COOPERATIVE TRAINING FOR SHIPS AND TUGBOATS PILOTS BASED ON INTEROPERABLE SIMULATION

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ABSTRACT

This paper presents an advanced training system for ship pilots and tug pilots involved in the last mile of navigation. Such training system relies on the interoperable simulation based approach and it is made up of a federation of simulators that have been integrated according to the High Level Architecture standard (HLA 1516). In particular, the federation includes, among others, the simulator of a container carrier and a tugboat simulator that can interoperate each other and share the same 3D virtual environment. The physical behaviour of the boats (both the containership and tugboat) and their interaction patterns have been recreated by using 6 Degree of Freedom (DOF) mathematical models encoded within the simulators. In addition, the 3D geometric models and the operational scenario (including the port area) have been carefully developed.

Keywords: Ships Pilots Training, Ship Tugboat interactions, Modeling & Simulation, marine ports

1. INTRODUCTION

On May 7th, 2013 the Italian container ship Jolly Nero slammed into a dock as it was exiting from the Port of Genoa striking and toppling the port control tower. The incident caused ten deaths, several injured and huge economic damages. So far, investigations into the causes are still underway but it is clear that:

- an intervention of two tugboats assisting the ship during the manoeuvre would have prevented the accident from happening;
- the lack of dredging of the west exit has required big ships to execute unusual manoeuvres to leave Genoa port.

The Jolly Nero facts, as well as other incidents occurred over the years, show that exit/entry manoeuvres within the port area are very complex and must be regarded as critical operations; in fact owing to the big dead-weight of commercial ships a single mistake, even at low speed, can cause unexpected and tragic consequences not only for the operators involved but also for those operators working in the same area. To this end, a good interaction and communication between the ship and the tugboat is important to prevent accidents; in addition, it is also important to define standard operating procedures and policies for entry/exit manoeuvres aimed at ensuring high security and safety levels (Bruzzone et al., 2012-a). Within this framework, considering also that the most of the ports impose to incoming and outgoing ships to be supported by a certain number of tugboats (according to the ship weight/dimensions), the cooperative training of both ship and tugboat pilots plays a critical role for security and safety levels enhancement as well as for a better productivity (indeed, according to the shipping company goals, ships must leave the port as soon as possible, Longo 2007; Bruzzone et al. 2012-b).

Obviously, training activities on the real system with real equipment would be too expensive and too dangerous, therefore Modeling & Simulation (M&S) based approaches, that allow trainees to act in a synthetic environment learning how to put in practice theoretical concepts/procedures and see the immediate consequences of their actions in a visual manner, can offer substantial advantages (Bruzzone et al., 2010; Bruzzone et al. 2011; Merkuryev and Bikovska, 2012). Hence, this research work is devoted to describe an advanced interoperable simulation based training system for ship pilots and tug pilots involved in the last mile of navigation. Such training system is part of an ongoing research project "HABITAT, Harbor Traffic Optimization System" co-financed by the Italian Ministry of Education, University and Research as part of the "PON Ricerca e Competitività " Program.

The proposed training tool 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, interoperability has been one of the main driving requirements that has been achieved integrating the simulation resources according to the High Level Architecture integration standard (HLA 1516). In this way a federation of simulators has been developed. The federation includes three federates:

- the ship federate, that reproduce different types of ships according to the initial settings (containership, tanker, ro-ro ship; in this paper the case of the containership is presented);
- the tugboat federate; such federate runs on a different PC, even distributed over a

LAN/WAN network, and can be used to recreate the operations usually carried out by tugboats in real port environments;
- the control tower federate; this simulator recreates the activities that usually take place within the port control tower including port traffic monitoring and control and communications with incoming and outgoing ships (in this paper only the first two federates are presented; the implementation of the control tower federate is still on-going).

As a result, pilots can exercise their operational and manoeuvring skills, became acquainted with the behaviour of the ship/tugboat and with the effects of their interaction patterns. Moreover, the proposed tool allows the pilots to learn the procedures that are currently adopted in a specific port, and decision makers to design and test new procedures.

To ensure a satisfactory level of realism, the dynamic behaviour of each federate has been implemented and is based on a 6 Degree Of Freedom (DOF) mathematical model. In particular, surge, sway and yaw are modeled using the so called Manoeuvring Mathematical Modeling Group (MMG, 1985) model, that takes its name from the Japanese research group that has implemented it between 1976 and 1980.

