especially for driver training. In large part, the state of the art in driving simulation has been contingent upon wider developments in simulation science. The challenge of ground-vehicle simulation provides stiffer challenges than simulation of airborne vehicles. Current advances have seen high-fidelity, multi-million-dollar facilities. The advantage is that they provide capacities now coming very close to the Turing test for simulated reality. The disadvantage is that they are so expensive as to be almost unique and so no replicable science is conducted on them. ***The Present to the Near Future.*** Simulation not only improves with the technical capacities of the age, it also diversifies. Thus, in modern simulations there are options associated with game-playing, full virtual environments, and augmented forms of reality as well as improvements on the traditional fixed and motion-based facilities. We anticipate that such branches of development will further diversify as new and innovative methods of rendering surrogate surroundings continue to proliferate. ***Worlds to Come.*** The fundamental function of simulation is to augment current reality with programmable objects or entities or to replace the whole environments with a surrogate experience. However, our whole world of experience is represented in the brain. Thus, all external technologies only serve to generate a pattern of brain stimulation. Our further future is thus headed toward direct brain stimulation. External facilities of the sort we see today at the most advanced facilities will be replaced by direct brain stimulation portable packages. Dangerously, one will be able to chose one's own reality and may therefore become confused about just what reality is. At such a juncture simulation and reality may no longer be distinguishable. Thus, the end point of all forms of simulation will be a philosophical paradox.

4.1 Philosophical Perspectives

> *"I never make predictions, especially about the future." (Yogi Berra).*

4.1.1 The Purposes of Driving Simulation

In trying to distill what the future of driving simulation will be, the central concern must be a direct examination of what we predict such simulations will be used for. This requires that we first step back and look at the larger picture of what motivates transportation in the first place, what motivates it now, and our expected future motivations for transportation in general, but road transportation in particular. In many European and old world countries, personal vehicles are a pleasant luxury but not a prime necessity of life in the same way that they are in the United States. Indeed, it is evident from even a brief visit to any of Europe's main conurbations that they were not conceived, designed, or constructed to deal with the mass of personal and commercial road transport which they are now required to accommodate. In this sense, contemporary roadway transportation systems in these older centers of habitation are modern creations overlaid on a palimpsest of previous forms of infrastructure. Now, major European cities such as London are being forced to introduce congestion charging to try to reduce the level of traffic density on roads that simply cannot handle the volumes created by contemporary demand. Pressures on space and the inability to re-engineer the local infrastructure to any significant degree directs political emphasis to other forms of transportation, and many modern countries are now seeking to respond strategically to these evolving demands. Thus, in many locations in Japan, Europe, and the near Middle East, a personal highway vehicle is something that one might like to have, whereas in countries like the United States and Canada such a vehicle is something that one almost cannot do without. The respective differences between desirable versus almost obligatory ownership affect each respective nation's transportation policies and therefore their need, desire, and use for driving simulation, both now and in the future. Nor should we ignore the vast increase in demand for personal vehicles in China where much of the expansion of the coming years will inevitably be focused (see Evans, 2004). Although our discussion focuses largely on personal transportation, the argument based on the supply and evolution of demand can easily be broadened to the consideration of the commercial sector of road transport and beyond to other intrinsically limited facilities such as ship, rail, and air transport, which themselves have their own respective unique simulation needs. We do not intend the present work to be a discourse on these respective societal requirements; we just wish to establish that there is a spectrum of different constituencies for transportation and, thus, varying sources of motivation for driving simulation.

In ground transportation, these various constituencies can, to a degree, be divided according to their emphasis on how fast any particular journey needs to be accomplished. Speed of transit is largely motivated by the economic imperative to improve movement efficiency. In contrast, the safety of the driver, passengers, and whatever other goods a vehicle is carrying, is largely motivated by public health needs to avoid collisions and resultant injury and fatality rather than any direct economic needs associated with speed of transit. In some countries, where there is a strong emphasis on social development and well-being, driving simulation is primarily motivated by the desire to facilitate this overall safety and thus to enhance collision prevention. This motivation, for example, is very evident in Sweden (e.g., Tingvall, 2009; see also, this book, chap. 3 by Kantowitz, "Using Driving Simulators Outside of North America"). However, for almost all nations, economic concerns are the primary motivators for both users and vehicle manufacturers and thus largely dictate the nature of simulation work undertaken therein. Like other practical sciences, simulation tends to respond to immediate needs and reacts to evaluate transportation innovations as they arise.

