Virtual trainers using low-cost platforms TIC2003-08933-C02

Luis Pastor Pérez[*]
Universidad Rey Juan Carlos

Antonio Pérez Ambite[**]
Universidad Politécnica de Madrid

Abstract

Traditionally, the continuous improvement in the computers' price-performance ratio has been fostering the development and diffusion of new application areas, which has brought about new advances in price-performance ratios. Virtual reality (VR) applications are a good example of this situation: the impact that these technologies will have into the training procedures of operators who have to carry out critical operations will be strong, given the cost and safety advantages of these approaches. Before this can happen, it is still necessary to progress in the understanding of the person-computer interaction process, in the quality of the sensory feedback returned by VR systems (essentially visual, auditive and tactile), and in the price level of VR systems and facilities.

The aim of this project is to progress in the development of virtual reality systems showing both low cost and high performance, for which two research lines will be followed:

1. The reduction of the systems' computational requirements through the development of advanced algorithms for the efficient manipulation of the geometric structures associated to the generation of images and haptic responses of 3D objects, within the time restrictions associated to the simulation processes.

2. The reduction of the hardware's cost, through the development of basic techniques for implementing VR systems on clusters made out of off-the shelf components.

Finally, two demonstration applications will be developed within the medical and industrial domains. For this purpose it will be necessary to adapt the developments described above to the particular applications, modelling also the visual and haptic response of systems.
Keywords: Virtual reality, surgical training, 3D modelling, parallel processing

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[*] Email: luis.pastor@urjc.es
[**] Email: aperez@fi.upm.es

1 Project objectives

1.1 Objectives

The main objective of the coordinated project "Virtual trainers using low-cost platforms" is to contribute to the widespread used of simulation, advanced visualization and virtual reality systems by means of the development of low-cost solutions. Two lines of work will be taken for this purpose:

1. To minimize the computational load associated to the image generation process through the improvement of the current 3D model techniques.

2. To reduce the price of the systems using clusters of low-cost computers.

The evaluation of the results achieved by these two lines of work will be performed while developing prototypes which cover different approaches in the operator training field, after considering their technical viability and social and economical relevance.

- An arthroscopy trainer, which includes a simple visualization process, but with the requirements to incorporate mechanisms of interaction between surgical instrumental and anatomical tissues and to supply force feedback through haptic devices.

- An industrial operator trainer based on immersive visualization with image projection on several walls of a reconfigurable visualization CAVE-like system or wraparound screens.

These objectives have been distributed between the two subprojects of the proposal in the following way:

- Subproject no. 1: Improvement of multiresolution representation techinques and development of demonstration applications. Within Subproject no. 1, algorithms for limiting the complexity of virtual objects and environments are being developed. Also, this subproject is in charge of developing the demonstration applications, which requires the development of a certain number of algorithms and techniques for several purposes, such as collision detection, deformation of non-rigid tissues, force feedback generation, etc.

- Subproject no. 2. Utilization of clusters for simulation, immersive visualization, alignment error detection and correction in projecting mosaics. The aim of this subproject is to create a basic experimentation environment for developing parallel and distributed versions of VR algorithms, particularly in the field of visualization.

1.2 Available resources

The currently available resources allow ensuring the correct development of the tasks programmed until the end of the project, having in mind to specifically make new acquisitions when needed. In the following, we show a short compilation of the most remarkable material resources.

Virtual reality and advanced visualization.

- A RAVE-like (Reconfigurable Advanced Visualization Environment) immersive projection system
- One portable 3D projection system.
- One laboratory of virtual reality equipped with virtual reality helmets, augmented reality helmets, - 1 Dataglove, several haptic devices (1 Phantom, several Phantom Omni and 2 Impulse Engine) and 1 VLI.
- A 3D laser scanner.

Computacional resources

- Access to a Cluster with 248 IBM Blade processors (no. 341 in the Top500 supercomputers ranking) in the CeSViMa consortium (Center of Supercomputation and Visualization from Madrid).
- Several Beowulf clusters, one configured with 40 processor nodes, another one with 20, another with 4, and the last one made up of 10 biprocessor nodes.
- Several Silicon Graphics multiprocessors: Prisma (16 processors), Altix (8 processors) Origin (8 processors), Challenge (10 processors).
- A SP2 IBM multiprocessor with 10 processors.
- A Sun multiprocessor with 10 processors.

