FORK-LIFT TRUCK SIMULATOR FOR TRAINING IN INDUSTRIAL ENVIRONMENT

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Abstract

Since their first usage simulators have been employed in training staff in civil aeronautics and in military fields to improve driving skills without compromising safety of people and machines. The system proposed in this paper is suited to transfer this activity into the industrial field, in particular an innovative fork-lift simulator is presented. Actually most frequent causes of accident with fork-lifts are wrong manoeuvres accomplished by drivers. This simulator aims to improve skills in driving and handling materials using a fork-lift. The system can reply inertial feedback on the operator and allows the user to control all the tasks of a fork-lift as driving and handling materials.

The paper presents an overall view of the system including Stewart platform, supporting structure, physical based model, wash-out filter, system architecture and a video system mounted on board of the moving platform.

1. Introduction: aims and goals of the simulator

Driving and flight simulators, since the beginning [8], have been mainly addressed to the field of the personnel training, for instance in aeronautical or aerospatial applications where the use of the simulators permits to gain great experience by simulating dangerous situations without risks for men and machines [2], [3].

The INDICA simulator aims to transfer the simulators technology and the training methodology to the paper mill personnel operating with the forklift; such a category is in fact particularly exposed to the risks on the workplace. The statistics show [10] that the most part of the injuries is due to the accidental forklift overturning generally caused by wrong maneuvers of the driver. Fast curves or turns, as well as displacements with the lifted load are other frequent causes of accident.The use of a driving simulator in the industrial context offers the opportunity to experience new personnel job-training methodologies. It will be possible to train the drivers by executing maneuvers or acting in dangerous situations, learning by his own mistakes without damages to himself or to other people in the work place.

The INDICA project [11] concerned the design and realization of a motion-based forklift driving simulator that can replicate on the driver the physical feelings produced by the movements of the vehicle (accelerations, breakings, turns etc.); in the meantime the driver can drive the forklift using the primary commands (steer, pedals, leverages etc.) obtaining the same sensations that he would obtain driving the real forklift. Some of the typical paper mill workplaces, as the row material store or the trucks loading/unloading, have been graphically reproduced by the means of 3D graphic rendering techniques. The workplace has been visualized both in the front and the rear side of the system so that is possible to simulate the forward and the backward motion. The system developed within the INDICA project is particularly innovative because it represents, at the present, the first example of motion-based forklift simulator for the personnel training operating in an industrial context, and in particular in the paper mill context.

2. State-of-the-art

During the preliminary phase of the project the state-of-the-art in the field of the simulation of working machines has been analyzed. One of the most relevant applications is the motion based Harbor Crane simulator developed by Valencia University (LSYM, Instituto de Robotica). Such a system is composed by a 6 dof motion platform on which is installed a real harbor crane cockpit. The visualization system uses an interesting retro-projection technique on a fixed screen placed under the driver plane. An application focused on the forklifts driving training is the simulator named F10G developed by Dr. Foerst GmbH. This is a static simulator that has a double (front and rear) TV screen visualization system. Particularly interesting is the application that is a realistic reproduction of the forklift working environment and situations.

3. Overview of the simulator

The hardware of the system presented is compound by:
 – a real forklift truck cockpit that has all the features the user can find on a forklift. Steer and pedals for driving and levers for handling loads are active and allows the user to interact both with the machine and the virtual environment;
 – a Stewart platform that is a parallel kinematics robot capable to move its end effector according to six degrees of freedom;
 – a graphical system capable to visualize the virtual environment in front and rear view and an audio system that provides a sound feedback;
 – 2 PCs, one for the management of all the real time processes and the control of the whole system; one that manages the graphical rendering for front and rear view.

3.1. Cockpit

One of the most impressive aspects for the good response of a simulation is the fidelity of the representation of the environment that surrounds the user. To reproduce tactile and visual perceptions in an exact manner allows the user to be more involved in the simulation. The best way to achieve this goal is to physically reconstruct a cockpit that reproduce exactly shape, dimension and reciprocal position of the primary commands of the vehicle. In the case presented in this paper a real cockpit of a 30 quintals forklift has been modified to fit the needs of the project. In details all the hydraulic connections for steer, brake pedal and levers have been disconnected in order to allay the structure by unnecessary weights.

