UVSim: A HARBOR CRANES TRAINING SYSTEM[*]

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ABSTRACT

This paper presents a simulation-based instructional system for harbor crane operators training. The configurable design of the simulator allows the training of several crane types: Quay-Side Gantry, Rubber Tired Gantry, Mobile, Reach-Stacker and Ro-Ro tractor. In this paper the simulator architecture, the Virtual Reality techniques, the projection system, the configurable cabin and the instructional design are described. The virtual environment design includes the representation of harbor terminals, container ship load and unload operations, mobile crane driving and bulk material handling. The simulator includes an automatic evaluation system that measures the trainees' evolution in terms of their abilities. The instructor's panel gives full control on the exercise and on many parameters such as weather conditions, crane failures or load distribution during the simulation. The system also includes an advanced debriefing system for exercise revision and evaluation.

Keywords: Training Simulator, Virtual Reality, Harbor Training

1 INTRODUCTION

In the last decades, interactive simulation based on Virtual Reality techniques has become a powerful tool for training purposes, specially in activities which involve high risks and costs, as it is the manipulation of heavy harbor equipment (different types of cranes, trucks, etc.) (Serón et al., 1999; Kim, 2005). The many benefits that can be obtained from the use of a simulator in training tasks, has motivated an increase of the use of such systems in the marine and port environment (Jiing-Yih et al., 1997; Wilson et al., 1998; Huang, 2003; Daqaq and A.H.Nayfeh, 2004; Rouvinen, 2005; Korkealaakso et al., 2007).

The use of a simulator forces the trainee to practice the theoretical concepts that have been taught and shows the consequences of the actions in a very immediate and visual manner (Farmer, 1999). Also, the simulator provides the instructor with a controlled environment where a large amount of data can be recorded and analyzed to evaluate the trainee's evolution. From the risk prevention point of view, it avoids the danger of an inexperienced user manipulating the real machine in the working environment.

Furthermore, it reduces the cost associated to training; it prevents inexperienced users from using the machinery, thus reducing machine breakdown due to misuse, and it releases machines for work that, without the use of a simulator, have to be used for training purposes.

In addition it provides with the possibility of working in any desired conditions. Arbitrary weather conditions can be reproduced and training for the climate conditions of a given harbor can be done thousands of kilometers away. Moreover, in the simulator any configurable situation can be easily reproduced, while it is not possible to modify the work flow of the terminal to train a given situation (emergency situations, unusual work load,...).

Many harbors around the world are currently profiting from the benefits of simulation technologies for training crane operators. Several companies have presented different systems for crane operator training during the last decade for different types of cranes (Drilling Systems, 2009; Globalsim, 2009; LAMCE, 2009; L3-Ship Analytics, 2009)

This paper presents a training simulator based on Virtual Reality technology that is currently being used for training tasks related with five different harbor equipment: quay-side cranes, rubber-tired gantry cranes, reach-stacker cranes, mobile cranes and ro-ro tractors. The main contribution of this development is the use of new modeling approach for complex subsystems, such as cable and pulleys hoists, bulk material or traffic, and a powerful analysis and evaluation system.

The paper is structured as follows. Section 2 describes the training system and its main elements. Section 3 gives an overview of the different hardware configurations that can be used with the current system. Section 4 describes the particular properties of the different equipments simulated. Finally, Section 5 gives concluding remarks and an overview of future work.

2 TRAINING SYSTEM DESCRIPTION

A harbor crane simulator is a tool aimed to the instruction of new operators and advanced training of experienced ones. Within this premise, a simulator has to include a

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set of tools that help both the instructor and the trainee to obtain the maximum performance of the equipment and enables an optimum use of the instruction time. The system comprises four main elements.

- The Instructional Design.

- The User Management System.

- The Evaluation System.

- The Simulation System.

Next, these modules are described in detail.

2.1 Instructional Design

The Instructional Design includes a complete series of exercises, which guide both the instructor and the trainee through the process of learning and training.

These exercises are grouped into practice modules, which cover different aspects of the maneuverability of the harbor cranes and the set of skills that should be acquired in the simulator. The exercises gradually increase their complexity and the number of activities involved, from simple control of the payload to avoid excessive swing, to complex operations involving trucks and container-ships. Also the working pace is increased gradually through the course, including exercises aimed to advanced training of experienced operators.

