A Reconfigurable Simulator System focusing on Port Environments

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1. Resumen

Los llamados simuladores de entrenamiento están aumentando su potencial en áreas donde el riesgo y por tanto la prevención del mismo son muy importantes. Teniendo en cuenta que el entrenamiento de ciertas habilidades prácticas es una de las fases más peligrosas involucradas en el proceso de formación de operarios expertos, los simuladores han sido introducidos en esta ámbito con bastante éxito.

En este trabajo presentamos un nuevo multi-simulador de grúas y una arquitectura específica para manejar gráficos en tiempo real en los amplios entornos portuarios.

Nuestro simulador consta de un conjunto de elementos, y como la mayoría posee dos elementos fundamentales: El subsistema dinámico, encargado de controlar las señales de entrada y reproducir un movimiento realista a través de cierta plataforma móvil y el subsitema gráfico. Este último es el responsable de manejar el amplio entorno portuario y de reproducirlo de la manera más realista posible, pero además su diseño permitirá el control flexible del sistema de proyección, el cual será reconfigurable en función del tipo de grúa simulado. Finalmente, para completar la revisión del sistema no deberíamos olvidar las fases de aprendizaje y entrenamiento, que están siendo desarrolladas en la Universidad de Valencia por investigadores en psicología del aprendizaje.

Como vemos es un sistema complejo, de modo que en este trabajo daremos una visión general, para posteriormente centrarnos en el subsitema gráfico y de proyección, explicando con más detalle el diseño específico de los mismos.

2. Abstract

Simulator systems are increasing their potential for training personnel in areas where the risks and the safety tasks at work are very important. Taking into account the fact that the practical training and related tasks are one of the most dangerous phases involved in the process of becoming a skilled operator, simulators have been introduced in these areas with a lot of success.

In this paper we present a new multi-crane simulator system and a specific architecture oriented to carry out real time graphic applications in large environments, such us ports.

Our simulator system consists of a set of elements and, like most, has two main components: The Dynamics subsystem, oriented to controlling the input signals and reproducing a lifelike motion through the motion platform, and the Graphics subsystem. This is responsible for managing the large virtual environment and reproducing it in the most lifelike manner possible, besides controlling a flexible and reconfigurable projection system for different cranes. Finally, to complete the review of the system, we shouldn't forget the teaching and learning phases, that are currently being developed at the University of Valencia for researchers in psychology and learning skills.

As we see this is a complex system, so in this paper we describe a general overview of the simulation system, focusing on the graphic and projection subsystems, explaining in more detail the specific design for this application.

3. Introduction

From a technological point of view, when we talk about simulation, we are thinking in the use of a specific *model* in order to obtain some information or conclusions with respect to a real world system [1]. The concept of the model, until now a little fuzzy, will have to involve all the of variables and factors which through a set of algorithms and equations achieve a high level of lifelike behaviour. Firstly, it's convenient to clarify the differences between a *simulator system*, a *simulated system* and finally a *real system.* As Figure 1 shows[2], the *simulated system* (subset of the *real system*) only involves the compendium of variables and factors that we will take into account for developing the *simulator system.* For that reason, it's extremely important that this last system was able to simulate these factors the more lifelike the better.

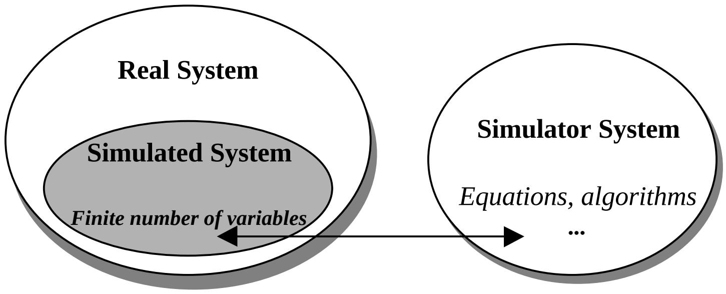

Fig. 1- Relation between the real system (simulated system) and the simulator system.