The MMG model has been studied extensively in conjunction with the findings of posthumous research works such as Kijima and Nakiri (2003), Lee et al. (2003), Hasegawa et al. (2006), Perez et al. (2006) and Armaoğlu et al. (2009). As a matter of facts, the MMG group defined for the first time a prediction method of ship manoeuvrability while Kijima and Nakiri (2003) proposed the approximate formulas for calculating the hydrodynamic forces, taking into account the effects of the stern shape. Moreover, Rhee et al. (1999) and Lee et al. (2003) have proposed some empirical formulas aimed at finding out the hydrodynamic coefficients for the ship manoeuvrings equations.

Hasegawa et al. (2006) have discussed the course-keeping ability of a pure car carrier in windy condition.

Perez et al. (2006) and Armaoğlu et al. (2009) describe how some parameters and dimensions influence manoeuvrability characteristics.

As for roll, pitch and heave, ship motions have been estimated based on the models of Jensen, (2001), Jensen et al. (2004).

In the sequel, a brief description of the paper organization is given. Section 2 describes the reference scenario, the port of Livorno, reproduced in the 3D virtual environment; in addition, the ship and the tugboat taken as a reference for the respective simulators are described. Section 3 deals with the mathematical models behind the dynamic behaviour of the ship and of the tugboat both when they are kept separate and when they are mutually interacting. In section 4, a tool developed in the C++ programming language and devoted to evaluate and validate such mathematical models is presented. Lastly, in section 5 the integration of the federates into the proposed HLA federation is discussed. The last section summarizes the contribution of the work.

2. THE MARINE PORT SCENARIO

The scenario that has been reproduced within the proposed simulation framework is the port of Livorno (Figure 1), which is located on the Tyrrhenian Sea in the northwestern part of Tuscany. It is one of the largest seaports in Italy and in the whole Mediterranean Sea with an annual traffic capacity of around 30 million tonnes of cargo and 600,000 TEU's. It can handle every kind of goods: bulk, liquid, frozen foods, fruits, cars and most of all containers. Moreover, the port of Livorno is the only in Italy, and the second in Europe, with a liquefied natural gas (LNG) terminal where double-hull gas tankers from North Africa unload liquid gas in artificial caves located below the sea level. Port areas cover about 800,000 square meters; however, surrounding areas include warehouses and yards devoted to support port activities therefore the overall port size is around 2,500,000 square meters. Other features that are worth mentioning include 11 km of quay, 100 docking points, and maximum deep water 40 feet. These features, along with its connection to the railway and to the major roads, make this port a strategic hub for both Italian and European freight traffic. For these reasons, the port of Livorno has been chosen as a reference scenario for the simulators development.

On the other hand, the ship simulator has been developed to recreate the behaviour of different types of ships including one containership, one tanker and one ro-ro ship. In this paper the case of the containership, that is based on the KRISO model (conceived by the Korea Research Institute for Ship and Ocean Engineering, 1997) , is presented. The main characteristics of the ship are given below (no real scale model of the KRISO exists, however the KRISO data have been used for executing flow physics and CFD validation for modern containership).

Figure 1: The port of Livorno

- Hull:
  - Length between perpendiculars: 230.0 m
  - Length water line: 232,5 m
  - Breath: 32.2 m
  - Depth: 19.0 m

- Displacement: 52030 m^3
- Coefficient block 0.651

- Rudder
  - Type semi-balanced horn rudder
  - Surface of rudder:115 m^2
  - Lat. Area: 54.45 m^2
  - Turn rate: 2.32 deg/s

- Propeller
  - Number of blades: 5
  - Diameter: 7.9 m
  - Pitch ratio P/D (0.7R): 0.997
  - Rotation Right hand

The tugboat is characterized as follows:

- Hull
  - Length between perpendiculars: 26.0 m
  - Breath: 8.3 m
  - Depth: 3.7 m
  - Displacement: 710 m^3
  - Coefficient block: 0.6

- Rudder
  - Height:1.38 m
  - Area ratio A_R/Ld: 0.02
  - Aspect ratio: 1.4

- Propeller
  - Diameter: 1.1 m
  - Pitch ratio P/D (0.7R): 0.86

3. SHIP AND TUGBOAT EQUATIONS FOR THE MOTION AT SEA

The dynamic behaviour of both the ship and tugboat has been modelled according to a 6 DOF model. The so-called MMG model was adopted for surge, sway and heading whereas for the remaining 3 DOF (roll, pitch and heave) the reference model is given by Jensens (2001) and Jensens et al. (2004).

