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

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Abstract

This paper presents a real-time physically based platform for multi-sensory interactive simulation. This platform is centered 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.

1. Introduction: classical instrumental VR

The introduction of haptic devices in VR platforms oriented towards manipulation has motivated lots of active researches the last 20 years. Like the geometrical modeling and light modeling, physically based modeling stage is also added in the simulation like an independent part.

For the classical instrumental VR from “Computer Graphics”, technical problems are generally to generate force at least of 1 kHz and compute complex cinematic treatments at the same time in a coherent way.

This part presents some examples of these platforms 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 [1]. 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 [2] 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 different displays.

Finally there is the “distributed approach” platform where simulation runs on PC cluster. SIMNET [3] 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 [4], a development library recently used, providing tools for the development of interactive applications on clusters of general-purpose PC. But contrarily to SIMNET environment, FlowVR is not reducing to the simulation of ballistic movements [5], and so results of mechanisms, implementing to keep coherence in the global simulation, are less powerful.

It seems that lots of instrumental VR don’t treat real dynamic tasks. That’s clearly showed by descriptions of their applications, and that’s can be deduced from the systematic and conceptual cut, software or hardware, between the global simulation and the physically based models treatment.

We have presented the main architectural tendencies of general VR platforms. However, an important part of works VR are focused on interactive simulation, that is, to give means to the human user to interact with the virtual environment that is simulated.

2. Ergotic interaction for Virtual Reality

2.1. Gesture controllers and the mapping strategy

Very soon the computer appeared as a mean to make the human enter into new virtual worlds. The emergence of new human-computer interaction

interfaces was already envisaged [18]. The first gesture interfaces were “manual-input devices”, that is, motion sensors: mice [19], tablets, etc. This approach is still used a lot currently in the fields of HCI and computer music [20]. One can summarize it as following: in mapping strategies (Fig.1), motion sensors feed the simulation process with position information from human motion [13]. The process responsible for the simulation gets position data or event-based information from the motion sensors. Gesture data flow from human to computer. This implementation strategy is mostly found into computer systems for electronic music, where the need is to provide an easily extensible set of very versatile gesture possibilities for the player [14]. It is however criticized when there is a need for the human user to be in contact with the physical mechanism represented in the simulation of the virtual object [13], [14].

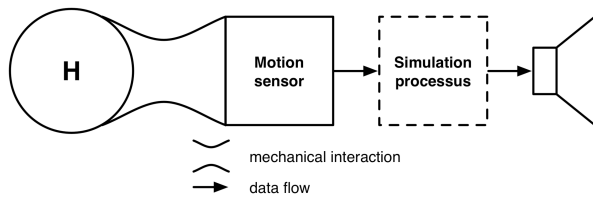


Figure 1. The mapping strategy

2.2. The haptic component in VR

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’ [7], [8]. 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 [9], [10]. In the field of Computer Graphics, the haptic device is considered as a device capable to “render” shapes or rigidity of the objects simulated thanks to force feedback [11].

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 modeling 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.2). 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, as in the mapping strategy).

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.

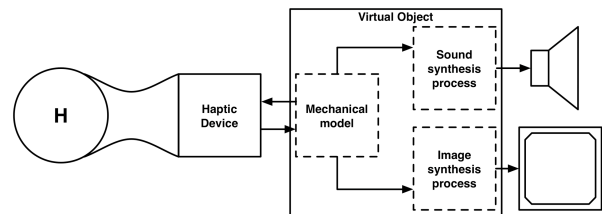


Figure 2. Common implementation of the haptic function into VR system

2.3. Instrumental VR

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 [13]. 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.3). This simulation process is responsible for the generation of all sensory information involved in the simulation (haptic, visual and audio).

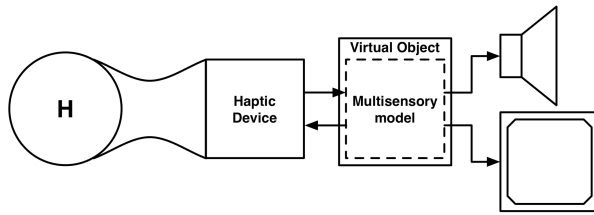


Figure 3. Common implementation of the haptic function into VR system

2.4. System constraints for instrumental VR

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 (Fig3). 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 [12]:

- 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 [21]. 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.

3. Architecture of the platform

3.1. General presentation

This part presents the main features of the platform developed to satisfy presented constraints of ergonomic tasks.

Concerning the modeling framework, the ACROE team has designed since 1984 computer formalism, called the CORDIS ANIMA system [23]. The fundamental choice of this system is the mass-interaction modeling. 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 1Go 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 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 analogs input and output up to 250 KHz each, both at 16-bit resolution for high quality haptics.

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 [22]).

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 quadrasonic sound), allowing for very short latencies (less than 5 μ s 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. Two of them have been realized and described in the two next parts. A third configuration, presented in the last part, is currently developed.

3.2. High Reactivity simulation

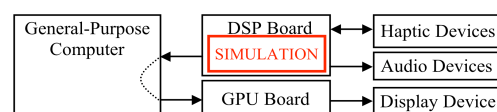


Figure 4. Configuration with DSP Board

This configuration is only based on the DSP-board with high channel of analog I/O.

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.

3.3. Simulation of complex 3D scenes

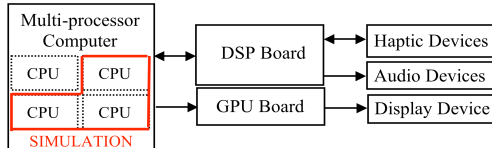


Figure 5. Configuration with multi-processor computer

Running simulation on the multiprocessor system 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 communication inter-processor 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 of models (fig.6).

The combination of this Multi-processor architecture and the Operating System specialized for Real-time applications [19] 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...)

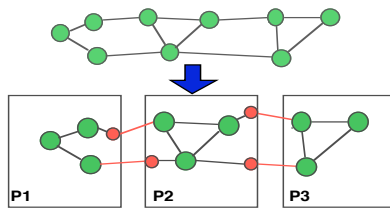


Figure 6. Multi-Processor (P1,P2,P3) repartition with «Ghost Modules»

A first evaluation of the system has been made with agglomerate, 10^3 masses and so 10^6 interactions. It can simulate this model with frequency of 500 Hz.

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

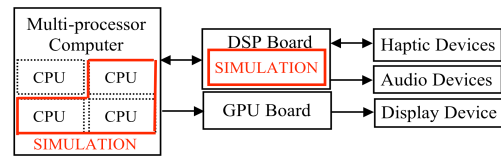


Figure 7. Configuration with multi-processor computer

The last solution consists in using every computation units: the Multiprocessor computer and the DSP board.

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.

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.

According to performances obtained with our different implementations on individual configurations (agglomerate, friction of bow, pebble box, smoke...), 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, this connection is in development and the optimization of PCI transfer between host and the DSP Board is the real last problem for our multi-frequency configuration.

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