VIRTUAL MOTION & ELECTROMAGNETIC RAMS

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We now have a technology which will allow a human being to control a personal simulator instantly and instinctively, using body movements. That is, the simulator motion system does not just exert forces on the body of a human being - it responds to forces which the human body exerts on it - directly, or in addition to the use of controls.

In 1989 we placed a motorbike on a motion base and fixed a screen in front of the rider in a good visual position. Then we ran a pre-recorded sequence of a race at Donnington Park and programmed the motion system accordingly. It was a real hit at the Geneva Motorcycle Show that year and we were intrigued to watch experienced motorcyclists wrestling the machine around the course and visibly sweating because they were "into the experience" without their normal ability to control the bike as they would have liked. Obviously, we did not have an expert racing motorcyclist on the staff, so our motion programming was not quite good enough for experienced riders, who felt very unsafe on the simulator!

In August 1993 I visited Simultronix in Los Angeles and for the first time I rode a fully-interactive motorcycle simulator which does allow the rider to throw it about whilst providing the proper visual, haptic and audible motion cues. Although the prototype was not perfect the experience was mind blowing. For the first time I felt totally in control of - physically at one with - a machine which I knew to be just steel and hydraulics but which seemed to understand what I wanted it to do without any conscious action on my part.

I realised that if I could devise a technology to make body movement interaction generally available, Virtual Reality would become powerfully convincing and much more than just a visual experience. Some of the most exciting and enjoyable things we do have a strong element of body movement control in them - and they are some of the most difficult and dangerous to learn. They would be great to simulate!

For example:-

Skiing, ski-boarding, ski jumping, skidoo racing .
Ice skating, roller skating, skateboarding.
Surfing, wind surfing, sail-boarding, jet ski racing, water skiing.
Sailing, yachting, white-water canoeing.
Tobogganing, Bobsleigh racing, Motor cycle racing, Horse riding, Hang gliding

And of course:-

Ptyranadon riding, Velociraptor racing, Magic carpet aerobatics, Space scooter racing
Superman flying, etc.

My team has developed an electromagnetic motion base technology which now replaces hydraulics as the pre-eminent system for simulators. **Our motion bases are uniquely sensitive to body movements, making it possible for us to design new, highly-interactive Virtual Motion experiences.**

The importance of body motion.

No one drives - or flies - in accordance with visual cues as the primary response. Careful studies show that a human being engaged in vehicle guidance control responds first to tactile disturbance and *only later* to visual field disturbance. This is thought to be due to the experiences of early life which teach balancing skills as fast reactions to external forces on the body. These reactions are entirely subconscious and they act to update the human model of its motion and to predict its future position - there is no delay in an interposed, consciously-accessible reasoning process. It appears that a similar subconscious and pre-programmed fast reaction is used to exert forces on the environment to cause movement; that is why we can play ball games which appear to require impossibly-fast calculation.

When we take control of a vehicle - surface, air or space - we bring with us our fast reactions to body forces and we use them to measure our mastery of the vehicle. We try to learn how to blend with the vehicle - to feel that it is a natural extension of our body - and to get an instinctive understanding of where the edges of the vehicle are and what is happening to them. By using the controls to move the vehicle we also gain an ability to predict the future position of the craft and when it is moving we learn how it interacts with the surrounding medium (land, sea, or air).

We say that a vehicle is under control when it "feels right" - when the driver is able to make the vehicle *feel* as he wishes, whether in response to his own input commands or against disturbances from the outside environment. The visual experience is not given the same level of importance in our assessment of our feelings of security in the vehicle. This is because what we feel is the complex of **accelerations**, which are integrated over time to produce velocities and further integrated to result in displacements. The displacements alter the visual field, but the changes are perceptible **later than the body sensations.** I am sure that many of us have had the electrifying experience of losing control of a car on an icy surface, even for a second. Visually nothing happens - the event is felt - and control can often be regained before a passenger knows anything about it.

I have quoted vehicle control as an example of how important sensations of force - of acceleration - are to us in our daily lives and how we use the instinctive responses of the human body to control machines and other devices we have created. The most important aspect of this brain function is that **motion sensations go directly to the subconscious. There is no conscious thought between sensory input and trained or instinctive response.** All the appropriate body chemical responses are triggered.

The essence of simulation - of Virtual Reality - is that it should be a compelling fantasy. That is, during the progress of the simulation it must appear to be "real", even if you know that it wasn't real when you think about it afterwards. If you have never ridden a good simulator then I can assure you that you will be very surprised just how compelling it can be. Thorough simulation is capable of disconnecting you thoroughly from the real world and immersing your mind within a Virtual World, in which you are not limited to being the self that you are in your existence outside the simulator.

