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Operative and procedural cooperative training in marine ports

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ABSTRACT

This article faces the problem of operative and procedural cooperative training in marine ports with particular attention to harbour pilots and port traffic controller. The design and development of an advanced system, equipped with dedicated hardware in the loop, for cooperative training of operators involved in the last mile of navigation is presented. Indeed, the article describes the software and hardware development of a distributed and interoperable system composed by two simulators (the bridge ship simulator and control tower simulator). Multiple problems are faced and solved including (i) the motion of the ship at sea that is based on a 6 Degree Of Freedom (DOF) model for surge, sway and yaw and closed form expressions for pitch, roll and heave and its validation; (ii) the development of the 3D geometric models and related virtual environments of a real marine port and vessel (to provide the trainees with the sensation to experience a real port and ship environment); (iii) the design of a bridge ship replica, the bridge hardware integration and the design of the visualization system; (iv) the design and development of the control tower simulator; (v) the integration of the bridge ship simulator and control tower simulator through the IEEE 1516 High Level Architecture standard for distributed simulation.

1. Introduction

Large ships manoeuvres in the aim of the entry to or exit from the harbour area can be complex and dangerous operations for several reasons. Indeed, in standard traffic conditions, harbour pilots and port traffic controllers deal with a great number of vessels of different sizes (i.e. small motorboats, huge container carriers, cruise ships etc.). In addition, manoeuvres times (and reaction times) of vessels are very slow compared to other vehicles especially for large vessels. Indeed, due to their prominent size and mass, in case of mistakes and accidents, large vessels may cause enormous damages (as clearly demonstrated by the recent accident on May 7th, 2013 of the Italian containership Jolly Nero in the port of Genoa, Italy, check http://www.bbc.com/news/world-europe-22444421 for further information).

In large facilities like marine ports like in many other industrial facilities, operative and procedural training has widely proved to be an indispensable approach that can be effectively supported by simulation based systems [2,19,21]; as far as the ship manoeuvres in the port area are concerned, simulation based systems can be profitably used for ship pilots training purposes, for procedures definition, evaluation and testing, for understanding vessels interactions within the port area, for evaluating the effects on ships of adverse weather conditions (including wind, sea waves and marine currents). As a matter of facts, simulation based system allows a greater standardization and effectiveness of training procedures. The trainees can control virtual ships in any critical or dangerous condition; they can perform both standard and non-standard manoeuvres and therefore they are trained to handle those situations that cannot be recreated during traditional training sessions in a real ship.

Therefore simulation based training is also characterized by a relevant reduction of direct costs. These costs reduction is related to the increase of productivity when workers (in this case ship pilots) are well trained to perform their job. There is also a reduction of indirect costs caused by accidents during training and normal activities as well as the possibility of collecting a large amount of data about trainees' performance in a controlled simulated environment.

Moreover, simulation-based training is fruitful not only for beginners but also for expert operators. For instance, it can be useful to have the first approach with a new ship or to learn how to put in practice the procedures currently adopted in a specific port. Moreover, the simulators can be used to understand how performing ship manoeuvres in critical conditions (i.e. strong wind and/or marine currents), how carrying out complex manoeuvres with the help of tugboats, how performing mooring operations and control the ship when close to the assigned berth area. A key feature of the simulation approach is the greater level of immersion it

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can provide compared to traditional training approaches. Indeed, immersion makes the training experience more captivating and therefore contributes to maximize the amount of information the trainees are able to acquire, the skills that can be developed and mostly the ability to transfer lesson learned to the real system. Basically, immersion can be diegetic and situated or intra-diegetic. The former occurs when the player gets absorbed into the virtual experience while the latter goes beyond the diegetic immersion and implies the player total engagement that is the illusion of existing and acting within the virtual environment. Needless to say that, in both cases, the virtual environment where the trainee acts and the hardware tools used to interact with the environment itself play a crucial role. To this end, the research proposed in this article has been focused on the development of a fully operational prototype system for harbour pilots and port traffic controllers training including not only the distributed virtual environments, but also a suitable hardware tools design and integration. The training system presented in this article is currently installed in the MSC-LES lab (Modelling and Simulation Centre-Laboratory of Enterprise Solutions) at the University of Calabria.

