DATA MANAGEMENT FOR SMART SHIP OR HOW TO REDUCE MACHINE LEARNING COST IN IoS APPLICATIONS

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SUMMARY

Shipbuilding process, generates a lot of information and data, which a priori makes it seem impossible to have all this data in real time, but the new processors, simpler and smaller, with a good connection to the Internet, make it possible.
The data management is, however, only one side of the coin of the Internet of Ships (IoS). Energy efficiency is a fundamental aspect also in new devices that connect to the network.
But IoS not only covers the stages of design or production of the boat. Once the sensors are in the components whose information want to monitor, we will be able to obtain information throughout the life of the ship.
IoS is presented as a solution capable of detecting when a component on a boat is close to fail and must be replace, when we take the boat to repair when we have to paint again, when corrosion has reached a certain limit ... and all this from our pocket tool and early enough to avoid late or unforeseen performances.
IoS reaches this sector to ensure profitable production, or safe, efficient and sustainable process for all types of fishing vessels, tugboats, tankers, charges, ferries, dredgers and oceanographic ...
Data management in Smart Ships, including collect, process, saving and third party distribution should be regulated, controlled and done in the most efficient and secure way for the ship owner. This can be accomplished based on a deep study of each part which is involved in close-to-real response systems and its machine-learning control unit. In this Systems, each parameter change generates stress and material fatigue, reducing its lifecycle.

NOMENCLATURE

CAD	Computer Aided Design
DDoS	Distributed Denial of Service
GPS	Global Positioning System
IoS	Internet of Ships
IoSS	IoS System
IoT	Internet of Things
IT	Information Technologies
OSC	Overall System Control
PLM	Product Lifecycle Management
RFID	Radio Frequency IDentification
RPM	Revolutions Per Minute
SSIC	Ship System IoT Cell

1. INTRODUCTION

If the naval industry wants to adapt itself to the new technologies it must to start with the entire design process of the product, in such a way that the product to be prepared for the new technology. The shipbuilding product has two well-defined and separated periods: the design phase and the operation life. These two elements can be sustained through working methodologies. Of particular note is systems engineering. Systems engineering appears to solve the problems that need to be addressed in sectors with high added value, such as products for defense or aerospace engineering, which are high-risk sectors that require a very good design and construction processes from very early stages to reduce costs and ensure planning and schedule within a budget. Systems engineering requires the use of more specific technologies in order to be applied effectively. In systems engineering, there are innumerable applications that can be used to provide solutions in the different stages of the life cycle of a ship.

Computer Aided Design (CAD) systems are traditionally used for the design and construction stage and in more recent times, the *Product Lifecycle Management* (PLM) solutions are emerging to provide valuable tools for product management. However, these tools require an enormous amount of information that must be provided during the ship design and construction project stages. Therefore, it is necessary to find a way to join these two technologies: CAD and PLM so that all the value mutually contributed in a project not to be lost.

Nevertheless, this is only a side of the problem. There are different technological trends appearing as the engines of the great changes that are affecting us. Among them, the *Internet of Things* (IoT) stands out because of the impact it has directly on the world we see and touch. How it affects or can affect this trend to the world of shipbuilding, and what can the software industry bring to enter the IoT to the shipbuilding industry.

First, we need to analyze what is actually the IoT nowadays and what are its challenges.

2. CHALLENGES OF THE IoT

We can recognize several areas where IoT presents problems that need a common solution: security, standardization, and scale challenge and business orientation.

We are still very aware of the recent *Distributed Denial of Service* (DDoS) attack by thousands of malicious software infected devices connected to the IoT. What could happen with a ship awaiting responses from internet in the middle of a storm with a load of millions of dollars on board or with thousands of people inside?. Security is the most important problem to be solved in a connected IoT ship. There are several issues related with this question: identification of devices, protection against attack, control of updates, redundancy, etc. There are still no guaranteed solutions to this issue.

The rapid growth of IoT has led to an uncontrolled growth of devices connected to the Internet through particular solutions of the manufacturers. Each device manufacturer has built their own IoT solution by connecting their hardware to their cloud server to service their requests. According to Ahmed Banafa wrote in (Banafa, 2016) [2], "*As the industry evolves, the need for a standard model to perform common IoT backend tasks is becoming more relevant*". Moreover, it becomes necessary to have a greater standardization if it is desired that this connectivity is a pole of growth of current society.