1.3 Task schedule

We have carried out a hierarchical breakdown of the performed activities following the same approach presented in the memory application. According to that, the project "Virtual trainers using low-cost platforms" has been decomposed in two subprojects:

- Subproject no. 1 (TIC2003-08933-C02-01): Development of virtual trainers in surgical and industrial environments.
In this subproject, a new level of subdivision has been performed in order to remark the significance and difference between two programmed general tasks:

- Subproject no. 1a (S1a): Development of efficient techniques for representing and visualizing 3D objects.
- Subproject no. 1b (S1b): Development of demonstration applications.

- Subproject no. 2 (TIC2003-08933-C02-02): Development of immersive visualization systems using low-cost platforms.

Besides the tasks belonging to the whole project, General Coordination (*cogen*) and Configuration and documentation management (*gescd*), in the following sections we detail the activities assigned to each one of the subprojects:

- Tasks related to Subproject no. 1a (S1a): Coordination of the research group, Selection and study of the bibliography (*s1aseb*), Market analysis and equipment acquisition (*s1amae*), Analysis and development of new multiresolution representation techniques considering simultaneously

geometry and texture (*tmgt*), Multirresolution techniques through the use of intermediate representations (*tmri*), Development of simplification techniques for complex scenes through object hidding (*tseo*), Model representations in artificial environments (*rmea*).

- Tasks related with Subproject no. 1b (S1b): Research group coordination (*s1aco*), Study of existing systems (*s1besd*), Market Analysis and equipment acquisition (*s1bame*), Analysis of the surgical and industrial trainers (*fae*), Design of the surgical and industrial trainers (*fde*), Implementation of a basic application for the surgical and industrial trainers (*fce*).

- Tasks related with Subproject no. 2 (S2): Research group coordination (*s2co*), Selection and study of the bibliography (*s2aseb*), Market analysis and equipment acquisition (*s2amae*), Visualization architecture's definition (*dav*), Design and implementation of the visualization architecture (*dcv*), Adaptation of the representation techniques (*atr*), Adjustment of the alignment among the projected images (*aip*), Nodes' synchronization (*sen*), Image synthesis parallelization (*par*).

Table 1 shows the initial planning of the project that highly fits the developments executed until now.

Table 1

Task	First year												Second year												Third year											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Cogen	•			•						•	•				•		•					•					•								•	•
Gescd	•			•						•	•				•		•					•					•								•	•
S1aco	•			•						•	•				•		•					•					•								•	•
S1aseb	•			•						•	•				•		•					•					•								•	•
Slame	•			•						•	•				•		•					•					•								•	•
Dav	•			•						•	•				•		•					•					•								•	•
Dcv																																				
Atr	•			•						•	•				•		•					•					•								•	•
Sen	•			•						•	•				•		•					•					•								•	•
Pars	•			•						•	•				•		•					•					•								•	•
S1bco	•			•						•	•				•		•					•					•								•	•
S1esd	•			•						•	•				•		•					•					•								•	•
S1bame	•			•						•	•				•		•					•					•								•	•
Fae	•			•						•	•				•		•					•					•								•	•
Fde	•			•						•	•				•		•					•					•								•	•
Fce	•			•						•	•				•		•					•					•								•	•
Aip																																				
S2co	•			•						•	•				•		•					•					•								•	•
S2aseb	•			•						•	•				•		•					•					•								•	•
S2amae	•			•						•	•				•		•					•					•								•	•
Tmgt	•			•						•	•				•		•					•					•								•	•
Tmri	•			•						•	•				•		•					•					•								•	•

Task	First year												Second year												Third year											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Tseo	•		•							•	•				•		•				•				•										•	•
Rmea	•		•							•	•				•		•				•				•										•	•

2 Level of success achieved in the project

In the case of Subproject no. 1a, the Computational Geometry group has obtained results in several aspects, giving theoretical support to the development of computer applications oriented to the representation and visualization of three dimensional structures.

- Advances in the development of speculative parallelization techniques, which allow obtaining automatically parallel algorithms from sequential algorithms. It works especially well when it is applied to geometric problems. In particular there are interesting results in the computation of convex envelopes.