The exercises include visual aids that are shown on screen during the simulation. All the indications to the user are given using the same sign convention that is used in the real port terminal. This helps the new trainees to get used to real operation, shortening the adaption time to the real environment.

An instructor's manual gives additional information to the instructor so that new training modules can be implemented by means of the selection of certain exercise sequences.

2.2 User Management System

The system includes a database system, the User Management System, that makes it possible to register the simulator users and to store every exercise that is done with the simulator. Thanks to the User Management System, every user of the training system can be tracked individually, storing all relevant data, in order to have an overview of the evolution of every trainee.

The system also includes the necessary database management tools to register or delete users, clean obsolete registers, make backups or archive old data to save disk space.

2.3 The Evaluation System

The Evaluation System analyses the data that is collected during simulations to provide the instructor with an objective and clear report of the progress of every trainee. This system is based on three tools:

- An automatic evaluation algorithm to monitor the evolution of every user along the training program.

- A report generator which summarizes in a printable document the results of the evaluation.

- A debriefing system, to visually reproduce and evaluate any finished exercise.

More detailed descriptions of these components are presented in the next sections.

2.3.1 Exercises Evaluation

One of the advantages of simulator-based training is the ability to perform an objective evaluation of the trainee, thanks to the possibility of capturing any system variable and the registration of the user actions during the simulation.

The Evaluation System is responsible for monitoring and store a set of parameters that will determine the performance and evolution of the student. For every exercise, the operator movements, the scenery details and any variation introduced in the exercise by the instructor are stored for later use in the report generation or exercise debriefing.

The Evaluation System stores the correct execution of the tasks and orders of the exercise, as well as the time taken to perform them. Every collision with trucks, containers, crane structure, etc. . . is recorded together with the load speed and the maximum accelerations suffered. The Evaluation System also detects and stores dangerous maneuvers, such as strong payload swing or heavy collisions, as well as the effectiveness of the user in the use of the crane controls, two-hand coordination, etc. . .

A set of mathematical algorithms have been implemented in order to transform the large set of raw data captured during the simulation into user readable parameters. These parameters have been chosen by experienced instructors during the simulator design process.

However, the captured raw data is stored after every exercise in the system's database. This enables the evaluation to be recovered at any time later on and also that the evaluation reports can be completely redefined in the case the instructor decides to include new parameters in the Evaluation System.

2.3.2 Report Generation

The evaluation results are shown by means of customized reports that can be seen on screen or printed. They can be used to give the trainees a summary of their progress and assessment of their skills during the operation of the machine. They can be also used as an examination system that objectively gives a report of whether a trainee has achieved the proposed goals.

The exercise report includes identification data, such as the exercise description, the academic profile of the student, the date and the time of the execution, the total time, etc. In addition, it shows the results of the exercise by means of the selected parameters and several
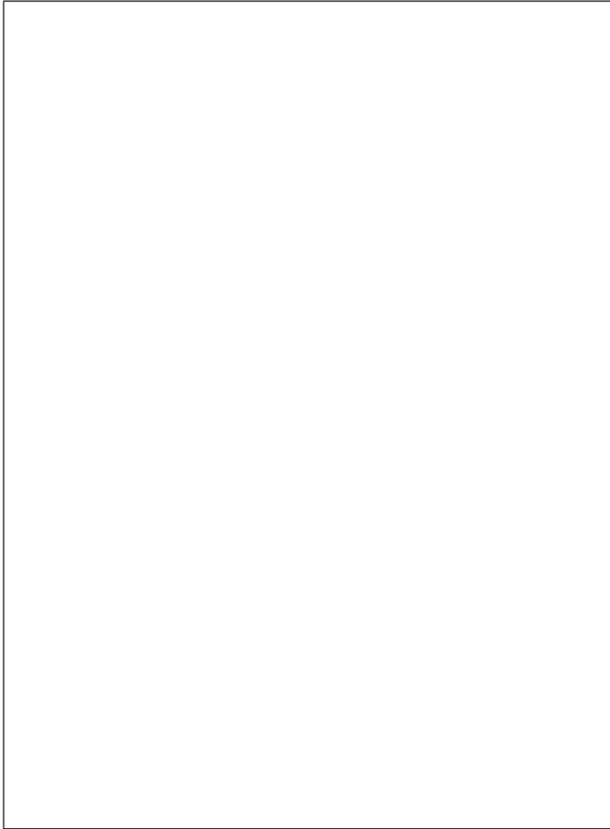
Figure 1: An example page of a report generated by the automatic Evaluation System