The steering feedback is reproduced by sliding friction, while the rotation and the extreme position of the steer itself is detected by an optical incremental encoder and a mechanical switch respectively. The brake pedal has been modified so to detect braking command by a mechanical switch; a spring provides reaction on the user's foot. Each lever is equipped by manufacturer with a switch that detect whether the user is moving the lever or not; the direction, positive or negative, is given mechanically exploiting the hydraulic plant of the vehicle. For hydraulic components have been removed an additional switch for each lever has been mounted in order to recognize the direction in which each lever is moved.

3.2. Moving platform

The platform selected to realize the present simulator is a commercial fully electric Stewart platform produced by Moog. This platform, named 6DOF2000E, has 1000 Kg of maximum customer payload and can reach velocity of 30 deg/s in Roll and Pitch, 40 deg/s in Yaw, 0.4 m/s in Heave and 0.3 m/s in Surge and Sway direction. Concerning the accelerations the platform is capable of 500 deg/s² in Roll and Pitch, 400 deg/s² in Yaw, 0.5g in Heave and 0.6g in Surge and Sway.

3.3. Video/Audio system

Because of the wide field of both front and rear view that a forklift allows to the user, the best choice for the visualizing system has been found in the retroprojection technique. Also Head Mounted Displays and LCD Wide Screen Monitors have been taken into consideration for this application [4], but being this simulator an instrument for training drivers it was impossible to avoid sickness using HMD with one hour long training session. Moreover a LCD screen has been found inapt because of the vibration that would arise in the structure during a normal training session. Vice versa a retro-projection system with all the hardware mounted directly on the moving platform can provide a wide visualization area avoiding sickness phenomena and, if appropriately designed, minimize vibrations.

The system mounted on board the simulator is compound by: two high luminosity consumer level LCD projectors generating front and rear images for forward and reverse gear; two 1600x1200 mm acrylic matt screens mounted in front of and behind the cockpit; two mirrors for beam reflection mounted on a supporting structure about 1.5 meter far from cockpit both in forward and reverse direction.
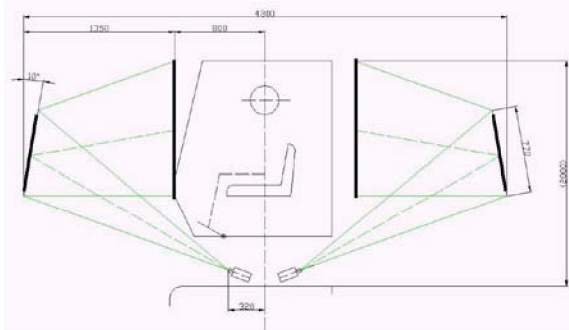

Figure 1: optical path after beam reflection.

In order to have a 1600x1200 image the optical path should be at least 3 meters. To lay projectors 3 meters far from the cockpit means to suffer largely for vibrations of the projectors themselves and therefore to have an unstable image. For this reason a mirror has been put in the middle of the beam path. In this way projectors could be placed very close to the center of the workspace of the moving platform and therefore the amount of vibrations that would afflict projectors could be minimize or even eliminate **(Figure 1)**.

The whole system has been designed in order to minimize vibrations: a reticular truss surrounding the cockpit supports the screens. This cell has been realized using commercial aluminium modular profiles in order to have as less weight as possible on the moving platform. On the frontal part of the cell another reticular truss is mounted to support the mirrors. This further

structure is made of slim stainless steel links in order to avoid too much encumbrances in the field of view. Attached to that links a honeycomb panel with the mirror is mounted. A similar structure is mounted on the rear of the cockpit **(Figure 2)**.
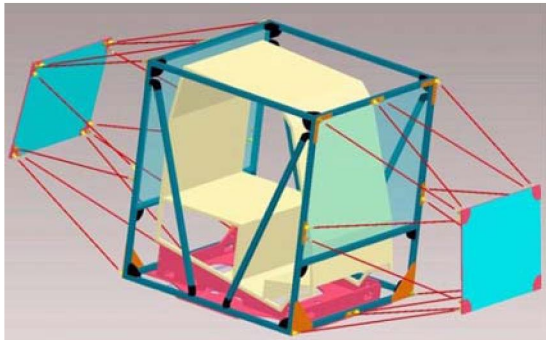

Figure 2: designing the structure: CAD Model.