In every simulation of a complex physical system, such as in this case, we will drag a finite number of variables that we will not take into account due mainly to a couple of reasons. The first of them is the computational cost, it's easy to see that the fact of including certain variables (turbulences or expensive visual effects) could cause certain bottlenecks, not allowed in these kind of real time systems. The second reason is the importance or the weigh of these variables in the whole system. For example if we want to simulate the human motion we can consider the relation between muscle mass and the joints with the bones, but it is too expensive in computational cost and it has little influence in the final result. Normally it's a rate between these reasons an approximate value to get the correct variables and factors to consider in the development of the simulated system.

When we study the situations in which we prefer a simulator system instead of a real system, a couple of cases pop up and they are consolidated in the case of training systems, like our system. Firstly, a simulator will be more suitable than a real system when the economical cost of working with this real one is high. Again, this assertion it's true in our case, and it's consolidated even more if we think about the process of teaching new operators at port environments, where the use of real cranes for learning is not a profitable operation so it reduces the productivity of the real crane. The second situation where we prefer to operate with a simulator system depends on the risk involved in the manoeuvres, where it is indicated as more hazardous is the real operation. The use of a simulated system on port environments again it's especially adequate, due to the intrinsic difficulty and risks that the crane operations show.

In addition, when a simulator system is developed oriented to the training and the learning of some skills , new advantages appear related to the real system such us the possibility of repeat operations, change of conditions and risks …etc.

These kind of ideas have produced the use of simulation systems in the field of training and human factor research had a long history spanning the last three or four decades. The initial steps were performed in the area of military training, also the air-space training took advantage of these kind of systems. At the beginning of 70's some big car manufactures started to use simulator for engineering and ergonomic tests [3]. During the present decade, the range of applications has been spread out in an important way and we can find a use of high and medium end simulation systems in many civil engineering and training areas where risks or cost make interesting use of this technology.

There are several factors that have contributed to this popularisation of the use of simulation systems in the process of training and as an instrument for research. One of the key points has been the evolution of hardware systems involved in the production of stimuli cues needed in order to make the subject feel totally immersed in the situation. The technology is now cheaper and more accessible than in past decades. Another important factor has been the transference of simulation technology from defence to commercial applications [10], this has made possible the re-use of an important technology developed during the last 30 years in the military sector with the consequent decrease of development times in the new civil simulators which otherwise would have had to have been developed from scratch.

The simulation systems cover a wide range of applications, however, in every simulation system we can find a way of producing the visual stimuli cues, that in most cases are the richest source of information for the user. When we talk about the visual cues usually we have to consider two main parts; first the generation of the visual cue –the scenario where the training takes place- and the second which visual cue is presented to the user.

The first part can be based on several technologies like the use of real images from video recordings [8], the use of physical terrain mock-ups filmed in real-time using mobile cameras and the most extended and most usual nowadays based on the generation of realistic synthetic environments based on dedicated hardware able to produce in real time up to 60 different images per second. This part will define the quality of the image for the simulation but not the degree of immersion achieved by the user during the training.

The second aspect is related to the visual cues to be considered and how the image is *projected* to the user. This will be the key aspect in order to produce a good feeling of immersion in the subject during the simulation. For an immersive experience it is important that the projection system is large enough to cover the whole field of view of the user during the training. To achieve these goals different methods have been used, and technologies that have been evolved in parallel with the simulators in general. [5] [11] [4] [9]

Another important aspect to be considered is the combination visual of the visual cues with other cues that may be involved in the simulation process. This is the case of simulators which include cues for the sense of *balance* using a motion system to produce the accelerations. That motion may affect the relative position of the user's point of view. To solve this problem, when the costs and system design allows the projection systems moves together with the subject. In other cases the image has to be corrected to minimise the effect of the displacement of the point of view.

In this paper we present some research in the development of a projection system for a general purpose simulation system for cranes in a commercial harbour area. Secondly we present briefly the scope of the simulation system. Thirdly we review the main hardware components used in the project. Fourthly we will explain the design of the projection system with the considerations used to make those design decisions. Finally we will present our conclusions and future works.

