AN EXPERIMENTAL VALIDATION OF SHIP-TO-SHORE GANTRY CRANE SIMULATOR COMPARING WITH REAL DATA DERIVED BY TERMINAL PORTAINER

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ABSTRACT
The objective of this article is to validate a mobile platform of a ship-to-shore gantry crane simulator named “Chameleon”. It can be used for both training and R & D activities.

The simulator has been built to provide an environment for high performance training, but also for basic and applied research, analysing operator performance by means of medical instruments.

The validation has been done comparing the vibration spectra recorded in the simulator platform with spectra recorded in a cabin floor of a true crane located in Cagliari Terminal Container port, measured during task executions.

Keywords: crane simulator, terminal portainer, vibration spectra

1. INTRODUCTION

The objective of this paper is the validation of a mobile platform of a ship-to-shore gantry crane simulator developed at University of Cagliari; it has been named “Chameleon” because it can be used for both training and R & D activities, changing equipments dedicated to measure performance and medical characteristics of crane operators.

Chameleon has been developed by a team composed by some researchers of University of Cagliari (the authors of this paper) and others of University of Genoa.

The aim of the simulator is double:

- regarding training activity, it is to reduce the error of quayside crane operators through training using virtual reality, improving the performances and thus the competitiveness of the port.
- regarding the Research & Development, it is to study physical and mental effects that the position and the work activity have on crane operator, evaluating thus issues of human factors.

Moreover , in container terminals, the gantry crane operators are strongly exposed to latent sources of stress: it depends by the specific task made and of the continuing advances in crane functionality.

This has led to an increasing demand for highly skilled operators in container shipping, a sector that has been experiencing exponential growth for many years now.

So a ship-to-shore gantry crane simulator allows to improve the performances of crane operators, increasing the quality of task and reducing the effect of physical and mental stress: therefore, simulators as Chameleon have to simulate real world as good as possible, regarding crane movements, vibrations, waves and so on.

The simulator has been designed to provide a full immersion environment for high performance training, but also and above all for basic and applied research, monitoring and analysing operator performance by means of electromedical instruments.. The specific activities conducted with the Cagliari simulator (training, research, technological advance) aim to reduce the possibility of accident occurrence, which are largely caused by the onset of fatigue. In this way, it is possible to obtain vibration spectra of linear and angular accelerations over time.

The objective of this paper is to validate Chameleon comparing the vibration spectra recorded in the simulator platform and in cabin floor in a true crane located in Cagliari Terminal Container port measured during task executions.

2. CHAMELEON SIMULATOR

The quay crane simulator “CHAMELEON”, is an innovative system designed for the purpose of solving human factor related problems (sight, ergonomics, anthropometrics etc.) associated with quay crane operator tasks, as well as for conducting advanced training activities

Chameleon simulator is located in a 40 ft High Cube container (purposely chosen for its internal height of 2.70 m, higher than a standard ISO container, allowing more space for designing the main platform). This minimizes the time required to prepare training and research sessions, providing on site training services for container terminal operators.

Figure 1: Traditional dynamic cockpit and graphic interface of the quay crane simulator

Figure 2: Brieda dynamic control station currently installed in the Chameleon simulator

As every kind of existing simulators for training a crane simulator is composed by 5 main components:

1. cabin interface(cockpit): it reproduces with fidelity the real place operator, composed by seat and cockpit (commands, two manipulators, one for movement and the other for elevation of the system spreader-container). It is usually positioned on a motion platform (3 degrees of freedom) that allows the operator to receive, not only visual and audio stimulation, but above all to perceive movement sensation. Platform is build with actuators under the cabin that provide movement based on input from the user and operative conditions. The motion system simulates real vibrations and collisions.
2. highly immersive basic CAVE (consisting of the four display screens-drapes, two side, one in the front and one inclined on the floor to ensure continuity of the virtual image) that provides the trainee with 270° horizontal and 120° vertical fields of vision.