The graphic card that manages the graphic subsystem is a commercial ATI Radeon 9700 Pro. The sounds are generated by a commercial card Creative Live!5+1. The speakers and the subwoofer are mounted all on board the platform; four speakers, two for front and two for rear sounds, are mounted on the four corners in the middle of the main truss, the central speaker is mounted on the dashboard. The subwoofer is placed on the room under the seat.

3.4. Control and Graphics PC
The PC that manages the physical simulation has a 2.8 GHz Pentium 4 processor and 1 GByte of RAM memory. A commercial I/O card, Advantech PCL- 711B with 8 single-ended analog input channels and 16 digital I/O channels, collects analogical and digital signals from the cockpit and a custom made card, based on PIC microprocessor, processes the signal of the encoder mounted on the steer.

The PC that manages the graphic subsystem has a 1.7 GHz AMD processor, 516 MByte of RAM memory and, as said, a graphic card ATI Radeon 9700 Pro and an audio card Creative Live!5+1.

4. Overall Software Architecture

The general organization of the system consist in the following components: 1) a control system which provides the servo control of the Stewart platform; 2) a physical based software model which animates the virtual components in the environment; 3) a dual output graphic subsystem to represent the front and the rear view of the environment and 4) a central control unit (CCU) which manages all the above components and integrates them with the mockup acquisition and motion unit. The software architecture is implemented on three computing nodes: one for the control of the Stewart platform (which integrates module 1), a second computing node for the management of the modules 2

and 4, and a third dedicated to the graphic module 3. Interaction among nodes is achieved with a fast Ethernet link (100Mbit/s), while communication within modules inside the node 2 is achieved using shared memory services. Node 1 uses a DOS like environment configured to run in real time the control of the platform. The system is configured to serve as an Ethernet-slave device; it receives the commands and the new position (in terms of RPY angles and SSH displacements) on a UDP socket, calculates the kinematics of the motion platform, actuates the motors and sends back answers to the Ethernet-master. This unit also provides a set of logical low-level hardware controls on the system such as distributed emergency signals over the system (emergency stop, on board stop and presence barrier). Node 2 runs a W2K OS integrated with a RT module that allows the CCU to run in real-time. The CCU acquires mockup signals to coordinate the other system units and to send command to the node 1 at a regular frequency of 60 Hz. On the contrary node 3 is based on Windows XP.

4.1. Central Control Unit
The organization of the central control unit is set out with modular blocks. The modularity imposed to the system can allow designer to efficiently test the system during the integration and maintenance phases as well as to reconfigure the system to support different system components (such as vehicle type, environments, mockups, Stewart platforms…).

All the components in the CCU operate accordingly to a predefined protocol that allows an easy introduction and/or removal of the modules from the control schemes without affecting the remaining system. The CCU is organized around the logic unit that receives informations and communicates commands to the other units about the state of the simulation. The three main units are the physical based model unit (PBMU), the graphic model unit (GRU) and the platform motion control (MBU) unit. These main modules look like a four-port system (2 inputs, 2 outputs): those units use two input/output ports to communicate their simulation state and to receive the state command from the logic unit, while the remaining ports are used for the data transmission. These three blocks have similar characteristics because their structure presents a S-function communicating the input data to an external module. From the PBMU the data are sent to the physical model and sent back to the CCU for the motion strategy management. In the case of GRU and MPU the data are communicated in open loop to an external module that controls the graphic and audio reproduction of the virtual environment and the motion of the platform. The other two units in the CCU are the motion unit (strategy manager) and the data acquisition unit. They present different schemes with respect to the previous modules. The data acquisition unit simply

collects and pre-evaluates the signals coming from the cockpit and communicates them to the PBMU, while the motion unit calculates and communicates the new positions to the MPU. All the system has been integrated using rapid prototype techniques available with a commercial development tool, which has been customized to the specific configuration of the system.

4.2. Logic Unit

The Logic Unit has been designed in order to achieve the safest and easiest operating conditions both for the operator at the console and the pilot of the vehicle. The principal task of the logic unit is the check of the simulation state, obtained by monitoring constantly the messages incoming from the single units, and the execution of the safety procedures. Furthermore the logic unit manages the state transitions in each unit in order to temporize and manage the simulation phases. This is obtained by commanding the units with the desired state, and enabling the state transition only when the unit has reached the required state. This procedure gives to the Logic Unit and to the whole control scheme the possibility of easy reconfigurations in the case of changing of the external conditions (external peripherals or control modules add or removal).