Within the past decades the major change in ground transport systems has been the introduction of any number of new advanced technologies into highway and vehicle operations. This has served to partially change their character by making them more into places of work and entertainment (or more widely information assimilation) as opposed to pure sources of transport. Such additions have posed any number of new problems and demands associated with multi-tasking and obligatory vehicle control performance (see Hancock, Lesch, & Simmons, 2003; Hancock, Simmons, Hashemi, Howarth, & Ranney, 1999; Strayer & Drews, 2004; Strayer & Drews, 2007; Trivedi & Cheng, 2007). This has led to a significant growth in simulation-based research (e.g., Horrey & Wickens, 2004) and thus reflects the response of the simulation community to the ebb and flow of social demands for necessary services. Therefore, to understand what current driving simulation is predominantly used for and, more pertinently, what it is likely to be used for in the near future, we have to ask who is paying for the simulation facility, and why. As one wise Washington commentator is reputed to have said "follow the money." Although money implies a financial motive, contemporary simulation tends more to lend itself to safety research by its very nature (and to some extent by the persuasion of the majority of scientists involved with it). Thus safety and its linkage to vehicle design and sales is also a very potent stream of funding for simulators. And, although we have tended to contrast the two major sources of motivation—safety and performance—it is certainly true that there is much overlap and that much research is undertaken which can well fit under both umbrella motivations. Indeed, advances in either area may well facilitate the goals of the other. After all, crashed vehicles tend to not be very efficient in terms of transit time. And exceptionally high-speed freeway vehicles (while evidently the aim of certain technological "autopians") are still more conceptual than practical in these first decades of the twenty-first century. Before we attempt to predict the near and longer-term future of driving simulation, it is important to comment on the issue of predicting the future in general.

4.1.2 On the Nature of Future Prediction

"The main value of prediction is the amusement it will give to those who live in the future."

We all want to know about the future. From the research physicist examining the tracks of elementary particles to the everyday consumer scanning the astrological columns of their local newspaper, we would each like to be more certain about what is to come. We can all make some accurate but fundamentally puerile assertions about the near future. A prediction that the sun will rise tomorrow is very likely to be true, but at the same time it is rather uninformative. In fact, Shannon's established concept of information is that the informational value of almost any prediction tends to co-vary with its improbability, such that for any longer range prediction, the more precise or detailed and therefore (potentially) informative that a particular prediction becomes the less likely it is to actually occur. Although the specificity-improbability relationship is a continuum, even scientists tend to make a distinction between their quantitative models and theories generated in the realm of science and their more generalized predictions, even of the most informed of individuals (see Bartlett, 1962; Bush, 1945; Teilhard de Chardin, 1964). Our notions for the present chapter are very much set in this latter, more general realm of discourse. We look to elucidate largely the qualitative trends in the future of driving simulation. Although we do provide some examination of evolving physical configurations for simulation, we do not engage in specific quantitative predictions in terms of the precise nature of supportive computational capacity (e.g., Moore, 1965), or the evolving cost comparisons of these respective systems (e.g., see Hancock, Caird, & White, 1990).

The cynic can point out the advantages of making only these more generalized predictions. If the prediction proves to be simply wrong then one advantage is that most people rapidly forget it and one's reputation as a prognosticator is hardly affected. Indeed, if one is careful not to make any prediction too precise, one can then interpret appropriately selected portions of almost any range of actual events as a match to an underspecified prediction. These so-called "hits" are then trumpeted to the world as evidence of prescience. This strategy has been ruthlessly exploited across many centuries by those who purport to be psychically endowed, from Nostradamus through Edgar Cayce to the present-day exponents of this doubtful "art" (Randi, 1980). Understanding and exploiting the flaws in common human reasoning has always been a profitable industry across the millennia.

For the purpose of discussion, however, there are two general characteristics of the future upon which we can rely in respect to our assertions about what is to come. The first characteristic is the degree to which the future is like the past. The second is the degree to which the future is not like the past. In what immediately follows we use this differentiation first: To identify currently evident trends and extrapolate them into the near and more distant future. Trends of this type are often used by futurists to derive their particular vision (see Kurzweil, 2005). However, it is the elements of the unknown or non-linear quirks in development that make the future really interesting. In the following section we seek to examine and explicate one of these interesting, non-linear possibilities. We focus first on the effect on driving simulation of simulating the driver, as compared to the more prevalent approach of simulating the vehicle and the environment.

