Case study: full-size virtual models of trains

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Abstract

Simulation of models, in all different areas, is an expanding, attractive line of work. More and more applications are taking advantage of the improving technology and knowledge in this field, achieving results that would have been impossible to achieve with a real model, or foreseeing facts that would have been encountered too late in the production process otherwise.

The train industry is one possible beneficiary of this approach. Usually, before commencing the fabrication process of a new train, the construction of a full-size model is mandatory. Instead of building this full-size real model, which leaves little room for later, last-minute modifications, a virtual model could be built in the digital realm, thus offering a new platform for easier interaction with it. In this article, a simulation of a train is presented for visual, aesthetics and ergonomic issues. The simulation runs on a PC-based CAVE-like architecture, and combines static and dynamic computer generated imagery, both with and without stereoscopy for 3D visualization, as well as Augmented Virtuality techniques for the integration of the train with its environment.

Key words

Simulator, CAVE, industrial design, stereoscopy, virtual prototyping

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1. INTRODUCTION

Simulation is a way of working that allows the study of a physical system by substituting it for another, more suitable to observation or measure.

Different interests can be addressed by means of simulation. These different approaches require different layers of complexity in the simulation: an astronaut trainer, for instance, will most likely need to be able to simulate, up to a certain degree, the dynamics of the system. On the other hand, a car company might not need such realism if only the visual appearance is to be discussed by means of the simulation. But, once the general shape is approved, it might then need to undergo a simulated wind tunnel test, which will require a new layer of complexity in the simulation. Thus, motivation guides the simulation itself.

Several simulations will work better by using Virtual Reality techniques [Hollands96] [Burdea96] [Kalawsky93]. These techniques create immersive environments that make the interaction between man and simulator as indistinguishable from reality as possible. Most of the times this implies the concept of real time, although as we have seen its necessity will be driven by the goal of the simulation.

The fields where simulators are most often used are military, civil and leisure [Dodsworth98]. Several internet addresses offer information about some of the best simulators nowadays, and can be found at [INRETS] [DAIMLER].

1.1 Virtual Prototyping

Virtual prototyping allows designers to test and improve their design as when using physical mock-ups, but better, earlier and with more opportunities for multi-site collaborations. Architectural building walkthroughs have been one of the most successful applications of virtual reality. These systems permit the architect to prototype a building and to iterate with his client on the detailed desired data for it [Brooks86] [Airey90]

Natural interaction with digital models is very important, especially for testing purposes. In an attempt to overcome CAD systems´ interactivity and concurrent design limitations, large engineering projects have often been accompanied by the development of various kinds of specialized virtual prototyping tools [Ellis96]. Examples include the ISS VR Demonstrator used by Rolls-Royce to make an assessment of how easy it would be to build an engine and maintain it [Greenfield96] and Boeing´s high-performance engineering visualization system used during the design of the 777 [McNeely96]. Moreover, the French Space Agency (CNES) and CISI have jointly launched the PROVIS [Balet97] research project in 1995 for developing solutions for satellite designers to create, manipulate, and study their models using digital mock-ups, while CRS4 and CERN have jointly developed the i3d system for supporting the deign of CERN´s Large Hadron Collider [Balaguer95] [Gobbetti95]. These efforts show the interest of interactive virtual prototyping for early testing of designs.

1.2 The CAVE system

The CAVE (Cave Automatic Virtual Environment) is a virtual reality and/or scientific visualization system. Its motivation was rooted in the SIGGRAPH'92 Showcase. Showcase was designed as an experiment, advocating an environment for computational scientists to present their work in an interactive way. The CAVE succeeded in attracting serious collaborators, thus establishing itself as a consolidated virtual reality display [Cruz-Neira93]. Several applications of the CAVE were featured during the Showcase [Cruz-Neira92], including visualizations of weather simulations, graphical planning for brain surgery, fractal exploratorium or the universe. Instead of using a HMD (Head-Mounted Display) it projects stereoscopic images on the walls of room (user must wear LCD shutter glasses). This approach assures superior quality and resolution of viewed images, and wider field of view in comparison to HMD-based systems.

As originally conceived, the CAVE is a theater of roughly 3m x 3m x 3m, made up of four rear-projection screens (three walls plus the floor). Projectors throw full-color imagery onto the screens. Stereographics' LCD stereo shutter glasses are used to separate the alternate fields that go to each eye (For a more complete description about steresocopy and other related issues, the reader can refer to [Lipton91] [Pastoor91] [Woods93] or [StereoGraphics97]). Four Silicon Graphics high-end workstations create the imagery, plus a fifth for serial communications to input devices and synchronization. The users' head and hand are tracked with devices equipped with electromagnetic sensors. The projectors' optics are folded by mirrors, thus reducing the space necessary for the setup.