Another issue can be known as scale challenge. The large variety of devices that have relationships with each other, but that have different workflows and of course different update times. If updating them freezes the operation of the system, the working time of the system would be significantly reduced. It is necessary to control the update cycles or perhaps to directly prevent them until it is decided that it is time to do it globally or selectively.

The success of IoT will not go hand in hand with the early adopters, but with the companies and this will only be possible if the initiatives have a clear component oriented to the business, that is to say to add a value. It is necessary to identify which of the initiatives provide a clear value to the business, but taking into account that this value can be in various terms and not all directly economic. The clearest ones have to do with the optimization of energy costs, fuel consumption, choice of routes, safety at sea, but also in the work itself inside the ship (Muñoz and Perez, 2017) [3].

One of the conclusions of all the analysis about the consequences of the IoT is that objects must be re-thought from the early design.

The fact is that ships are subject to harsh environmental conditions makes that any technological advance to be applied inside a ship have to take into account from the very beginning. Currently all the designs in the modern society are made by information technology tools, computer aided designs, supported with adequate databases and with lifecycle management of the information. To address the challenge of the IoT for ships, it is necessary a new concept, the *Internet of Ships* (IoS).

3. A NEW CONCEPT. THE INTERNET OF SHIPS

It is estimated that in 2020, 25 billion of devices will be connected to Internet (Kirsch, 2015) [5]. This revolution that began a few years ago has aroused enormous interest in all industries and in some of them already works with apparent normality.

Nowadays it is possible to order directly from our refrigerator as soon as it detects that we need our regular products or smart lamps that light up alone when needed lighting. The world go on steadily toward what will be undoubtedly one of the most important revolutions in the history of humanity.

We could define the IoT as consolidation through the network of networks a "network" that staying a multitude of objects or devices, that means, to connect all things of this world to a network, we are talking about vehicles, appliances, mechanical devices, or simply objects such as shoes, furniture, luggage, measuring devices, biosensors, or anything that we can imagine.

At its core, IoT is simple: it's about connecting devices over the internet, letting them talk to us, applications, and each other. But IoT is more than smart homes and connected appliances, however. It scales up to include smart cities *think of connected traffic signals that monitor utility use, or smart bins that signal when they need to be emptied* and industry, with connected sensors for everything from tracking parts to monitoring crops.

In this context the question is if the naval sector is ready for this revolution. Is it possible that this traditional and conservative sector moves into this technology? There is already evidence that the shipbuilding industry is no stranger to these developments and is already connected to the Internet some components of ships, as it is shown on [Figure 1].

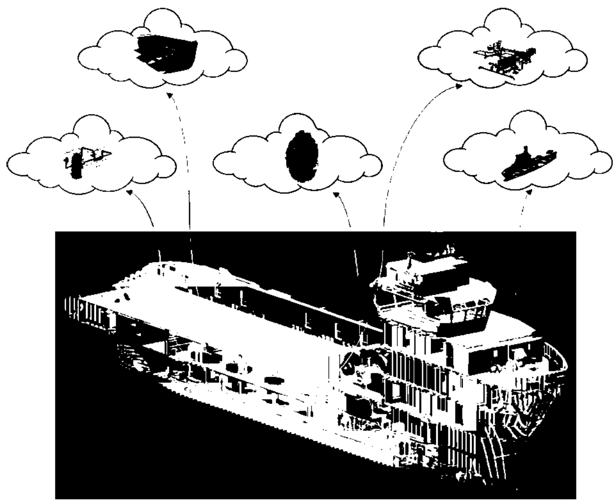

Figure 1. Ideal representation of a 3D model with access to the different ship design disciplines (Liu et al., 2016) [6]

As there smart home or smartphone, there are new smart ships that will be equipped with a network of sensors that capture a range of voyage information, including:

- Location.
- Weather.
- Ocean current.
- Status of on-board equipment.
- Status of cargo.

Ship owners can monitor the vessel's status in real time and apply analytics to current and historical data to make decisions that enable them to run more efficiently, saving time and fuel.

Sensors and *Information Technologies* (IT) are facilitating the introduction of new applications at sea, like energy distribution, water control and treatment, equipment monitoring in real time… The aim is to take this technological revolution also acting in the design and production phases in order to build efficient, safe and sustainable vessels.

In a decentralized sector, like naval, where often the engineering and production are in different locations and where critical decisions cannot wait, the IoS or connection through the network of critical components in the design / shipbuilding, starts to glimpse as something that the sector cannot obviate.