4.1.3 Modeling the Driver Versus Simulating the World

As we conceive of the future of driving simulation, it is almost inevitable that our minds first spring to the physical entities which compose the assemblages with which we work. This list includes scene generation projectors and associated screens combined with computational software; motion bases or ride motion effectors; and in-vehicle displays with the necessary analog-to-digital conversion technologies. All of these are the items that we think of when we look to understand how improvements are to be made in future driving simulations. Yet, important as these technologies are, they will not be the most important things in the future, or even, in fact, in current driving simulations. The most important component is the driver. (See also, this book, chap. 9 by Ranney, "Psychological Fidelity: Perception of Risk".) Not only do we fabricate the artificial circumstances of our surrogate driving worlds to convince human drivers that they are undergoing a veridical experience, it is the very responses of those drivers which represents the subject matter of why we are engaged in driving simulation in the first place. The logical question now becomes: Can we do without all the paraphernalia of representative world generation and focus directly on the simulation of the drivers themselves? The question devolves to the following: What is the present state-of-the-art in human performance modeling?

The answer to the above question is limited at the present time but is cautiously hopeful for the future (see Ness, Tepe, & Ritzer, 2004). It is certainly the case that a variety of constituencies are strongly in pursuit of more veridical and reliable human performance models. Among these groups, the military is probably the highest in its profile and its financial support. There are any number of military modeling efforts, such as IMPRINT, which are trying to use ever-more sophisticated modeling advances to help predict the capabilities, capacities and training potential of their individual and collective human resources (e.g., Allender et al., 1995). There are, of course, many other interested agencies beyond the military pursuing the same basic goal. Added to these fundamentally pragmatic efforts there are the ongoing projects of many groups of research scientists who are using human performance models for their own purposes in order to understand more about the basic science of human behavioral response. Outstanding in this realm are computational models such as ACT-R (see Anderson, 1996; Salvucci, 2006) which seek to wed knowledge in psychology and neuroscience and advanced computational techniques in order to generate structured hypotheses as to the organization of cognition. As either separated projects or welded together as hybrid structures, these steps towards progress now begin to render it more likely that context-contingent models of human response capacities in specific conditions such as driving become ever more feasible.

Within the community of transportation research itself, we have any number of important theoretical advances such as Boer's "driving entropy" conception whose insights can serve to inform and constrain the form and operation of applicable models which would make outcomes from a successful "model driver" most useful to driving researchers. (See also, in this book, chap. 42 by Salvucci, "Cognitive Architectures for Modeling Driver Behavior", and chap. 43 by Flach, Jagacinski, Smith, and McKenna, "Coupling Perception, Action, Intention and Value: A Control Theoretic Approach to Driving Performance".) This and similar valuable advances have been the topic of purpose-directed research meetings over the last few years (see McGehee, Lee, Boyle, & Rizzo, 2007). In reality, many of the questions for which we construct driving simulators are motivated by the particular practical need of some company or organization. And even if such pragmatic concerns do not drive the actual fabrication of the simulator itself, they most often support its daily operations. Given that this is so, we must then assess when and where any improving "model driver" can replace the requirement for human

FIGURE 4.1 The National Advanced Driving Simulator (NADS) of the National Highway Traffic Safety Administration, housed in Iowa City, Iowa. At present, this is probably the most advanced facility in the world for driving simulation. (Reprinted with permission of NADS.)

subjects to be brought into facilities which currently represent the highest achievement in the field of driving simulation (see, for example, Figures 4.1 and 4.2; color versions available on the *Handbook* web site as Web Figure 4.1 and 4.2).

4.1.4 For Future Consideration

If advances in driver modeling represent one potential source of non-linear development, what other advances are possible which could radically alter driving simulation? To provide at least a shadow of an answer to this largely impenetrable question, we would have to go back to the very nature of simulation itself (see Hancock, 2009). Simulation is a surrogate phenomenon that seeks to generate and control both proximal and distal perception-action experiences to create an alternative reality for the exposed individual(s). Of course, we are focusing here almost exclusively on real-human-in-the-loop simulation, since a wider definition of simulation in general, while valid, is beyond our present purview. Given our present functional definition then, the vital issue is the immediate experience of the human participant. If this is correct, then one of the possible non-linearities of the future would seem to arise from innovative solutions to the fundamental questions of consciousness itself. Two questions now thrust themselves to the fore: First, is the reliance on proximal stimulation of the various senses an appropriate line of progress? For example, in the same way that the philosopher George Berkeley argued for the superfluity of matter (Berkeley, 1710), can we find better ways to directly stimulate the appropriate brain structures so as to create an experience that is indistinguishable from reality but still a simulated one? The answer, from recent research in brain-machine interfaces, neuro-ergonomics, and the virtual relocation of self (Ehrsson, 2007; Hancock & Szalma, 2003; Parasuraman, 2003), seems to be that yes we can. The question which follows concerns the individual phenomenological experience under these conditions of direct stimulation. Will we be in danger of creating a "schizophrenic" episode for such an individual? And how would they empirically re-establish contact with what we like to call reality after such exposure? If direct brain stimulation experiences can fully satisfy the "Turing" test for reality, we will have created potentially dangerous conditions, and not just for driving simulation. These exciting developments are likely to be the topic of discussion and exploitation in the coming decades. Even partial perfection of these technical issues may render the present, multi-million dollar facilities, such as those shown in Figure 4.1 and 4.2, completely obsolete.