Several actual applications of the CAVE system are [Laszewski99], which involves interactive analysis of synchrotron light source data; interaction with a distributed multiagent system [Spoelder]; CAVEStudy, which allows interactive and immersive analysis of a simulation running on a remote computer [Renambot00]; VIRPI, an integral toolkit for interactive visualization in virtual reality environments [Germans]; Imsovision (IMmersive SOftware VISualizatION), the development of a Virtual Reality Environment for software visualization. It acts as a research platform to investigate how immersive visualization environments can assist in the problems of software development and maintenance [Maletic]; GeomCAVE, a system that uses Virtual Reality to visit 3D manifolds [Hudson95]; [Leigh93], realistic modeling and visualization of the synaptic interaction between two mammalian neurons; the Cosmic Worm, which is the implementation of a distributed system that uses the CAVE to control and steer scientific simulations being computed on remote supercomputers [Roy95]; or the KidsRoom, a perceptually-based, interactive, narrative play space for children [Bobick96].

It is important to know that the terms "CAVE" or "cave" cannot be used to refer to generic technology, since the University of Illinois Board of Trustees registered the trademark, and subsequently licensed it to Fakespace Systems exclusively and worldwide. Given this legal frame, we will refer to our system as "a CAVE-like system", or CLS.

2. DEFINITION OF THE PROBLEM

The process of building a train is by no means simple. Usually, the contractor will make a call for tenders and, based on engineering aspects, awards the project to one of the proposals. Once the project is signed, the phase of designing the train begins. This might include a third party, concentrating only on this task. The process involves a lot work, including conceptual designs, color palettes, sketches… The information goes back and forth between the parties involved, until the contractor is satisfied with the results.

This design process is way more important than what most people might think. Engineering considerations set aside, the visual aspect plays a key role. How the public will accept the train depends of course on functionality issues such as speed or accessibility, but also on considerations relating comfort (are the seats too packed together? Are the corridors wide enough?), ergonomics (is the monitor visible from this specific place? Is the luggage area accessible?) and pure aesthetics (does this color scheme work? Do the shapes seem to belong to one unified design?).

To address most of these not-so-technical issues, the contract includes as a requirement the construction of a full-size model of only one of the cars that make up the train, usually the most representative, due to budget limitations. More often than not, the contractor finds out that what worked as a sketch on paper does not work when built full-size in 3D, but changing it is costly in terms of time and money. Even though this full-size model approach allows one person to actually get into the car, walk through it, sit down to test the seats etc, it imposes serious restrictions:

- Size and mobility. The full-size model is obviously hard to transport from one place to another, thus limiting the physical space where it can be shown. Only one car is built, and it is a fixed model with no movement capabilities at all.
- Versatility. After examining the full-size model, changes in shapes, lighting or appearance can only be realized by rebuilding whatever parts are involved in the change, then reinstalling them in place. This is not only expensive, but involves heavy time delays as well. Consider the trouble it means to change a critical element such as the seat, for instance. Or a change in the color of the floor, that would involve fixing a new carpet to the whole car.
- Economy. These full-size models tend to be very expensive, which affects the number of changes can be done within a reasonable budget.
- Life. Once used and approved, the full-size model is usually destroyed for storage reasons.

As an alternative to this classical approach, the authors proposed the construction of a CAVE-like System (CLS). The CLS has been designed to overcome all these shortcomings and change the methodology of the design process, turning it into a cheaper and more flexible one. More precisely, by building a digital model, the restrictions mentioned above are solved, while extra features are added:

- Mobility. The proposed CLS can be dismantled and shipped to be shown in different places or cities, in different frames (fairs, congresses, train stations...) which helps the dissemination of the product. Also, scaled-down versions can be given away in CD or DVD formats for yet deeper and wider dissemination.
- Versatility. All kinds of changes in shapes, lighting or appearance are feasible with the digital model, and much less costly in terms of time and money. Pre-planned changes and different options are only a mouse click away. For instance, the user can compare between five different color schemes, three types of seats and six floors to see which combination works best, add people, change from natural daylight to artificial night lighting... On top of that, the digital model can simulate movement through rendered animations.
- Economy. Once the initial hardware investment has been made, the digital approach is one order of magnitude cheaper than building the physical model. The first model, including the hardware investment reusable for subsequent models, has roughly the same price as one full-size model.
- Life. The digital information lasts virtually forever.
- Extension. Using Augmented Virtuality techniques [Milgram94], the model can be inserted in real environments, or ergonomics can be studied placing people and objects in the desired places, providing at the same time a greater sense of realism to the viewer.
- Quality. The digital model is a perfect medium for presentations. In addition to this, it also remarkable the spectacular nature and innovative side of this approach, an added value for commercial and publicity issues.

