A Real-Time Simulator for Virtual Reality conceived around Haptic Hard Constrains

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Résumé This paper presents a real-time physically based platform for multi-sensory interactive simulation. This platform is centred on high quality dynamic requirements driven by the concept of instrumental interaction. It is oriented towards the simulation of « vis-à-vis »human-object interactive simulation for a broad range of physical phenomena, with a specific focus on simulations with demanding capacities regarding dynamics such as tool use, object manipulation, music instrument playing, etc. The platform consists in a precisely synchronized multiprocessor architecture extended with a DSP board used for the simulation of very reactive models. Two versions have been implemented corresponding to specific simulation requirements : (1) a highly reactive simulator for models with strong dynamical requirements but low computation needs, such as sounding instruments ; (2) a 64 bit floating point multiprocessor architecture for large 3D models with complex interactions such as fluids, smoke, crowds.

Key words: Virtual-Reality, Instrumental, Real Time, Synchronisation, Multi Frequency, Multi Processor, Mass Interaction

1 Introduction : instrumental Virtual Reality

The introduction of haptic devices in VR platforms oriented towards manipulation has motivated lots of active researches the last 20 years. Today, everyone is in agreement with the fact that human interaction with an object or an environment necessarily involves mechanical coupling and exchange of mechanical energy.
C. Cadoz first coined this particular property of human gesture under the term 'ergotic' [1]. In the case of computer mediation this situation involves the use of bidirectional transducers to connect the digital world of the simulation process to the physical world of sensory-motor phenomena : sensors to measure human motion and actuators to recreate the mechanical effort. The existence of a bidirectional flow of information is a necessary condition for the implementation of 'ergoticity' in human-computer interface. HCI science has shown that performance of human-computer interaction could be greatly improved by the use of haptic interfaces [2].

1.1 The haptic component in classical Virtual Reality

In the field of Computer Graphics, like the geometrical modelling and light modelling, physically based modeling stage is also added in the simulation like an independent part to enhance the VR platform with haptic devices.

The haptic device is considered as a device capable to "render" shapes or rigidity of the objects simulated thanks to force feedback [3]. A different approach, which we support in our work, merely considers the haptic device as a mean to recover, in artificial interaction situations that are mediated by computer, the ergotic function that exists in natural human-object interaction.[12]

Within this approach several positions can be found, corresponding to different modelling paradigms of the instrumental chain. In most of VR applications, the gesture interface becomes a haptic interface instead of a motion sensor. Currently, it is commonly admitted that the flow of data between the haptic device and the simulation process must be exchanged at sampling rates between 1 and 3 kHz. This simulation process includes the simulation of the mechanical part of the virtual object or environment that is directly related to the haptic device and to human gesture (Fig. 1). Due to computation limitations and/or modeling choices, only a part of the simulation process is running at such frequency, and the rest of the simulation process is either running at lower frequency, asynchronously of the mechanical model, or is based on the triggering of pre-recorded samples controlled by events (generally for sound generation).

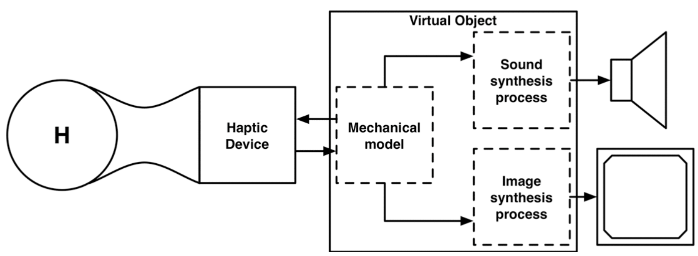

Fig. 1. Common implementation of the haptic function into VR system

In this approach, platforms of simulation are generally categorized in function of their computation load repartitions. Currently, it appears three types of VR platform architecture.

SPORE (Simulation of Physically based Objects for Real-time Environments) is an example of "centralized approach" for surgical simulation [4]. The simulator is composed of three units : a mechanical unit, a visual unit and a collision unit that run on one general-purpose PC with a Phantom haptic device. A minimal kernel is dedicated to common processes : ODE and collision detection. A part of the kernel a collection of complex physically based models is proposed.

SPRING is a surgical simulation system dedicated mainly for Collaborative task [5] based on the "Client-Server" configuration. The simulation process runs on a single computer, haptic and audio devices are connected to the simulator through Ethernet network and visualization is duplicated on displays.

