A Vicarious Adrenaline System: Developing Immersive Haptic Experiences

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***Abstract*— This project investigates the transference of adrenaline-based motor sport experiences to an observer through a complex inter-modal interaction. Two riders competed in the Irish National SuperBike Championships in 2003 with rider and motorcycle data recorded onboard. A haptic experience was subsequently designed and built at Media Lab Europe where people (including those with disabilities) can experience this high adrenaline sport vicariously through a tightly coupled visual, audio and haptic presentation. The result is an experience which uses a multi-axis force stimulus through an Active Chair with an audio overlay of a heartbeat on the video and audio footage from the race. The visual stimulus provides the primary activation of the experience and hence the context. The use of an active haptic device augments this experience with the aim of achieving a strong sense of observer immersion in high adrenaline sports. Subsequent work has extended these technologies to immersive virtual environments.**

***Index Terms*— User interfaces, tactile system, control algorithm**

I. Introduction

THERE are a considerable range of sporting activities that require significant learning, time and commitment in order that one can participate. Consequently, not everyone has the opportunity or possibly the ability to participate in high-adrenaline extreme sports. On the other hand, the huge popularity of MotoGP or Formula 1 for example, demonstrates the potential for expanding on the 2-dimensional television-based experience that currently exists. Multi-modal haptic interfaces can facilitate a 3-dimensional physical experience-based interface for an observer whereby they become more involved in the extreme sporting event.

Haptics is viewed as the science of implementing some form of touch (tactile) sensation and control to our interaction with a generally computer-based application. The word haptic is derived from the Greek word “haptesthai” which means to grasp or touch with Braille readers being the first computer-based haptic interface. Recent work in haptics has demonstrated the power of being able to physically feel objects in virtual reality haptic devices, for example, the Virtalis SensAble Phantom Desktop [7] or the CyberGrasp CyberGlove [8].

Figure 1. Team Media Lab Europe

Figure 2. A member of Team Media Lab Europe competing at Nutts Corner race circuit in Northern Ireland in 2003 with onboard data logging.

This paper deals specifically with the design and construction of an active haptic chair and the corresponding control mechanisms employed which exploit the data retrieved from two riders and their motorcycles competing in the Irish National Motorcycle Championship in 2003. The use of the haptic chair augments the traditional visual experience when participants watch a race on a screen, and aim to achieve a stronger sense of immersion in high adrenaline sports.

The Active Chair was specifically chosen in preference to motorcycle-like model as the armchair is well adapted to a general audience, and particularly people with disabilities (one of the objective of this project). The user is placed in a more comfortable and stable position. Another advantage is that the acceleration-breaking sensation is more significant and easier to reproduce.

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II. Haptic Interfaces - Background

While current research on motorcycle simulators primarily aim to provide as a realistic a force and displacement experience as possible such as found in the MORIS project [1], this work aims to use the physical actuation of the user via the Active Chair as a *reinforcement* of the visual stimulus to create an adrenaline-based experience. The Honda Riding Simulator [4] uses the reference of a motorbike mock-up to develop a sense of realism in order to "train the riders to anticipate and react to potential road hazards in a 'safe environment'". The Motorrad-fahrsimulator SAFE II [3] has similar aims.

Experiential devices, on the other hand, aim to develop and maintain an experience which, in this case, draws on real data from a season's competitive racing. In understanding the motivations behind not using a physical replica of a motorbike for the vicarious adrenaline experience, an analogy can be drawn with Mori's Uncanny Valley [2] regarding anthropomorphism. The closer the artificially created experience is to the real, the greater the risk for a complete perceptual failure in experiential devices. It's an issue of managing expectations. The true sport of motorcycle racing is a lot more than forces acting on the rider and a visual stimulus. This work consequently aims to fuel our expectations and allow the user employ their imagination to experience the race and *not* to explicitly recreate a race as accurately as possible for an observer through using a mock-up model of the motorcycle. If the experience is not real, then the artificial should aim to be a judicious balance between expectation and experience.

III. System Design and Construction

A. Data Capture System

Two riders (Brian Duffy & John Bourke) competed in the Irish National SuperBike Championships in 2003. The competition motorcycles were equipped with an onboard camera, 3-axis accelerometers, a Polar PCBA receiver and each rider wore a wireless Polar heart-rate monitor. The data is recorded onboard using a Hewlett Packard iPaq PDA and subsequently downloaded after each race.

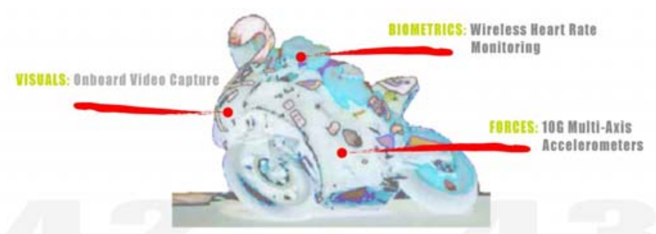

Figure 3. On-bike video capture and data logging (3-axis accelerometer & heart-rate)

Figure 4. On-bike video capture: DV recorder & data logging: HP iPaq

An Active Chair and a corresponding software control interface were designed and built to process this data and provide a seamless control system for an immersive environment for the participant. The construction and control mechanisms are developed in the following sections.

