Use of HLA Federation for the Evaluation of Naval Operations in Ship Design

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Abstract. Simulation, physic based analysis, computational calculations has been largely used since long time in ship design process but an exhaustive evaluation of ship's performances and capabilities is unlikely to be done in the early design phase. In this sense a proper simulation tool can be a valuable solution, giving the possibility to test and validate a wide range of naval operations' procedures in different environmental conditions. Usually these operations involve more entities than the single ship, so it becomes important to arrange a synthetic environment in which different simulators and simulations can cooperate for demonstrating complex operations. Besides this, the "system of systems" approach finds its applicability in the naval field where a warship can be represented as the cooperation of several subsystems. HLA distributed simulations represent a good solution for creating and simulating complex scenarios, allowing several simulators and partners to work together just exchanging inputs and outputs, but keeping safe intellectual properties rights. Experiences in using this framework either in a single company or with multiple companies scenario are presented. CETENA's experience in using its HLA based simulator for the development of complex interactive man-in-the-loop federations to evaluate operations like Replenishment At Sea, Landing Craft maneuverability, Vertical Take Off and Landing, Small Craft Launch and Recovery, is presented in this paper.

Keywords: High Level Architecture, ship design, naval operations.

1 Introduction

The ship is a very complex system of systems and interacts with an even more complex environment which influence and is influenced by the ship behavior.

Large ships are usually stand alone constructions. Even twin ships are usually slighting different among them. This means that usually the ship is the only prototype of herself. It is quite difficult and very expensive to modify the ship when built.

All these assumptions are the reasons why simulation, physic based analysis, computational calculations has been largely used since long time in ship design process.

The point is that all these tools and methods are usually used separately, in different ways and by different expert people.

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Moreover, the final user is rarely involved in the process since interactions are usually among experts and not final users.

These are only some of the reasons for improving the use of simulation in a Virtual Reality environment in order to produce an interactive synthetic environment as much realistic as possible.

2 Virtual Prototyping as a Tool for Decision Making

A prototype is any preliminary working implementation of a product, component or system. It is often more abstract or less detailed than the final version. Two main classes of prototypes are used in design processes: physical prototypes and virtual prototypes.

A physical prototype is a physical model of a product, component or system. Physical prototypes are characterized by fabrication time that typically requires weeks-to-months and by modification procedures that require days-or-weeks.

A virtual prototype is a computer simulation model of a final product, component or system. A virtual prototype can be used in a design process specifically for : exploring design alternatives, demonstrating design concepts, testing for requirements satisfaction and/or correctness [1].

To be useful in a system design, a virtual prototype must comprise three elements:

- Visualization: virtual reality can be used for navigating inside the model. The user can walk through the complex project viewing exactly how the product will look like. Since the environment in which he is moving is all virtual and controlled by the computer, the user can easily query physical, topological and geometrical characteristics to any system or component.
- Simulation: a static 3D view or a flythrough can be insufficient to point out problems deriving from the movement of objects on deck or interaction between correlated components. Virtual reality can help in keeping together simulation results and real time photo-realistic visualization in synthetic environments.
- Interactivity: the capability to consider the human interaction with the object we are designing may represent a considerable step forward in the ergonomic field or in stressing operational efficiency during design time. The “man in the loop” represents an important design aspect rarely or difficulty taken into account in standard design processes.

Virtual prototyping is a good way to synthesis and visualize all design efforts either for the designer than for the client who can be more directly involved in strategic decisions from the very beginning since they can view and choose between different solutions [2,3].

Opposed to a physical prototype, which requires detailed hardware and software design, a virtual prototype can be configured more quickly and cost-effectively, can be more abstract and can be invoked earlier in the design process. Comparatively, virtual prototypes introduce some risks due to the possibility of modeling inaccuracy or incorrectness.

Moreover a single simulator can improve its capabilities and usefulness if included in a common environment where more simulators interoperate each other to reproduce the behavior of a more complex system.

Great effort is necessary to combine design expectation (simplicity, integration, etc.) with physical and mathematical modeling and simulation. Some interaction effects which are automatically accounted for in physical models need to be consciously accounted for in numerical modeling. E.g. a problem that we frequently face during our simulations is the "hull to hull" interaction which involves interactions between two or more ships and hence ship motion models. Few numerical codes are able to completely model the interaction between two ships, while reality accounts for interactions automatically.

