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LOW COST DRIVER TRAINING AND VIRTUAL REALITY PARACHUTE SIMULATION FOR TRAINING AND MISSION REHERSAL

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ABSTRACT

Vehicle operation simulations have a range of potential applications in research, development, training and certification/licensing. The extent of the applications will depend on the realism, validity and cost of the simulations. Advancements in PC (personal computer) and associated technologies are dramatically reducing cost of creating realistic virtual environments. Increased understanding of the computational requirements in simulating the vehicle operator's in simulating the vehicle operator's tasks allows enhancing the realism and validity of the sensor environment provided to the human operator. This paper discusses the general components and requirements for vehicle operation simulations, and the issues that influence the realism and validity of the sensory environment. two examples are described of low cost PC based simulations. The first example is driving simulator that has been used in a range of research, development and driver evaluation applications. The second example is a flight simulator for training parachute jumpers that includes realistic manoeuvring characteristics and also can represent deployment malfunctions.

Key words*: Vehicle Operation Simulators, Driver Simulator, Parachute Simulator, Virtual Display.*

INTRODUCTION

Vehicle operation simulations can provide a safe, convenient, and comprehensive environment for conducting research, development, training and certification of human operators. Traditionally the equipment and development costs have been quite high for simulations with adequate realism and capability. As the capacity of PCs (personal computers) and associated technologies has increased, however, it has become possible to develop low cost simulations with relatively high end capabilities (e.g., Allen, et al., 1998; Hogue, et al., 1997). To achieve these capabilities, rich sensor information must be fed back at high update rates and with low transport delay so that the human operator's sensory, psychomotor and cognitive tasks are equivalent to those when operating the real vehicle. In the context of this paper, low cost could be in the range of tens of thousands of dollars. Cost is very sensitive to the amount of hardware required, and for demanding physical requirements such a realistic cabs and motion the cost could be significantly higher. Visual, proprioceptive and auditory sensory feedback can easily be provided with recent advances in low cost technology. Motion cueing still requires relatively expensive mechanical capability and will not be covered here. In this paper we will discuss the requirements for real-time, human-in-the-loop simulations, and how low cost PC technology can achieve the required sensory feedback and computational capability required for relatively high end simulation applications.

BACKGROUND

The central thesis of this paper is that low cost PC and related technology can be used to reproduce realistic sensory feedback to the human operator in vehicle operation simulations. Processors, display accelerator chips and cards and operating system software advancements over the last few years permit the presentation of virtual environments that can quite adequately simulate the visual, auditory and proprioceptive cueing involved in vehicle operation tasks. Furthermore, the feedback is provided with adequate update rates and minimal transport delays required for simulating the psychomotor and cognitive tasks typically involved in vehicle operation in complex environments. Pentium processors (i.e. 166 MHz MMX and above) are now powerful enough to compute complex vehicle dynamics responses to the human operator's control input with adequate update rate to satisfy visual, proprioceptive and auditory cueing requirements (Allen, et al., 1998). Windows NT software allows networking several processors for increasing computational capability. Networking can also be used to allow the interaction of several simulators. Low cost PC related display technologies including head mounted VR devices allow visual and auditory information to be provided to the human operator.

Low cost electro-mechanical torque motors and actuators can be employed to provide active control loading for effective proprioceptive feedback in vehicle control tasks. These low cost capabilities are adequate to meet the requirements of vehicle control simulation as discussed below.

Graphics accelerator and sound processor cards make visual and auditory cueing practical on PCs. These cards plug into the PC (i.e. PCI or AGP) bus, and can carry out complex processing without loading down the host processor. The current flock of graphics accelerator processors and cards allows reasonably photorealistic scenes to be generated at 30 Hz. Based on simple commands from the host processor, current sound cards allow the reproduction of prerecorded sounds and the synthesis of complex sounds. Control loading can be provided with low cost electro-mechanical motors and actuators. There is also a new standard for interactive game controls that give force feedback, and controllers in aircraft and driving configurations are currently available (e.g., Burdea, 1996). However, the response fidelity of this game controller standard is uncertain in terms of bandwidth and update rate. The basic processing requirements in a vehicle operation simulation can be described in terms of the diagram outlined in Figure 1. Here we show the human operator's closed loop control of vehicle motions through visual, proprioceptive and auditory feedbacks. The visual modality is the most important since it allows the operator to compare the vehicle's path with a desired path in the environment and make appropriate corrections. With a VR head mounted display, representing the effects of head movement is particularly critical, and delays or other artifacts in accounting for head motion on the visual line of sight will be disorienting to the human operator.