Considering all the pros and cons of the digital, virtual model approach, it makes sense to think it is worth the effort. The decision to build the digital model was taken by Construcciones y Auxiliar de Ferrocarriles (CAF), Renfe Cercanías [RENFE] and the Grupo de Informática Gráfica Avanzada (GIGA; Advanced Computer Graphics Group) of the University of Zaragoza. The proposed methodology changes the old full-size model paradigm, providing the CLS as a working system since the early stages of the design. The parties involved can propose a design, see it in a full-size stereoscopic display, change it or tweak it if necessary, go back to the CLS to test it and so on, until the cycle converges into the final design. Needless to say, all the changes done in the digital realm are a lot cheaper and can be done faster than with the real model. In addition to this, the digital model can be seen in different daylight conditions, at night, inside a tunnel, integrated with different real environments, with real people etc.

Computer generated imagery has therefore been generated, both static and animation, for regular and stereoscopic viewing. The following paragraphs describe the system specification as well as certain decisions taken during the implementation.

3. SYSTEM SPECIFICATION

A low-cost CLS was chosen as output format [SGI]. Four to six people can fit in comfortably, although there is only one ideal point of view from which perspective and stereoscopy look perfect, since it is the point of view for which both have been calculated [McAllister93].

Given the nature of the project, the notion of real time was turned down in favor of high quality imagery. That means that the images have all been prerendered, instead of using some graphic library such as OpenGL [Woo96] [Kempf97] to calculate and display them in real time. Softimage XSI was used for modeling and animation. The chosen rendering algorithm was ray tracing, favored over more advanced Global Illumination methods such as photon mapping [Wann01] due to the lesser time needed to generate one frame with the former approach. Global Illumination effects were cheated for a more soft, natural look than what off-the-shelf ray tracing usually offers.

3.1 Hardware

Hardware-wise, the system is made up of the following elements:

- 3 flat panel screens for rear projection (two screens of 4x3m, one of 3x3m) assembled with wedge frame, t-bars and light baffles. Additional characteristics are gain 1.0 and 180 degrees of viewing angle. The washable, flame retardant screens do not depolarize the light projected on them to allow for stereoscopic images.

- 6 LCD projectors (XGA panel, 1800 ANSI lumen, 1024x768 native panel resolution) to project images and videos onto the screens.
- 6 fixed short focus lenses with throw ratio: 0.9:1. They are used to reduce the distance between the projector and the screen, instead of folding the projectors' optics using heavy and fragile mirrors.
- Polarizing filters placed in front of the projector lenses and polarizing glasses for the audience for stereoscopic views.
- Two mid-sized PC's (P-III @ 800 Mhz, 256 Mb RAM) running W2000. One is equipped with two MPEG-2 decoder cards, each one offering four channels of simultaneous MPEG-2 decoding. The two cards combined assure that the six videos projected during certain moments of the presentation (two for each eye times three screens) run in sync, keeping both the stereoscopic effect and the continuity between them. The other one will send static SVGA imagery, so it must have six SVGA output channels (different combinations of regular SVGA cards assure that).

The screens are supported by a frame made up of four beams assembled together, forming a rigid rectangle; the cantilevering wedge screen framing system allows each image to be rear projected completely to the outer edge of the seam – which minimizes the apparent gap between all adjacent images. The screens material is flexible, thus allowing for easy transportation by just rolling them up carefully. To assemble it, the screens are unrolled over the frame, fastened to it and tightened with a towrope. Once the screens are completely assembled, their frames are fixed to one another in their final position, so that no additional structure is needed for the screens to stand in the upright position.