Validation, verification and accreditation of simulation will be the next important step for virtual prototyping credibility and interoperability.

2.1 A Laboratory for Virtual Prototyping

Starting from this perspective, CETENA has developed during the years, tools, SW, competence in Virtual Prototyping for Ship design. In its Virtual Integrated Ship Laboratory (VISLab) experts from different ship design fields and IT experts created a technology architecture devoted to incorporate and reuse all available software tools (commercial or developed in-house) normally used for different purposes with the objective of building a common environment for studying, use and operate virtual prototypes of existing and under design ships [4].

The underlying approach is HLA (High Level Architecture – IEE1516) which let the development of complex distributed simulations [5].

Being the ship an intrinsic system of systems, the HLA approach results well suited for modeling and building federations which are able to have different levels of details in the implementations of complex behaviors.

In particular the approach let us create simulation systems which can easily updated inserting new or more detailed physic effects and new interacting entities in the synthetic environment.

2.2 SAND: CETENA's Ship Simulator

First step in the development of the VISLab has been the implementation of the interactive ship simulator system called SAND.

SAND is the simulation system used for manoeuvring simulation and training. It is compliant with the HLA 1516 architecture and it includes a ship console and high quality visualization system (Fig. 1). A dedicated computing station is used to set the simulation conditions, in terms of scenario, environmental conditions, ship characteristics; the controls on the console can be easily set up through reconfigurable LCD touch panels in order to reproduce those of the simulated ship. During each simulation, all relevant data are stored for subsequent debriefing sessions.

Fig. 1. SAND and 3D visualization system

In the tack of reusing all existing tools and competences and thanks to more than twenty years of R&D in ship design and consultancy for harbor designers and Port Authorities, SAND has rapidly reached a very high level of confidence in the representation of the ship behavior.

The CETENA's ship mathematical model included in SAND is based on a Maneuverability and Seakeeping model integration, that allows to calculate the six degrees of freedom (Surge, Sway, Heave, Roll, Pitch, Yaw) and has been validated during the years either from the use and sensitiveness of the Port pilots who used it during the port assessment activities and, moreover, from the huge real data coming from the experiment activities CETENA performs onboard ships.

The simulation model is designed to be "open" and configurable for all type of ship (cruise, bulk carrier, petrol, LNG, container ship) and for all environmental scenarios (map, sea state, wind, sea current, time of day).

Different type of vessels can be easily configured using wide range of characteristics like:

- hull data
- engine type (diesel, diesel-electrical, turbine, or every combination of them)
- propulsion (azimuth, fixed/controllable pitch propeller, POD, water-jet)
- thruster
- rudder (simple type, compound butt, under hung deep horn, shallow horn, spade)

The physical model is completely modular allowing the implementation of add-ons to take into accounts new or more detailed environmental and interaction effects.

The user can choose the environmental condition through a set of sea state, wind intensity and sea current and the software compute the interactive ship behavior for very accurate and realistic vessel simulation taking into account several aspects like:

- shallow water effects
- navigation in narrow channel

- collisions
- anchors and chains

SAND can be used either as a stand-alone system or as a federate, therefore as part of a more complex HLA federation. This can be useful when other simulation entities has to be considered as actors in the same simulation environment. For this reason a basic standard HLA federation (Fig. 2) was designed and developed within the VIS-Lab and it is structured as follows:

- *Execution Manager federate* is used to set up the whole federation and to specify all the initial parameters.
- *Data Logger* records all the data send through the RTI, in order to be able to replay the federation in offline mode.
- *3D Visualization federate* visualize the simulation scenario in a 3D environment.
- *Environment federate* sets all the parameters concerning the marine and atmosphere conditions, as sea state, current, wind.