B. Active Chair Design

Core to the design and development of the Active Chair was the aim to achieve a relaxing posture for the participant in order to facilitate their immersion in the Vicarious Adrenaline Experience. The chair has been explicitly designed to provide the degrees of freedom sufficient for the Vicarious Adrenaline Project while maintaining a limited level of overall engineering complexity. While a number of different actuation solutions can be employed, a pneumatic was chosen because of its simplicity and portability. The physical construction and inclination of the chair are designed for increased relaxation with the aim of facilitating the immersive experience, with the visual-physical stimulus reinforcement being the most important.

Figure 5. The Active Chair

The base of the chair was designed with a three legged base with adjustable feet for use on uneven surfaces (old wooden floors in MLE). This also allowed for a degree of suspension action for shock absorption while the chair was in motion. The frame of the chair is constructed from rectangular section steel with leather upholstered foam and plywood sections. The foam has varying densities to ensure user comfort.

The chair's physical dimensions took into account the American National Standards Institute (ANSI) and Human Factors Society (HFS) standards for ergonomic seating:

Seat Depth:	340-375mm
Seat Width:	430-450mm
Seat Height:	390-430mm
Armrest Height:	200-250mm above seat

The positioning of the body in the chair has also been specifically designed to facilitate relaxation. Posture refers to the angle between two adjacent segments of the body. A neutral posture consequently refers to the angle of relaxation for each joint where minimal stress is placed on the corresponding muscles. This encompasses the biomechanical relationship between two body segments and involves the midpoint between the position of greatest extension and greatest contraction (relative to the capable forces).

The angle of inclination of a seated occupant in the Active Chair is variable from 33-43 degrees. Work undertaken by NASA on the Neutral Body Posture promotes an inclination of approximately 38 degrees which holds the occupant in a minimal-stress posture between the neutral body posture of zero gravitation and a normal posture of relaxation on a flat, level surface [6].

The chair is driven by three pneumatic cylinders with variable air speed and pressure controllers. A constrained 1-degree of rotational freedom at the base of the cylinder mounts and the use of universal joints at the top mounts allow for a simple and effective range of motion of the chair. An angle of 45 degree between the pneumatic pistons and the horizontal was used to minimise the horizontal displacement error during actuation to a negligible level.

A USB hardware interface allows a PC control the position of each of the pneumatic cylinders and provides a simple and flexible control solution. This is achieved through a custom circuit using a PIC controller (PIC16F87x) with a serial communications interface in full duplex mode (asynchronous) with a USB interface board.

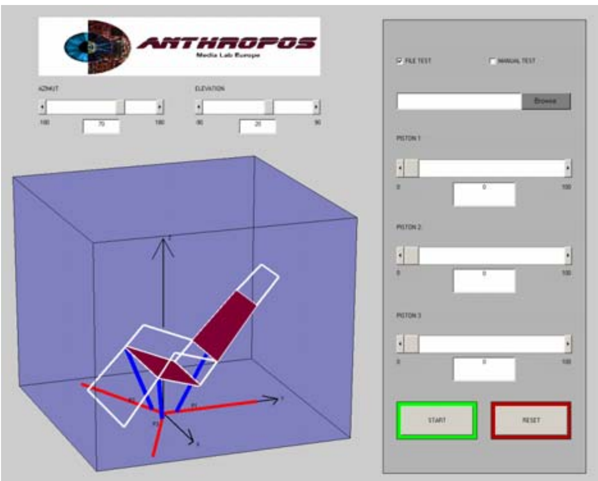

Figure 6. MatLab control interface for the Active Chair

In figure 6, the MatLab developed PC-based interface shows a schema of the chair with the three cylinders (blue lines), which can move simultaneously with the movement of the chair. The interface allows a controller to manually fix or move any piston. A "load file" option allows the user select a data file which controls the actuation of each of the pneumatic cylinders of the chair for a period of time.

In designing the Vicarious Adrenaline Experience, three key data sets were retrieved whilst participating in the 2003 racing season: 3-axis accelerometer data, video footage from an onboard camera mounted at the front of the motorcycle, and the heart rate of the rider (which is not discussed in this paper). The displacement of the motorcycle during a race is consequently translated into the movement of the Active Chair (figure 7). The number 1 piston at the rear of the chair provides the sensation of acceleration (down) and braking (up). The pistons number 2 and 3 angle the chair right and left according with the motorcycle tilt in cornering.

Fig 7. Vicarious Adrenaline Haptic Chair

In order to obtain a data signal to describe the acceleration, braking (acceleration-braking signal) and tilt (tilt signal) of the motorbike and hence drive the actuation of the chair, two methods have been considered: Visual Method, Accelerometer Method.