graphics and data plots, becoming a powerful evaluation tool. The collision count rate, number of dangerous maneuvers, collision severity, spreader trajectory representation, etc. are also shown, providing the instructor with a complete summary of every exercise. One page of a report generated by the simulator is shown in Figure 1.

The report of an exercise is available just after the exercise has been finished, so that the instructor can discuss with the trainee any issue that is considered of interest for the learning process. Additionally, it can be recovered from the database at any time on a later session.

2.3.3 Session Debriefing

The debriefing system is a powerful tool that enables the automatic, off-line reproduction of any exercise done in the past, with the possibility of pausing or moving to any instant its reproduction. Following the realization of an exercise, the debriefing mode can be activated and the exercise can be revised by the trainee and the instructor who can make any comments or remarks on it. Additionally, the debriefing of any past exercise can also be activated, providing the instructor with a demonstration system to support theoretical concepts and with a revision tool to evaluate the evolution of a trainee.

In order to do that, the system does not store a movie

of the simulation, but instead, the minimum number of variables necessary to completely reproduce the simulation session are stored. This presents two main advantages. First, it reduces the amount of space needed to maintain the database, since the storage of full movies is unaffordable. And second, as the visual representation is being rendered again during the debriefing of an exercise, it is possible to change the point of view of the scene according at the instructor's discretion.

2.4 Simulator Architecture

A crane simulator aimed to training tasks is a complex Virtual Reality system composed of several modules. Together, they make it possible to acquire the user's actions, to reproduce the behavior of the environment and to visually represent the simulated environment. The simulator considered in this work is composed of the following elements:

- Visualization system, which provides a graphical representation of the environment.

- Physically based model of the machine and the environment.

- Immersion system, including the projection system, Input/Output devices and 6-Degree of Freedom (DOF) mobile platform.

- Control panel.

During the simulation, the user provides the input data by means of the input devices, which reproduce the control panel of the simulated machinery. These input data are used by the dynamic models in order to determine the evolution of the machinery and of the environment. The dynamic models, which are discussed later in this work, are a combination of multibody models, implemented by means of the ODE programming library, and a set mathematical models of other complex systems.

The state of the simulated environment is reproduced by means of a 3D graphics application which stores a scene graph of the virtual world. This application is implemented by means of the OpenGL Performer programming library. The 6-DOF mobile platform is controlled using the dynamic model output, to simulate the accelerations experimented in the real machinery in order to provide a better feeling of *presence* (Reid and Nahon, 1985; Reid and Nahon, 1986).

The control panel is the Graphical User Interface of the application from which the instructor has full control of the system. Together with the virtual environment and the immersion system, the Instructional Design, the evaluation and debriefing system and the user database convert the simulator into a powerful training equipment.

2.4.1 Visual Subsystem

One of the most important elements of a training simulator is the visual subsystem. This module is responsible for rendering a visual representation of the virtual

environment of the simulator. It reproduces a complex scenery which includes the harbor environment including containers, several vehicles, quays, etc. and the simulated machines.

This application comprises a scene graph, which stores a large database of geometrical data, and a logical model that computes the evolution the scene graph and other system outputs. The geometrical database contains all the data necessary to represent the different elements that appear in most international harbor terminals, while the scene graph is a complex data structure that permits an easy update of the positions of the different elements through the scene. The logical model is a state machine which determines whether the position, the topology or the visibility of an object, or a compound of objects, must change to represent an event, e.g. the attachment of a container to the spreader, the extension of the spreader, etc.