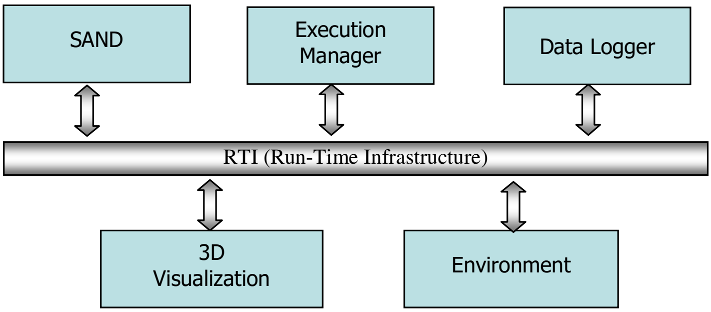

Fig. 2. CETENA's basic standard HLA Federation

Fig. 3. Portable SAND

In order to be compliant with HLA distributed simulations standards, the above mentioned federation was developed using the VS-FOM (Virtual Ship – Federation Object Model) [9], deriving from the RPR-FOM (Real-Time Platform Reference – FOM).

Multiple entities of SAND can be run in a federation allowing different ships interact in the same synthetic environment.

A portable version of the SAND simulator (see Fig. 3) was recently developed in order to easily transport the simulation system into possible partners' facilities and to participate to any other HLA based federation.

3 Experiences in Evaluating Naval Operations

As previously stated, the driving idea in the VISLab activity is that interactive real-time simulation can be used for investigate complex ship operations for verifying performances and receiving feedback for the design phase.

The implemented architecture and the open structure of the SAND "federate" are the basic ingredients for implementing complex distributed federation simulating operations involving multiple ships or multiple other entities.

All these with high attention to the physic representation of the involved effects rather than the visual aspects which are surely important but are not the primarily focus of the investigation.

In all the following presented experiences, many of the engineering and physical aspects simulated comes from experiences, tools and studies previously performed but, probably, with the focus on particular effects and scenarios but not interactive and not composed each other in a more complex and "realistic" scenario.

From a strict engineering point of view, traditional approach is sufficient and expert people are able to take decisions but non expert people, operative people, the final user, usually are not involved in these decisions and can't bring their experience in the design loop. The Virtual Prototyping approach can facilitate this man in the loop approach. The Virtual Ship can be tested by the final user before cutting metal.

Moreover Virtual ships can be efficiently used to verify contractual requisites and also extreme conditions scenarios which may be dangerous to verify in reality.

3.1 Replenishment at Sea (RAS) Operation

Replenishment At Sea is one of the more complex operations performed by modern navies. The operation is executed in three main phases:

- The vessels approach each other and sail alongside.
- The transfer system is established between the vessels using a cable system and the fuel is transferred.
- The transfer system is removed and the ships depart (breakaway).

In all these phases there is a risk of ship collision, especially in high sea states, and when small receiving vessels are involved. A simulation of the RAS operation will allow safe operating conditions to be determined and may influence the design of the supply ship, receiving ship and transfer rigs.

Primary goals of the simulation scenario are:

- to simulate Replenishment operations in open seas with different meteorological conditions;
- to verify operation constraints (ship speed, distance, etc.);
- to analyse different RAS devices in term of position, operative behaviour and efficiency;
- to study refuelling operation (no solid objects transfer).

Basically the operation is focused on the capability of the two ships to navigate parallel for a enough long period of time avoiding collisions and early breakaway. Studies of port manoeuvrability or approaching operations also in open seas are similar to RAS operations and the implemented federation reused all these experience improving the mathematical model of interactions between the two ships.

The two ships are interactively manoeuvrable and the systems reacts in real-time to any change in speed and direction of each ship. In particular the federation can take into account problems deriving from a malfunction in the manoeuvring devices (rudder, propeller…) of one of the two ships in order to accordingly evaluate the capability of the other ship to avoid collision and to continue in the parallel course. This may be very interesting in the design assessment of either the supply and the receiving ships.

From the implementation point of view, two SAND federates were involved in the federation in order to simulate both the supply and the receiving ships. In addition to the standard CETENA's federation two federates were developed and inserted in the federation: a RAS equipment federate and an Interaction federate.