IV. Feature Extraction

A. Visual Method

The visual method utilises the fixed camera mounted on the front of the motorcycle which shows the engine RPM counter and the route simultaneously.

Fig 8. Motorcycle lean calculated from video

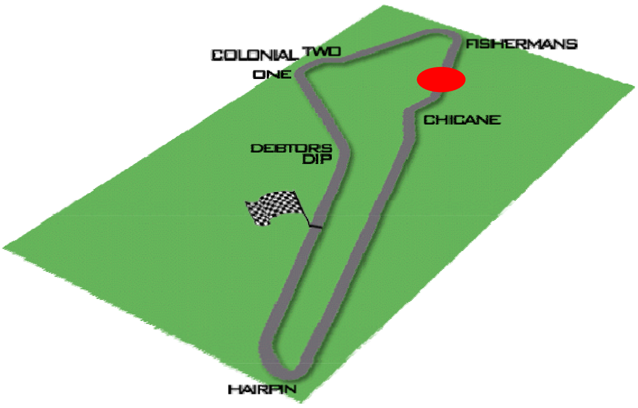

Figure 9. Kirkistown race track, Ireland

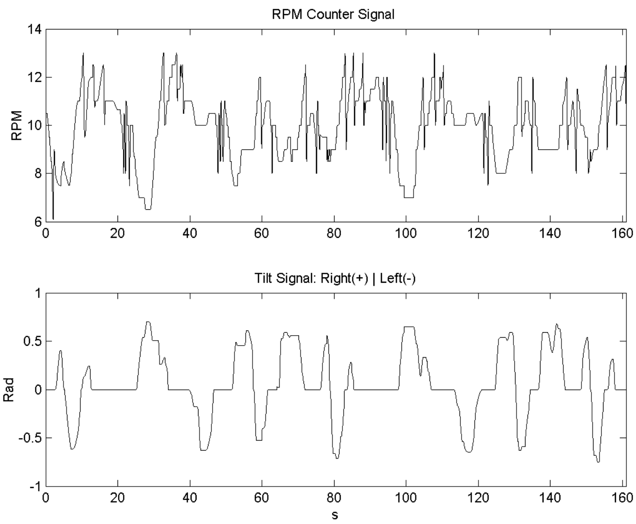

Figure 10. Motorcycle acceleration/braking and tilt data respectively calculated from video

A video is a succession of fixed images. Using a graphical interface to visualise every image, it is possible to visualise the RPM (revolutions per minute) value, with the tilt values of the motorbike obtained by rotating each image (figure 8) until a horizontal horizon is achieved. The RPM Counter provides information about the acceleration and braking as there is practically a direct correlation (neglecting infrequent tyre spin on hard acceleration). The acceleration-braking term and RPM values are calculated relatively, thereby allowing gear changes to be ignored. The data obtained from the Kirkistown circuit give the acceleration-braking and the tilt signal presented in figure 10. They are the signals of two laps with a start and end point between the Fisherman's corner and the Chicane (red dot in figure 9).

With a suitable selection of images and using a cubic or spline interpolation [10] we obtain both signals.

B. Accelerometer Method

The accelerometer method used the 3-axis accelerometers mounted on the motorcycle during each race. The X-acceleration signal gives information about acceleration and braking, Y-axis corresponds to tilt and Z-axis is ignored due to the stiffness of competition specification suspension and the resulting noise.

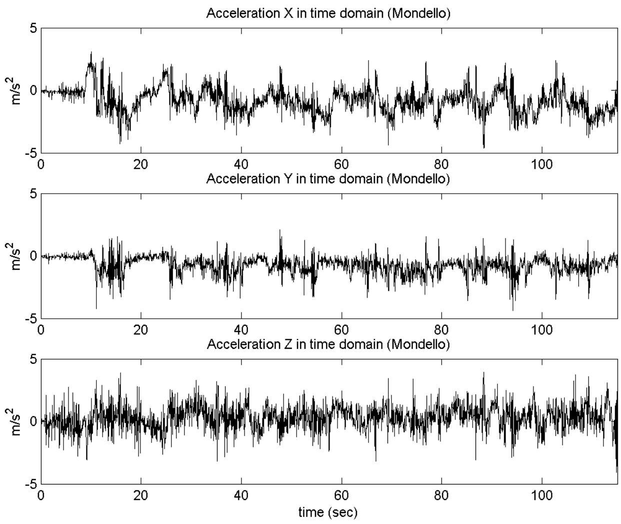

Figure 11. The 3-axis accelerometer data from a race at Nutts Corner, Ireland. While features are evident, the degree of noise is clear

The acceleration data is numerically integrated to obtain velocity data using a cumulative trapezoidal numerical integration. The result of the integration is multiplied by the sampling time to properly scale the velocity data. It appears as a linear trend, a by-product of the DC offset in the acceleration data, which is removed using a high pass filter. Using the same method, the velocity data is numerically integrated to obtain displacement data. The acceleration-braking signal corresponds to the Y acceleration signal.