Finally there is the "distributed approach" platform where simulation runs on PC cluster. SIMNET [6] was one of the first platforms using the distributed approach ; it was a multi-users platform for the training of shooting. We can also cite FlowVR [7], a development library recently used, providing tools for the development of interactive applications on clusters of general-purpose PC.

This implementation strategy is interesting in a large panel of situations because it leads to an efficient use of computation resources, and to suitable, yet not satisfying, solutions for the user, from the point of view of gesture interaction.

1.2 Ergotic interaction for Virtual Reality

The common implementation strategy detailed above is not satisfying from the point of view of instrumental playing, as the energetic chain between the human and the simulated object, taken as an instrument, is cut in the simulation process [8]. Indeed, such implementation strategy can be satisfying when the mechanical part of the object that is in direct interaction with the human body is decoupled from the rest of the object. For example, in the mechanism of the piano, one can consider that the key mechanism is not structurally coupled to the vibrating structure of the piano (the strings and the soundboard). But there are situations where such decoupling is not possible without breaking the targeted phenomenon that is emerging from human-object mechanical coupling. This is the exemplary case of violin playing, or of having your wet finger making 'sing' a crystal glass. To simulate properly such situation, one cannot avoid having only one simulation process as the sounding part and the mechanical part of the object are intimately coupled (Fig. 2). This simulation process is responsible for the generation of all sensory information involved in the simulation (haptic, visual and audio).

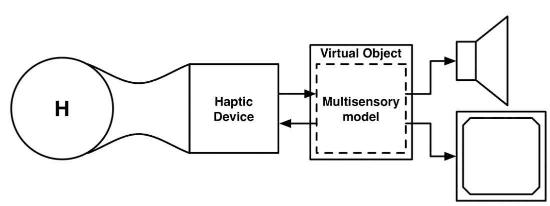

Fig. 2. Our implementation of the haptic modality into VR system

1.3 System constraints for instrumental VR

In the classical Virtual Reality, haptic computing is generally inserted into simulation system conceived around constrains for graphics computing. In instrumental VR, the relation between the gesture interface and the simulated object is not based on phenomenological information, but rather on a bidirectional exchange of data flows that are synchronized with the simulation process. Dynamics of the physical phenomena that are simulated should be correctly represented into computer simulation, both in terms of simulation frequency and temporal latencies. Therefore, technical requirements are introduced so that instrumental playing is respected :

- The bandwidth of the simulation should encompass the cut-off frequency of the physical phenomenon that is simulated : if the simulated model includes acoustical parts, simulation bandwidth should be high enough to generate acoustical frequencies of the sound signal (10 to 50 kHz).

- Dynamic range of the physical variables should encompass the dynamic range of the reference physical phenomenon.

- The simulation process should be synchronized with the other devices involved in the interactive simulation, such as transducers (haptic devices, loudspeakers, etc). Especially, I/O latency of the simulation process should not exceed one simulation period as latency introduces physical distortion[9]. Time determinism for each simulation process is the only way to guaranty I/O latency : a step of simulation must be computed within fixed time windows.

2 Architecture of the platform

2.1 General presentation

This part presents the main features of the platform developed to satisfy presented constrains of ergotic tasks.

Concerning the modeling framework, the ACROE team has designed since 1984 computer formalism, called the CORDIS ANIMA system [8]. The fundamental choice of this system is the mass-interaction modelling. A physical object or a set of physical objects are modeled and simulated as a network where the nodes are the smallest modules representing inertia (the MAT elements) and where the links (the LIA elements) represent physical interactions between them. The modules are all implemented with explicit algorithms, allowing for deterministic computation. Thus our multi-sensory simulation is based on one model composed of a large number of simple algorithms allowing a regular computation synonymous of determinism.

The input/computation/output sequence can also be easily synchronized on an external clock. Simulation frequency can be adjusted between 1 and 50 kHz according to the bandwidth of the physical phenomenon targeted. According to the expected task and circumstances of platform use, simulation requirements are variable. This platform is also conceived like a modular hardware platform composed with different computation units.

One of the hardware components is Multi-processor (bi or quadri-processors) computers from « Concurrent Computer ». Processors used are AMD Opteron 2 GHz with cache of 1024 KB and 64 bits architecture. The computer is equipped with a Real-Time Clock and Interrupt Module, a PCI Board, which provide a modular synchronization (from external clock or for the synchronization of external modules).