4.3. Motion Unit

The Motion Unit (washout filtering) has in input the linear accelerations and the angular velocities evaluated at the pilot head by the PBM that the simulator shell replicate [6], [8]. The most interesting features, from a scientific point of view, are the flexibility and the easy reconfigurability of the washout filter with respect to the platform workspace performances. This features are achieved by a full parametrization of the software that allows the developer to modify the behaviour of the system. The desired linear accelerations are elaborated in the Linear & Splitter Strategy that evaluates the gravitational strategy for each axis. The task of this block is in fact to separate the fraction of the desired linear acceleration that will be replicated by tilting the platform (gravitational strategy around Roll, Pitch and Yaw angles) from the one that will be replicated by a linear displacement of the platform (linear strategy along X, Y and Z axis). The block inputs are the desired linear acceleration; the effects of the Coriolis accelerations are also taken into account. Within this block the linear accelerations are low pass filtered in order to separate the linear and gravitational component. Then a Safety block evaluates the linear fraction to modify the acceleration values when the platform operates in proximity of the workspace boundary. The outputs are the linear position of the platform in the next time step and the fraction of gravitational acceleration. The portion of linear acceleration that will be replicated with the gravitational strategy (Agrav) is an input of the Tilting Unit; this block calculates the RPY tilt angles that permit

to reproduce the Agrav, avoiding at the same time the perception of the tilting by saturating the platform angular velocities. Furthermore this block can optimize the workspace taking back the platform in the central position of the workspace while tilting. The RPY angles due to the angular velocities, calculated separately in a different block of the motion unit (Angular Motion), are then added to the previous tilting components. The output of the Motion Unit (RPY angles, SSH displacements) is an input of the MPU [1], [8].

4.4. Physical Based Model

One of the more critical aspects in the simulation of dynamic phenomena in virtual environments is the modeling of the contact between objects (collision detection) [9]. Often may be useful (i.e. in the INDICA context) to approximate the bodies involved in the contact phenomena to completely rigid bodies to simplify the collision detection analysis. This approximation is such that if two or more objects get in contact or in collision they cannot compenetrate. This permits to ignore localized deformation and contact phenomena, whose mathematical and physical description and resolution would request the introduction of non-linear differential equations into the PBM equation set. The problem consists instead in the individuation of the normal in the contact point as regards the directions and the velocities after the collision will be calculated. The rigid body schematization permits an almost accurate simulation of a large category of physical phenomena, without significant drawbacks in terms of simulation realism.

In the case of the INDICA simulator, the PBM was realized by the means of an open-source library (ODE, Open Dynamic Engine) especially setup for the modeling of rigid and articulated bodies systems. ODE has a set of pre-defined elements, like constraints, couples, joints etc. whose behavior may be fit on the specific user's need. The choice of using the numerical approach in the INDICA context was motivated by the accuracy in the modeling and the high stability (1 KHz) in the simulation of the physical events, conferring an optimal interaction with both the dynamic and graphic model (60 Hz) and the motion control model (60 Hz).

5. The simulations and the environment

As said the simulator will be employed in training forklift drivers, so much attention has been focused on the simplicity of use, so to let each user to run the simulation without the need of trainer staff. Once the user sits in the cabin a series of messages on the front screen tell the user the procedure to follow in order to run the simulation. This operational modality has been implemented in order to reduce the personnel request during the development of the system as well as during the training phases.

At present days three different scenarios are implemented. Each one refers to a SCA Packaging factory located in Lucca (Italy). Forecourts and buildings have been photographed, and then texture have been created according to these pictures and applied on a geometrical graphical model of the landscape. Each scenario lets the driver makes the typical maneuvers and tasks he would do driving a real forklift in a paperpackaging factory **(Figure 3)**.
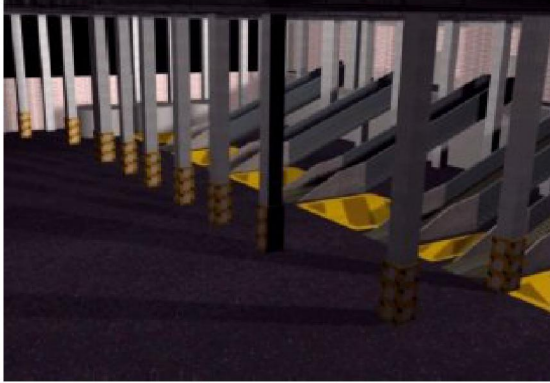

Figure 3: the pulper feeder zone.