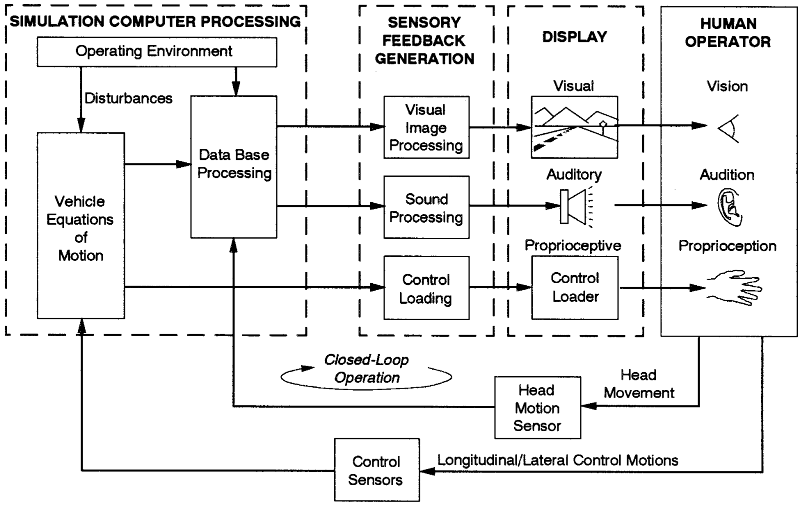

Figure 1. Basic Processing Requirements for Vehicle Operation

Proprioceptive feedback can provide added information about the magnitude of control inputs. Auditory feedback can provide some additional information about the magnitude of vehicle manoeuvring and possible situation awareness. The sensory feedbacks must reach the operator in a timely fashion, and can be delayed by the simulation computer processing and the sensory feedback generation. The feedback elements in order of decreasing sensitivity to computational delays are as follows: Proprioceptive (control loading) information must be returned to the human operator at the highest rate and lowest time delay of any sensory feedback in order to give realistic feel characteristics (e.g. Young, 1982). If proprioceptive cueing is dependent on simulation computer processing, update rates of hundreds of times a second with transport delays on the order of a few milliseconds are important here in order to give realistic feel. Visual information must be returned to the human operator in less than 100 milliseconds with update motions on the order of 30 Hz or greater to give the appearance of smooth motion (e.g. movie frame rates are 24 Hz). Input sampling and processing can give delays on the order of 2 ½frames, which result in transport delays of less than 100 milliseconds at a 30 Hz update rate. Transport delay compensation can also be used to offset the effects of computation delay (Hogema, 1997).

The maximum delay requirements for VR head mounted displays are not well understood.

Resolution and quality of the visual display must be adequate for the required visual discrimination tasks. Current resolutions of 1024x768 pixels at 30 Hz are quite feasible. For a 60-degree lateral field of view, this would allow a resolution of 3.5 arc minutes per pixel, so high acuity real-world tasks such as highway sign reading are difficult to simulate without special display augmentation. Auditory feedback has the least severe requirement for transport delay, with hundreds of milliseconds probably being acceptable. The frequency content or bandwidth of the auditory stimulus must match the human ear (on the order of 15 KHz), however, in order to produce sounds that are natural and recognisable. Low frequency sound in to the infrasound region can be used to simulate high frequency motion effects such as road roughness in a driving simulator.

EXAMPLE SIMULATIONS

Two examples will be given of vehicle control simulations that each employ aspects of the low cost technology discussed above. The first example involves a driving simulator that has found application in research and driver evaluation (Allen, et al., 1998). The second example involves a flight simulator for training parachute jumpers (Hogue, et al., 1997). Both of these simulations have recently been upgraded with photorealistic visual image generators that include graphics accelerators to provide high speed texturing, shading and lighting effects in the rendering process.

Driving Simulator

This application involves complex and validated equations of motion that allow vehicles to spinout and rollover under aggressive manoeuvring conditions (e.g. Chrstos and Heydinger, 1997). The equations of motion also provide a steering alignment command to a torque motor connected to the steering wheel, which provides appropriate proprioceptive feedback consistent with steering input, vehicle manoeuvring, and road coefficient of friction. The operating environment includes road and aerodynamic disturbances, roadways of various alignments and interactive traffic. Sound processing with a 64 bit PC sound card can represent own vehicle sounds (engine, wind, tire screech) and sounds of interactive traffic. Visual display can be provided by monitors, projectors, or a head mounted display as with the flight simulator described below. Three visual image generators have provided wide-angle displays with scenes.4 projected on a 135 degree curved screen. A head mounted display can be implemented in the same manner as described for the above parachute simulator. Typical roadway visual scenes are shown in Figure 2.