4. The General Harbour Training Simulator

The project that we present here has been developed in collaboration with the Valencia Harbour. The needs of this institutions were related to integration systems oriented to the training and evaluation of the personeel in charge of the loading and unloading of commercial ships. The range of the diferent cranes used in the harbour operations involves up to five main categories (Three of them are shown in the figure 2).

Fig. 2- View of Three different crane system to be considered

A modular architecture has been devised to tackle the problem of generality of the simulation system. The Figure 3 shows the main software components considered in the simulator.

The **visualization module** is in charge of generating the visual cues that are sent to the projection system that we will explain in point four. The visual database changes for each crane model because the work environment is different for each of them. To have a realistic appearance in the aspect of the synthetic environment real textures have been used. The number of images to be generated and the point of view depends also on the model of crane to simulate.

The **mechanical model** is in charge of the simulation of the physical behaviour of the crane. There are in the mechanical database parameters for the different crane models because it is obvious from their work environment that the mechanical behaviour changes for each model. The mechanical model provides the position of the point of view used as a base for generating the images, the position and the orientation of the load, the accelerations suffered by the subject, which are the base for the working of the motion platform in charge of providing the motion cues, and the possible collisions with the rest of the objects in the scenario (ship, other containers, etc.)

The **sensorization and control module** is in charge of recovering the information about the actions of the subject and sending to the control panel. These actions will be used for the mechanical model as input parameters for the computation of the crane behaviour. Throughout this module it is possible also to perform the scenario control of the system that includes the change in the model of crane being simulated and also the conditions or test to be performed in each simulation.

All these modules are communicated and synchronised by the synchronisation channel in charge of ensuring that the systems work in real-time and that the information is received immediately in each subsystem belonging to the same simulation state of the general system. The synchronisation channel is also the way throughout which the software modules transfer and receive information for the hardware subsystems, briefly explained in the next point.l

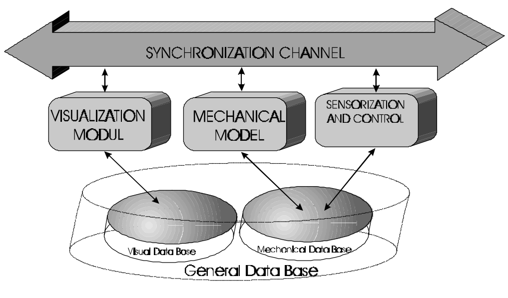

Fig. 3- Component diagram of the Software System

5. Specification of the System Components

As stated before, the whole simulator is compound by several subsystems that interact in order to provide virtual reality to the user. These subsystems are the dynamic model, the movement simulator subsystem, the projection subsystem, the cabin and the visual model.

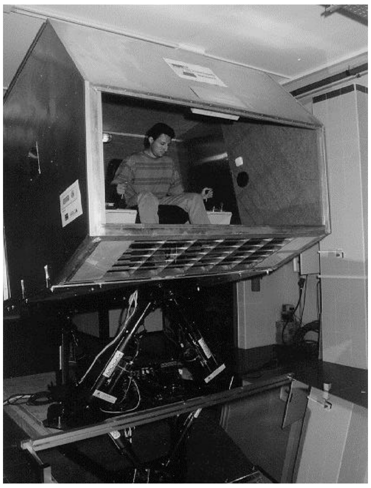

Fig. 4- Motion System

The heart of the simulator is the dynamic model. It is a mathematical model with a finite number of differential equations that predict in real time the cabin and the spreader movements. The inputs of the model are the cabin joysticks and buttons, the container weight, the wind speed and also the collisions detected by the visual model. The outputs are split into two main functions: to form a frame in order to move the platform and to send to the visual model spatial information about the position of the cabin and the spreader.

The motion system is an electrically powered six-degree of freedom system with a flying frame for 1000 Kg payload mounting. On its flying frame it is located on a real cabin, with real handlers, controls and status lights. Inside the cabin, the user watch through several windows the progress of his work and also feels the accelerations and sounds produced by this work in the same way that he would experience in the real world.