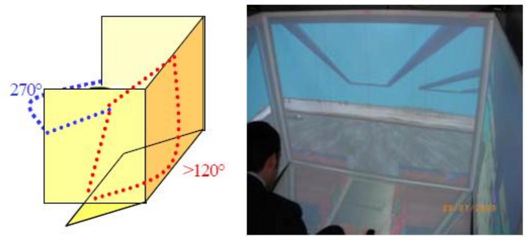

Figure 3: Trainee field of vision

3. Operative trainer interface: it is axternal to the operator cabin, it's provided with monitors to observe the training session phases. From the trainer observatory it is possible:
   - to reproduce different simulation scenario, with several weather conditions (wind, rain, sun, etc.), daytime (day with sunlight, night with artificial light) and general (the selection of the different set up allows to alternate several scenario, with different ships configuration harbors and equipments as different kind of spreaders);
   - for the instructor to repeat the trainee test with the same conditions in case of failed scenario or to analyze mistakes;
   - to provide scenario with growing level of difficulties if the trainee shows improvements.

Figure 4: Instructor workstation

4. visual system: it reproduces the real environment by screens projection.
5. audio system: it reproduces sounds effects produced by vibrations (movement of the crane cabin on the portal), collisions, wind.
6. central operative system: the “brain” of the simulator, it controls operations and provides different simulation scenario

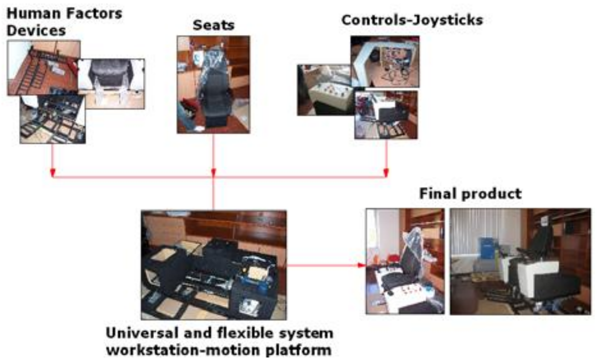

Figure 5: Interchangeability Concept of the Integrated Seat-Pulpit System of the Cagliari portainer simulator

This high-tech and completely original simulator, able to satisfy the real requirements of the cargo handling sector, is equipped with highly versatile and flexible hardware and software and differs from all other quay crane training simulators currently in use in other centres. In fact with the Chameleon, operator training can be tailored to all types of control stations and existing crane types.

Evidence of its great versatility, is its current configuration for accommodating two different types of control stations: the traditional type and the innovative dynamic control station manufactured by Officine Meccaniche Brieda, as shown in fig. n°2.

Figure 6: Electro-medical instruments

The simulator has been designed to conduct three different activities:

- Research: studies of human performance under different operating conditions through objective medical parameters (EEG, ECG, EMG plots, goniometer, Inclinometer, Accelerometers, Eye tracker, etc.) as well as by means of standard procedures already used for fatigue testing in the field;
- Technology advancement: applied research activities and validation of new design options for the crane command and control systems, aimed at enhancing operator performance and thus at optimizing the man-machine interface;
- Training and refresher training for crane and truck-trailer drivers in port terminals.

3. THE METHOD

The measurements were carried out on 6 points of measurement shown schematically in figure below. The use of measurements on three axes is under the operator's seat has allowed to evaluate the absorption by vibration of the mass located between the support structure and the seat.

For the measurements were used six accelerometers; they have been positioned on the support structure of the seat, so as to be able to acquire the values along the three axes and calculate the rotation values with simple arithmetic operations.

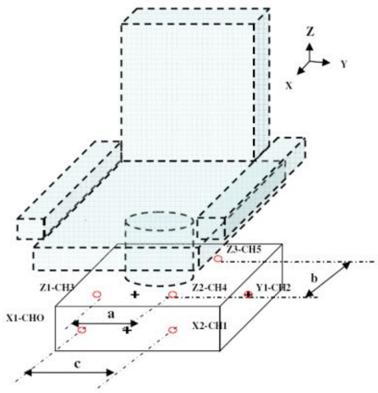

Figure 7: Location of six accelerometers

First analysis was performed of the work cycle of loading-unloading of the crane gantry, thus identifying four basic stages:

- Phase 0: positioning of the spreader, locking and lifting the container from the dock
- Phase 1: Progress of the spreader, coupled with the container from the quayside to the ship
- Phase 2: Place the container, releasing the spreader
- Phase 3: Return of the spreader toward the dock and the beginning of the next cycle

The data were obtained with a scanning speed of 2000 data / s; for each linear and angular acceleration component have been reported the maximum values obtained and the RMS values refer to successive samples of data in 1000 and evaluated for an entire work cycle. In this way it was possible to highlight the critical values of the accelerations during the various stages.