3.1 MMG model

The MMG model (MMG, 1985) includes two coordinate systems: a global coordinate system where the axes are marked as x_0 and y_0, and the other is a body-fixed coordinate system, where the axis are labelled as x and y and are centred at the ship centre of gravity.

The MMG model is based on the three equations of motion (given in 1, 2 and 3), one for each DOF. Such equations have been found out applying the Newton's second law.

$$(m + m_x)\dot{u} - mvr = X \quad (1)$$
$$(m + m_y)\dot{v} + mur = Y \quad (2)$$
$$(I_{zz} + i_{zz})\dot{r} = N - x_G Y \quad (3)$$

In equations 1, 2, and 3:

- m is the mass of the ship;
- m_x and m_y are the added mass in the x and y directions respectively;
- I_{zz} is the moment of inertia;
- i_{zz} is the added moment of inertia around z;
- u is the surge speed;
- v is the sway speed;
- r is the rate of turn;
- the point above the variable identifies the derivative of that variable;
- x_G is the distance from amidships to the center of gravity of the ship
- X and Y are respectively the total external surge and sway forces;
- N is the yaw moment;

External forces are generated by the hull resistance, the propeller and the rudder, such forces are identified by the subscript *H, P* and *R* respectively as shown in equations 4, 5 and 6.

$$X = X_H + X_P + X_R \quad (4)$$
$$Y = Y_H + Y_R \quad (5)$$
$$N = N_H + N_R \quad (6)$$

According to the The Specialist Committee on Esso Osaka (2002) it is possible to use the equations 7, 8 and 9, where the variables marked by the primed symbol are non-dimensional variables, to calculate the hull forces.

$$X'_H = -(X'_0 + (X'_{vr} - m'_y)v'r') \quad (7)$$
$$Y'_H = Y'_v v' + (Y'_r + m'_x)r' + Y'_{vvv}v'^3 + Y'_{vvr}v'^2 r' + Y'_{vrr}v'r'^2 + Y'_{rrr}r'^3 \quad (8)$$
$$N'_H = N'_v v' + (N'_r + m'_x)r' + N'_{vvv}v'^3 + N'_{vvr}v'^2 r' + N'_{vrr}v'r'^2 + N'_{rrr}r'^3 \quad (9)$$

The equations 7, 8 and 9 define relations between velocities and hull resistance using hydrodynamic non-dimensional coefficients. These coefficients are normally calculated with thank tests but in Lee et al. (2003) a set of semi-empirical equation is given.

In equation 10 X'_0 is the total non-dimensional resistance, C_T is the total resistance coefficient (obtained from model resistance tests), S is the wetted surface, L is the length between perpendiculars and d is the draft.

$$X'_0 = \frac{C_T S}{Ld} \quad (10)$$

The propeller force has been evaluated according to Kijima and Nakiri (2003), see equation 11.

$$X_P = (1 - t)\rho n^2 D_p{}^4 K_T \quad (11)$$

In equation 11, ρ is the density of the water, n is the propeller rate expressed in rounds per minute (RPM), t is the suction coefficient, D_p is the propeller diameter and K_T is the propeller thrust coefficient (that has been calculated according to Kijima and Nakiri, 2003).

In addition, the equations 12, 13 and 14 used to evaluate rudder forces, are taken once again from Kijima and Nakiri (2003).

$$X'_R = -(1 - t_R)F'_N sin\delta \qquad (12)$$
$$Y'_R = -(1 - a_H)F'_N cos\delta \qquad (13)$$
$$N'_R = -(x'_R - a_H x'_H)F'_N cos\delta \qquad (14)$$

When evaluating rudder forces, t_R is the rudder drag coefficient; F'_N is the normal force applied on the rudder; a_h is a coefficient that expresses the interaction between rudder and hull forces; x'_R is the non-dimensional coordinate of the centre of lateral force along the x-axis; x'_H is the non-dimensional coordinate of the centre of additional lateral force along the x-axis; δ is the rudder angle.