FIGURE 4.2 The VTI driving simulator in Linkoping, Sweden. This also is one of the most advanced, state-of-the-art motion-based driving simulators in the world. (Photograph: P.A. Hancock, reproduced by permission of VTI.)

Among our predictions for the future of driver-centered driving simulation, we must also consider the reasonable possibility of its complete demise. This depends upon just how far are we from the goal of a totally automated transportation system. Such an achievement might still seem more in the realm of science fiction than fact. However, as the mixture of inventory between partially-manual and fully-automated vehicles begins to favor the latter, can human-in-the-loop control be sustained as a practical feasibility? Soon, the operational time-horizons for the automated vehicles will have grown so short that human intervention may be not only practicably impossible but perhaps even disastrous if attempted. The vision that most probably represents an unfortunate fiction is the generation of lightning-quick human reactions as epitomized by the modern movie hero. In reality, it cannot be much longer before human response capacities are exceeded in practice, as well as in theory. If this vector of progress continues, it may well be that all human-centered ground simulation is rendered null and void because all ground transportation will exclude direct human control. These respective scenarios as to momentary versus supervisory control and adaptive human-machine systems have been the topic of extensive discussion elsewhere and is thus not pursued in detail here, although the interested reader is directed to our own work and that of others (see Hancock, 1997; Parasuraman & Mouloua, 1996; Sheridan, 1991, 1992, & 2002, among others).

Of course, as we are discussing non-linear potentials there is no barrier to speculation that alternative forms of transportation (of the Star Trek kind) will be discovered. Although this seems unlikely, the development of remote presence technologies may well obviate the need for many human journeys that we now consider obligatory. This "being there" (Clark, 1997) question is one that may well dominate our thinking over the next few decades (see Ehrsson, 2007), especially as we now seem to have recently passed the "peak oil" threshold (Campbell, 1997) and the pressure to search for transportation alternatives grows heavier. If these issues occupy our long-term concerns, what then of the developments of the immediate decades to come? It is to these issues that we now turn.

4.2 Specific Needs and Possibilities

Having proffered some skeptical, and sometimes pessimistic, perspectives about simulating the driving environment, we now suggest why certain aspects of the environment that we deem critical to safety research and driver training will still need to be simulated in the immediate future. In respect of these immediate needs, we describe a novel and emerging way in which to do this. This novel technological innovation can best be approached by first considering the role of motion systems in advanced driving simulation.

4.2.1 The Need for Motion Simulation

In understanding the emergence of innovative driving simulation systems, it is instructive to compare and contrast flight simulation and driving simulation with respect to both the current state of the art and what is likely to be needed in the immediate future for training and research. Human-in-the-loop simulation began in the aviation domain with the Link trainer and some French counterparts relatively early in the last century. These early simulators had no motion base per se (see Figure 4.3; Web Figure 4.3). However, with the development of hydraulic and electric motor control systems for aiming large guns on World War II ships and the invention of the Stewart platform or hexapod (six independent legs whose lengths are actuated by hydraulic pistons or ball-screws) it became possible to generate small motions in six degrees of freedom to support cabs that included both the pilot trainee(s) and the cockpit instrument mockup. Sustained accelerations lasting more than a second were possible only by tilting the platform so that the human experiences the sensation of longitudinal or lateral acceleration; in these situations sustained vertical acceleration was not possible. Such motion simulators were quickly adopted by the military for training fighter pilots where the rapid onset of G-forces combined with higher frequency vibrations and "seat-of-the pants" cues were significant to aircraft control and training. The latter cues included vestibular otolith linear acceleration, and semicircular canal rotational acceleration, as well as muscle and tendon joint sensing. Soon vendors were able to sell such hexapod motion-base simulator technology to airlines for training and currently all of the large airlines use these for "full mission" simulation training. Interestingly, only recently has evidence revealed that pilot training for commercial carrier aircraft is not significantly improved by training in motion-base simulators over training in corresponding fixed-base (non-motion) simulators (Bürki-Cohen & Go, 1995). Apparently, while turbulence can be reproduced nicely by hexapods, such disturbances are not useful in training, and the very low frequency small magnitude acceleration cues, which are barely sensed by commercial pilots, seem to make little difference as action feedback for controlling large aircraft in mild maneuvers (as compared to fighter aircraft).

