CAB SIMULATORS

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Most public experience of Virtual Reality to date has been in cab simulators like the big Rediffusion machines, the Super X fourteen-seater machines, and the wide-screen simulators in Universal Studios and Luxor, the new experience at Las Vegas. These illusions use pre-recorded visual imagery and pre-programmed motion of the "hang on tight" variety.

The recent breakthrough in electromagnetic motion base technology means that we are about to see a new range of PERSONAL CAB SIMULATORS come onto the market. Research predicts that these small, real-time interactive machines will dominate the field for Virtual Reality applications in entertainment.

The important features of this sort of Virtual Experience are that:-

* In a good cab simulator all attention is riveted on the visual display, which is seen as a window which looks out onto the immediate future experience, towards which the cab and its occupants rush headlong.

* There is no need to wear a helmet: the visual illusion is created on screens which are inside the cab, or close to the cab and visible from within it.

* The experience most often includes the illusion of travel, in which case the cab may represent part of a Virtual Vehicle.

* Control of the experience is not always available: like a theme park ride it can be arranged to happen uncontrollably after the initial commitment!

* Motion cues are a fundamental part of the illusion: they have a powerful and subconscious - and therefore irresistible - effect on the occupants of the cab.

* For the simulation to work the cab has to be enclosed: the external (real) environment must not be visible to the occupants.

Cab simulators are, of course, what the general public thinks of as "Flight simulators" and they have been around a long time. Douglas Trumbull, famous for his work on special effects for "2001, a space odyssey" was one of the first to patent a cab simulator design.

The first successful use of the idea was probably by Doron Precision Inc. whose 12-seater SR2 was originally built as an amusement machine on electric screw jacks. Doron's main business was in driver training simulators but it occurred to them that an amusement machine might be devised by mounting a projector which plays a three minute film loop behind a rear projection screen, taking cues from the film sound track to drive the screw jacks to provide some additional "interest" in the picture. The sort of pictures used were short excerpts from roller coaster rides, racing cars, bobsleighs and so on, in an exciting and constantly-changing sequence.

In 1981 a businessman called John Barman came into possession of a shop on Scarborough seafront as part of a financial deal and decided to exploit its location to promote an entirely novel form of entertainment. John used a local coach builder to

construct a long "fuselage" having 20 seats with a projection screen at the front. For visuals he used 8 mm films showing a selected sequence of excerpts from science-fiction films (space flight and alien monsters), dubbed with a voice-over. The motion of the machine was originally produced by an operator using a joystick in real time for every ride, but it was later encoded on a synchronized audio tape.
In 1984 Mitsubishi began to construct a machine at an amusement park next to the Tokyo Dome which used a full six-axis motion base and a sixty-seat wide-screen cinema showing a space travel sequence. The machine is beautifully designed and built and is reputed to be very reliable. But the power and bandwidth of the system is too small and the ride is "whimpish", with no vigorous motion effects.

In October 1985 the first really effective leisure simulators opened in the "Tour of the Universe" at the base of the CN Tower in Toronto. The "Tour" used two Rediffusion 6-axis motion bases fitted with 40-seater wide-screen cinemas showing 70 mm film produced on Douglas Trumbull's "Showscan" system running at 60 frames per second. In July of the same year I had built the first of the "Super X" 14-seater three-axis machines and installed it in the basement of the Dolphinarium in Brighton. Twenty or so Rediffusion machines are now operating in theme parks worldwide and more than 170 Super X machines are operating in 25 different countries.

Modern leisure simulators differ from the early machines in two very important aspects:-

1. They use more power (over 2 hp per person) and they have a wider bandwidth (more than 20 Hz)
2. A great deal of expertise and computing power is applied to the precise synchronization of motion cues and visual imagery.

The result of this power and precision is that important subconscious reactions are triggered in the human occupants and **this is the very essence of the experience.** The effect, as you will find if you have not yet ridden one of these vehicles, is that, apart from the first few seconds of the experience, no time or attention is spent thinking about the motion! In a good cab simulator you are not conscious of the machine, nor of your companions; the visuals become a compelling and immediate reality, however strange or artificial that reality may be.

INTERACTIVE MACHINES

From the very earliest days of simulators for the leisure environment there was a requirement to make simulators interactive - to have a "pilot" to control the experience. It was also understood that several simulators under individual human control should interact with each other.

Of course, if you have a large simulator with forty or more persons in the machine they cannot all be the pilot at the same time! The original idea was that one of the staff, suitably uniformed, would fly or pretend to fly the simulator through its pre-programmed sequence of about five minutes excitement.