3.2 Viewer–centered perspective

Our aim is to have the users see exactly the same things, at 1:1 scale, that they would see if they were standing inside the real train. We must make the projection planes in our perspective match the real CLS walls, and the projection focus should be exactly at the viewers' position. Since our CLS renders off-line in order to achieve the required photorealism in the images using low-end hardware, we must choose an "ideal user" fixed viewer position inside it. The obvious choice is to have this ideal user standing at the center of the floor, and looking at a point located at the center of the front screen, with the same high as the viewer's eyes (which are also fixed to a mean standard value of 1.65 m.). This means our CLS ideal user has to be looking at the front wall, while the side walls are used to fill the field of view, i.e., to bee seen through the corner of the eye; if the user rotates his head to look directly to, say, the left wall, he will not see a real stereo view. Figure 1 shows this viewer-centered perspective.

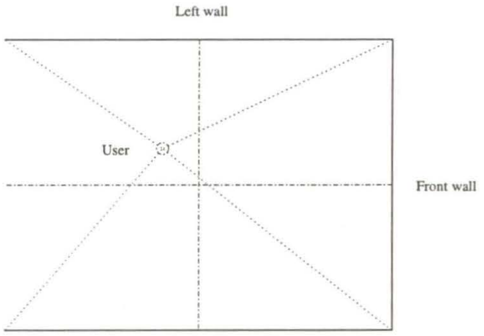

Figure 1: Viewer-centered perspective.

This off-axis projection must be achieved using the standard perspective available on most rendering software, which allows just a symmetric projection around the viewing axis (the usual "camera view"). An easy way to get the desired asymmetric projection (remember we have to render both eyes' views, so the will be displaced a bit from the ideal user's center) is to render at the minimum resolution which will cover the full projection plane and crop to the final wall coordinates. Figure 2 represents this for a left eye projection:

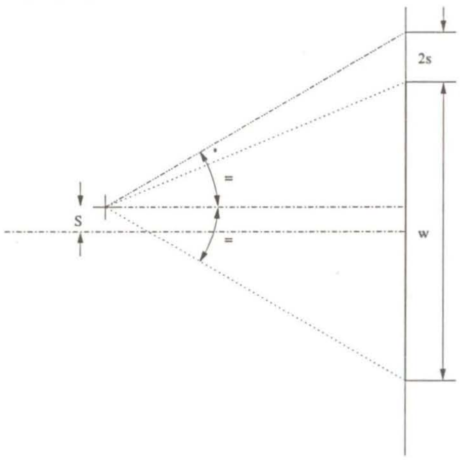

Figure 2: Asymmetric perspective s: distance from central axis w: width of projection plane

As we can see in Figure 2, the symmetric standard perspective which covers the desired projection plane, centered at viewer's position, is obtained by increasing the resolution in an amount equal to two times the distance between the viewer's eye and the perpendicular axis to the centre of the plane(s). This operation should be done both for width (when the viewer is not exactly on the center of the CLS, or for stereo views when the viewer is located at the center, where we have to use the eye-separation value, estimated as 57 mm) and height (for taking into account the height of the viewer's eyes over the center of the wall).

From this theoretical resolution, measured in "real" units, we will have to crop off the region which will lay outside the wall, which obviously will match the increment used (2s) and will be located at the edge closer to the viewer. Then, both the final resolution and the crop window have to be translated to pixel units using the projection device resolution (720x576 for MPEG-2 PAL output and 1024x768 for SVGA).

This process needs to be done six times (three screens times two eyes). We used a simple program, designed as a plug-in for the rendering software, which would take the input data shown in Figure 3 and would define the six cameras necessary for correct stereoscopy.

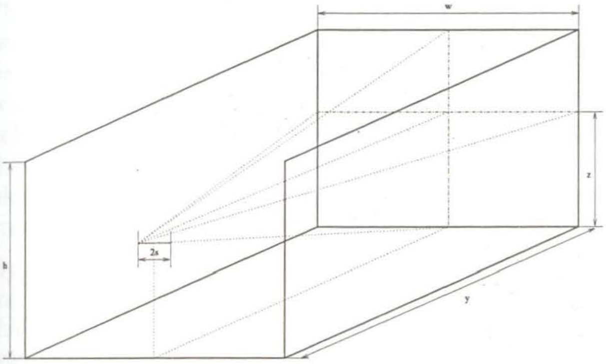

Figure 3: Input data. w: width of CLS h: height of CLS y: viewer's distance to the front wall z: height of viewer's eyes 2s: inter-eye distance

3.3 Video display and slide show

We faced two main issues in the process of designing the video display subsytem:

- The ability to deliver six (three stereo pairs) video streams in real time from a single computer.
- The need to play them synchronised at frame level.