Figure 2. Typical Driving Simulator Roadway Visual Scenes.

Display requirements for tasks such as sign reading require resolutions on the order of 1 minute of arc. This is a difficult requirement to meet with a low cost image generator and display system. One partial solution to this requirement is to use separate high resolution but limited field of view sign generators with projected images that are optically combined with the overall roadway display (Hopkins, et al., 1997).

A unique scenario definition language (SDL) associated with the driving simulation allows users to define visual data bases, event sequences and performance measures with simple text files that can be composed in a text editor. The 3D data base is object oriented, and the SDL allows objects to be placed, called up and manipulated as desired to create a range of situations that challenge the driver's sensory/perceptual, psychomotor and cognitive abilities. The SDL allows the user to define roadway layout in terms of lanes and markings, and roadway geometry in terms of horizontal and vertical curvature. The SDL also allows the placement of other static features such and buildings, intersections and traffic control devices (i.e. signs, signals, barrels, cones, etc.). The SDL also allows the programming of interactive traffic and pedestrians, and the timing of signals. The amount of interactive traffic that can be programmed is essentially unlimited; however, the update rate of the visual scene begins to slow down when the 3D model becomes excessively complicated. The severity of this limitation continues to recede as processor speeds increase.

Multiple processors can be networked through the capability of Windows NT to increase the driving simulator capability. Complex vehicle equations of motion can be run on a dedicated processor networked with the cueing command computer. Multiple visual image generators can also be run on separate processors and networked to a central cueing command processor to obtain multiple screens, wide angle and/or rear view displays. The use of a head mounted display requires only one image generator and gives a full hemisphere head field of view thus permitting drivers to look down side streets, or even over their shoulder to view rearward scenes. A variety of physical and display configurations for the driving simulator are shown in Figure 3.

Figure 3. Various Physical and Display Configuration for a Driving Simulation

The driving simulator has been used in a wide range of research and driver evaluation applications (Mollenhauer, et al., 1994; Musa, et al., 1996; Stein, et al., 1990). Simulator sickness with single screen displays (45 degrees FOV) has been less than 5%; with wide-angle displays (135 degrees FOV) the sickness rate has been on the order of 10-15%. Experience with the head-mounted display is just beginning, but experience with the parachute simulator below suggests that the simulator sickness rate will be minimal.

Flight Simulation

This parachute manoeuvring application includes vehicle equations of motion for both round and square (i.e. ram air) canopies that include typical oscillating behaviour caused by overly aggressive control inputs. The operating environment can include other jumpers and a range of ground scenes as provided by the visual data base model. Rural scenes are illustrated in Figure 4.

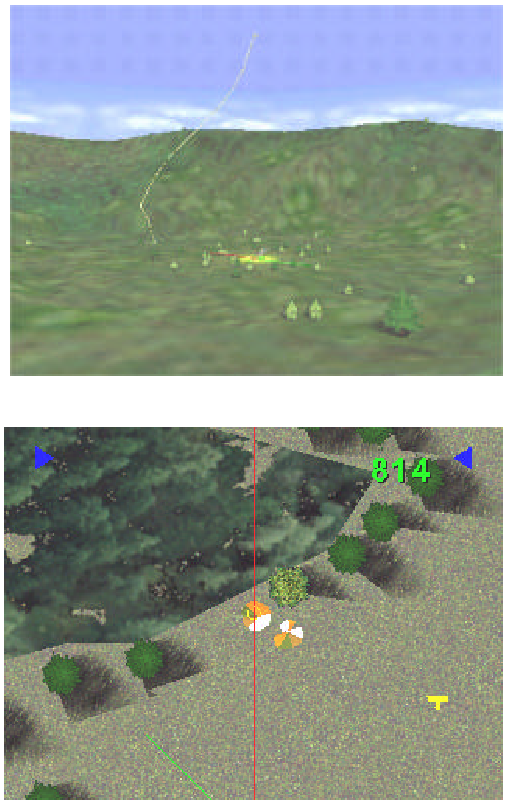

Figure 4. Parachute Flight Simulator Rural Scenes.

Sound feedback includes components due to rushing air past the canopy and shrouds, and fabric flapping. Visual feedback is provided by a head-mounted display with a 30-degree eye field of view. A head mounted sensor provides pitch, roll and yaw signals to the simulation computer, which then presents the appropriate line of sight to the jumper that allows a fairly unrestricted head movement field of view.