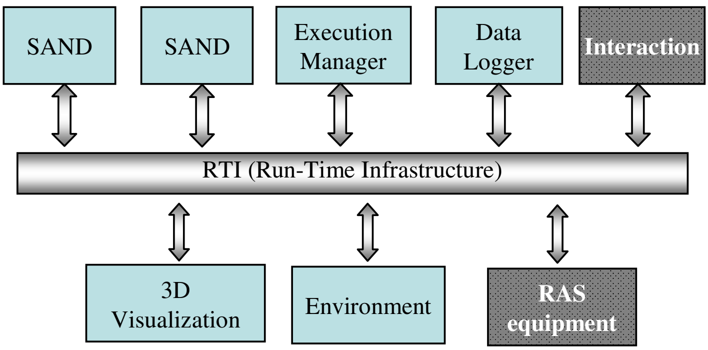

Fig. 4. RAS federation

RAS equipment federate was design for the calculation of the forces applied to the cables used for the fuel transferring operation. In case the RAS cables were subjected to a tension exceeding the maximum allowed, federate is able to give a warning representing the unsuccessfully result of the operation.

Interaction federate was designed in order to simulate the forces due to the side by side shipping; it was developed using mathematical models deriving from towing tank tests and it can be configured to simulate this specific behaviour for different kind of ships.

Fig. 5. Screenshot of the RAS simulation

The implemented simulation system is completely configurable and parameterized so that it can be used to simulate ship-to-ship transfer of liquids for:

- Any pair of ships
- Any sea state
- Any type of transfer rig
- Any type of liquid
- Any flow rate of liquids transfer.

The used architecture allows the reuse of each federate in other federation and the improvement of the mathematical model for any of the effects to take into account. This evolutive approach let us maintain and upgrade the developed software for future purposes.

Nowadays some of the federates will be used in an international project having the purpose of validating the simulation results with sea trials data and other towing tanks tests results.

We are now implementing the heavy load transfer between the two ships simulating the cable and the transfer mechanism adding in this way another functionality to the already existing RAS federation.

3.2 Landing Craft Unit Operations Inside Amphibious Ship

Another example of complex operation involving multiple interactive but independent entities is the federation we designed an built for reproducing the manoeuvrability of a landing craft (LCU) inside the wet dock of an amphibious ship (LPD) and the transfer of a tank from the Landing Craft to the dock of ship.

As in previous case, the development of the federation takes inspiration and reuse all the already available competences, expertise and software using in the past for studying similar scenarios [8]. In particular stand alone simulation for collision detection of the landing craft with the interior (bottom and sides) of the dock was reused in the new federation.

All the entities in the scenario are completely manoeuvrable interactively: the ship, the landing craft and the tank. This last one was simulated in a very simplified but enough realistic way while the ship and the boat are modelled in details and their behaviour is accurate. Again, the ship is implemented using the SAND federate while the Landing Craft Unit is a completely new mathematical model due to the particular type of hull and propulsion and moreover due to the shallow water effect inside the dock.

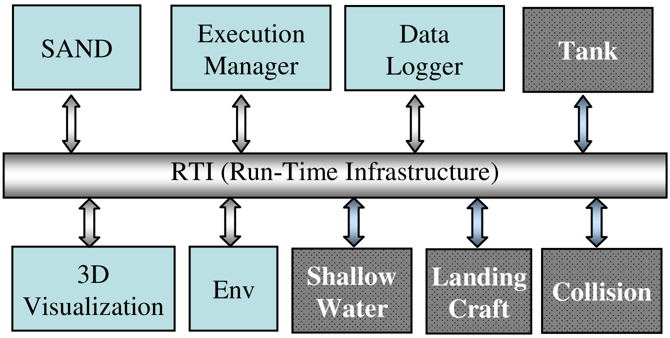

Fig. 6. Federation for LPD-LCU simulation

Four additional federates were developed in order to simulate the following entities:

- The Landing Craft maneuverability: this model was developed using Physx SDK, an open source physics simulator [10]. With Physx it is possible to simulate the dynamics of one or more objects with different geometries and characteristics. Moreover, Physx allows to interact with the simulated objects by applying to them some forces and moments.
- The Shallow Water effect: the hydrodynamic forces due to the shallow water inside the dock were applied to the Landing Craft. The Tank: when the Landing Craft approaches to the dock and it is stable, the tank can be moved from the landing craft itself to the LPD dock.
- The Collision Detection: when the Landing Craft is inside the LPD dock it is important to monitor the clearance among the craft and the dock. At the end of the simulation the federate can produce a report with the list of collisions detected during the running.