1) Mondello Race Data

Figure 13 shows the tilt signal from the Visual Method and its speed and acceleration signals for the Mondello race track.

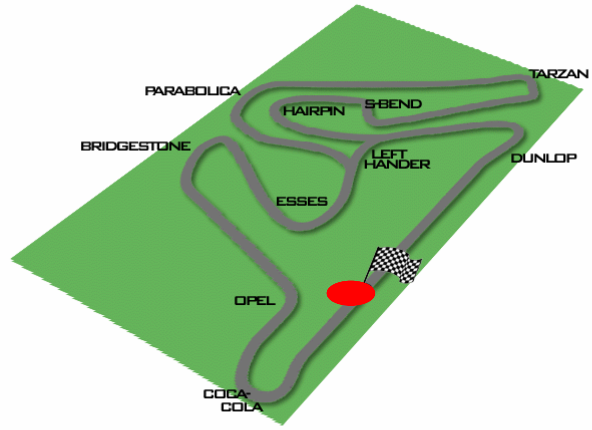

Figure 12. Mondello race track, Ireland (edit image for intermediate circuit and put in start and end point)

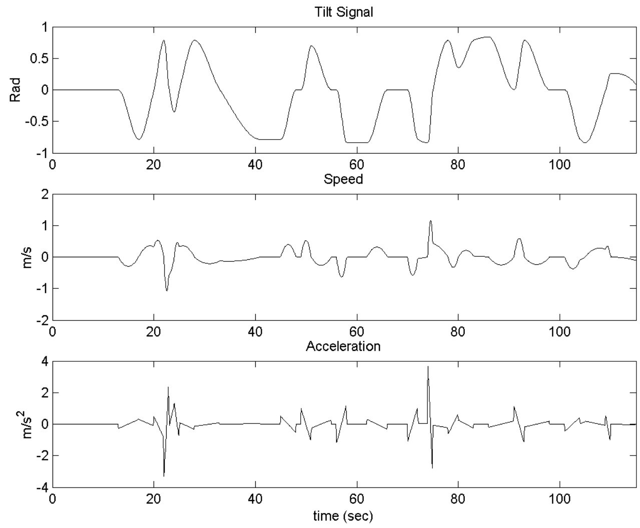

Fig. 13: the tilt signal from the Visual Method and its speed and acceleration signals for the Mondello race track

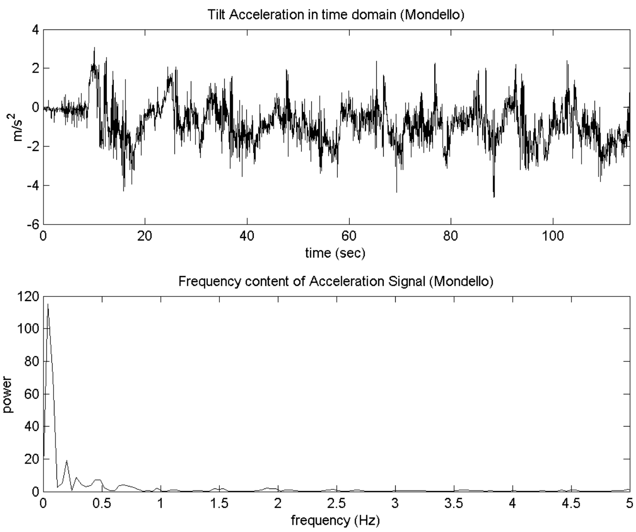

Fig. 14: The experimental tilt data from the onboard accelerometers and its frequency content for the Mondello race track

The acceleration signal was obtained with a 2nd approximate derivative from the tilt signal.

It was found that the useful 3-axis acceleration information from the race was buried in noisy data. Acceleration Data was filtered in order to find an acceleration signal similar to the visual method (figure 13). Filtered acceleration signals had different features than visual data acceleration, with no direct correlation being found. Consequently, data from the accelerometer method did not provide sufficiently useful information to control the Active Chair.

Using the accelerometer method, we expected a similar signal with a high frequency content of noise. After that, a low pass filter could be used.