The first point above lead us to the need of special hardware add-on cards to play the six streams. These cards also offer the posibility to link the streams on a time or frame basis for synchronisation. The control software is based on the SDK provided with the aforementioned cards, that gives some low level functions to programm the cards the way it is needed. This software offers access to functions like synchro-start, state querying, etc. We had to program the high-level flow logic of the system and the error control and recovery. GUI programming was done with the GTK+ for Windows library, that offers both an efficient and complete toolkit.

On the other hand, the slide show program is a conceptually simple tool: it just takes six images and displays them in six monitors. The main problems came from the state of the technology in COTS (commodity-off-the-shelf) hardware in PCs.

One of the conditions of the design was that the show could not be stored in memory, so the slides must be loaded on real time. For this purpose we designed a caching-prefetchig system that loads from disk the next frame the user is going to see after displaying the current one. This lets the computer unusable while heavily reading from disk (and perhaps decompressing JPEG or other format), but this time is spent by the users either discussing about what is on screen in that moment or just paying attention to the specific details shown in the picture. We wanted the presentation to include some nice effects, like fading between slides. Hardware acceleration is defective (in the best case) under Windows in multimonitor conditions (remenber you only have one AGP slot, so many of the additional cards were on a 33MHz PCI bus). Just the process of dumping raw images to the cards works roughly at 5 fps. In addition we needed to generate the intermediate frames for the transitions in real time, and an opperation like weight-averaging two frames for a simple fade is very time consuming. This process was added also in the prefetching code.

The amount of interaction with the program is limited. The system is built to be controlled from inside the CAVE, so the remote control has to be radio-based (ie, non optical). This kind of controls are usually mouses or small trackballs with 2 or 3 buttons, and are not very comfortable to use (try turning the trackball with the thumb while you press a button...). So no complex operations were designed. Just step forward and backwards, and the possibility to add a popup menu of basic functions (rewind, fast-forward) on the third button. This limited amount of interaction, though, proved to be more than enough for the desired type of presentations.

Before the presentation, the audience is given polarized glasses. During the presentation, they are prompted (by means of a static virtual actor) to put them on or take them off, depending on whether or not the images are stereoscopic.

Figure 4 shows roughly the dimensions of the system described. Figure 5 shows a few pictures of the actual CLS built. For simplicity, it was decided not to have a floor or a ceiling, at least in this first prototype. The ceiling, though, has been covered with a black canvas, not to let any light out. Similarly, the room the CLS is in has been painted in matt black to absorb any light filtering in or bounced off the screens.