A DSP PCI board from Innovative Integration, called TORO board, is the second main component of the platform. The DSP embedded is the TMS320C6711 characterized by a computation frequency of 150MHz. This card provides 16 simultaneous analog input and output up to 250 KHz each, both at 16-bit resolution for high quality haptic.
A/D and D/A converters are synchronized on the same clock signal as the simulation process and are used for the exchange of data with the haptic device (ERGOS panoply [11]). Considering that commercial sound boards present non negligible latencies, we have also chosen to take benefit of the 16 bits precision D/A converters for sound outputs (up to 4 channels, for quadraphonic sound), allowing for very short latencies (less than 5 us for a simulation frequency of 44,1 kHz).

These hardware components could be use together or independently providing a range of configurations for various performances. These configurations are presented in the next parts.

2.2 High Reactivity simulation.

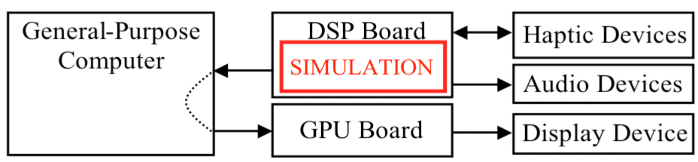

Fig. 3. Configuration with DSP Board

This configuration is only based on the DSP-board with 16 high channels of analog I/O. (Fig. 3). This module is particularly adapted to be used for models requiring hard reactivity and a low computation power. The simulation runs on DSP and its host, a general-purpose computer, is only used for simulation control and for visualization. The emblematic example of this configuration is simulation of violin playing.

2.3 Simulation of complex 3D scenes

Running simulation on the multiprocessor system (Fig. 4) increases the computation power and so the complexity of scene simulated. Moreover our physical models simulation algorithms with its network topology are very pertinent for a multi-processor repartition. Indeed, the inter-processor communication is resolved with a specific physical module satisfying time and physical coherence called «ghost module». It consists in a semi-mirror that allow cutting network

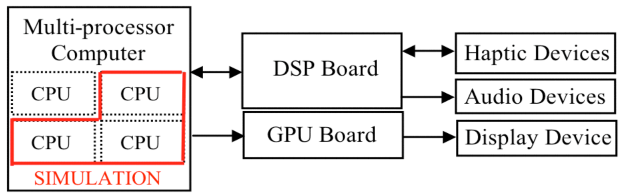

Fig. 4. Configuration with multi-processor computer

of models (Fig. 5). The combination of this Multi-processor architecture and the Operating System « RedHawk », distribution linux specialized for Real-time applications, [10] allow satisfying time determinism requirements. Some low-level tools provide the means of controlling computation :
- Management of access right (memory, processor,...)
- Processor shielding against process execution, interrupts, daemons
- The deactivation of scheduler
- Assigning process to processors
- Protecting process execution against memory swap
- High quality inter-process synchronization (spin lock, active waiting. . .)

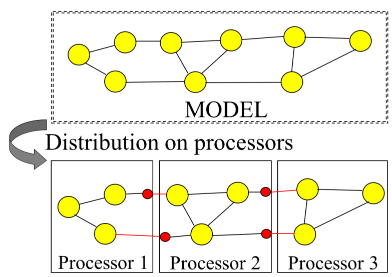

Fig. 5. Multi-Processor (P1,P2,P3) repartition with «Ghost Modules»

2.4 Simulation of complex scenes with high reactivity of haptic modality.

The last solution consists in using all the computation units : the Multiprocessor computer and the DSP board. (Fig. 6) Thus the distribution of model can be done in order to simulate a complex scene with high reactivity for haptic modality. For example, a large model can be simulated with 3kHz frequency on computer and connected to a cinematic transform simulated with 44KHz on DSP.

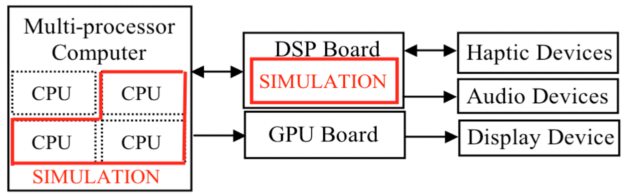

Fig. 6. Configuration with multi-processor computer and DSP Board

3 Main Results of the multiprocessor and multi-frequencies configuration

The realization of this configuration has been organised according two axes. In the first time, work has been focused on the model distribution between the processing units, and next on the multi-frequencies implementation.

Results presented have been observed with the bi-processor computer. One processor is used to run simulation and the other to run the operating system. The simulation process unit is shielded from background processes, interrupts, and local interrupts, and protected against memory swap, that provide the high degree of determinism wished.