Particular attention has been put in the sloshing effect which is very complicate due to the fact that it is generated by the LPD Ship and is characterized by the volume of the water in the wet dock. Experimental test have been performed to tune the mathematical model.

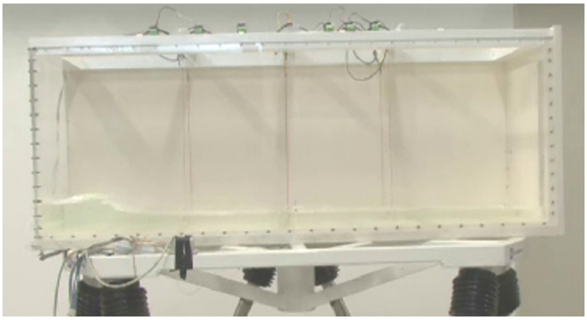

Fig. 7. Sloshing experimental tests

The implemented federation has been used during the design of a possible LPD ship and one of the asked question was to determine which was the optimal trim for the internal wet deck in order to have enough ware to avoid collisions with the bottom of the LCU during movements inside and especially loading and unloading operation of the tank.

During the development also the external approach phase of the LCU has been simulated with a very simplified but effective mathematical model. Even if the main purpose is for inside operations, also external behavior of the ship and the LCU are simulated

Fig. 8. Screenshot of the Landing Craft simulation

Now the work is going on and the federation will be updated with a more sophisticated physic model of the behavior of the LCU behind the Ship. The LCU travels in a wave field that is the superposition of the LPD's stern wave and the sea waves modified by the presence of the LPD.

Hydrodynamic motion and forces due to the wave actions are now accurately predicted in frequency domain and time domain module accounting for complete wave actions is under development.

All these development will be included as supporting effect to the main SAND engine and will be reused in future federations requiring them.

3.3 Vertical Take Off and Landing (VTOL)

Take-off and landing operations involves different issues related to the interaction between the ship and the air vehicle.

One of the problems is related to the forces during touch down: the ship moves and air vehicle approaches her choosing the best moment for touching the deck. The forces involved are the ones coming from the ship motions and the ones coming from the drop of the vehicle. Especially in heavy sea state the sum of the forces can be very high and can damage the air vehicle landing devices [6].

This effect has been studied in one of the first federation developed inside an international group studying the best landing period for an helicopter to land on a frigate [7].

Besides this impact effect, another important aspect to take care of is the turbulence generated by superstructure in the surrounding of the landing spots. This aspect involves an heavy interaction between fluid dynamic calculations (CFD) for simulating the flows around the structures (Air Wake) and the relative position of the two moving entities: the helicopter and the ship. As in other experiences, these two separated effects were already studied in CETENA and we have the competences and codes for simulation the two effects separately.

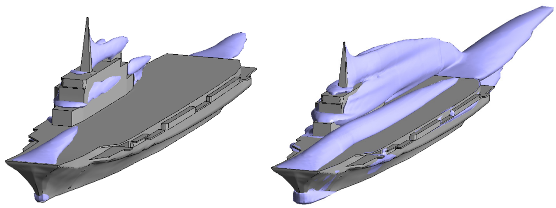

Fig. 9. CFD results for VTOL simulation

Again, reusing these knowledge and making the relative tools interoperable, has brought to the design and implementation of a federation simulate the interactive scenario of an helicopter landing on a ship dynamically taking into account in real-time of the air-wake effect and the relative movements and forces between the two moving entities.

The developed system was composed by the standard basic federation for the ship with the addition of some new federates: the helicopter and the airwake.

The helicopter federate is in reality a ultra simplified federate which simulate a point in the space and collect information from the flows deriving from the airwake and the distance from the ship.

The airwake federate is basically a sophisticated interpolator of pre calculated values coming from offline CFD processing. Depending on the relative position from the ship, the speed, the wind direction and other physical parameters, the federate determine the flow pressure and speed in a certain point.