For data acquisition we have used six single-axis accelerometers, IEPE cubic Dytran series 3097; it is a cube miniature titanium from 0.4 inches to the side, weight 4.3 grams, low noise electronics JFET, circuit TEDS.

During two days tests, a set of data about the movements of a portainer cabin have been collected: using six Accelerometers IEPE (Integrated Electronic Piezoelectric), all vibrations spectra along three axes: x, y and z, have been recorded. They have been placed at the crane operator seat base, for measuring the accelerations along:

- X axis for cabin frontal movement;
- Y axis for cabin lateral movement;
- Z axis for cabin vertical movement.

Data have been collected respect to wind speed, crane movements, container weight and so on. Tests have been made at the beginning of the work shifts of Cagliari terminal container: each test session is gone on for two hours and 30 minutes. The details of test are:

- Test 1: from 7,00 a.m. to 9,30 a.m.;
- Test 2: from 3,00 p.m. to 5,30 p.m.;
- Test 3: from 7,00 p.m. to 9,30 p.m.

Globally, 103 cycles have been measured: each cycle represents a complete movement to load or unload one container from ship to shore.

The acquisition of data in separate periods of the day and in different shifts allowed the assessment of any changes in the results caused by different "styles" of work of operators and crane operators from different environmental conditions (eg day / night or intensity of the wind).

Regarding data collected in Chameleon simulator, data have been acquired with the same methodology, placing the 6 accelerometers symmetrically in groups of three along the three main axes X, Y, Z, positioned at the base of the chair of the operator.

4. RESULTS

First of all, for each measured cycle , it has been recorded the RMS (Root Mean Square) for each axis, defining the minimum and the maximum of the acceleration wave; then, the mean between maximum acceleration values of X, Y and Z have been calculated.

The minimum and maximum values of three axes, have been reported in the table below:

Table 1: Min and Max acceleration wave for crane

	acceleration wave $\frac{m}{s^2}$		
	X	**Y**	**Z**
Min	0.02	0.02	0.01
Max	1.68	2.11	2.71

Same survey has been made in Chameleon simulator for recording same data at the same way. The minimum and maximum values of three axes, have been reported in the table below:

Table 2: Min and Max acceleration wave for Chameleon

	acceleration wave $\frac{m}{s^2}$		
	X	**Y**	**Z**
Min	0.01	0.02	0.01
Max	0.35	0.39	0.83

The results show as the platform of Chameleon simulator repeats quite well all movements of a real gantry crane.

The results show some interesting issues, particularly regarding the comparison of average of values of acceleration for each axis:

- comparing of spectra shape and so the profiles of wave recorded during simulator and quay crane tests are well fitting and very similar. The waveform shapes are similar, the points of minimum and maximum are located in the same position and there are the same proportions between peaks. The qualitative drawing of single spectra wave for three axes (X, Y and Z) are quite similar with the work cycle structure of a portainer.
- regarding the real values of spectra acceleration for medium wave, the simulator platform has a similar behaviour respect to real cabin crane; analysing each axes.
  - for X axis, the differences between simulated and real acceleration are low and not more than 0,2 m/sec^2; the spectra of Chameleon are regular instead the spectra of true crane have irregular shape.