Figure 4: Dimensions of the system in centimeters

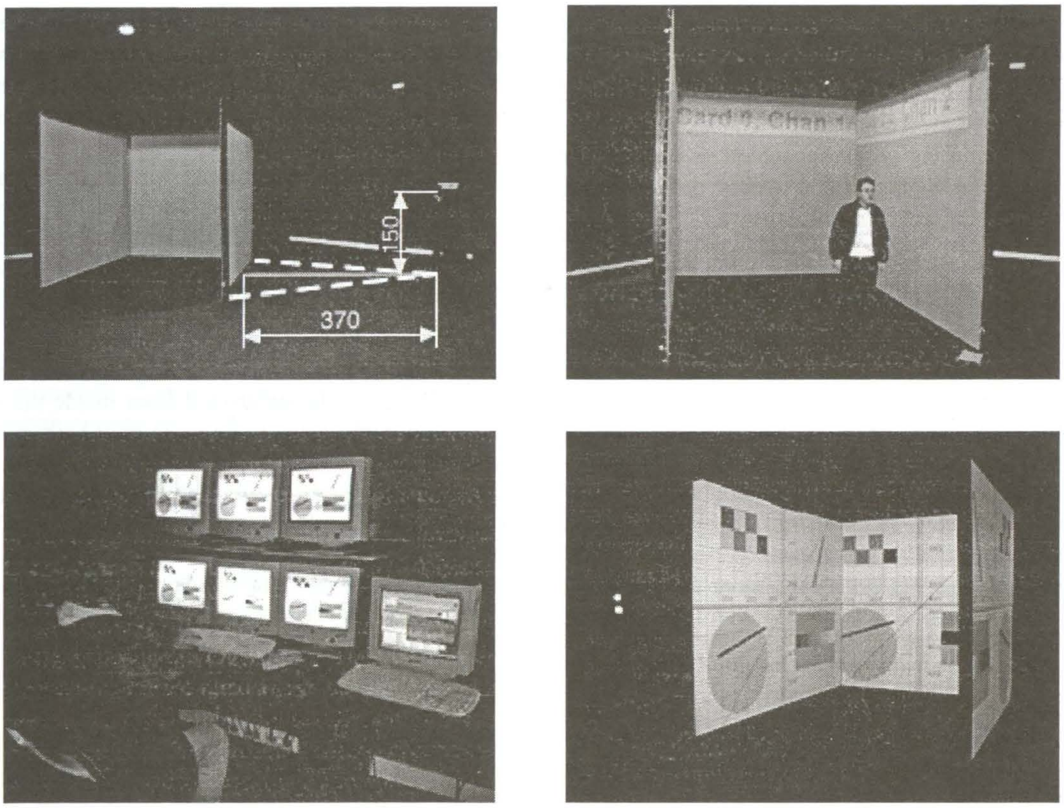

Figure 5: The CLS system

4. RESULTS

The simulation was asked for by Construcciones y Auxiliar de Ferrocarriles (CAF), with Renfe [Woo96], the biggest train company in Spain, as the final client. More than twenty minutes of computer generated imagery made the cut for the final version of the simulation. As it has already been stated, this imagery included both static images and animation, with and without stereoscopy. In addition to pure synthetic images, Augmented Virtuality techniques were also used to, for instance, have the train come to a stop in a real train station carefully photographed in advance for that purpose. The images were sent to the projectors either in SVGA format or S-Video format. SVGA was used for static imagery, with transitions and fades calculated in real time by one of the PC's. Those images were rendered at a resolution of 1024x768. Images were limited to that resolution by the projectors' native panel. Animations were sent in S-Video, at a resolution of 720x576. This time, the limitation was imposed by the graphic cards used to decode six MPEG-2 channels simultaneously. Perfect synchronization of those cards was required in order to keep continuity in the images projected onto the different screens, and to maintain the stereoscopy. This was achieved by writing another program, that would use the software libraries of the own cards.

The simulation was controlled by one script in the case of static imagery. A wireless mouse was used to advance or go back. An automatic version of the script that required no mouse interaction was also written but never used, since one of the goals of the simulation was to be able to stop at any given point and discuss as much as desired over the selected image. The animations were run by the graphic cards' software, since not too much interaction was required.

After initial tests, it was decided to start the presentation with the S-Video animations, including the train coming to a stop in the real station and the surrounding stereoscopic walks inside the train. Then we would turn to SVGA, thus presenting higher-resolution images. Doing it the other way around would have mean a decline in the quality, which initial tests showed to be unpleasant.

A synthetic hostess guides the users throughout the presentation, explaining what parts are going to be seen, and prompting them to put on the stereoscopic glasses or take them off. A small map of the train is shown on one of the side screens when necessary, to help the users locate themselves.

Animations were rendered on a render farm made of six double-processor stations with 1 Gb of RAM, running Windows 2000. For static imagery eight additional machines were used whenever the user would log off.

Table 1 shows some of the most relevant statistics of this simulation. Figure 6 shows the simulation running on the CLS, as well as several of the images produced.

We would also like to mention the fact that the legal patent process for the system has already been started by the authors.

5. CONCLUSIONS

A train simulator entirely developed by the Grupo de Informática Gráfica Avanzada of the University of Zaragoza has been presented. The simulator, based on a low-cost CLS architecture, is fully functional, and has been used in several simulations already with CAF and Renfe staff with satisfactory results.

The possibility of not using a real model for the design process of a train has been proved. Lots of variations can be presented sharing a common design in a cheap, fast way. Images with different floors, seats, doors, windows or color schemes can be rendered to be viewed and compared full-size, even side to side if necessary. Elements can be hidden or shown in isolation, full-size or blown up full screen for better study.

By adding people to the images, the real perception of the train can be seen. An empty train interior tends to look dull, since usually the color schemes used are meant that way. As the Renfe management puts it, "*people are the color of the train*". That fact was proved by showing empty images first, then adding different configurations of people sitting, staring out the window, walking down the corridors...