All the scenery models have been modeled using a 3D modeler environment, and stored in ASCII text files, which can be converted into OpenGL Performer's native format `.pfb`. All the models have been texturized with photographic textures obtained at several harbors. In addition, several techniques, such as *bump-mapping* or *environmental maps* have been implemented in order to increase the realism of the virtual environment. These techniques, together with the use of different Levels Of Detail (LOD), provide the simulator with a very realistic and efficient environment.

The virtual environment considers different types of cranes and vehicles (trucks, ro-ro tractors, etc.) that provides it with the realism needed. Furthermore, container yards, quay sides, container-ships, bulk material yards and other locations have been modeled using the information provided by port authorities of Valencia Harbor.

Also, several state-of-the art techniques have been used to reproduce different weather conditions that can be modified during the simulation; rain, fog and snow can be simulated, affecting the operator's visibility. Additionally, a *skybox* represents the aspect of the sky at different day hours and with different cloud conditions and, by night, OpenGL illumination techniques are used to simulate artificial light.

2.4.2 Dynamical Model

In order to obtain a realistic simulation environment, not only a high quality graphic application is necessary, but also the behavior of the machine, considering its subsystems, and its interaction with the user and with the environment has to be reproduced based on its physical properties. In order to reduce the computational cost of the final application the properties of the crane that are considered more relevant for training purposes are considered, discarding irrelevant behaviors . This leads to a very efficient, yet realistic simulator adequate for training purposes.

The dynamic model used for every crane is based

Figure 2: The virtual environment can reproduce different weather conditions that can be modified during the simulation

on its mechanical properties, using the multibody system dynamics methodology. The crane is decomposed into different bodies, that are linked by means of kinematic constraints, and implemented using the Open Dynamics Engine Library (Smith, 2001). The characteristics that are considered in the crane models are summaryzed following.

- Collision detection and response against the elements of the scenery, using complex geometric models for accurate collision point determination.

- Flexible elements to simulate the deformation of the crane structure.

- Realistic modeling of the different engines, brakes, electric and hydraulic subsystems, etc. present on the simulated machinery, according to the real machine specification, including different machine failures.

- Ship movement due to load distribution.

- Effect of wind and rain over on the payload and on collisions friction.

- Liquid loads and other complex mass distributions.

All the models are defined using a set of parameters which determine their main properties (sizes, speeds, response curves,. . .). This enables to simulate a large set of different cranes through the adjustment of these parameters, adapting the system to the needs of most crane models.

In addition to the mechanical behavior of the cranes themselves, the physical properties of several complex systems have been also considered. More precisely, the developed simulators include new models for the simulation of bulk materials, hoists systems and traffic flow.

Granular Systems Simulation The simulation of a mobile crane requires the modeling of the bulk material

that is being handled. Load and unload works, together with bulk material arrangement in the yard, need to be simulated in a realistic manner.

According to most common types of goods that are present in a harbor terminal (grain, granulate fertilizer, coal, etc.) bulk materials have been modeled as granular systems with different properties. However, modeling and simulation of granular material is a complex problem, which involves a very high computational cost (Pöschel and Schwager, 2004). For these reason, most common methodologies are not adequate for real time simulations. Then, new models have been developed in order to meet both the physical realism and the computational efficiency necessary in training simulators.

A model based on the Cellular Automata formalism has been developed for the evolution of the surface of the granular system (Pla-Castells et al., 2008). It represents the granular material by means of a grid, which covers the material surface, and a local rule, which determines the evolution of the system. The model also considers mechanical interaction between the granular system and the objects of the scene, permitting bulk material manipulation (Pla-Castells et al., 2006). In addition, the model uses an implementation strategy that exploits statistical properties of granular systems in order reduce the number of computations.

Cable and Hoist Simulation Another subsystem which shows a highly complex behavior is cable and pulleys systems that are used in most elevation equipments. Quay-side, gantry and mobile cranes use a set of pulleys and cables in order to hoist the load and also to move some of their structural elements.

Cable systems have been usually simulated as massless spring elements, discarding cable oscillation and complex pulley systems (Abdel-Rahman et al., 2003; Daqaq and A.H.Nayfeh, 2004; Servin and Lacoursière, 2007). However, this leads to an important loss of realism both in the visual aspect of the simulator and in the physical properties of the crane models.