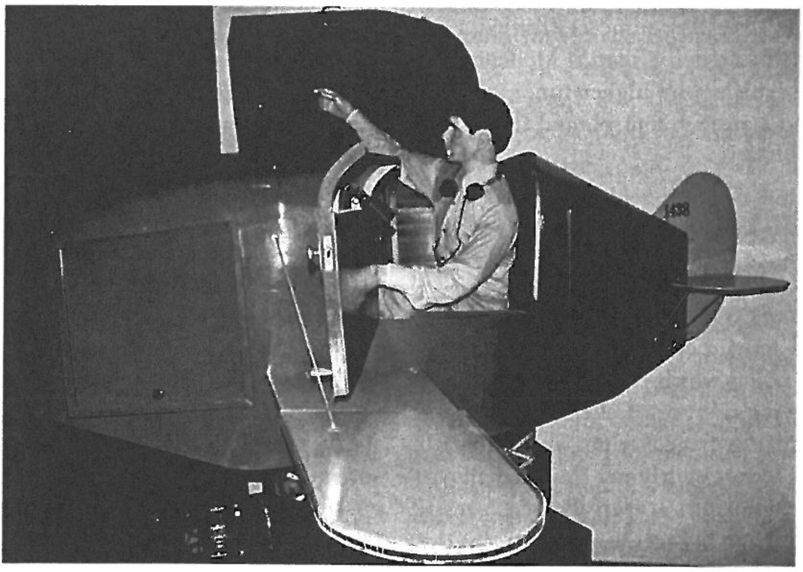

FIGURE 4.3 The original Link Trainer or "blue box" as it was affectionately known. Although there is no true motion base per se, the facility did sit on a platform which provided some movement.

The situation with driving simulators is a stark contrast. The hexapod technology, and computer-graphic visual displays that accompany it, are commercially available; however the driving safety research and driver training communities are not as wealthy as the airlines and military, the principal purchasers of motion-base simulators for aviation. In one evident exception, the U.S. Department of Transportation National Highway Traffic Safety Administration did finance the most sophisticated motion-base simulator (at roughly 80 million dollars), the National Advanced Driving Simulator (NADS) at the University of Iowa in Iowa City (see Figure 4.1). This simulator incorporates a feature not found in aircraft simulators: A roughly 25 × 25 meter X-Y translational platform which carries the hexapod. The X-Y platform allows for large amplitude low frequency longitudinal and lateral translational movements so critical to simulating braking and steering maneuvers. There are several other hexapod motion simulators built by automobile manufacturers for their own use in both the U.S. and Europe. Unfortunately these simulators are, by and large, not available to driving safety researchers from universities and/or small firms (but see Figure 4.2) since the usage fees are often simply prohibitive.

Perhaps the most important contrast between aviation and driving with regard to simulators is the need in relation to the use. While airlines have regularly used hexapod motion simulators for many years, their usefulness for training is questionable—as we have noted—because there is relatively insignificant motion feedback for the slow maneuvers in commercial aircraft, and the high frequency turbulence accelerations do not provide feedback to any intended pilot actions. On the other hand, in driving, the higher amplitude, higher frequency motion cues from rapid control maneuvers are absolutely critical driver feedback for avoiding obstacles and preventing crashes. Complex visual feedback without acceleration cues is well known to lead to over-steering as well as motion sickness (and for work on simulation sickness see Kennedy, Lane, Berbaum, & Lilienthal, 1993; see also, this book, chap. 14 by Stoner, Fisher, & Mollenhauer). Any control engineer can explain why higher time-derivative sensing is essential to good transient control, and the human organism is no exception.