The idea is to monitor all those parts in which early detection of events allows us to make the right decisions. In this sense, the available sensors during the early stages of construction of the ship, allow us to identify if the construction of the boat is completely according to the design we have created with CAD. If we can reduce materials or use another material, if we must change anything according with naval architecture calculations… The continuous monitoring integrated with a naval design CAD as FORAN will reduce costs and avoid mistakes and make decisions in real time from the shipyard, design offices or from remote locations.

Nowadays solutions CAD like FORAN can be used in a pocket tools, making it the indispensable ally in this new technological revolution, see [Figure 2].

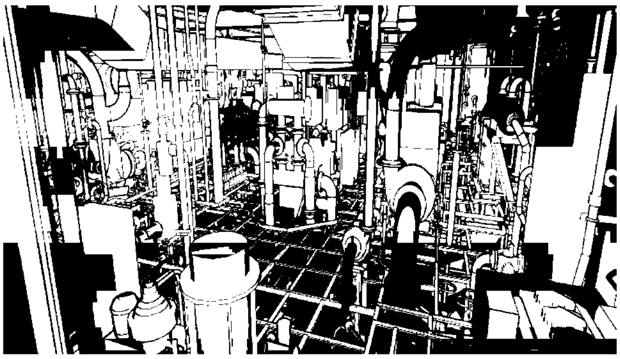

Figure 2. 3D model on a virtual portable solution like tablets or smartphones (Alonso et al., 2017) [1]

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4. INTRODUCTION TO MACHINE LEARNING APPLIED TO SHIP. CHALLENGES AND LIMITS.

Machine learning is mainly associated to neural networks and deep learning. According to M. Nielsen wrote in (Nielsen, 2017) [4]:

- *Neural networks, a beautiful biologically-inspired programming paradigm which enables a computer to learn from observational data.*
- *Deep learning, a powerful set of techniques for learning in neural networks.*

These methods are commonly applied to image, speech or handwriting recognition methods. These methods can be applied for a full learning of a subject or to improve automatic correction in certain parts of a ship system. These corrections are made like operators but in real time and compensated inside the full system.

Neural networks are based on neurons or perceptron, as it is shown in the [Figure 3]:

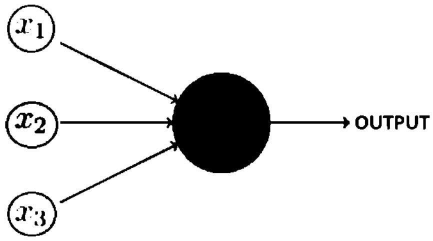

Figure 3. Perceptron taking several binary inputs and one binary output

These items several inputs and one or more outputs, depending on the expected result. One example of this is the exercise develop by M. Nielsen in it book about number recognition (Nielsen, 2017) [4] [Figure 4]:

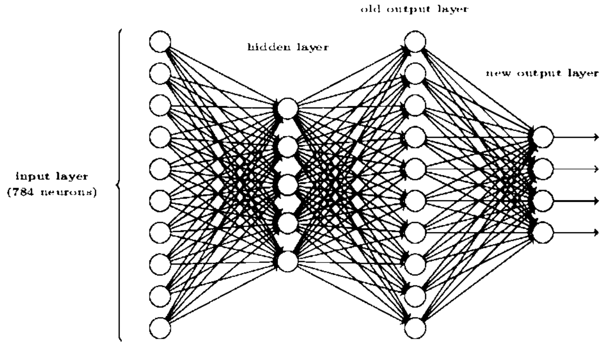

Figure 4. Neurons and connection for a handwritten number recognition

Each connection between neuron represents how previous neuron value affects to next layer neuron (weight), creating an influence pattern. Also, to correct this pattern of the full effect of all neuron connected to one, it is use a scalar number called bias.

The combination of weights and bias defines how our neural network works. Each neural network, has an apprentice time, based on this learning we set and correct the network parameters, which are these weights and bias.

To neutralize influences of one layer to another, we can use a function to set the values of the next neuron between certain values, like the sigmoid function which establish the values between *0* and *1* for any result in the other layer of the network:

$$\sigma(z) \equiv \frac{1}{1+e^{-z}} \qquad (1)$$

This function is useful for slow learning networks, because offers a smooth transformation of the values in each side. Most changing values are between *-2* and *+2*, representing *0* value of sigmoid the *0.5* of the activation level in each neuron. *z* function represents the activation propagation between un layer of neurons and a certain neuron connected in next layer, using weights and bias as corrections:

$$z = \sum_j w_j \cdot a_j - b \qquad (2)$$

Where:

- w_j: weight of neuron j to affect next layer neuron.
- a_j: activation of neuron j to affect next layer neuron.
- b: bias correction of the result activation of next layer neuron.