In order to increase the quality of the simulation, providing the model with cable oscillation and with arbitrary pulley configurations, a new model has been developed (García-Fernández et al., 2008).

This model uses a combination of simple pulley models and cable segment models to efficiently simulate a hoist with cable oscillation. Cable behavior is reproduced by means of a series of layered models that represent different vibration features. The decision of which layers are used is taken durnig the simulation in an adaptive manner. The model is designed to be able to handle the high mechanical tension situations that appear in the cranes considered in the simulator (García-Fernández, 2009).

Traffic Simulation The simulator includes a Traffic Simulation Module. It controls the different mobile elements of the scene, such as trucks and other yard cranes, and its behavior can be modified during the simulation. It determines the container flow rate and the amount of goods that the operator must handle per unit time.

The Traffic Simulation module is redesigned for every harbor in order to reproduce their particular operation procedures, average and peak container-per-hour rate, types of goods, classification in the container yard, etc. . .

The combination of all these state-of-the-art models provide the Simulation System with a high degree of realism and interactivity, improving its training capabilities.

2.4.3 Immersion System
The Simulation System is usually formed by an immersive projection system and a cabin, where a seat and the Input/Output devices are installed. This cabin, and potentially the projection system, can be mounted on a 6DOF Stewart platform to produce inertial stimuli that simulate the accelerations experienced in the real crane.

However, the system presented here comprises a wide range of hardware configurations which make it more versatile. They are described in detail in Section 3.

2.4.4 Instructor's Control Panel
During a working session, the instructor has full control over the simulator through the Instructor's Control Panel (see Figure 3). It is an interactive panel from which the different aspects of the simulation can be controlled. It includes a 2D view of the state of the simulation, with the crane and the containers that are involved, and a set of frames and menus that give access to the following actions:

- Crane setup

- Weather conditions setup

- On-line failure injection and container modifications

- Traffic management

Crane Setup Before the exercise starts, the instructor can access a graphical user interface which controls all the adjustable parameters of the crane. Through this panel, the crane model can be modified and many customizations can be done to introduce new situations that can improve training tasks.

Options such as anti-swing systems, automatic flippers, cell guides or other features can be activated through this panel. In addition, there are several parameters that provide the instructor with additional tools. E.g. joysticks sensitiveness can be increased to force the users to be more careful in their manipulation, a delay can be introduced to the controls in certain exercises to train quick responsiveness, etc.

Figure 3: The Instructor's Control Panel during a Quay-Side Gantry Crane simulation exercise

Weather Conditions   As it has been stated before, one of the benefits of using a training simulator is the control over weather during the simulation. Through the Weather Conditions panel, wind, precipitation and fog can be controlled, as well as the daylight properties or the use of artificial light during night. All these properties are reproduced in the virtual environment by means of the appropriate techniques, as described in Section 2.4.1. Also, dynamic models consider the parameters of weather conditions in order to modify the friction properties with wet floor or the payload behavior under the action of wind.

Failure Activation and Container Management   During the simulation, the instructor can activate a series of failures that depend on the particular equipment that is being simulated. All of them correspond to failures that happen with certain frequency in the real cranes. When a failure is activated, the trainee is expected to detect it and to act accordingly. Failure activation is recorded in the stored data in order to determine whether the reaction was adequate.

In the case of container handling cranes, it is also possible to modify every container's properties individually through the Control Panel. The instructor can select a container through a graphic interface and modify its weight, type and load distribution. A container can also be marked to activate a failure when it is attached to the spreader.

Traffic Management   Another frame of the Control Panel manages traffic properties in the corresponding terminal. The frequency at which trucks appear can be configured, and the appearance of a truck can be fired at any time. This forces the pace at which the trainee has to work, as traffic jams can appear if containers are not moved at the needed frequency, and permits to simulate work overload situations to train experienced operators.

3 SCALABLE HARDWARE CONFIGURATIONS

A training simulator is a complex system which needs a series of hardware components to achieve a high level of presence of the simulator. However, depending on the needs of the harbor, it can be implemented using different hardware configurations that range from a simple desktop PC to a fully immersive system installed on a 6-DOF platform.