3.1 The biprocessor monofrequency implementation

The objective of first stage was to obtain a synchronized and mono frequency simulation along the chain of computation. In order to avoid modelling problem and focus on the architecture problem, a simple bypass has been realized at 20 KHz. A sinusoidal generator sends a signal to AD Converter and an oscilloscope shows the output on the DA Converter (Fig. 7).

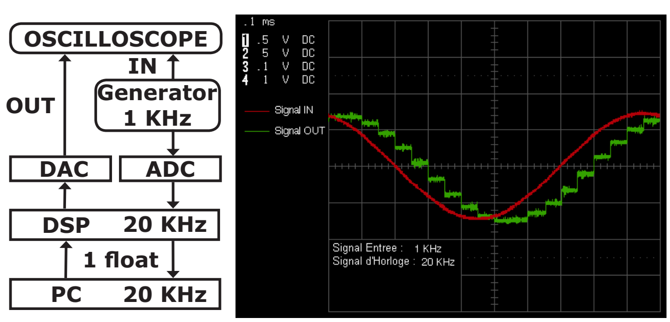

Fig. 7. Configuration with multi-processor computer and DSP Board

3.2 Simulation of complex scenes with high reactivity of haptic modality.

The figure illustrates the main result wanted. The input and the output signals are strictely synchronized and de-phased of one period of sampling. The synchronization of computing units is based of active waiting. This allows ensuring an I/O latency of the simulation process, which don't exceed one simulation period and a communication between processing unit realized in a fixed time windows. This test of hardware architecture runs at 20 KHz on the complete chain of computation.

3.3 The biprocessor bifrequency implementation

The second part of implementation concerns the multi-frequencies computing. In order to obtain a platform with high reactivity and a high computation power, one computing unit must run at high frequency, in this case the DSP, and others CPU at low frequency. This realization is based on two points, or dates, of synchronization per simulation cycle. Naturally, the signal coming from CPU to DSP is also under sampled (impulse under-sampling : see Fig. 8). For this example, one times out of five sample treated by DSP, is treated by the CPU.

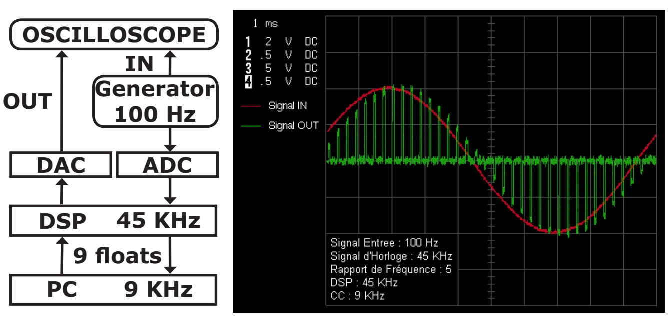

Fig. 8. Configuration with multi-processor computer and DSP Board

To validate, the consistency of simulation chain, the first physical model realized is a coupling between to oscillators (one on DSP at 5KHz and one on CPU at 1KHz). On the figure (Fig. 9), , position response and force response of impulse input are plotted. The position response shows the two own softened oscillations of the oscillators. This model is the tool of test concerning the rigidity allowed by the architecture.

3.4 The first simulation of a complex scene with high reactivity of haptic modality : « La crepe »

This is the first model realized with this new simulator. It is the metaphor of the pan for cooking a « crepes »(pancakes) (Fig. 10). The crepe paste is simulated