For deeper information, refer to (Nielsen, 2017) [4].

All this parameters represents possible point of improvement of the neural networks, learning is based on corrections made in the weight and bias, also in the intermediate function, applying a different one from sigmoid, which can improve this learning, to obtain the expected result for correct inputs and a null result for incorrect inputs.

When an algorithm is set, cost function of a neural network, as the sum of the differences between expected result and obtained in last layer neuron normalized to one, represents how efficient is our algorithm against a test, and the weight and bias is our correction set of parameters.

Based on this, each group of elements of a ship system can be considered as an isolated cell, all the sensors and internal control unit can be programmed to react in real-time to internal stimulus, starting and element, stopping another, adjusting, etc., and finally communicating all the minor changes to a central unit in the ship.

Per each stimulus caused internally in the *Ship-System-IoT-Cell* (SSIC), normalized to *1*, the inner control takes a decision:

- Stable system part: do nothing.
- Adjust internally: correct one parameter which affects to the result of the neural network.
- Request an external adjust of any element out of the SSIC which directly or indirectly affects to this cell.
- Emergency: start secondary-emergency cell to avoid system failure, and stops securely all is internal components to minimize damage. This is direct connection, avoiding to wait for an external decision, even if this is taken by an operator or a control unit.

Any system of the ship can be divided in autonomous groups which are connected by a common element.

To avoid a fully abstract explanation, this article is going to be centered, as an example, in one of the systems of the ship, main engine refrigerating system.

This system is one of the principal help for the propulsion of the ship, even if is based in a purely fuel, diesel-electrical or nuclear propulsion, refrigeration is one of the main problems.

5. DIVISION OF SHIP SYSTEMS IN INDIVIDUAL IoT CELLS

Each cell needs to be autonomous, which is not the same as isolated, because in a ship all the items are related in a direct or indirect manner.

Steps to separate systems in SSIC:

- Divide each system in the smallest items-related groups. Each group can be considered as a module.
- Each group can be considered as a cell to be feed, and which is related with other system cells or even with other cells in other systems.
- Items should be enough close to have a direct relation.
- Adjusting parameters need to be also related. Any change in one affects to others.
- Add all elements an operator checks to adjust this group.

- Admit external signals as another control mechanism. This signal are always considered as inputs.
- Emit some external signals as inputs for other SSIC.
- Communicate status to main control system.

Developing these steps in previous example of sea water refrigerating system, in one of its cells. One of the groups which can be considered as a SSIC in the main engine refrigerating systems, usually sea water, is main pump group. This group usually for huge engines can have a configuration of *3* pumps, working in interchangeable cycles of *2* working and *1* remaining until required.

This SSIC is feed in two manners: sea water, as principal element, and electricity: high power to run the pumps & actuators, and low power to run the sensors and interchange information.

Main difference with common installation of this group or SSIC is the fact of it needs to be autonomous.

External input signals are:
- Start/stop command which can be translated as required flow in main engine for refrigeration. Input signal.
- Inlet or suction flow.

Internal input signals are:
- Remember which is the last pump started, controlling if this pump has complete a working-cycle or not, decide if it needs to started again.
- If last pump is restarted due to not a complete cycle is cover, begin to count the working time in an equivalent way as if it a non-stop group. This is one of the input parameter of our neural network.
- Check which valves are open and which are closed.
- Avoid "*water hammer*" in pumps and in solenoid valves. It is one of the most disrupting elements in pressure systems. This have a simple solution, the use of slow solenoid valves, but this behavior should also be included in our neural network.
- Each solenoid valve, due to previous points, represents two input parameters: first is open/close state and second time required to change state, because the slowness of the valves can be controlled.
- Non-return valves should represent another input parameter, with the open/close state.
- Check if pumps are primed or need to be prepared. Each prime state of a pump represents also a parameter in our neural network. This state can be represented as a yes/no or as a level. Second option has better options for regulation of our neural network.
- Each pump should emit also current *Revolutions Per Minute* (RPM). This is an input/output parameter of our neural network.
- Initially, an electronic thermometer should be installed in inlet and outlet to control fluid temperature, these two parameters are also inputs.
- Electronic pressure gauge, flow meter and thermometer should also be installed in the inlet and outlet of the cell. Input parameters.
- Electronic pressure gauge and flow meter should be installed in each pump outlet, after the output valves to control if pumps are in the expected pressure and flow required by external start order. Input parameters.