- Solutions for geometric problems with applications to the mechanic engineering and architecture fields have also been obtained.

- Problems related to supply planning delivery and transport planning have also been considered, where new Voronoi diagrams take part of the solution in a decisive way.

- New results related to visibility problems that can be applied in different areas of the project, as well as in other areas such as illumination and surveillance.

- Some combinatorial problems have also been solved.

- The study of some of the existing algorithms to perform frustum culling and occlusion culling has been dealt in great depth, both for the rendering of interior and exterior scenes. The studies are focused in the algorithms of portals combined with the use of leafy BSP's to render interiors, and multiresolution techniques for representing the ground geometry for the exteriors. In this context, the PhD Thesis "A multirresolution model for plane graphs representing geographic maps" has been finished.

- A 3D chat system has been developed, where the conversations among different users take place outwards, and both frustum culling and the occlusion culling are executed through BSP's implemented using genetic algorithms.

The developments carried out by the Computational Geometry group have been complemented with the work developed in Subproject 1b, applying some of the theoretical results to the development of VR trainers. During this process, also new algorithms have been developed which have resulted in new publications and achievements. In particular:

- There is an important advance in the development of a surgical trainer for arthroscopy operation. A preliminary version of the prototype has been presented in the last conference organized by the Spanish Arthroscopy Association in Sitges, from the 25th to the 27th of may 2005, achieving an outstanding success in its presentation and raising a great excitement about the possibilities of this tool in relation to the training of arthroscopy surgeons. As a result of the first developments, an agreement was reached with the company GMV in 2004. It was focused on achieving a commercial exploitation of the trainer (more details of this agreement can be found in the next Section).

- Many efforts have been devoted to the improvement of the techniques for representing 2D and 3D objects stated by the research group in previous projects and in the quest of new and more efficient techniques from a computational point of view. One example would be the consideration of new multiresolution techniques using intermediate representations.

- The techniques for content-based 2D image retrieval previously developed by some of the members of the research group have been extrapolated to video sequences, finishing the PhD Thesis "Content-based image and video retrieval techniques on parallel architectures", reported in the Section "PhD Thesis".

Next, we explain the development progress for the tasks assigned to Subproject no. 2. Some of them entail the adaptation of representation techniques and the parallelization of image synthesis procedures using the algorithms developed by the other partners. Because of this, it was decided that, in addition to keep working on load balancing issues, to set up a system (with its corresponding prototype) for testing parallel solutions. This strategic decision is implemented using as a base the free distribution Chromium software and porting it to our system, and adapting the Softgenlock free distribution software to add its functionality to the Chromium tool. At the present moment, the last version that has been distributed of this tool (cr 1.8) is being used, so the required changes are applied to introduce the realignment and synchronization mechanisms and part of the objectives of the subproject will be covered.

To complete the activities associated to the considered objectives, we have started to work on the adjustment problem that appears when several images are combined, tackling it in a global way with the objective of achieving an automatic alignment of the projectors, both before beginning and during the projection, and correcting also in real time the small failures that could happen during the projection of real images.

Also, as a result of the collaboration between the participants in Subprojects no. 1 and no. 2 and considering the importance that it has for these type of systems, a general line of research about clusters and load balancing has been kept active all the time. In this line the following work has been done:

- Scalability model for heterogeneous clusters: a new model for heterogeneous efficiency, necessary to obtain a model of heterogeneous isoefficiency has been developed. Analytic studies complemented with implementation works in deeply heterogeneous clusters have been executed.

- Parallel computation model: the model LogGP has been generalized so it can work with heterogeneous clusters leading to the new HlogGP model.

- Load balancing: new procedures have been proposed for measuring the computational power of a node in order to decide which is the most suitable one to execute one task in a given moment. A detailed analysis of all the phases of a load balancing algorithm has been made, proposing for each case new models of work and performance metrics and obtaining the best solutions for each one of the phases.

In this course of action, the Doctoral Thesis "Load balancing in heterogeneous clusters" also reported in the Section "PhD thesis", has been recently finished.