Lots of changes in the design of the train were induced by the images produced. The seats, for instance, which design had been approved based on their ortographic views, were found not to look so good from a natural, passenger's point of view, and so they were sent back to the drafting table. Also, a slightly darker hue was chosen when early render tests showed poor contrast with the train walls and ceiling. Displays on the outside were made bigger for better reading, after the Augmented Virtuality test of the train coming to a stop in a real station showed poor readability. Monitors were raised a little bit higher, after visibility tests were conducted placing virtual people standing up next to them. Several seats were removed after animatics showed they took up too much space. The original color chosen for the floor carpet was changed after illumination tests, waste baskets redesigned, speakers made a bit smaller... These are just some of the changes that could be easily done in the digital realm, but would have cost a lot more to do with a real model. Not only they were faster this way, but the flexibility of the system allowed CAF and Renfe to explore more creative paths than they usually would have, coming up with a far better product from an aesthetic and ergonomics point of view.

Rendering time for the animations	576 hours
Animations generated	27.997 frames (18 minutes 40 seconds)
Animations selected for the simulation	17.275 frames (11 minutes 31 seconds)
Number of static images rendered including low-rez	5000 (roughly)
Number of static images selected for the simulation	207
Postproduction and generation of MPEG-2 files	360 hours
Textures	23,5 Mb, 217 files
Materials and shaders	3.140
3D Objects	9.379, for a total of 194 models
Polygons	2.029.027

Table 1: Statistics of the simulation

Running the simulation with people inside the CLS let us come up with two important conclusions as well. First one is the fact that, even though there is only one ideal point of view from which perspective and stereoscopy have been calculated, any mismatches or discontinuities perceived by people not standing exactly on the ideal point are subconsciously assumed, not causing any discomfort while viewing the images. Inside a circle with a one-meter diameter, centered at the ideal point of view, both stereoscopy and perspective still hold. Outside that area, stereoscopy still looks alright, but perspective discontinuities appear at the corners between the frontal and the side screens. Second conclusion is the tendency of people to look up front to the central screen. Unless the focal point of the image lies intentionally on one of the side screens, people use them just as peripheral vision, enough so they can feel the sense of immersion. This fact helps in the stereoscopic views, since they are calculated supposing the person is looking straight down the central screen.

5.1 Users' feedback

An approximate number of 300 people have seen the presentation in the CLS, distributed in more than fifty sessions. The feedback gotten from them has always, without exception, been extremely positive and enthusiastic.

Everybody could see the stereoscopic images in 3D, which was a big concern at the beginning. As warned in the existing literature, stereoscopy is a subjective matter. To begin with, it has been calculated for an ideal observer, placed on an ideal spot. It is safe to assure that none of the estimated 300-plus people exactly matched all the measures and distances involved in the calculation. The accommodation-convergence issue was also a source of worries, but again everybody was able to see the stereoscopy without much effort.