In the first scenario the forklift tool is a plain gripper to catch and carry waste paper bales. The user must download the bales from a truck placed on the forecourt and stock them in the store placed in a building either in another forecourt. In the second scenario the user must convey with the same tool the previously stocked bales from the store to a set of sliding ramp placed inside a building. The third scenario refers to the end-line handling task that is to take paper reels from the end-line store and load them on a truck in the forecourt.

A test course has been done in November 2004 upon a sample of six workers. This first course was spread on three days, during each of them every person used the simulator for two sessions of 15 minuetes. The training followed these steps:

- driving without the load through the courtyard and the sheds of the factory;

- handling of material uploading and downloading waste paper bales from a truck placed in the middle of the courtyard;

- driving with the load inside the factory buildingn carrying the loads from the courtyard to the pulper feeding ramp.

6. Conclusion

The presented simulator is working in a room of the Industrial Design Division of PERCRO Laboratory sited in Lucca **(Figure 4)**. It has been experimented by forklift users that gave positive responses in terms of reality of simulation and virtual environment.
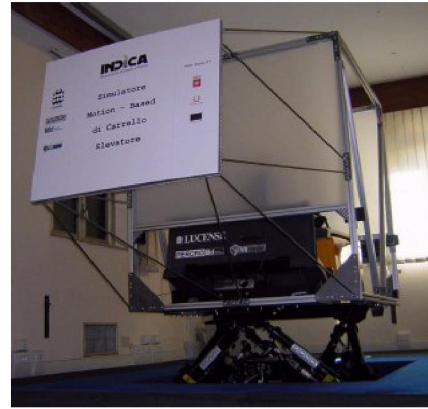

Figure 4: INDICA forklift simulator.

At the present the INDICA simulator is going to be employed in training beginning forklift drivers. In the future it will be also employed in annual or semestral sessions for expert users.

References

[1]. Bowles RL, Parrish RV, Dieudonne JE, "Coordinated adaptive washout for motion simulators", Journal of Aircraft, Vol 12, n.1, 44- 50, 1975

[2]. W. Kading; "The Advanced Daimler-Benz Driving Simulator", SAE 9530012, 1995.

[3]. H. Soma and K. Hiramatsu; "Driving Simulator Experiment on Drivers' Behaviour and Effectiveness of Danger Warning Against Emergency Braking of Leading Vehicle", Proc. of 16th ESV, Canada, 1998.

[4]. K. Yoshimoto, D. Kawasaki et al.; "Development of a Motorcycle Simulator Using a Parallel Manipulator and a Head Mounted Display", Proc. of DSC2000, France, 2000.

[5]. F. Barbagli, D. Ferrazzin, C.A. Avizzano, M. Bergamasco, "Washout Filter Design for a Motorcycle Simulator", Proc. of VR2001, Yokohama, 2001.

[6]. J. B. Sinacori, "A Practical Approach to Motion Simulation", AIAA Visual and Motion Simulation Conference, Palo Alto (CA), 1973.

[7]. P. Howard, "The vestibular system" in "Handbook of Perception and Human Performance", John Wiley, 1986.

[8]. D. Ferrazzin, P. Moncini, G.M. Prisco, F. Salsedo, M. Bergamasco, "Inertial Force Feedback in a Motion Based Two-wheeled vehicle simulator", Proc. of RO-MAN '97.

[9]. D. Baraff, "An Introduction to Physically Based Modeling", ACM Siggraph '92 Course Notes.

[10]. R. Cianotti, "Linea Guida: adeguamento carrelli elevatori in riferimento al rischio di perdita accidentale di stabilita'", ISPESL Dip. Tecnologie di Sicurezza, Luglio 2002.

[11]. M.Bergamasco, M.Franceschini, S.Perotti, C.A.Avizzano, C.Bianchi "Simulatore di carrello elevatore finalizzato all'addestramento del personale", ATICELCA 2003, Rimini, Italy.