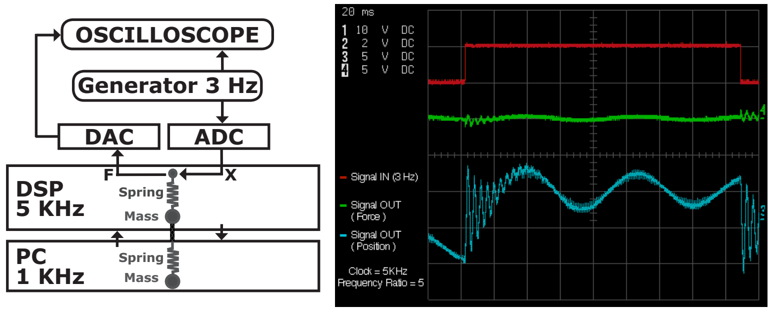

Fig. 9. Configuration with multi-processor computer and DSP Board

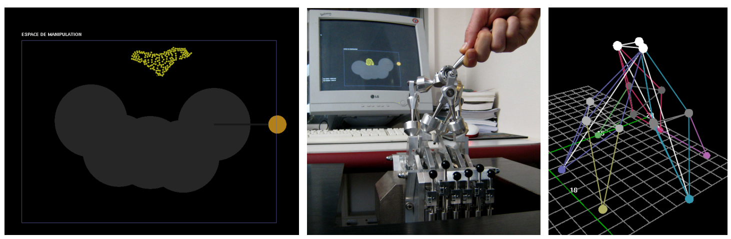

Fig. 10. Configuration with multi-processor computer and DSP Board

on the biprocessor in a 2D space, it consists in 190 particles completely connected network (17955 interactions) where the interactions are defined by a viscosity and an elasticity with independent thresholds. The result seems to be between gel and batter. The pan is simulated with 8 masses on the biprocessor in 2D too.

The inverse cinematic transform of 6dof parallel device (Fig. 10) is calculated on the DSP to provide the virtual space coordinates of the manipulated joystick position data. This cinematic transform is cadenced at 5 KHz by an internal clock of DSP Board, and the biprocessor is slaved at 1KHz. The model constitutes a real test to validate the chain in terms of rigidity. The contact perceived during manipulation is interactions between crepe and pan. Three stages of mass separate the point of manipulation and the point of contact. For the moment, the model is compute for 3D but constrained on a plan

Qualitatively, the sensory results, received at Enactive07 in Grenoble where this simulation was in demonstration, seems to be sufficient to make the task. Actually, the model is developed completely in 3D.

4 Conclusion

Unlike other Virtual Reality platforms, this new real-time physically based hardware platform allows a complete synchronous multi-sensory interactive simulation. Its hardware modular architecture provides a range of configuration adapted to different issues (individual use, laboratory use..). According to performances obtained with the model presented above, the connection between the multiprocessor computer configuration and the DSP board configuration is a really promising solution for a future virtual reality platform allowing the simulation of complex scene with high quality of haptic interaction. Actually, different works are in development : 3D models (pan, mortar and pestle..), cinematic transform library (2D guided plan, guided circle...).

Références

1. Cadoz, C. (1994) "Le geste, canal de communication homme/machine. la communication instrumentale". Technique et Science de l'Information, 13(1), pp. 31–61.
2. Rosenberg, L. B. and Brave, S. (1996) "Using force feedback to enhance human performance in graphical user interfaces." In Proceedings of CHI'96 : Conference on human Factors in Computing Systems, Vancouver, Canada.
3. Basdogan, C. and Srinivasan (2002) M. A., Handbook of Virtual Environments, pp. 117–134. Lawrence Erlbaum, Inc., London.
4. Meseure, P., and al, "A Physically-Based Virtual Environment dedicated to Surgical Simulation", International Symposium on Surgery Simulation and Soft Tissue Modeling (IS4TM), June 2003.
5. Montgomery, K., and al, "Spring : A general Framework for Collaborative, Real-time Surgical Simulation", Medicine Meets Virtual Reality, IOS Press, Amsterdam, 2002.
6. Calvin, J., and al, "The simnet virtual world architecture", IEEE Virtual Reality Annual International Symposium, pp. 450-455, 1993.
7. Dequidt, J., and al, "Collaborative interactive physical simulation", 3rd International Conference on Computer Graphics and Interactive Techniques in Australasia and Southeast Asia Proceedings, Dunedin, New Zealand, Nov-Dec 2005.
8. Florens, J.-L. and Cadoz, C. (1991) Representation of Musical Signals, chapter The physical Model, Modelisation and Simulation Systems of the Instrumental Universe, pp 227–268. The MIT Press, Cambridge, Massachusetts, USA.
9. Florens, J.-L. and Urma, D. (2006). Dynamical issues at the low level of human / virtual object interaction. In DBL, pp. 47, Arlington, VA, USA.
10. Castagne, N. and Florens, J.-L. and Luciani, A. (2005) "Computer Platforms for Hard-Real Time and High Quality Ergotic Multisensory Systems - requirements, theoretical overview, benches", Proceedings of ENACTIVE05 - 2nd International Conference on Enactive Interfaces, Genoa, Italy.
11. Florens, J-L., and al (2004) " ERGOS : Multi-degrees of Freedom and Versatile Force-Feedback Panoply", pp. 356-360, Munchen, Germany.
12. Luciani, A., Florens, J.-L., and Castagné, N., "From action to sound : a challenging perspective for haptics". In WHC'05 : Proceedings of the First Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, pages 592–595, 2005.