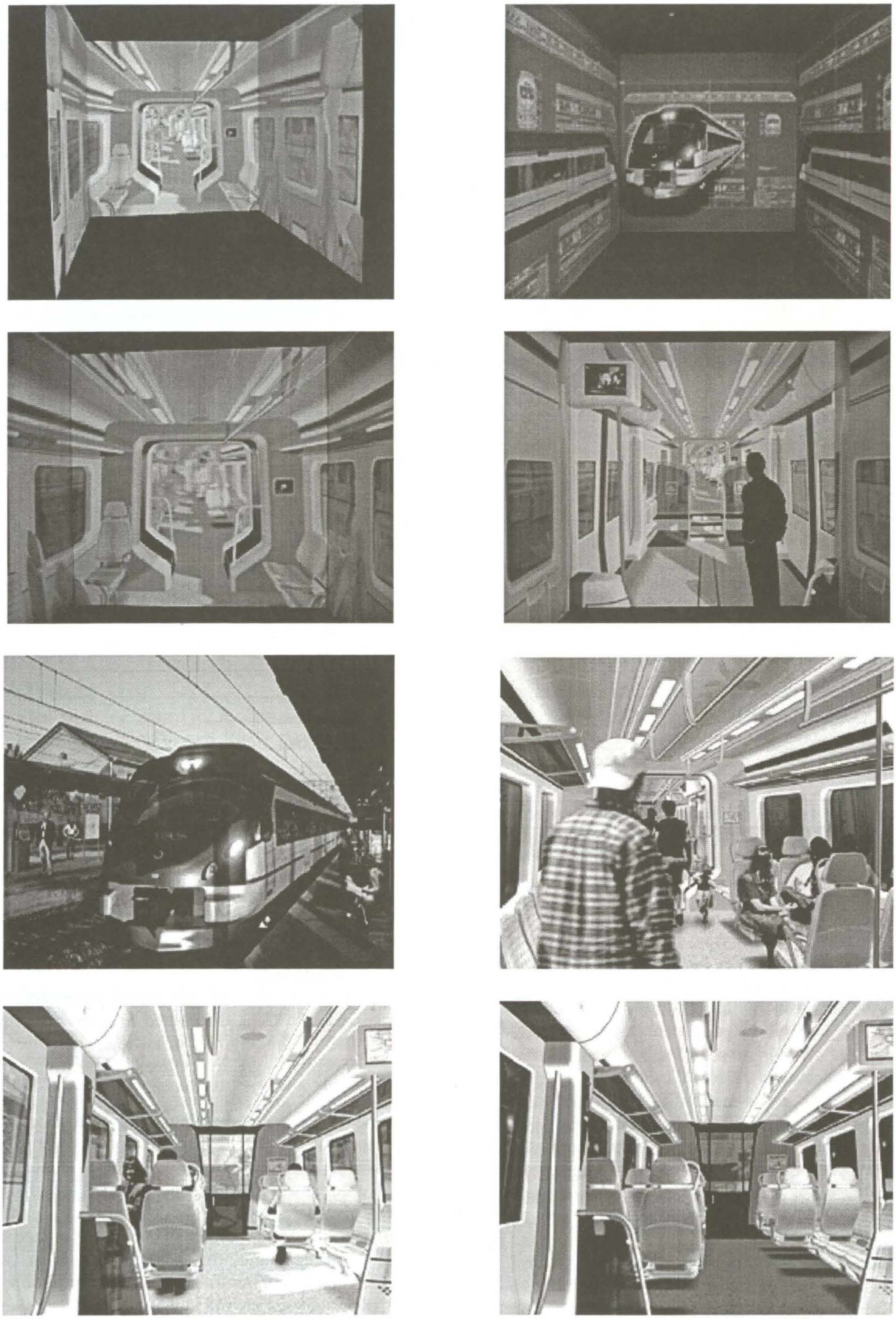

Figure 6: Simulation running on the CLS and several of the images produced

The stereoscopic images are lengthy enough to provide the observers with plenty of time to adapt, in case they can not see the stereoscopy right away.

People with a certain degree of knowledge of the technology involved did perceive the loss of quality in the MPEG-2 animations when compared to the S-VGA static imagery, but understood the causes and were willing to ignore it during the presentation. People with no knowledge of the technology considered the initial MPEG-2 animations as being high quality already, only to have their expectations surpassed even further when the following, higher-resolution S-VGA images were projected.

Nobody felt any motion sickness at all, which was another major point of concern for the CLS design team. The system has no floor projection, so during animations the three surrounding walls are "moving" while the floor remains static. That, plus the logical absence of inertia were factors for potential motion sickness. The effects were minimized from the beginning by not panning the camera around, limiting the movement to straight trajectories inside the train. Short animations and an appropriate walking speed did the rest of the job of keeping motion sickness away.

From the point of view of the train companies (CAF and Renfe), the presentation was also a complete success: Renfe came to the conclusion that this digital approach is a better alternative to the conventional full-size model, and will demand it as part of future contracts with CAF. On the other hand, Renfe and CAF have plans under way to move the CLS to Madrid and Valencia respectively for public exhibition, presenting it as a revolutionary an innovative approach to the train design process.

6. FUTURE WORK

The most obvious future line of work is to include real time imagery in the system, with head-tracking devices that would receive the position of the head as input and would calculate the corresponding perspective and stereoscopy accordingly. That would necessarily impose a reduction in the quality of the images that could be generated, in keeping with the PC-based, low cost approach of the CLS. Instead of pre-rendered, high quality imagery, the images would have to settle for a more basic OpenGL-shaded look, with pre-lit, fine textures. Therefore, an hybrid approach that would mix between real time and high quality seems the most favored combination.

The addition to the CLS of a floor with projected images is one of the issues that could be addressed in a future version. It would be necessary to achieve a greater sense of immersion, specially during animations. However, the current setup would grow more complicated and expensive, verging on overkill for the intended simulation.

Another field open for future work is the substitution of the S-Video channel for another option that imposes less restrictions on the output resolution, as well as hopefully less compression. One option would be to change the PC with the MPEG-2 decoding cards by seven PC's under a master-slave architecture, and synchronize them so that each one sends one SVGA video. Another option would mean converting the animations to digital video showing them in progressive DVD format.

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