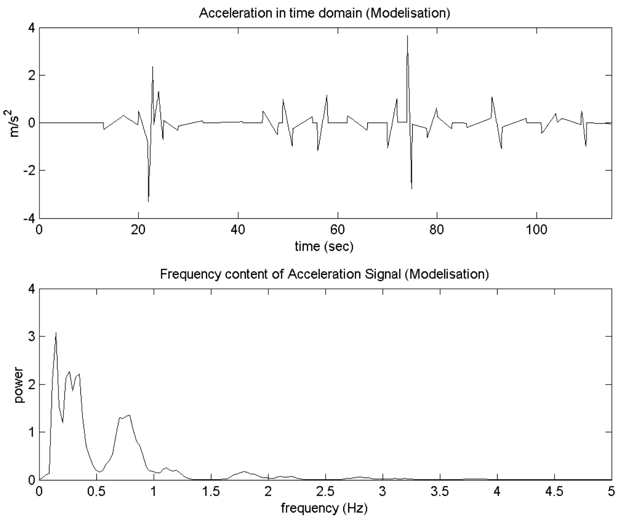

Fig. 15: The acceleration tilt data derived from the Visual Method and its frequency content for the Mondello race track

The experimental acceleration data were converted to the frequency domain to compare its power spectrum with the one of the modelled data shown in figure 15 taken from the Visual Method. Comparing spectrums (figures 14 and 15) it is possible to again observe that both signals have very different behaviours.

We deduce from this result that the accelerometer strategy and hardware employed were not sufficient to overcome the problems introduced by the noise sources present including the motorcycle suspension and engine vibrations. The Accelerometer Method could therefore not be used.

Due to the constraints of the project, further investigation into managing the noise problem could not be undertaken. Consequently, the Visual Method strategy was investigated which resulted in a cleaner strategy for feature extraction.

The major issue found with the work on employing 3-axis accelerometers for athlete analysis in sports training was the "problem of presenting useful data to the end user, being a coach or an athlete" [5]. While basic features were recognisable in the accelerometer data sets, their extraction from the pervasive noise in order to provide more useable information about the event proved difficult. This problem was exacerbated by the significant vibration induced effects of a competition specification engine and suspension characteristics on the motorcycles.

C. *Discussion*

The visual method was found to be most successful as it removed the issue of considerable noise present in the accelerometer data, but was found to be computationally intensive. On the other hand the accelerometer method would be the fastest technique if the severe noise issue could be resolved or at least significantly reduced.

V. Control Algorithm

Using the resulting acceleration-braking and tilt signals from the Visual Method, the pistons displacement signals were calculated. This therefore requires that the data is translated into the linear actuation of three angled cylinders (see figure 5 and 16). The control system then has to subsequently perform two functions: to translate the position values of the pistons as a set of data messages, and to send these messages with respect to time to the PIC board, which acts as the hardware interface with the pneumatic solenoids of the chair. The PIC controller performs the order Equal, Up or Down for a time Δt

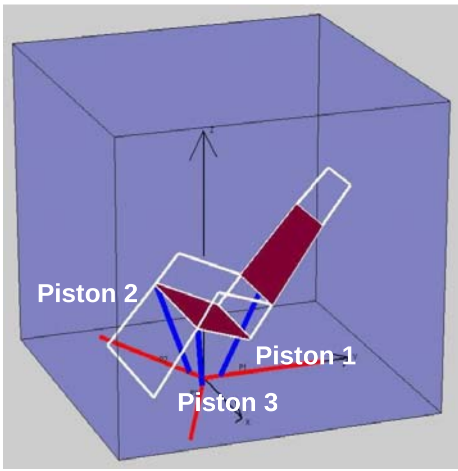

Fig 16. The Active Chair showing pistons 1,2, and 3

The first step involved the calibration of the speed of actuation of each pneumatic cylinder of the chair for a given weight of participant (comfort speed). A speed of v_c equal to 10 cm/s was decided upon through preliminary tests as it provided a sufficient degree of physically sensed reaction to the visual stimulus to the participant sitting in the chair watching the video feed from the onboard camera of the race bike. This comfort speed is easily adjusted for differing weighted participants through the variable air speed controllers on each pneumatic piston input/output port.

A. *Piston 1 Displacement*

We use the RMS signal as a displacement signal to move piston 1. When the RMS signal reduces, piston 1 moves up. The opposite occurs when the RMS signal is raised.

The requested speed of actuation of piston 1 has to respect the comfort speed selected. The derivate of the displacement sometimes gives a higher speed value than this limit. A high pass filter is therefore used with a f_c=1.45 Hz to obtain a displacement signal which has a derivate with a speed lower or equal than the comfort signal. The displacement signal obtained was configured according to the real movement of the pistons of between 0 and 10 cm, located as indicated in the following figure 17.