The visual subsystem generates in real-time the views that the operator see through the windows of the cabin. These images involve taking into account the operations performed with the cabin controls, and also the vertical movements of the cabin. As the projection subsystem is a static one, located outside the cabin, it is not desirable that the user feels how accelerations are obtained. The visual model is implemented in a Silicon Graphics Onix2 workstation with two Mips R1000 and an Infinite Reality graphical accelerator.

In order to provide real time capabilities in the simulation, a continuous stream of data is interchanged between the subsystems. Several continuous and digital lines take care of the status of the joysticks and the buttons of the cabin. The status of these lines is sampled by a general purpose I/O board inserted in one slot of a Pentium II – 400. Whenever a new integration step is to be performed, this information is acquired and introduced into the model There are two joysticks to control the linear speed of the crane and one more to control the vertical speed of the spreader. Furthermore, in order to drive the motion base in a real-time interactive system, the personal computer sends frames through a RS422 serial interface to control the movements and accelerations of the platform. This link is half-duplex, therefore the platform acknowledges every frame with status response data. In order to increase the reliability of the system and to provide proper communication between the system controller and the motion base computer, a frame sending at a rate of 60 Hz has been programmed. Slower rates are acceptable, but will result in vibrations noticeable to the rider. The critical data-paths of the system, where a high bandwidth is required, are those related to the integration of the visual model. We use sockets to send through an Ethernet link, information about the location of the elements in the virtual scene and also to receive information about collisions and many other user events, all of them related with the parameters of the model (wind, light, halt).

6. Projection system

A fully immersive display is not possible on a normal CRT monitor, and moreover, as describe d above, we want access to a standard desktop working environment when developing an application[7]. One of the keys, in order to obtain an immersive system, consist of providing the user the same visual references that he has in real life. In a medium-high gamma of simulators, is very important to obtain a system with enough visual power to guarantee the immersion of the user in the virtual environment. In this way, the user can be immersed in this environment and we obtain one of our goals, the transfer of training from a synthetic or virtual environment to the physical world [6].

Certain parameters have been considered, in order to study and design our projection system:

Projection quality: At this point, we have to consider the types of projectors, screens (curved, flat ... etc), and the performance of these elements to achieve the quality required.

Space/Volume available: Some restrictions, about the whole projection system, will have to be taken in order to assemble the system in the place reserved for it.

Real System Views: Obviously, each one of the cranes, that we will consider in our multi-simulator system, will have to receive the visual information from the same channels or views (windows in a cabin) as in real life. So, the projection system designed must provide all the necessary channels to simulate real experiences.

Reconfiguration of the system: As we have to perform a multi-simulation system, we have to at this point think about the cost of the configuration change related to the type of crane. Our projection system will have to be designed for an easy and quick reconfiguration.

Summarizing the previous notes, our goal, will be a projection system that allows for the real views of all the cranes that we have to consider and at the same time permits reconfiguration with a minimum effort. Furthermore, the quality factor and the available volume for the whole system can be taken in account.

The real views for each type of crane are shown in the next figure.