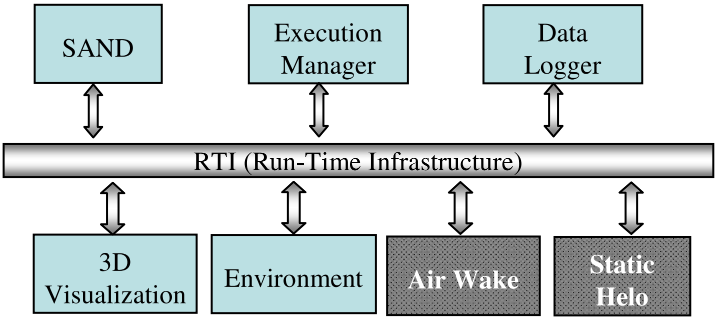

Fig. 10. VTOL federation

Fig. 11. Screenshot of the VTOL simulation

As a matter of fact, since the federation was developed in compliance with both the VS-FOM and the RPR-FOM, a whatever Helicopter federate compliant with the above mentioned FOMs can be easily integrated

3.4 Small Craft Launch and Recovery

CETENA, as a member of CRS (Cooperative Research Ships) group, participated to a Simulation Group focused on the design and implementation of a HLA federation to be used to simulate Small Craft Launch and Recovery (SCLaR) operations.

Also in this context many of the expertises and algorithms developed in previous studies has been reused and integrated in the complete federation.

In particular, in the international project, CETENA provided its VISLab laboratory to integrate the whole federation structured as described in Fig. 12 where the "blue" federates were developed by CETENA and the "yellow" ones were developed by other partners.

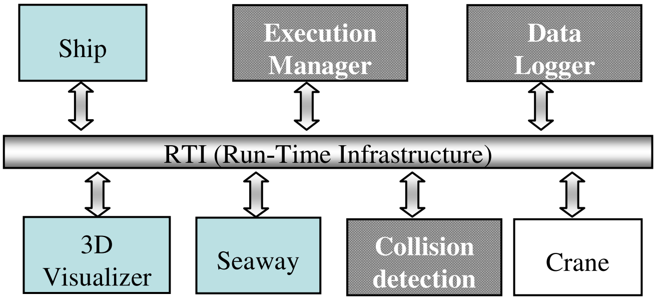

Fig. 12. SCLaR Federation

Primary scopes of this application were the following:

- To share with CRS-SIM group members the knowledge in the development of distributed simulations.
- To set up a common framework able to be improved with detailed simulation models, for the following purposes:
  - To test the winch system in different weather conditions
  - To monitor the waves contact on the small craft during the launching phase
  - To measure the time spent to perform the whole Launch/Recovery operation.

Many of the software and solutions identified in the development of the project have been reused in other applications during the years.

4 Conclusions

New technologies, higher computational resources and a new cultural way in the relationship with the computer (especially derived by video games) have foster the idea that something new could be done to face the above mentioned distortions.

Tools, systems and standards are growing. Now it is our turn to put all these staff together and build the Virtual Ship. Two major obstacles on the horizon: costs and culture.

The first one is mainly evident when simulation is seen only as a tool for design purposes and no "reuse" is foreseen. In this case, yes, simulation is a cost and the return of the investment is very small. Making simulations and simulator reusable for other purposes and for other project is a solution to overcome the problem. In this perspective if most of the models and algorithms developed in the design phase can be reused for instance in a training environment, the ROI is shifted in this second phase which can start before the ship is built and can be a benefit for the customer who can train the crew in advance but also for the shipbuilder who has the chance to expand its business also in the post sale area of the ship and can build an even more strong relationship with the ship-owner.

The cultural obstacle is more complicated. Why I need to enhance the way I'm doing my job? What's the benefit to make things more sophisticated? Why using a realistic visualization, may be also in real time? People who usually play computer games have become accustomed to certain visual and interactive performance and recognize the effectiveness. Unfortunately usually these people are not the decision makers of today but they will be the ones of tomorrow.

If visualization and interactivity are important features, what distinguish a Virtual Ship from a ship in a video game is the realism and the reliability of the behavior which should be deeply physic based and comparable with actual one. In other words is important that the actual expert becomes confident in the behavior of the Virtual Ship as he is now in the results of the detailed analysis tools he is using.

A effective and accredited validation of the simulation is one of the most important challenges in Virtual Ship implementation.

These and other issues are driving the creation and re-use of new technologies, standards and methodologies will bring us closer to realizing the dream of the virtual ship.

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