4.2.2 A New Augmented Reality Paradigm for Driving Simulation

Fixed-base driving simulators have been used effectively for studying driver distraction, fatigue, car-following behavior, signage placement and other issues which do not involve sudden onset acceleration cues. Driving safety researchers certainly want to attack critical crash-avoidance maneuvering, which, after all, is the most life-threatening aspect of driving. However, all current high-end motion-base simulators are largely too expensive or cannot even faithfully recreate the acceleration patterns that occur in crash-avoidance maneuvering in all six degrees of freedom in actual highway vehicles (except at an almost prohibitive price-tag). In concluding a report on research needs for the future, Smith, Witt and Bakowski (2007, p.8) stated: "We need to find repeatable methodologies that allow us to replicate single-exposure imminent-collision warning trials on test tracks, where subjects (falsely) perceive that they are at risk of an imminent collision. To assess safety benefit directly the worst cases must have virtual collisions..." This necessity obviously holds true whether the goal is driver training or driver maneuvering in crash-avoidance.

There is, however, a way to achieve this desired end that can provide the needed fidelity in both vision and motion *and* is within reach economically. As we noted earlier, new technologies of sensors, computer graphic software, and displays have each made very rapid advances in recent years. These collective steps now enable advances in driving simulation that permit experimental subjects to safely experience dynamic hazards (scenarios with other vehicles, pedestrians, highway geometry, etc.) while still experiencing full motion cues—in fact, perfect motion cues—all at a cost and convenience much improved over high-end motion-base driving simulators. This is achieved by having the driver drive an actual vehicle (e.g., a car or truck) on a test track while viewing an out-the-windshield scene which is the actual environment *except for* the object that poses the pending collision hazard. The collision hazard is a virtual one. It is generated by a computer and is continuously sized and oriented on the roadway to correspond to the moment-to-moment position and orientation of the vehicle as if it were real. It is thus displayed continuously at the proper location relative to the driver's viewpoint. This technological assemblage is a prime example of what is termed an applied Augmented Reality (AR) system (see Goldiez, Ahmad, & Hancock, 2007; Sheridan, 2007).

All the software to model and generate convincing, rapidly-changing images of vehicles, people or other collision hazards is already available. The technological challenge now is how best to measure the position and orientation of the vehicle relative to the environment, and how to superimpose the virtual image on the real roadway image so that it is properly sized, oriented, aligned with the environment, and moving in a way that is perceived to be natural. In the present context both the measurement and superposition can be done in several ways. One means of achieving continuous measurement of vehicle position relative to the environment (e.g., test track) is to add real objects to the real environment that can be seen and recognized by a video camera mounted on the vehicle (and appearing in the camera field at locations corresponding to their position relative to the vehicle). Another way is to use a gyroscope or accelerometer whose signal can be integrated to determine position. A third method is to set initial conditions into a mathematical model of vehicle response to steering and braking a few seconds prior to the (virtual) appearance of the impending collision, where measurement of steering wheel angle and brake actuation continuously update the model throughout the duration of the virtual image generation and display.

Superposition of collision objects onto the view of the actual forward environment may also be accomplished in several ways. One is to use a half-silvered mirror mounted in front of the

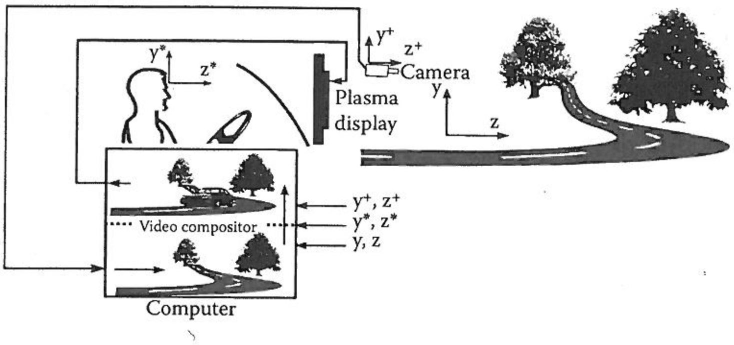

FIGURE 4.6 Video mixed-image approach with vehicle-mounted display.

with the background scenery, promises a new simulation paradigm. Most of the situation involves the normal actual reality: The driven vehicle along with its controls; and the roadway and environment (except that it is likely to be a test track for safety purposes). Only the hazard objects (one or more vehicles, people or other objects) need be artificial. This can allow for enormous saving in both time and money in building and managing a special simulation test facility; savings in motion-base technology (the greatest share of the cost of a motion-base simulator); savings in vehicle modeling and simulator programming for generating faithful motion cues; and savings in modeling and displaying the moving environment (except for the hazard objects which occupy only a small fraction of the display). However, since the foundation of this technology requires the use of real-world conditions, it is limited by the surroundings which the experimenters can conveniently access.