3.1 Desktop System

Desktop based system configuration is intended to provide a virtual environment through an standard desktop computer. The main advantages of this configuration are its accessibility to any user, its low cost, and its small size. In this system, both a set of special controls that emulate the crane control desk or a set of standard game devices can be used. In order to improve the perception of distance in the virtual scenery, the use of guidance systems or trackers have been also included, as shown in Figure 4.

Figure 4: A desktop configuration, with several displays and conventional game devices as controls

Desktop systems are designed as a basic approach to the training of operators through virtual reality, but the effectiveness is much lower than that achieved in fully-immersive systems.

3.2 Medium-Size System

This system incorporates a real seat with real instruments that is located in front of the projection system (see Figure 5). This one is usually compound by a big LCD or plasma or even by a single rear projection screen, although multiple projection screens or monitors can be also arranged to configure several views or a high resolution tiled display. Moreover, stereographic imaging can be achieved, using some type of shuttered glasses in synchronization with the graphics system.

This system can be appropriate for the simulation of quay-side or gantry cranes, since they only need the single front view of the virtual environment and do not

Figure 5: A Medium-Size System used for training in Guayaquil (Ecuador)

precise to look around.

3.3 Fully Immersive System

In this configuration, the user is fully immersed in the virtual environment, using a replica of a real crane cabin, where several projection screens and LCD projectors are attached to it. In turn, the cabin is mounted on a motion platform, which reproduces in the user the forces generated by the movements of the vehicle simulated. The motion simulation is a very important factor in immersive environments, since it simulates the accelerations caused by the real crane, improving realism, avoiding motion sickness caused by the absence of movement.

The sense of full immersion is achieved by providing the user with a environment very close to real. A replica of the crane controls, provided by the manufacturer, are used in the cabin desk. The types of controls present are: joysticks, pushbuttons, illuminated pushbuttons, LEDs (indicators), switches, combiners (lever position) switches, digital displays and buzzers. Several USB Data Acquisition Boards are used to capture the sensor's state.

In the case of Reach Stacker and Maffi crane, an special frame, integrating a steering wheel, levers and switches, direction indicators and a set of pedals has been built. This piece is attached in the cabin, between the desks and in front of the driver's seat, and is easily removable when it is not used.

Every crane simulator can use this fully immersive system, but Reach-Stacker and Ro-Ro tractors are particularly suitable for this configuration, since they need a panoramic visual environment in order to drive along the yard. In addition, since the movements of the vehicles are faster than the other cranes', a motion platform is recommended to avoid simulation sickness.

3.3.1 3D Sound

The Simulation System integrates spacial 3D sound that reproduces the environmental sound, the engine noise

Figure 6: A CAD view of a Fully Immersive simulation system

of the crane during normal operation and the different sounds of collision and alarms. The sounds have been implemented using the library *OpenAL* (Yuzwa, 2006) to render positional and multi-channel audio in three dimensions.

4 USE CASES

Based on the described architecture, five harbor crane simulators have been developed: quay-side gantry crane, rubber-tired gantry crane, mobile crane, reach-stacker crane and ro-ro tractor. After describing the main properties of the Simulation System, next an overview of the particular features of every crane simulator are given.

4.1 Quay-Side Gantry Crane

Quay-Side Gantry Crane simulator (see Figure 7) is based on Paceco cranes of types PANAMAX and OVER-PANAMAX. The cranes have been modeled in detail to reproduce their physical behavior and their different subsystems.

Figure 7: A view of the Quay-Side Gantry Crane simulator

One of the most important elements of the crane is the spreader, as it is the tool used to hold the containers, and is involved in most of the interactions of the user with the environment. For this reason, it has been modeled in great detail including its geometry, mobile flippers and twist-locks, for accurate collision detection.

Trim, list and skew movements are simulated and the hydraulic system is modeled in order to simulate its behavior and several malfunctions. Different spreader sizes and types are simulated, including twin-lift and over-height spreader, which can be used in different exercises included in the training course.

The simulator includes a library of container ships for training in many different situations. Load and unload operations can be simulated inside holds or on the deck, including the removal of hatch covers for operation inside holds. Cell guides can be included when the instructor considers that it is adequate.