In the "Tour of the Universe" experience in Toronto the illusion of a pilot is built into the experience by introducing visual shots of "Captain Moses" during the preliminaries to the intensive motion experience. The scenario also provides a continual background of the captain talking to the passengers throughout the flight and there is a pseudo intercom. discussion between the pilot and various controllers as part of the experience itself. A similar effect is produced in the Walt Disney "Star Tours" ride by using an animated "robot" in view of the occupants to the side of the screen and creating the impression that the flight is somehow under the control of this crazy little animated being.

But the essence of true interactive simulation is the visual imagery, which must be computer-generated or at least computer manipulated, so that the pilot has freedom to manoeuvre the Virtual Vehicle. Unfortunately, good computer-generated imagery costs money: when the Leisure-related simulation industry was just getting started we were talking about several million pounds for the computer system. Nevertheless, the idea that an exciting travel sequence can be created, if you like, "in the mind of a computer", limited only by the imagination of the programmers, has always been very attractive to the promoters of leisure simulation technology.

By early 1986 it was clear that the general public has no idea of the cost and computational difficulty of CGI and demands real-time graphics which have the same quality as the ray-tracing off-line graphics with which they are familiar from television advertisements and logos. The customers say that they prefer films of real experiences because of their better visual quality, even though these are not so novel as the fantasy experiences of real-time CGI.

It was also clear that the Virtual Motion has to be artistically composed and that it should not be an exactly-calculated sensation of the type used in training simulators. The public wants the action to be much more vigorous and exciting than reality itself.

ARCADE SIMULATORS

A common misunderstanding of the word "simulator" relates to the interactive videogame machines made by companies such as Sega, Taito, Namco and Atari. These are small arcade machines in which the punter plays a video game on a television screen whilst the seat moves under control of electric motors driving a mechanism with a very low bandwidth and power output. In most of these machines the surroundings are always visible and the gamester can "show off" to his/her friends. There is only a limited potential for the motion to be linked to the visual system and, because the real horizon is always in view, there is no significant psychological disturbance and no "simulation" in the true sense.

Nevertheless, the games are popular because they provide an enhanced sensation of involvement, since the forces on the body are generated by the computer and therefore out of the control of the participant. There is a continual sensation of struggle against the opposition of the computer which adds to the novelty of the game. Both Sega and Taito have recently introduced arcade game products which use a gimballed system capable of 360 degrees rotation on any axis and on several axes simultaneously, linked to a video game in the central housing into which the participants are firmly strapped. There is no lateral translation and the bandwidth is very low. The coordination between the visuals and the movement is not easy to understand and half the fun is the general confusion as to what is actually happening to you or how you are doing in the video game.

Atari, and now Sega and Namco, have introduced better simulators in the form of driving games which exclude the external environment to some degree and which have good modelling of vehicle dynamics and tactile feedback via the steering wheel. Electromagnetic motion systems will soon be added to these products.

GENERIC, INTERACTIVE CAB SIMULATORS

The machines provided for entertainment have previously been special-to-type; shaped to suit the idea which is being represented, such as a motorbike or a racing car, and changed every season. But several companies are now developing twin-seater simulators to be sold into the arcade market. The concept of this type of Virtual Reality machine dates from 1986 when Super X began development of the "Bandit" project for a client in Salt Lake City. It is interesting to note that the experimental software for the "Bandit" was produced by W Industries in 1988 and 1989 and later transferred to their "SD" machines.

The small cab simulators now in development use high-performance **electromagnetic** motion bases of wide bandwidth, linked to a sophisticated graphics display, with the motion cues derived from a complex software model of the supposed "vehicle". (An aircraft, for example.) Not only is there a subtle and sensitive interaction between the pilot, the environment which is simulated and the mechanism of the simulator itself, but the machines are designed from the start to be networked, so that several such "aircraft" or other vehicles can compete against one another in the same Virtual World. Although the products are intended for the arcade - or rather the "simulation centre" - market, they are thoroughly-professional machines using technology which pushes to the limit what is achievable at an acceptable market price.

Motion bases

In **Stacked** systems each axis of motion has its own actuator - one actuator produces a heave motion (up and down) for example, a second actuator produces the roll motion and so on. An example of this can be seen in the early Intamin cinema seat mechanism. **Synergistic** mechanisms, on the other hand, require more than one actuator to operate for each axis of motion and therefore each actuator is shared between several axes. Since motions in several axes occur simultaneously, the design makes great demands on the physical limitations of the actuators. Nevertheless, a rigorous analysis will show that a synergistic mechanism is lighter, simpler and more reliable than a stacked mechanism although the controlling software is more complex.

A rigid object may be manoeuvred in space with any combination of six motions - in three rotational axes and three linear axes. If we think of the set of Cartesian coordinates and imagine ourselves to be travelling along the X axis, the rotational axes are **Roll;** (rotation about the X axis), **Pitch**; (rotation about the Z axis) and **Yaw**; (rotation about the Y axis). The translational motions are **Surge**; (motion along the X axis), **Sway;** (motion along the Z axis) and **Heave**; (motion along the Y axis). It will be appreciated, of course, that when the vehicle is in motion the Y axis is not always aligned with the gravitational vector and the X axis is not always coincident with the motion vector. The convention is that the axes of motion refer to the vehicle.