As I have previously explained, many of the effects on you are induced subconsciously; they go directly to the part of your brain over which you have no immediate control. Even if you are intellectually aware of how the simulator is designed and how it is achieving these disturbing effects, it is almost impossible to stand back and observe yourself objectively in such a situation. Every instinct acts to concentrate attention on all the action in this virtual environment and get on with the interesting and exciting job of flying or driving the simulated vehicle and participating in the competitive event which is taking place, between you and the machine or between you and your friends in other “Virtual Vehicles”. You will find that the stress which is placed on you by your natural urge to compete and even to “survive” does not make you want to get out of the simulation but actually to go further in. This effect has been observed for many years in professional training simulators.

Stress, especially stress from motion cues, increases the psychological “grip” of a simulation on the participant. Because motion is always involved in the most exciting entertainment experiences, and because motion cues have such a powerful and irresistible effect on a simulation, a Virtual Reality experience without them is a relatively weak, intellectual experience instead of an emotional one.

The new motion base technology

Until now, the only way to produce precise and powerful motion cues for simulation has been by using hydraulics. Electric motors driving screw-jacks can be “beefed-up” to produce a large thrust but they cannot be designed to have also the extreme sensitivity and fast response which is vital to the simulation illusion. A good motion system must be equally capable of producing (say) the strong sensations of “cornering” in a vehicle as in providing the differences in road feel from gravel or tarmac or grass. Hitherto, only hydraulic rams have been able to do this, at great expense and complication.

The real killer for hydraulic motion systems is their extreme inefficiency. Whenever a hydraulic ram is moved, oil at high pressure is transferred from the power unit into the system and an identical volume of oil, at zero pressure, returns to the tank. There is a great deal of energy in this oil and it can be shown that almost all of it disappears as heat when the oil passes through the flow control valve. Hydraulic motion systems are profligate wasters of energy.

In the new technology we replace the hydraulic rams with pneumatic rams and we fill the space beneath the pistons with gas at a pressure sufficient to support the dead-weight of the capsule. Then we connect the pressurized part of the pneumatic ram to a small reservoir (a few litres) so that it forms a long-stroke gas spring. With the correct pneumatic parameters, the motion base can be moved about with fingertip control and it will stay wherever it is put. The gas springs remove from the actuators the requirement to support the deadload and they act as reservoirs from which energy can be extracted and returned for transient movements. There is no hydraulic oil, so we have eliminated the oil friction and the wasted energy.

At the beginning of each simulation sequence the system is smoothly pressurized to bring the capsule to its mid position, upon which the gas valves are closed and the gas pump is switched off. No gas is used up during the simulator experience - during the operating sequence the capsule literally floats on gas springs.

The actuator rams need to provide impulsive forces only. There is no requirement for a steady upthrust. Power is only consumed when the simulator is in motion and the only power required is that necessary to change the kinetic energy of motion and to overcome any frictional losses.

Actuators.

Since the forces must be coupled to a floating mass the actuators have to be electromagnetic. No suitable electromagnetic rams were available, so we have had to develop a new design, which has many other industrial applications.

What we have done, in concept, is to slice an electric motor down to the middle, roll it out flat and then roll it back up again by taking the long edges of the strip and bringing them round to form a cylinder. We do the same with the armature and we put the armature shaft down through the centre of the cylinder to make a piston. What we now have looks just like a pneumatic or hydraulic ram.

The mathematics gives us a wide range of ram thrusts from off-the-shelf magnets and these fall into exactly the right ranges that we need for our simulator motion bases. The efficiencies are quite high and because it is only necessary to apply power to the ram for very short intervals of time and because the whole system is completely silent, the product is very attractive.

One of the most interesting features of the design is that there is nothing but copper and silicon between the computer and the ram output shaft. The electric current itself provides the force and the acceleration of the ram is a direct function of that current. Acceleration is what the occupant of the simulator actually feels. The system is inherently of wide bandwidth, able to respond as rapidly as it is possible to change the current in the coil inductance. The movement is extremely smooth and there is absolutely no backlash. The machine is so precise that it can move across the width of a human hair in several separate steps.

Electromagnetic motion bases consume only a few hundred watts in place of the several kilowatts required for even a small hydraulic motion system. They can be plugged into a single phase power supply socket anywhere in the world. They can be used for cinema seat simulator mechanisms and they are capable of being scaled up for larger machines if necessary. They can be used for low cost personal training simulators or for Virtual Reality seats.

The principal features of the new technology are therefore:-

- A “floating” capsule with no hard supports.
- No hydraulics, no flow-control valves, no accumulator.
- No pump, no pipes, no noise, no mess.
- Direct electrical action. Clinically clean.
- Zero backlash, ultra smooth motion
- Zero power consumption when static; negligible heat.
- Excellent power efficiency in motion.
- Minimal moving parts count, simple assembly of sub-systems.
- Rapid diagnosis and repair, wholly unique technology.
- Can be scaled up for larger machines.