3 Results' indicators

The developed work has generated numerous publications, most of them of international diffusion in relevant journals and conferences (see Annexe I). Also, a technology transfer of the results to the industrial sector has already been produced. As a result of the first developments performed by the Modeling and Virtual Reality Group (GMRV) to design and build a surgical trainer, we have contacted the Spanish company GMV to study the possibility of exploiting these results from a commercial point of view. These initial contacts have resulted in a collaboration agreement among the company GMV and the URJC and UPM universities to commercialize the system. The collaboration agreement lasts up to the end of 2005, being already foreseen its extension when the present agreement concludes [DPD05]. Furthermore, the company GMV has applied for public finance to CDTI and PROFIT programmes to subsidize the mentioned agreement [CDTI05, PROFIT05]. In this course of action, GMV has invited GMRV to participate to in new collaborations to develop a laparoscopy trainer [INFUS05].

Taking into account the analysis carried out and the acquired experience in the development of the medical trainer, it will also be possible to apply to the industrial trainer some of the techniques of representation and animation used in the surgical trainer. Then, we can say that at the present moment there is a solid base to guarantee the success of the development of the industrial trainer and it is possible to transfer the results to companies interested in the project.

Moreover, the GMRV group from URJC and UPM has obtained some funds from the Autonomous Community of Madrid to continue the research in the virtual surgical trainer area [SARA05]. Basically, the funds obtained guarantee the incorporation of a Doctor with a profile based on the simulation deformable objects with tactile feedback to the research group.

Recently, we have applied for additional funds from the Autonomous Community of Madrid to coordinate the development of I+D programs among different research groups in the Community of Madrid, where the participants in the present project have played a basic role to agglutinate and boost the presented initiative.

In the international area, the collaboration initiated with the Dipartamento di Informatica e Scienze dell'Informazione from the Genova University still continues. Professor Enrico Puppo, external participant in the project, carried out a one week visit to the Alcala University and gave a conference in the URJC.

Shortly, a visit from the Canadian professor Godfried Toussaint, from the McGill University of Montreal is expected.

Furthermore, we have contacted the Australian University of Western Sydney to set a schedule to exchange visits of researchers from both groups. Within that context, Prof. George Bryan will stay at URJC for a month by late 2005.

Also we maintain contacts with researchers from the University of Dublin, Trinity College from Ireland in tasks related to content based retrieval systems and with the Uppsala University from Sweden in the area of 3D representation.

To conclude, statistic summary of the works published until now is shown:

- International publications with impact index: 15 publications. 5 of them have been published in journals or as chapters of books with impact index. The other 10 have been published as part of proceedings. They all appear at the ISI Web of Knowledge.

- Other international publications: 10. A few of them are so recent publications that they have not been collected yet in impact indexes.

- National publications: 10

4 References

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[CDTI05] Título del proyecto: "Desarrollo de un Prototipo-Demostrador de Herramienta de Simulación Avanzada y Entrenamiento de Cirugía Mínimamente Invasiva – SIME(CMI)" (Ref. 04-0698) Entidad financiadora: CDTI-MITC Entidades participantes: GMV, Dpto. de Informática, Estadística y Telemática de la Univ. Rey Juan Carlos, Dpto. de Tecnología Fotónica de la U.P.M. y Hospital Severo Ochoa de Leganés. Investigador principal del proy.: D. Jorge Potti Duración: 2005

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Annex I: List of publications

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TIC2003-08933-C02

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- M. Abellanas, S. Canales y G. Hernández. "Buena iluminación." Actas de las IV Jornadas de Matemática Discreta y Algorítmica, pp. 239-246; Cercedilla. Sep.2004.

Annex II: PhD Theses

Title: "Content-based image and video retrieval techniques on parallel architectures"
Author: Oscar D. Robles Sánchez
University: Politécnica de Madrid
Center: Facultad de Informática
Date: December 2004
Director: D. Luis Pastor and D. Ángel Rodríguez
Mark: A cum laude unanimously

Title: "A multirresolution model for plane graphs representing geographic maps"
Author: Raquel Viaña
University: Alcalá de Henares
Center: Informática
Date: November 2004
Director: D. Enrico Puppo and D. Pedro Ramos
Calificación: Sobresaliente cum laude por unanimidad

Title: "Equilibrio de carga en clusters heterogéneos"
Author: Marta Beltrán Pardo
University: Rey Juan Carlos
Center: Escuela Superior de Ciencias Experimentales y Tecnológicas
Date: July 2004
Director: D. José Luis Bosque Orero