This approach permits the jumper to look at the ground for the landing zone, watch for and avoid other jumpers, and also allows viewing the parachute overhead for malfunctions. It is also possible to cut away a malfunctioning chute and deploy a reserve canopy.
A Jumper Operates a Parachute Flight Simulator as shown in Figure 5.
The head-mounted display used in this application is a low cost, low-resolution unit

Designed for the home/game market. The head motion device involves tilt sensors for pitch and roll and compass like sensor for azimuth. Neither the visual displays nor head movement sensor cause appreciable delay in the visual sensory feedback. Higher resolution displays with wider field of view are available at significantly higher cost. Better head sensors are also available at increased cost. In the parachute simulation visual resolution is not a significant requirement so the home/game level of device is adequate. More Expensive devices may be required for other applications involving higher resolution demands.

Figure 5. A Jumper Operates a Parachute Flight Simulator.

The jumper exerts control with two toggles that are retracted with spring restrained reels mounted in a box above the jumper. In this case the control loading is provided directly by springs and is not dependent on the simulation computer for active control. The jumper can also exert limited control by pulling on the canopy risers, which simulate distortion in the chute resulting in aerodynamic inputs to the equations of motion. A jumper operating the parachute simulator is portrayed in Figure 6.

Figure 6. Different applications of parachute simulators.

This simulator is currently in use by several training groups in the military and smokejumper communities. Experience to date indicates that the device provides effective training, and does not cause overt simulator sickness which is common in exposure to virtual environments (e.g. Casali and Wierwille, 1986). The lack of simulator sickness is probably due to the relatively narrow eye field-of-view, and also the relatively benign motions in the visual scene due to the low speeds and slow motions involved in parachute manoeuvring.

There is no documented research on the use or efficacy of the parachute simulator for training, but there is significant demand for its use by a wide range of military and smokejumper training groups.

DISCUSSION

The success of the above applications indicates that low cost PC and related technology can provide useful simulation capability. Given the current speed of Intel Pentium processors it is quite feasible to implement a complete VDM (vehicle dynamics model) as part of a PC based driving or flight simulator. The vehicle dynamics involved in the example driving simulator described herein include lateral/directional and longitudinal dynamics, including driver train, steering and braking system characteristics. Even when a trailer is added to simulate an articulated vehicle, the VDM can still run at 200 Hz, well within real time. This means that even in the most demanding of simulation conditions, a Pentium based processor can adequately handle situations such as hardware-in-the-loop applications, and high fidelity steering feel. Running similarly complicated flight dynamics should not be a problem. Pentium processor based PCs can also adequately handle the generation of other cueing dimensions, including visual displays and sound. Graphics accelerators are available that will provide photorealistic rendering of visual scenes including texturing, lighting effects and shading. Sound processing cards can provide and mix a range of recorded and synthesised sounds, and can also include stereo and Doppler effects. Thus, PCs seem poised to provide low cost vehicle operation simulation for a wide range of applications:

- Research on human operator behaviour (impairment, psychomotor and cognitive behaviour), vehicle characteristics, and the operating environment, such as; -Human factor research, - Driving evaluation, - Hardware-in-the loop simulation, -Cap design and ergonometrics, - Medical research (pharma-ceutical, alcohol, fatigue, cognition and physicomotor, rehabilitation).

- Training of novice and professional vehicle operators (e.g. parachute jumpers, pilots, truck drivers)

- Evaluation:
  - Impaired/disabled operators
  - Certification/licensing
  - Screening for operator aging effects.

These applications will benefit from current and ongoing developments in the PC industry as processor and graphics accelerator capabilities become faster and more powerful. Cueing devices such as visual displays and sound systems are also becoming more capable. Although not included here, there is also significant development occurring in electromechanical motion systems which will improve performance and lower cost to the level that can be considered in low cost, PC based simulations. Simulator validation will become an increasingly important issue as low cost applications increase. Validation is a complex, multivariate issue and can include the face validity of the physical and sensory environment, the validity of tasks (e.g. driving in traffic, negotiating intersections) as well as the validity of the behaviour and system performance evoked by the simulator. Face validity can be important in the appropriate motivation of experienced operators (e.g. drivers, pilots). For research and training applications it is important that the simulator evoke appropriate operator behaviour when tasks are performed successfully. Ultimately, in training applications, transfer of training is the appropriate validity criterion. That is, when placed in the real operational environment, there should be some measurably positive effect associated with simulator training. If simulator training replaces some or all of more expensive real vehicle training, it will be important to show that adequate training has been achieved.

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