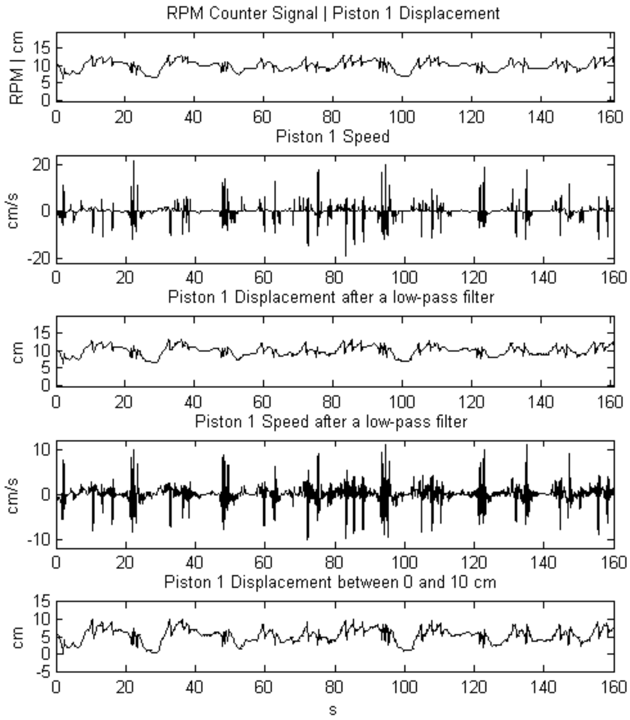

Figure 17. Graphs showing the displacement of piston 1 which has been adapted for the displacement range of the pneumatic cylinders (100mm) with a speed less than the maximum comfort speed value selected (v_c).

B. *Piston 2 and 3 Displacement*

The tilt signal was used to move pistons 2 and 3. When the motorbike tilts on the left during cornering with an angle α, piston 3 comes down and the piston 2 comes up an angle β. The relation between a tilt of angle α and the tilt of angle β of the arm chair is shown in equation 1.

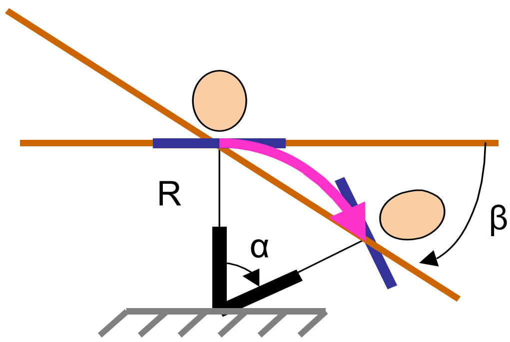

Fig 18. Correlation between the angle α and the angle β

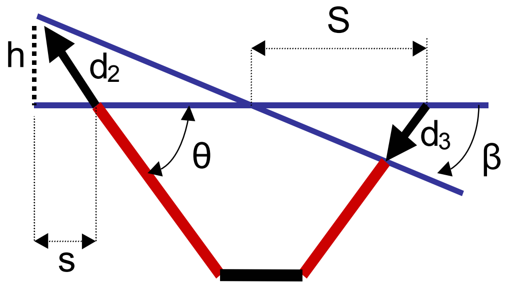

Fig 19. Correlation between the pistons 2 and 3 displacement (d_2 and d_3) and the tilt of angle β

$$tan(\beta) = \frac{1 - \cos(\alpha)}{sin(\alpha)} \tag{1}$$

The equations between the pistons 2 and 3 displacement (d2 and d3) with the tilt of angle β is:

$$d_2 = \frac{-S \times \tan(\beta)}{\cos(\theta) \times \tan(\beta) - \sin(\theta)} \tag{2}$$

$$d_3 = \frac{S \times \tan(\beta)}{\cos(\theta) \times \tan(\beta) + \sin(\theta)} \tag{3}$$

Using these equations with the tilt signal we have the piston 2 displacement signal and the piston 3 displacement signal as shown in the following figure.

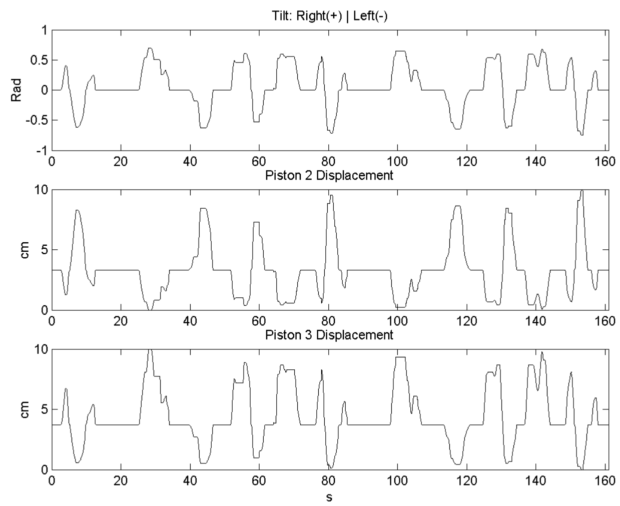

Figure 20. Piston 2 and 3 displacement signals

C. Control Algorithm

Each piston i (i=1,2,3) has a displacement signal S^i and comfort speed v_c. A piston i at the instant t_k will have a position d^i_k. At a time $\Delta t= t_{k+1}-t_k$ later, a piston i will have a displacement d^i_k+D if the movement is up, d^i_k-D if the movement is down, and d^i_k if the position doesn't change ($D \cong v_c \Delta t$) (see figure 21).