Human movement interaction

The electromagnetic motion base is a force-balance system. The force generated by each ram is controlled at all times to be exactly that which is needed to hold its desired position - no more and no less. The current in an electromagnetic ram is a direct measure of the load on it, having taken the gas spring pressure into account. This is in complete contrast to a hydraulic system or to an electric screw-jack system, both of which are “hard” and insensitive to changes in load on the ram.

Now imagine that a human occupant, initially central on the motion base, moves or leans to left or right, fore or aft. The currents flowing in the rams immediately adjust themselves to the degree necessary to compensate for the shift in the centre of mass, holding the position of the motion base constant. By monitoring the relative values of the currents flowing in the rams, it is possible to know the position of the c.o.g. of the moving platform - that is, to sense the movements of the human occupant(s). ***The new technology now makes it possible for VR designers to create a whole new range of exciting, intimately-interactive Virtual Motion experiences. The ram also has many industrial uses.***

Some Industrial Uses Of The New Ram

Civil Engineering.

Many passenger lifts in buildings up to five storeys high are raised by hydraulic rams. Electromagnetic actuators, several metres long, can replace the hydraulic rams with an efficient, silent, clean and much more reliable product - that might eventually be made for a price low enough for general private housing.

Automobile Suspensions.

We have been asked by several makers of luxury cars to consider the use of the ram in suspension systems. Studies show that it has several advantages in this market. Not only can it do the active suspension job, but the same device, acting as a damper, can vary its characteristics under computer control in milliseconds if required. That is, an electromagnetic suspension system can be tuned for every road condition as it is encountered. What is more the energy absorbed by the damper (sometimes 300 Watts a wheel) is not thrown away as heat but is fed back into the battery supply, saving fuel. Simultaneously, the sealed armature of the ram can act as part of a self-levelling, height-adjusting fluid spring system.

Rail Coach Suspensions.

Mathematical studies carried out by Loughborough University as part of an EEC programme show that the ideal suspension for a rail vehicle is an electromagnetic one. Parallel studies in association with two major European companies show that the necessary forces, displacements and power levels are within the reach of electromagnetic technology.

Industrial Automation.

The advantages of cleanliness, extreme precision, silence, high peak thrust, unlimited speed, intrinsic force-sensing, reliability and wide control bandwidth mean that the electromagnetic ram has many industrial applications. For example, they can replace hydraulics in food and drug manufacture, where contamination is very expensive. In high-speed machinery such as that for sorting, transferring and packing goods, the unique ability of the electromagnetic ram to "freewheel" when handling inertial loads saves a great deal of energy.

Although vent actuators only operate at infrequent intervals and their first cost must be low, they are often placed in almost inaccessible positions, so maintenance is very expensive and reliability is vital. A stepping linear electric motor has only one moving part - the actuator output shaft itself.

Security.

The power needed to operate an electromagnetic ram can be stored in a small space - for a year or so in a battery or for several minutes in a charged capacitor. This means that the device can be self-contained, so that it may be used to carry out a security action in an emergency. It is possible to design a mechanism that will drive a security screen into position faster than a robber can pull the trigger of a gun.

Stabilised Platforms.

When optical devices like cameras or measuring equipment have to be mobile on a land or sea surface they need to be isolated from disturbances when they are in use. This is also true for guns, radar antennae and missile launchers. The servosystems that were previously employed have interposed powerful motors, gears and cranks between the platform and its hard connection to the moving surface. A very much simpler and more reliable mechanism can now be designed to use the intrinsic "floating" action of the gas-sprung electromagnetic ram, its very rapid response and its extraordinary precision.

Cross-country vehicle seating.

Human beings need stabilisation to avoid fatigue and injury when driving vehicles such as earth-moving equipment across rough terrain. Although soft springing has been used for some time, a significant improvement would result from the use of electromagnetic actuators that combine a gas spring and an active stabilising function.

Pile Driving.

As a result of earlier studies by a British consultant, it seems to be feasible to use both the fast rise-time and the intrinsic feedback properties of the electromagnetic ram in a novel form of high-speed pile-driver.

Bulldozing, Planing and Ploughing

Similar reasoning about soil mechanics is now being applied to reduce the mechanical forces used in earth-moving equipment of various kinds.

The *Cyberseat*

The largest market for simulation is in the home. Electromagnetic technology can be applied in an interesting way to produce an exciting consumer product - a home simulator seat that can be plugged into a computer to bring a videogame to life. The Cyberseat actually connects a human body to a computer - and therefore to the Internet - providing an entirely new way for people to communicate remotely. The seat may also be used for massage and to "feel" musical rhythms, perhaps as part of a relaxation routine. **It can even be designed to sense the body motions of its occupant, providing a two-way human computer interface.**

Luxury aircraft seating

The application of electromagnetic technology to home simulators can also be extended to luxury aircraft seating. This is because the control can be applied in reverse - to hold a passenger steady against outside disturbance, thus providing an extremely cushioned ride. Of course, it would also be available for in-flight videogames or for other purposes if required!