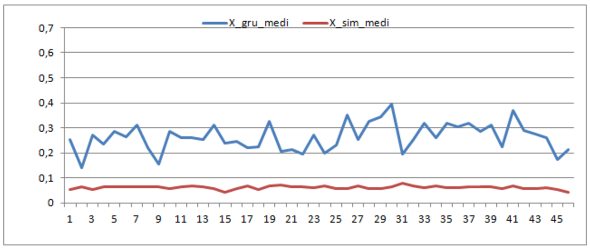

Figure 8: Comparison of spectra for X axis;

  - for Y axis, the differences are smaller than X axis and differences of real values are less than 0,1 m/sec^2; looking the profiles of spectra for chameleon and true crane, there is nearly a coincidence of values in the shape: in some points two lines coincide.

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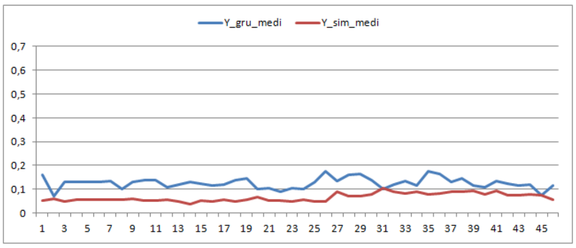

Figure 9: Comparison of spectra for Y axis;

- for Z axis, the differences are bigger than two previous cases (medium values about 0,25-0,3 m/sec^2). Infact, in the first part of spectra, there is little difference between the real and simulated acceleration, but in the second part they increase. The differences between the two spectra are less than 0. m/sec^2 in the first part, while in the second part the trend is similar except for some cycles where the differences reach 0.3-0. m/sec^2. The evolution of the spectra is quite similar in both cases: it is rather uneven.

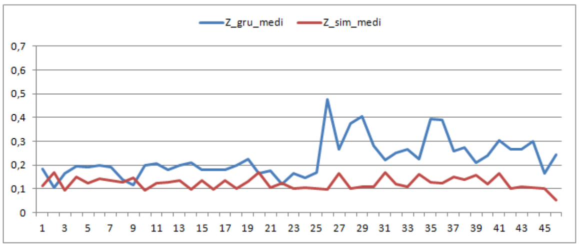

Figure 10: Comparison of spectra for Z axis;

Comparing the average of maximum values of each cycle, obviously the differences between real and simulated accelerations are higher than medium values:

- for X axis, the waveform shapes are similar and differences between real and simulator values are about 0,7-0,8 m/sec^2;
- for Y axis, differences are smaller than the previous case(less than 0,3-0,4 m/sec^2, but some cycles present high peaks);
- for Z axis, there are some differences evaluated in 0,4-0,5 m/sec^2.

There are many reasons for explaining these differences between real and simulator data:

- high values of the acceleration data recorded for cabine crane can be caused by wind: infact during registration only the average wind speed has been observed, not the peak values;
- the cranes used for real tests are fifteen years old: during movements for loading/unloading containers, they suffer high vibrations caused by work use. Probably using a new crane, those high acceleration values would be lower.

5. CONCLUSION

The work carried out has allowed us to deepen the basic knowledge and the trend of the spectra of vibrational waves that develop in the cockpits of the gantry crane of the industrial port of Cagliari during the course of loading and unloading. As for the simulator, it was the first test and thus made it possible to gather information necessary for its future development and improvement.

The spectra of vibrations produced by the simulator have a trend similar to the real (referring to a single work cycle) ; if one considers the qualitative trend of the spectrum (ie, the trend of the peaks and the design of the spectrum), for both the X axis and for that of Y and Z, the shape can be considered very close to the real performance. In the transition from one phase to another is maintained the right proportion in the sequence of lows and highs and keeps track of the maximum (for all three axes), as well as on the real crane, in moments of "loading" and "unloading".

The simulator encounters some difficulties as regards the intensity of the accelerations to be produced: the average of the oscillations vibrational force was lower for a delta of 0.4 m/sec2. This difference is visible to the X and Y axes while the Z axis of the delta difference is smaller.

Therefore, it is suggested, first, to calibrate the platform of the simulator with the new spectra. Also it would be useful to provide the mechanism or a fifth horizontal piston or of a system of sub-woofer in order to make more marked oscillations along the horizontal (ie, along the axes X and Y).

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