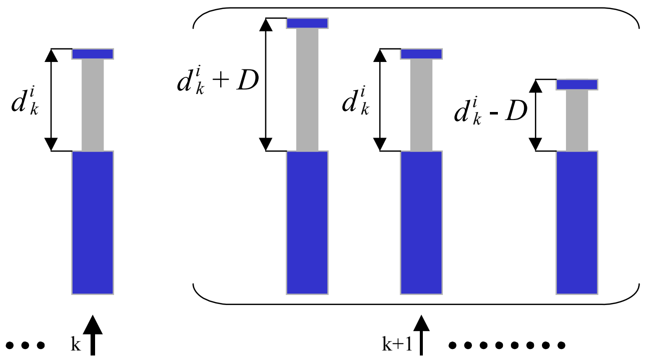

Figure 21. Piston displacement

The control algorithm compares the value of displacement signal S^i_{k+1} at the time t_{k+1} with three positions of the piston: the position of piston d^i_k at the time t_k , d^i_k +D and d^i_k -D. Subsequently, it chooses the min {abs {Equal=S^i_{k+1} – d^i_k, Up=S^i_{k+1} - (d^i_k+D), Down=S^i_{k+1} - (d^i_k-D) }} where S^i_k , d^i_k and D are ≥ 0.

The PIC controller performs the order Equal, Up or Down for a time Δt through the use of either a “0”, “1”, or “2”.

D. Displacement Control Performance

The value of v_c is fixed by the degree of comfort (severity of actuation of the chair and therefore the participant seated in the chair), the error between the displacement of piston i and its displacement signal S^i depends of period Δt. With a small value for Δt the error reduces and the sensation of continuity (smoothness of the experience) raises but this value must allow the control algorithm to work in real time. A value of Δt = 40 ms was selected. With this value the system works with a sensation of continuous movement in real time and the Mean Square Error (MSE) between the normalised displacement signal $S^i/\|S^i\|$ and the normalised piston position $d^i/\|d^i\|$ was 0.1857, 0.0128, 0.0147 for the pistons 1, 2 and 3 respectively for the Kirkistown circuit. This demonstrated the very high correlation between the piston actuation signal (a form of stepped wave) and the input displacement curves.

$$MSE = \frac{1}{N}\sum_{k=1}^{N}\left(\frac{S^i_k}{\|S^i\|} - \frac{d^i_k}{\|d^i\|}\right)^2 \tag{4}$$

The output signal interval from the PC control software to the hardware interface that controls the pneumatic pistons of the chair can be reduced but it is necessary to achieve a balance between the speed of actuation of the chair and the responsiveness of the pneumatic system. Fine tuning of the air pressure of the system (6 bar), the variable speed controllers on each pneumatic ram (for an average user weight of 75kgs) and using the signal interval of 40ms, was found to provide a successful balance between smooth chair motion and the physical response time of the chair.