Internal outputs:
- Which pump is started and which is stopped.
- Which pump is in prime process.
- Which pump should increase its RPM.
- Which valves are in an opening process.

External output parameters, out of neural network:
- Inlet and outlet circuit parameters, pressure, temperature and flow.
- Pumps working time.
- Cell error codes, to be calculated in the Main Cell Controller which can be a PLC or any industrial programmable device.
- Start emergency cell to avoid full system failure. This is the unique neural network output.

Our network for this example has: 35 input neurons and 16 output neurons.

The hidden layers or intermediate layers are going to define the interactions between inputs and outputs, also, in this case, outputs affects inputs. Each output sets a change in the cell.

Main advantages of this simplification is that training this neural network cell can be do in laboratory, creating a set of working circumstances, from old values or any other situation, even with operators experience, improving the circuit and minimizing onboard impact.

Also, a set of errors can be reproduced and simulated on workshops during the training improving the parameters of this neural network and reducing human impact in the usual work of the cell.

More inputs and outputs can be add, improving the quality of this cell and the set of detected, autonomous corrected and avoided errors.

Last but not less important, electronic neural network represents also a piece of the system which can cause the error, due to this, it is important to set a group of zero test which helps ship machine engineers to identify if problem should be localized in any sensor or in the neural network itself develop by deep corrections.

If neural network in some circumstances makes the SSIC fails, with this test data can be restored to its default values, and all data collected till failure can be transmitted also to the shipyard in order to study and correct the issue.

6. SHIP SYSTEMS LIKE SHIP IoT ORGANS

By dividing each systems in autonomous, auto regulated and interrelated IoT cells or SSIC, reduces system overall failures and prevent problems in other parts of the ship which are not directly related to system under in issue circumstances.

Refrigerating systems can be divided in SSIC cells as follows, for example:

- Sea water suction.
- Main pump group.
- Secondary/auxiliary/emergency pump group.
- Main engine circuit.
- Sea waters discharge.
- *Overall System Control* (OSC).

Each SSIC generates inputs for other parts of the system, and globally, can collect from all parts of the system in the engine control room, where the OSC shows in a easy way the status of each cell and, also, some data can be distributed to the main bridge control console.

In this way, each OSC represents an "organ" of the ship as a summary of all the cells of the system represented by its shared information.

Each organ have a relation with others by OSC communications. Following with our example, refrigerating system full failure can communicate with fueling and lubricant system, stopping main engine to avoid a bigger problem. Also with main bridge to give an alarm, send a report to the ship owner and communicate with the nearest port ship last *Global Positioning System* (GPS) location.

With all this information, engine room engineers can start reparation process, or wait if problem cannot be solved with onboard tools and materials.

Extending the biological concept of "system" to the ship, all system related direct or indirectly with the propulsion can be an *IoS System* (IoSS) which groups all these organs to produce a simple action in the ship.

Creating bigger groups helps to classify errors, problems and also improves maintenance, due to each simplification requires a shorter list of spare parts.

Last organ is represented by the "brain" of the ship, this is the main OSC which recovers information from all IoSS, their organs and SSICs.

7. CONCLUSIONS.

As an example of IoS, the connectivity in smart ships will be extended to the commercial mission to act autonomously in operation conditions. A commercial vessel can transmit its navigation situation or its loading conditions.

All these means a huge amount of information to be managed and analyzed. New programs have to be developed to obtain the best use of such information so that the design can be improved from real function information of the design and it can be self-maintained with the connection with this huge cloud information to create method that the objects can achieve certain intelligence.

The growth of the IoS is linked to the increase of information and the management of Big Data, with the property that somehow IoS identifies information and direction and order to a specific purpose, while the concept of Big Data is more generic.

Treating ship like an alive being, and trying to simulate its parts such as organs or cells helps to introduce a neural network learning which can adjust each SSIC to work in the best conditions extending the life of its parts, preventing from damage other parts of the ship and helping to make a preventive maintenance of each part.

Neural networks represents an automated adjust of each simple group of things, because its parameters can be set to absorb external interferences.

Other advantage is that this systems can be trained individually, creating common, rare and unusual conditions.

Last advantage is, if something happens in a sailing ship, it can be reproduced in the shipyard based on this model, and getting a full condition simulation. This helps to focus the problem.

Adding some *Radio Frequency IDentification* (RFID) tags to the parts, can improve system information in ship brain, and if some parameters can be improved due to new known experiences can be downloaded in the ship to improve SSIC behavior.

8. ACKNOWLEDGEMENTS

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