3.2 Heave, Pitch and Roll model

The response of a ship to wave induced loads is quite complex. As a matter of facts complex interactions between the ship dynamics and several hydrodinamic forces have to be considered. Basically, the equations of motion can be derived from the Newton's second law. In particular, recalling the linear theory, acting forces and moments can be divided into excitations and radiations forces/moments. Excitation forces are the forces of the waves acting on a restrained ship while radiation forces are caused by ship motions.

Considering heave, roll and pitch denoted by w, θ, and φ, the related coeffiecients labelled with the subscript *3, 4* and *5* respectively, the excitation and radiations forces/moments labeled with the subscripts *EX* and *H* respectively, for sinusoidal uncoupled motions the equations are given in 15, 16 and 17 where derivation with respect to time is denoted by a dot (Lewis, 1989).

$$(\Delta + A_{33})\ddot{w} + B_{33}\dot{w} + C_{33}w = |F_{EX3}\cos(\varpi t + \epsilon_3)| \qquad (15)$$

$$(I_{44} + A_{44})\ddot{\varphi} + B_{44}\dot{\varphi} + C_{44}\varphi = |F_{EX4}\cos(\varpi t + \epsilon_4)| \qquad (16)$$

$$(I_{55} + A_{55})\ddot{\theta} + B_{55}\dot{\theta} + C_{55}\theta = |F_{EX5}\cos(\varpi t + \epsilon_5)| \qquad (17)$$

In equations 15,16 and 17, the coefficients A_{33}, A_{44}, and A_{55} have the dimension of a mass and are called hydrodynamic masses or added masses, the coefficients B_{33}, B_{44}, B_{55} have the dimension of a mass per unit of time and are called damping coefficients; the coefficients C_{33}, C_{44}, C_{55} are the restoring spring coefficients. Interesting theoretical insights about such coefficients and equation of motions can be found in Lewis (1989). In addition, Δ is the displacement, ω is the wave frequency, ϖ is the frequency of encounter and I_{44} and I_{55} are the mass moment of inertia for roll and pitch respectively.

Obviously, in order to obtain numerical values for motion amplitudes the coefficient values and exciting forces amplitudes have to be known. The calculation is easy for the C_{33}, C_{44}, C_{55} coefficients that can be derived from stability calculations, but is very difficult for excitation forces, added mass and damping coefficients since a very complex hydrodynamic problem has to be solved. In most practical application the Strip Theory is applied (Ogilvie and Tuck, 1969). However, it has been found out that the implementation of a numerical code based on the strip theory was out of the scope of this study. As a matter of facts the simulator should work real time and therefore a lightweight computation model is needed even for visualization purposes. To this end, past related works such as Chen and Fu (2007), Ueng et al (2008), Sandaruwan et al. (2009), Sandaruwan et al. (2010), Yeo et al. (2012), have been investigated. These works seek to calculate buoy motions arising from waves in order to achieve realistic visualization results and are based on simple dynamic models. However, ship responses are evaluated just in terms of visualization and the numerical results have been accepted even if in some cases they have proven to be far from real empiric data. Under these considerations a more realistic and accurate model has been selected. This model has been proposed by Jensen, (2001) and Jensen et al (2004) and is based on simplified equations for ship motions in regular waves where the coupling terms are neglected and the sectional added mass is equal to the displaced water.

$$2\frac{kT}{\omega^2}\ddot{\omega} + \frac{A^2}{kB\alpha^3\omega}\dot{\omega} + \omega = aFcos(\varpi t) \qquad (18)$$

$$2\frac{kT}{\omega^2}\ddot{\theta} + \frac{A^2}{kB\alpha^3\omega}\dot{\theta} + \theta = aGsin(\varpi t) \qquad (19)$$

$$\left(\frac{T_N}{2\pi}\right)^2 C_{44}\ddot{\varphi} + B_{44}\dot{\varphi} + C_{44}\varphi = Macos(\varpi t) \qquad (20)$$

The equations 18 and 19 refer to heave and pitch respectively; k is the wave number, B is the ship breadth, T is the ship draught, a is the wave amplitude and A is the sectional hydrodynamic damping that can be evaluated according to Yamamoto et al., (1986). Moreover, F and G are the forcing functions whose values can be worked out according to Jensen et al. (2004). As for roll, the equation is given in 20 where, T_N is the natural period for roll, B_{44} is the ship hydrodynamic damping, C_{44} is the restoring moment coefficient and M is the roll excitation moment. The hydrodynamic damping coefficient, B_{44}, can be found by applying the method described in Jensen et al. (2004), the roll excitation moment M can be derived from the Haskind relation (one of the most outstanding results in the ship oscillations theory), while the restoring moment coefficient C_{44} can be expressed as a linear function of the displacement Δ, the transverse metacentric height GM_T and the acceleration of gravity g (see equation 21).