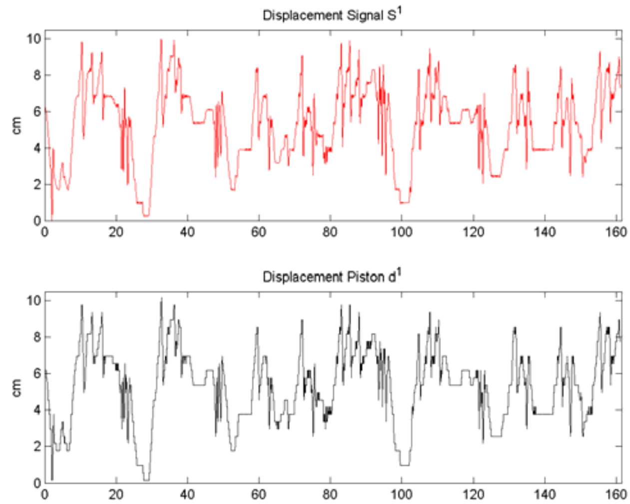

Figure 22. Piston 1 control showing the correlation between S^1 and d^1

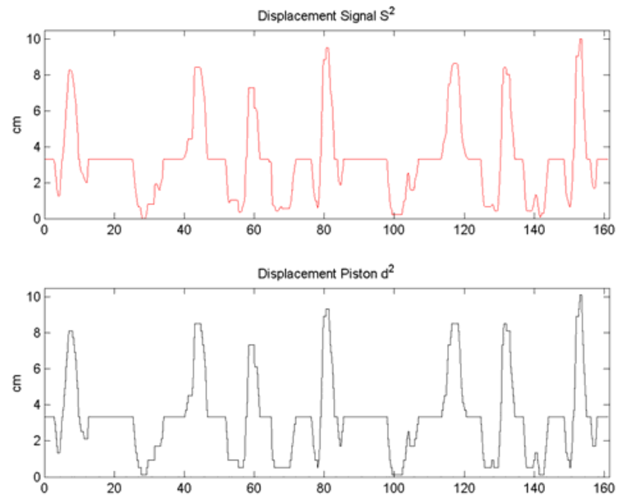

Figure 23. Piston 2 control showing the correlation between S^2 and d^2

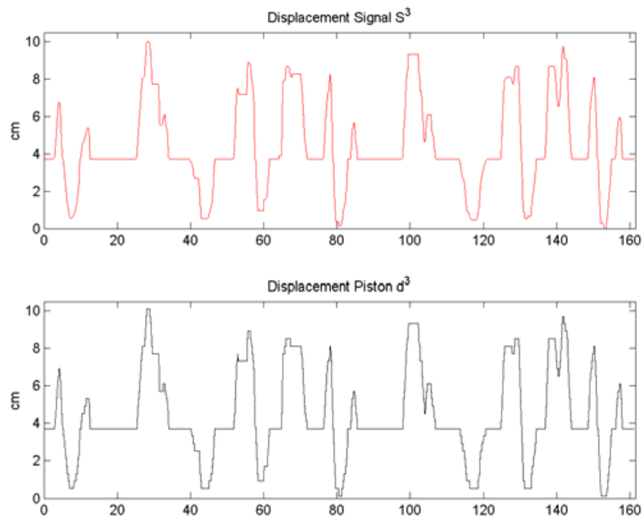

Figure 24. Piston 3 control showing the correlation between S^3 and d^3

VI. IMPLEMENTATION

This work has shown how two very different methods have been researched to animate the Active Chair based on data retrieved from a motorbike race. The visual method was found to be the most successful as it removed the issue of a problematic noise present in the accelerometer data. When the rider suddenly turns into a corner or alternates direction as found in a chicane, the chair must move at the exact same time. By directly linking the chair actuation system to the video feed through the Visual Method proposed, this has been achieved. The visual stimulus has been reinforced and hence a more important sense of immersion is possible.

An additional result is the use of the Active Chair for people of very limited mobility who, consequently, can not undertake motorcycle racing.

Subsequent work has looked to refine the technologies implemented and use the Active Chair for immersive virtual environments. A similar, but scaled down version of the Active Chair with a similar control strategy were employed in a sister project: TRUST.

Figure 25. The TRUST game world

The objectives of the TRUST Project were to develop game-based interactive play in order to aid in children rehabilitation and ease the stresses associated with hospital scenarios. The play environment is designed to be inclusive, i.e. not solely for the able-bodied and able-minded people. The virtual environments and game scenarios have been tailored to an audience of 8 to 13 year old children (http://www.give-trust.org).

TRUST framework has integrated several modes of artistic and technological innovation; a game engine and associated software framework (figure 25) and a scaled down version of the Active Chair (figure 26) which provides a closed loop haptic interface that is synchronised and congruent with the game play. In addition, an array of joysticks allows users with constrained mobility to interact with the system. The system is currently installed in the KK Women & Children's Hospital in Singapore.

Figure 26. The Active Chair in NTU Singapore

The next stage is to incorporate biomedical signals (heart rate, Galvanic Skin Response (GSR), ECG and EEG) to investigate the correlation between the race data and the vicarious experience data for rider and participant. Heart rate data has already been retrieved from riders competing during these experiments.

VII. Conclusions

This paper presents the Active Chair, a system that looks to, through haptic technologies, provide physical experiential motion and promote immersion in virtual spaces based on data generated from video footage (in the motorbike experiments: acceleration-braking and tilt), and through its integration with a full computer games engine in virtual environments (TRUST Project). These two system implementations have demonstrated the systems two primary features: its simplicity and its generality. It can move using a minimum set of resources and significant target user flexibility through its basic chair-like design for, in particular, people with physical disabilities.

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References

[1] Ferrazzin, D. Salsedo, F. Avizzano, C.A. Di Pietro, G. Brogni, A. Vignoni, M. Bergamasco, M. “The MORIS Motorcycle Simulator: An Overview”, SETC 2001.
[2] Mori, M., The Buddha in the Robot. Charles E. Tuttle Co., 1982; ISBN 4333010020
[3] Motorrad-fahrsimulator SAFE II http://wsvst25.site.uni-wuppertal.de/dirk/motsim1.html
[4] Honda Riding Simulator http://www.honda.com.au/ discover+honda/hart/rider+training/riding+simulator.htm
[5] Lin, A., Mullins, R., Pung, M., Theofilactidis L., “Application of Accelerometers in Sports Training”, , (http://www.analog.com/).
[6] Park, B.V., “Moving Chair for Virtual Reality”, NASA Technical Report MSC-22623
[7] http://www.virtalis.com
[8] http://www.immersion.com
[9] Duffy, B.R., Goodman, L., Price, M., Eaton, S., Riedel, J., Sudol, J., O’Hare, G.M.P., “The TRUST Project: Immersive Play for Children in Hospitals and Rehabilitation”, IEEE SMC UK-RoI Chapter Conference on Applied Cybernetics, City University, London, UK, September 2005
[10] De Boor, C., A Practical Guide to Splines, Springer-Verlag, 1978.

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