4.3 Summary and Conclusions

In many ways we expect that the near future will probably look very much like the present. Although there will be predictable advances in technology, the basic version 1.0 human being is unlikely to experience any evident, natural change in the immediate future. Of all the elements of modern driving simulation, what we have seen change most rapidly in our own era is the computational capacity associated with visual scene representation. In keeping with Moore's Law (Moore, 1965), we have seen enormous gains in graphical capacities and scene-generation systems, which less than two decades ago cost millions of dollars but can today be bought for a fraction of the cost at the local computer store. This progress is evident in the fact that the vast majority of the most sophisticated driving simulation facilities use PCs and their associated graphics cards to generate pictorial scenes. In one sense there becomes a functional limit as to just how good visual scene representation can become and this limit appears to be set by the resolution of the human eye (and see Hancock, 2009; see this book, chap. 2 by Allen, Rosenthal, & Cook, "The History of Driving Simulation", Table 2.1). However, this apparent barrier need not be an immutable one and a further generation of "super-simulation" is both conceivable and feasible as we understand more about the interactive role of attention and visual physiology. Super-simulation implies sensory and perceptual capacities that exceed any unaided individual but look strongly like those abilities possessed by our fictional superheroes (see Hancock, 2009; Hancock & Hancock, 2008).

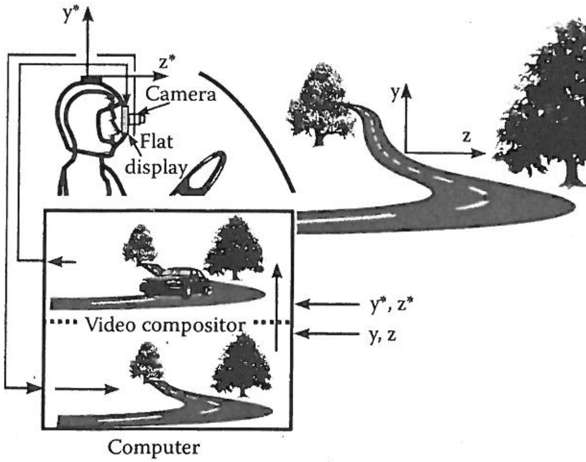

FIGURE 4.7 Video mixed-image approach with head-mounted display.

If highly sophisticated visual graphics are now within the range of every scientist's pocket-book, conventional motion-bases are certainly not, except by the means we have suggested in Section 2. Unlike the economic impetus for better computational facilities, conventional motion systems have neither the constituency nor the market to drive down investment costs. And indeed, a poor motion system might actually hinder the transfer

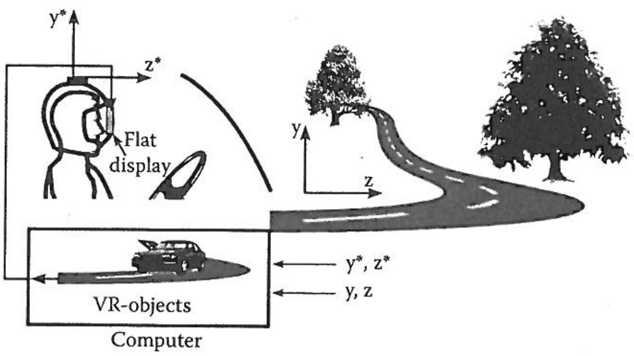

FIGURE 4.8 Full VR approach with head-mounted display.

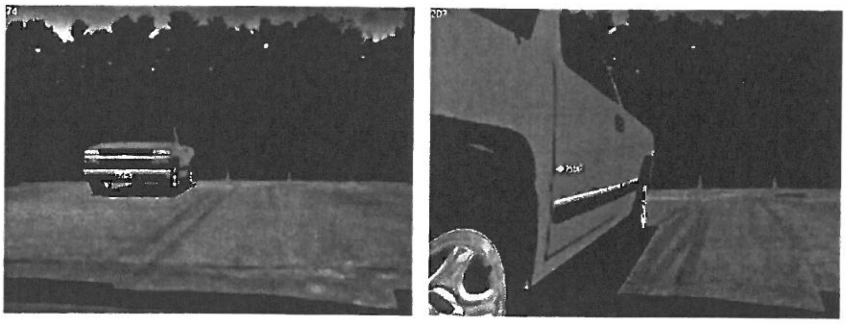

FIGURE 4.9 Two images from a video clip of the driver's display in a test maneuver in a school parking lot. A (virtual) truck approaches in a near head-on collision. The driver swerves his (actual) vehicle. The background is the real environment. The traffic cones were used as fiduciary landmarks.

of outcome results to real-world circumstances. Surely one also has to ask of what real use is accurate reproduction of motion cues. The answer, we believe, is for simulating critical braking and steering maneuvers to avoid near collisions (Hancock & de Ridder, 2003). We have suggested what we believe to be a viable approach, though much further development needs to be achieved to realize and exploit its full potential.