Indeed, the literature review confirms that there is quite a large amount of research works that show how simulation has already been successfully applied to support decision making [5] and training of operators working within the port area, i.e. cranes, trucks, straddle carriers operators, etc. [15]. Many simulators are intended to quay cranes operators' training [31,11,7,26] and specific research works have also investigated the training for supporting security procedures integration in the marine port operations [17,18,20]. To this end, it is worth mentioning that a comprehensive survey of research projects dealing with advanced simulation systems for operators training in marine ports is the main deliverable of the OPTIMUS project (Operational Port Training Models Using Simulators, financed by the European Community) [23]. The OPTIMUS project provides a detailed description of many commercial simulators for marine port operators training. Such simulators include crane simulators mainly.

In addition, innovative approaches based on interoperable simulation have been proposed. Specific examples regarding the training of marine ports operators, e.g. [1,3,4] propose interoperable simulators (based on the High Level Architecture, HLA, standard) for different container handling equipment (gantry cranes, transtainers, reach stackers, trucks, etc.) offering advanced solutions in terms of external hardware, e.g. motion platforms, different types of external controllers from joysticks to wheels and pedals and even containerized solutions.

As for ship simulators, interesting applications can be found in [30,28,27,33]. Although in such works an immersive visualization system and the dynamic behaviour of the ship have been implemented, there is still substantial room for improvement above all in terms of ship motions predictions and validation. Moreover, in these works no attention has been paid on the last/second last mile of navigation (including manoeuvring and mooring operations in the port area) that, as explained before, it is as important as offshore navigation. A review of the state of the art related to traffic controllers and ships pilots training in marine ports can be found in [6].

Indeed, the main goal of this paper is to present an advanced simulation based system, equipped with dedicated hardware in the loop, for training, safety and security of operators involved in the last mile of navigation. The system includes a ship bridge simulator (with a full replica of a ship bridge), a full control tower simulator and a tugboat bridge simulator (with a full replica of a tugboat bridge; the last simulator is not described as part of this article). The proposed training system is conceived in order to provide its users with a realistic experience thanks to the possibility of experiencing a joint and cooperative training environment. To this end, the three simulators have been integrated according to the High Level Architecture standard (IEEE HLA 1516). As a result, pilots can exercise their operational and manoeuvring skills, became acquainted with the behaviour of the ship and with the effects of their interaction patterns. Moreover, the proposed system allows the harbour pilots to learn the procedures that are currently adopted in a specific port, and decision makers to design and test new procedures.

Along the article different problems are presented and solved, namely: (i) the sea-keeping problem in terms of implementation and validation of the ship motion equations at sea for a 6 Degrees of Freedom (DOF) model; (ii) the design and development of all the 3D geometric models and virtual environments; (iii) the design of a bridge ship replica, the bridge hardware integration and the design of the visualization system; (iv) the design and development of the control tower simulator; (v) the integration of the bridge ship simulator and control tower simulator through the IEEE 1516 High Level Architecture standard for distributed simulation.

The prototype system presented in this article has been developed within the framework of the on-going research project: HABITAT (Harbour Traffic Optimization System). This project is co-founded by the Italian Ministry of Education, University and Research as part of the PON01_01936 research project.

Before going into details, the paper is organized as follows: Section 2 discusses the sea keeping problem and explains the 6 DOF model used to simulate the ship motion at sea. Section 3 presents the 3D geometric models and the virtual environments based on the Port of Salerno (Italy). Section 4 proposes the design of the ship bridge replica, the hardware integration and the visualization system, while Section 5 presents the control tower simulator. Finally Section 6 shows the overall system prototype including the ship bridge simulator and the control tower simulator and the last section summarizes the scientific contribution of the paper and points out some aspects for future development.

2. The sea-keeping problem: the ship motion equations

The ship included as part of the ship bridge simulator is a commercial containership based on the Kriso containership model, whose main particulars are summarized as follows:

- Hull
  - Length between perpendiculars 230.0 m
  - Length water line 232.5 m
  - Breath 32.2 m
  - Depth 19.0 m
  - Displacement 52,030 m^3
  - Coefficient block 0.651
- Rudder
  - Type semi-balanced horn rudder
  - Surface of rudder 115 m^2
  - Lateral area 54.45 m^2
  - Turn rate 2.32°/s
- Propeller
  - Number of blades 5
  - Diameter 7.9 m
  - Pitch ratio, P/D (0.7R) 0.997
  - Rotation Right hand

A 6 DOF mathematical model is used to reproduce the ship motion at sea. In particular, for surge, sway and yaw, the Manoeuvring Mathematical Modelling Group model (MMG) [22] has been used (and tuned). Such model takes the name from the Japanese research group that implemented it for the first time between 1976 and 1980. Hence, the MMG group (1985) defined for the first time a prediction method for ship manoeuvrability.