The behavior of trucks that transport containers from the quay side to the container yard and vice-versa are also simulated. A discrete event model produces a realistic truck traffic that feeds the trainee with containers during loading operations and takes them away during ship unloading.

4.2 Rubber Tired Gantry Crane

The rubber tired gantry cranes stack and unstack containers in the container yard using an spreader (see Figure 8). The same spreaders that were considered in the Quay-Side Gantry Crane have been simulated in the Rubber Tired Gantry Crane simulator.

Figure 8: A view of the Rubber Tired Gantry Crane simulator

In this crane, an aspect that is of special relevance is the influence of tires in the gantry movement. During its displacement, differences in tire erosion and in the load distribution among the tires can lead to different friction in both sides of the gantry. As a consequence, the gantry can deviate from straight line during displacement. Rubber tired gantry cranes incorporate a control to change

throttle of both tire groups. This system has been modeled, obtaining a very realistic simulation of gantry displacement.

The rubber-tired gantry also uses the truck and traffic simulation model. Trucks carry and take away containers that have to be manipulated by the crane operator.

4.3 Mobile Crane

Mobile cranes, mainly used to load and unload bulk material, are also considered in the simulator (see Figure 9). The mobile crane consists of a mast and a moving lattice boom that is supported by a cable and pulleys system. The sceneries of this crane also consider the simulation of several ships, including hold operations and yard bulk movement. Different bulk materials are realistically simulated. Vessel load and unload operations can be done, as well as bulk material movement through the yard. In addition, the translation of the mobile crane, which is a complex and dangerous operation, is simulated.

Figure 9: Bulk material handling in the Mobile Crane simulator

4.4 Reach-Stacker Crane

A Reach-Stacker crane is a heavy vehicle with a boom and a spreader attached to its end (see Figure 10). The dynamic model of the crane involves, in this case, soil-tire interaction which is made by means of Pacejka models (Pacejka, 2006). The spreader subsystem is simulated in a similar way as it is done in Gantry or Quay-Side cranes but, in this case, the hydraulic system is connected to the rest of the vehicle, thus influencing its behavior.

Two hydraulic pumps are considered, separately feeding boom and vehicle operation. The simulation of the hydraulic subsystem includes the loss of power if too many operations are being performed at the same time, and also the possibility of simulating different failures. As well as in the previous cases, the Reach-Stacker simulator also includes the truck traffic simulation system.

Figure 10: A view of the Reach-Stacker Crane simulator

4.5 Ro-Ro Tractor

A roll-on/roll-off (Ro-Ro) tractor (see Figure 11) is used to move road trailers onto and off roll-on/roll-off ships (ferries). It is a powerful machinery with high maneuverability, and the driver must have a good knowledge of its operation to properly park a trailer inside the vessels when it has to be left in a difficult position.

Figure 11: A view of the Ro-Ro Tractor simulator. The trailers are taken with the tractor head and loaded into a vessel

Several types of loads and trailers are considered in the simulator and the different exercises force the trainee to drive up ramps and through narrow corridors as those found in real ferries.

5 CONCLUSIONS

An immersive crane simulator for the training of operators of five different cranes has been presented. The system is highly flexible, allowing several hardware configurations, and uses the latest Virtual Reality techniques available.

A highly realistic Virtual Reality environment is used to reproduce the harbor, using different techniques to reduce its computational complexity. A set of advanced dynamic models simulate the evolution of the different systems involved, including systems that had not been simulated before, such as arbitrary cable-pulley systems or interactive bulk materials simulation.

The system includes an Instructional Design with a large set of exercises, which guide the instructor through the training process to take the most advantage of the system. The simulator provides the instructor with a helpful automatic evaluation and report system and a powerful debriefing tool to review any exercise done in the past. Also, through a complete control panel the instructor has full control over the simulation parameters.

The Training System is currently being used in Valencia Harbor and in several South American international terminals, and it is in continuous revision by the instructors therein. The main improvements that are currently in progress are the develvment of an exercise designer and the extension of the physical and mathematical models to improve the realism of the virtual environment. Also, a series of tests and questionnaires are being designed to evaluate the users experiences in order to improve the system.

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