Of course, the Virtual Motion base itself is fixed in relation to absolute coordinates. This gives the simulation engineer the ability to fool the occupants of the capsule by interchanging inertial and gravitational forces, using pitch to produce a sensation of surge, roll to suggest sway and a combination of both to imitate the centrifugal force dependent on the rate of yaw. The simplest machines therefore use a three-axis mechanism, providing a facility for simultaneous heave, pitch and roll. To an extraordinary degree, it is possible for a such a three-axis motion system to behave convincingly as a full six-axis mechanism.

Display systems

The video display in an interactive simulation experience does not have to be of ray-tracing standard with crisp shiny edges, fine detail and subtle colorations. The enjoyment of an interactive experience is not centred on an appreciation of the scenery but on the convincing representation of movements, distances and the perception of a three-dimensional environment. For a satisfactory and absorbing experience, we have found that a few hundred polygons properly shaded are quite adequate providing that attention is given to the increase of detail at short ranges and low relative speeds.

In an interactive motion simulator one of the most crucial parameters is that of frame update rate. It is no good having a beautiful picture which jerks along at ten frames per second; it is much better to have a simpler picture flowing smoothly at thirty frames per second. (Of course, as computing power increases we can do both, but when compromise has to be made, **frame update rate is more important than picture detail**).

The choice of visual angle is a difficult one. The sense of motion is lost if the visual angle is narrow vertically or horizontally; but every increase in the visual angle also increases the demand on computing power by the requirement for more detail. More importantly the size and weight of the display components (CRT systems or projectors and screens) make it difficult to design a suitable motion system - and the operator has problems if the simulator is too large.

There has been some discussion as to the appropriateness of stereoscopy in interactive simulators, particularly now that the Virtual Reality goggles are available. In fact, stereoscopy for cab simulators is only important for objects which are relatively stationary and relatively close: neither is common in an interactive motion simulator. When the head moves and the body travels the brain builds up its concept of size and distance from a series of views as the participant moves towards or past the object in question; those of you familiar with radar systems will recognise this as a sort of "synthetic aperture" effect. However, in computed views of a scenario seen from the probable location of the participant's head it is often necessary to generate images of the "controls of the vehicle". In these circumstances it is very effective to have the controls stereoscopically adjusted to be much nearer than the scene "out of the window".

There is another interesting aspect of stereoscopy which might be worth the use of another computing channel to produce it. Stereoscopy reduces perceived noise in the picture because the noise is seen differently in each eye and the brain carries out a noise cancelling adjustment which has a remarkable effect of cleaning up the picture. This also applies to the perception of television scanning lines and to the perceived clarity of moving objects.

Sound

Computer-generated sound is becoming a very sophisticated business, with the objective of increasing the sensation of "ambience" and even the perception of distance and speed from appropriately-generated sound cues. This means that care must be given to the design of the sound amplifiers and loudspeaker systems in the confined space of an interactive simulator.

Ergonomics

The participant must feel comfortable - in fact he should lose all consciousness of his actual whereabouts and be convinced that he is fully immersed in the Virtual Reality of the simulation. This means that the controls have to be carefully designed to blend into the consciousness of the human being, in the same way that a properly-designed automobile steering and pedal system quickly becomes an unconscious extension of the human body.

But steering wheels and control pedals are not easy to design so that they can be used by a fully-grown adult and then, moments later, just as effectively by a youngster. There are problems of health and safety "obstruction to emergency escape" and of course there are problems of vandalism. It therefore seems likely that the controls of a general-purpose interactive simulator will always be a couple of stubby joy sticks tucked out of the way of escape, but just as accessible to young children as to adults. There are similar constraints relating to the capsule entry and exit arrangements and to the movement of the hood which obscures the external environment and encloses the occupant. The hood has to be moved easily and safely by a small child, but without any danger of it being damaged by the vigorous actions of a hasty adult.

Software

There is a lot of common ground between software for "Helmet VR" experiences and that for personal cab simulator experiences. As I mentioned earlier, some of the experimental software for the "Bandit" four or five years ago was produced for me by W Industries and then modified for their first "SD" products.

But there are some structural differences which are important and these relate to the motion system control and to the terrain data bases. For example, the motion system must be updated much more frequently than the visuals and the update frequency cannot vary. The terrain data base also needs to be more comprehensive and more finely-grained than would be necessary for a purely-optical illusion.

Unfortunately, it is not possible to take existing videogame or helmet VR software and "just add motion cues". We are therefore looking for some software houses to specialise in motion-related VR to support the new market for personal cab simulators. They should pick up a lot of business!