We expect to see advances in general systems modeling, including significant steps in human-operator modeling. A much more cohesive program would then see rapid, synthetic simulation studies in which all elements are encoded in software and periodic checks with live drivers and actual vehicles will be used as discrete points of confirmation from the output of large collective models. In this manner, all the present material components of driving simulation will metamorphose into software agents in which fast-time processing will allow for "virtual" years of testing to be conducted in moments. How such outcome information is to be validated and verified will represent one of the next great challenges to the driving simulation community.

Key Points

- Driving simulation has been used for research and training.
- The development of driving simulation has been contingent on the development of flight simulation.
- Modern technologies have largely dissociated this dependence.
- Such technical capacities not only enhance simulation they diversify it.
- Crucial forms of driver simulation can now be achieved by augmented forms of reality.
- Gradually, all simulations evolve toward the threshold of the Turing Test for reality.
- Passing such a threshold poses fundamental questions about the nature of reality itself.
- Creating surrogate realities may therefore not always be beneficial or even moral.

Keywords: Augmented Reality, Driver Modeling, Driving Simulation, Future Trends, Virtual Reality

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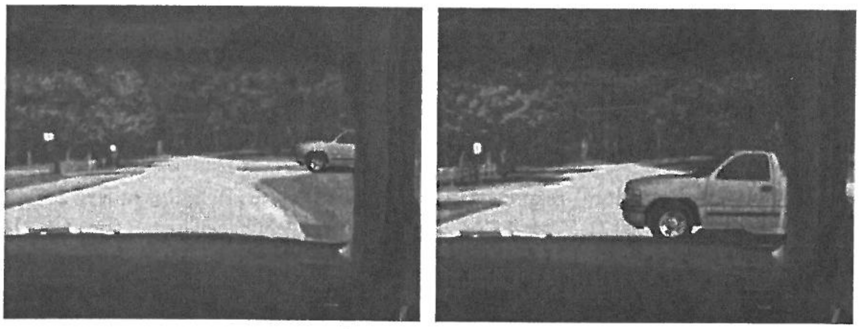

FIGURE 4.10 Two images from a video clip of the driver's display in test maneuver on a country road. A (virtual) truck approaches from the right in a near collision and the driver brakes. The background is the real environment. The white signs on the trees were used as fiduciary landmarks.

Web Resources

The *Handbook*'s web site contains supplemental materials for the chapter including all of the chapter's figures in color versions.

Web Figure 4.1: The National Advanced Driving Simulator (NADS) of the National Highway Traffic Safety Administration, housed in Iowa City, Iowa. At present, this is probably the most advanced facility in the world for driving simulation. (Reprinted with permission of NADS). (Cover version of Figure 4.1).

Web Figure 4.2: The VTI driving simulator in Linkoping, Sweden. This also is one of the most advanced, state-of-the-art motion-based driving simulators in the world. (Color version of Figure 4.2). (Photograph: P.A. Hancock, reproduced by permission of VTI).

Web Figure 4.3: The original Link Trainer or "blue box" as it was affectionately known. Although there is no true motion base per se, the facility did sit on a platform which provided some movement (Figure 4.3).

Web Figure 4.4: Road scene viewed directly through semi-transparent mirror (Head-Up Display) (Figure 4.4).

Web Figure 4.5: Optical-see-through approach with a head-mounted display (HMD) (Figure 4.5).

Web Figure 4.6: Video mixed-image approach with vehicle-mounted display (Figure 4.6).

Web Figure 4.7: Video mixed-image approach with head-mounted display (Figure 4.7).

Web Figure 4.8: Full VR approach with Head-Mounted Display (Figure 4.8).

Web Figure 4.9: Two images from a video clip of the driver's display in a test maneuver in a school parking lot. A (virtual) truck approaches in a near head-on collision. The driver swerves his (actual) vehicle. The background is the real environment. The traffic cones were used as fiduciary landmarks (Figure 4.9).

Web Figure 4.10: Two images from a video clip of the driver's display in test maneuver on a country road. A (virtual) truck approaches from the right in a near collision and the driver brakes. The background is the real environment. The white signs on the trees were used as fiduciary landmarks (Figure 4.10).

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