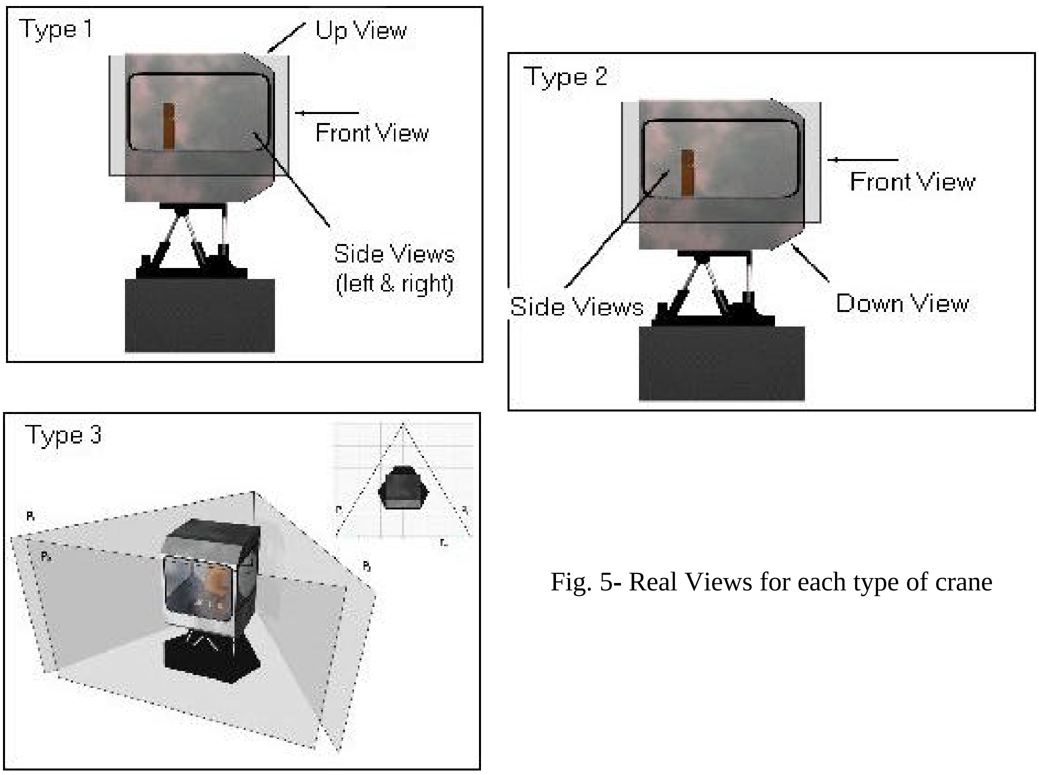

Fig. 5- Real Views for each type of crane

At this moment and according to the restrictions imposed above, we can divide our design in three parts: Side View, Front + Up View, and Front + Down View.

Projection systems based on curved-screens [SZC98] could be adequate to allow the front and side views, nevertheless they have been rejected for several reasons. The first of these reasons is related to the continuity of the view, these systems provide a horizontal continuity with a large field of view (FOV). In our system we consider that the vertical field of view (Up + Front + Down) and the vertical continuity is more important than the previous horizontal case. This occurs due to the structure of the cabin and the operativity of the machines we want to simulate. A solution based on a semi-spherical projection system could be technically possible but too expensive.

So, we have divided our projection system into a pair of retro-projection subsystems:

Front + (Up | Down) Subsystem: By means of a flat screen with a 1DOF system, and by turning over the horizontal axis, we can easily obtain the required views with vertical continuity. When we want to change the configuration, we only have to turn the screen until the right position (prefixed previously) is reached. We have to state that we have only two configurations for this subsytem, one for the [Up + Front] views, and the other for [Front + Down] views. This subsytem is completed with a pair of mirrors, to get the right distance between the projector and the screen, and the projector with an adjustable base. Due to the screen dimensions (4x3m) and the optics used by our projector (JVC - DILA G-10) the scheme of this subsystem is shown in the next figure:

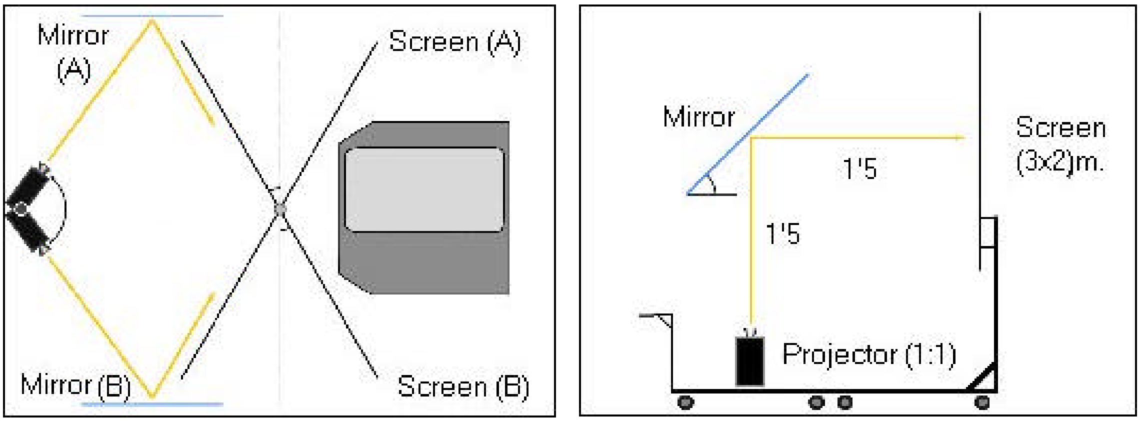

Fig. 6- Left) Front + [Up | Down] retro-projection subsystem; Right) Retro-projection subsytem for Side Views .

The resolution required (1280x1024) and the rest of the performance factors, such as brightness, colour quality and easy tuning have been taken in account and the JVC, that we are using, guaranteea all these quality factors.

Side Views: Due to the configuration obtained for the Mafi crane (see figure above), this subsystem has to have again the possibility of movement and we have to consider its easy reconfiguration. The subsystem designed is like a *"trolley"* and is formed by a projector, a screen and a mirror. The mirror again is used to obtain the right distance for each ray of light, and the projector is equipped with specific big-angular optics (1:1), so the scheme obtained is the following:

By means of the wheels that this subsystems possesses, we can easily place it at the right position (fixed again previously) and obtaining in this way a very quick an easy change of our subsystem.

The whole system is shown in the next figure, already included in the real environment dimensions, where it will be placed soon.

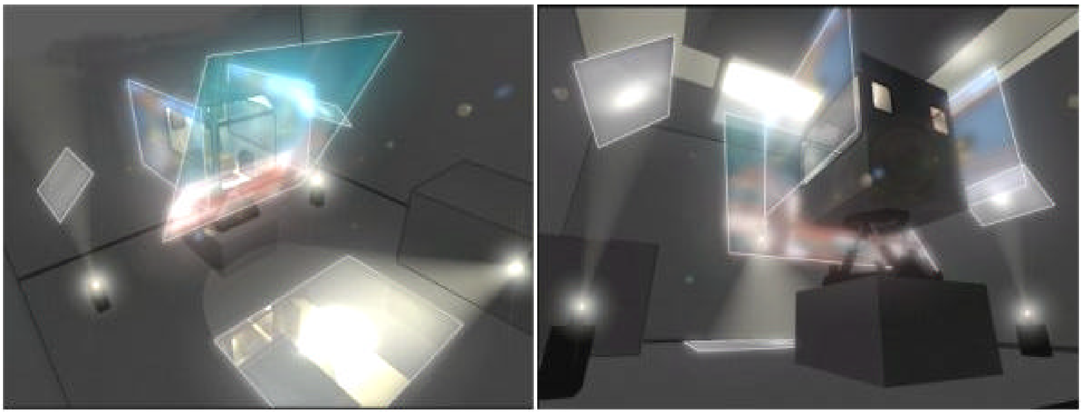

Fig. 8- The whole system representation

7. Conclusions and Future Work

As we mentioned before, our goal, the transfer of training from a synthetic or virtual environment to the physical world [6] will be produced once we have obtained some evaluation results. Actually another university group (INTRAS) at the University of Valencia, which has a lot of experience in the field of training and evaluation related to Driving Simulators, are working jointly with us in order to perform a course of training for crane workers.

So, at the present moment, our research groups are working in parallel, designing the multi-simulator system and designing the training and evaluation module.

The future prospects at the Port of Valencia are very optimistic, since they are actually training people with a single crane simulator and they expect to complete the learning phase with these new simulator. In this way, they are saving the training costs normally associated with using a real crane, alleviates the real crane scheduling problems, and at the same time they are enhancing the safety procedures at the initial phases of the job.

8. References

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