$$C_{44} = gGM_T\Delta \quad (21)$$

In addition, it is worth noticing that the semi-analytical approach proposed in Jensen et al (2004) is intended to derive frequency response functions of wave-induced motions. Therefore, the model, as it is, is mainly addressed to naval engineering applications. However, the application proposed in this research work is quite new since the model has been solved in the time domain by the Euler's method and is used to provide the simulation and visualization system with real time data.

3.3 Ship and tugboat interactions

A tugboat can support ship manoeuvres in two ways: it can either pull the ship using a rope or push it. As for the interactions between the ship and the tugboat, since in calm water such interactions are not critical for roll, pitch and heave, only their effects on surge, sway and yaw have been modelled. However, before going into the details of the interaction model, it is worth saying that, while interacting, the ship and the tugboat can be considered as a single system that can be described with a single mathematical model. In particular, a new external force needs to be added in the dynamic model of both the vessels; this force is labelled with the subscript T and is the force that each ship applies on each other. As a result, the ship-tugboat system can be described as reported on equations 22, 23, 24, 25, 26, 27, and 28.

$$(m_S + m_{x_S})\dot{u}_S - m_S v_S r_S = X_{H_S} + X_{P_S} + X_{R_S} + \mathrm{T}\cos\gamma_S \quad (22)$$

$$\left(m_S + m_{y_S}\right)\dot{v}_S + m_S u_S r_S = Y_{H_S} + Y_{R_S} + \mathrm{T}\sin\gamma_S \quad (23)$$

$$(I_{zz_S} + i_{zz_S})\dot{r}_S = N_{H_S} + N_{R_S} - \mathrm{T}\cos\gamma_S A_{Y_S} + \mathrm{T}\sin\gamma_S A_{X_S} - x_{G_S}\left(Y_{H_S} + Y_{R_S} + \mathrm{T}\sin\gamma_S A_{X_S}\right) \quad (24)$$

$$(m_{TB} + m_{x_{TB}})\dot{u}_{TB} - m_{TB} v_{TB} r_{TB} = X_{H_{TB}} + X_{P_{TB}} + X_{R_{TB}} + \mathrm{T}\cos\gamma_{S\ TB} \quad (25)$$

$$\left(m_{TB} + m_{y_{TB}}\right)\dot{v}_{TB} + m_{TB} u_{TB} r_{TB} = Y_{H_{TB}} + Y_{R_{TB}} + \mathrm{T}\sin\gamma_{TB} \quad (26)$$

$$(I_{zz_{TB}} + i_{zz_{TB}})\dot{r}_{TB} = N_{H_{TB}} + N_{R_{TB}} - \mathrm{T}\cos\gamma_S A_{Y_S} + \mathrm{T}\sin\gamma_S A_{X_S} - x_{G_{TB}}\left(Y_{H_{TB}} + Y_{R_{TB}} + \mathrm{T}\sin\gamma_{TB}\right) \quad (27)$$

$$D_{STB} = l \quad (28)$$

In equations 22-28:

- The subscript S identifies ship-related variables;
- The subscript TB identifies tugboat-related variables;
- A_x identifies the y coordinate of the T force application point;
- A_y identifies the x coordinate of the T force application point;
- l is the length of the rope if the tugboat is pulling and it is 0 if it is pushing;
- *DSTB* is the distance between the application point of the force T to the ship and application point of the force T to the tugboat; it depends on the ship accelerations, on the tugboat accelerations, and on the force.
- γ is:
  - the angle between the rope and the *axis* of the ship/tugboat when a rope is used (the force T has the same direction as the rope);
  - the angle between the perpendicular to the hull, in the vessels point of contact, and the x axis of the ship/tugboat if they are pushing each other.

Such system of differential equations has been solved by the Euler's Method.

4. PRELIMINARY TEST FOR SHIP AND TUGBOAT INTERACTIONS

The aforementioned mathematical model has been evaluated by an ad-hoc tool implemented by the C++ programming language in the Visual Studio 2008 Integrated Development Environment.

This tool allows setting some input parameters such as:

- pushing/pulling;
- points of contact for pushing;
- docking points of the rope for pulling;
- ship/tugboat position and orientation;
- ship/tugboat engine turn rate;
- ship/tugboat rudder angle;
- sea state;

Based on the input parameters, the tool draws a dynamic plot about the trajectory of both the ship and the tugboat. The ship is shown as a segment with a circle on the top (indicating the bow), while the tugboat is depicted as a smaller segment with a circle indicating the bow. In addition some relevant data, as linear and angular velocities, position and orientation, are recorded on a text file.

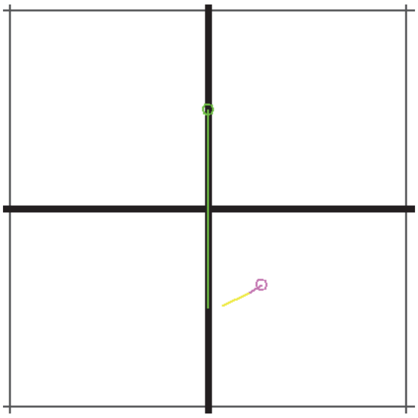

Figure 2: Chart of the ship and tugboat during a pushing experiment at time 0

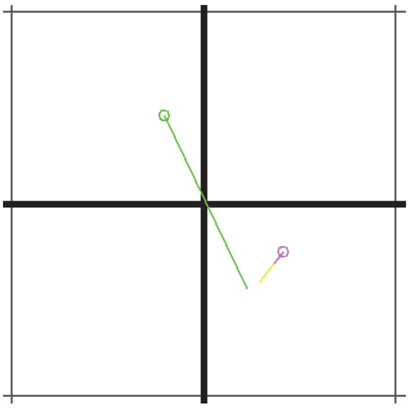

Figure 3- Chart of the ship and tugboat during a pushing experiment after 175 seconds

Figure 2 and Figure 3 depict the plots related to a particular pulling experiment. The ship engine has 0 RPM and the initial speed is 0.0 kn, the tugboat engine has 400 RPM, the initial speed 0.0 kn and the rudder angle is 0°. The green object is the ship, the violet one is the tugboat and the yellow line is the rope (this line becomes red in colour when the rope is not taut). Figure 2 shows the ship and tugboat position at the instant of time 0, while figure 3 shoes their position after 175 seconds. It is worth saying that the system is able to predict the position of the ship and tugboat even if the engine of the ship or the side thrusters are operating. Indeed, most of the times, ship manoeuvrings in the port areas are executed by using both the help of tugboats and the ship propulsion systems (including main engine and bow/stern thrusters). The system is also able to take into account the effects of the wind and marine currents.

The C++ tool developed by authors has been particularly useful to test the interactions between the ship and the tugboats in many different cases; indeed the interactions has been verified and validated with the help of subject matter experts (ship and tugboats pilots). After some preliminary analysis subject matter experts were able to identify errors in the behaviour of ship and tugboat during their interactions (i.e. by executing manoeuvres such those depicted in figures 2 and 3 they noticed errors in the positions of the ship and tugboat). Such errors have been corrected by acting iteratively on the values of the hydrodynamic coefficients; therefore the simulators have been used as system for tuning the model parameters according to subject matter experts' suggestions.

5. THE HLA ARCHITECTURE FOR COOPERATIVE TRAINING

As already mentioned, the ship simulator and the tugboat simulator are fully interoperable. Interoperability has been achieved integrating the simulators according to the HLA 1516 integration standard.

Before going into the details of the simulation architecture, it is worth focusing the attention on some basic definitions and concepts within the HLA framework. Basically, HLA relies on three elements namely the federates, the federation and the Run Time Infrastructure (RTI). A federate is an individual, HLA-compliant simulation application; a federation is a simulation system composed of two or more federates; the RTI is the software that manages the simulation execution and data exchange among the federates (Bruzzone et al., 2008; Massei et al. 2013).

In turn, our federates include three components: the hosting environment that is the virtual environment where the federate is located, the geometric models and the dynamic process module that includes information about the federate configuration, state, dynamical behaviour, etc, including the interfaces with the RTI (the authors have already successfully applied a similar approach to develop interoperable simulators in logistics area, Bruzzone and Longo 2013; Longo, 2012).

Within the proposed simulation architecture, there are three federates: the ship federate, the tugboat federate and the control tower federate (the latter not described in this paper because still under development). As already stated in Section 2, the reference scenario is based on the port of Livorno (Italy). Both the virtual environment and the federates' geometrical models have been developed by the tool Creator provided by Presagis. The figure 4 shows the geometric models of the Livorno Port area as it appears after texturing operations and ready to be imported in the virtual environment.

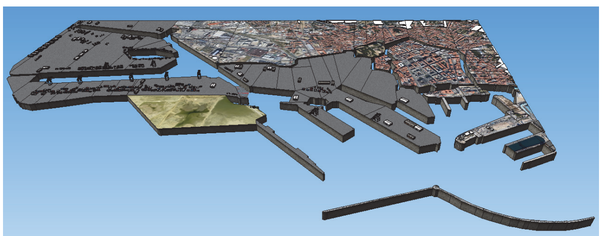

Figure 4: the geometric model of the Livorno port area after texturing operations

On the other hand, the dynamic process modules of both the federates has been developed from scratch by programming code, algorithms and functions written in C++ (most of the programming code is the same used to developed the testing tool presented in the previous section). In particular the code that allows the federates to reproduce the behaviour of the real ship/tugboat, to interact with the virtual environment, to collect data and performance measures is called internal functions. Conversely, there are external functions responsible for data management and information exchanges between the federates; therefore such functions play a crucial role in reproducing the interactions between them. The graphical engine that has been used is Vega Prime from Presagis.

Figure 5 and 6 show a screenshot of the container ship simulator interacting with the tugboat simulator according to two different viewpoints.

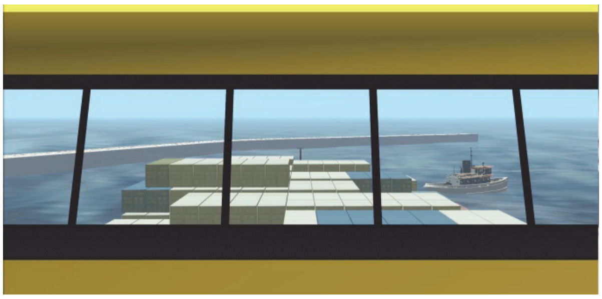

Figure 5: Ship simulator: tugboat pulling the ship (bridge view).

As mentioned in the previous sections great attention has been paid on modelling the interactions among the federates. To this end the simulation architecture has been provided with interoperability capabilities that allows reproducing with satisfactory accuracy the real operational processes taking place in the last mile of navigation.

However, it should be noted that, even if the federates have been integrated into a federation in order to allow the cooperative and joint training of ship pilots and tugboat pilots, the integration via HLA does not prevent each federate from being executed standalone or to be reused in different federations (Longo, 2011). In this perspective, the proposed tool ensures a great flexibility that is very important because it allows the trainees to train alone with the single ship/tugboat when necessary.

6. CONCLUSIONS

Even though several ship simulators are already on the market few of them offer the possibility of setting up combined and integrated training sessions involving both ship pilots and tugboat pilots. In fact, the last mile of navigation has not been subject of particular scientific interest until the recent disaster in the port of Genoa.

However, in standard conditions, manoeuvres within the port area may be the most critical moment of the whole navigation and during these operations, ports regulations, may require that a certain number of tugboats support the ship. Even if this rule facilitates the manoeuvres inside the port, on the other hand it makes the operations even thornier than expected since ships and tugboats have to work in synergy and relatively close to each other; therefore training is crucial in order to carry out such manoeuvres in a safe and efficient way.

Considering these aspects this paper describes the work done (that actually is still on-going) to develop an interoperable simulation framework for training of ship and tugboat pilots and for port traffic controllers with the aim of:

Figure Ship simulator: the tugboat pushing the ship, rear view.

- improving the trainees skills on steering a ship/tugboat;
- learning about the procedures adopted in a certain port (it is important in this sense to underline the possibility to replace the virtual environment easily with another one);
- improving synergy and communication between ship pilots, tugboats pilots and control tower;
- defining new policies and designing new procedures;
- testing the effectiveness of new policy/procedures.

Since HLA allows creating a distributed federation, it is possible to locate each federate (simulator) in a different rooms (or even geographic areas) in order to recreate the conditions that occur in the real word. To this end the research activities are still ongoing with the following objectives:

- tune the effects of the wind and of the side thrusters;
- design and provide each simulator with a reproduction of a real cockpit (external hardware);
- complete the development of the control tower simulator that will be integrated within the federation.

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