How to improve the shipbuilding industry with the Internet of ships concept

Como mejorar la construcción naval con el concepto de Internet of Ships

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Abstract

The goal of this research is to explain one of the most interesting technologies that exist today, Internet of Ships (IoS), the IoT applied to the maritime sector. This technology is an enabling of other existing within what is known as Industry 4.0, such as the digital twin, cloud calculations or augmented reality.

Something as common as barcodes, were precursors of this technology and have been the cause of many stores have made the leap to smart tags, like RFID ones, which help them to perform both inventory and collection of things in the cashier, making that one jacket in the store an individual item in the collection of objects but perfectly controlled by the system. During the last years we have worked on implementing this transversal technology in the naval industry, and in this paper some examples will be shown.

Key words: Ship design, industry 4.0, IoS, digital twin.

Resumen

El objetivo de este artículo es explicar a los lectores una de las tecnologías más interesantes que existen hoy en día, Internet of Ships (IoS), el IoT aplicado al sector naval. Esta tecnología es habilitadora de otras existentes dentro de lo que se conoce como Industria 4.0, como por ejemplo el gemelo digital, los cálculos en la nube o la realidad aumentada.

Algo tan común como los códigos de barras, fueron precursores de esta tecnología y han sido los causantes de que muchas tiendas hayan dado el salto a etiquetas inteligentes, tipo RFID, que les ayudan a realizar tanto inventario como cobro en las cajas, haciendo que una chaqueta de la de al lado sean objetos completamente diferentes pero controlados por el sistema. Durante los últimos años se ha trabajado en implementar esta tecnología transversal en la industria naval, y en este artículo se van a mostrar algunos ejemplos.

Palabras claves: Diseño naval, industria 4.0, IoS, gemelo digital.

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Introduction to the future of CAD systems applied to shipbuilding

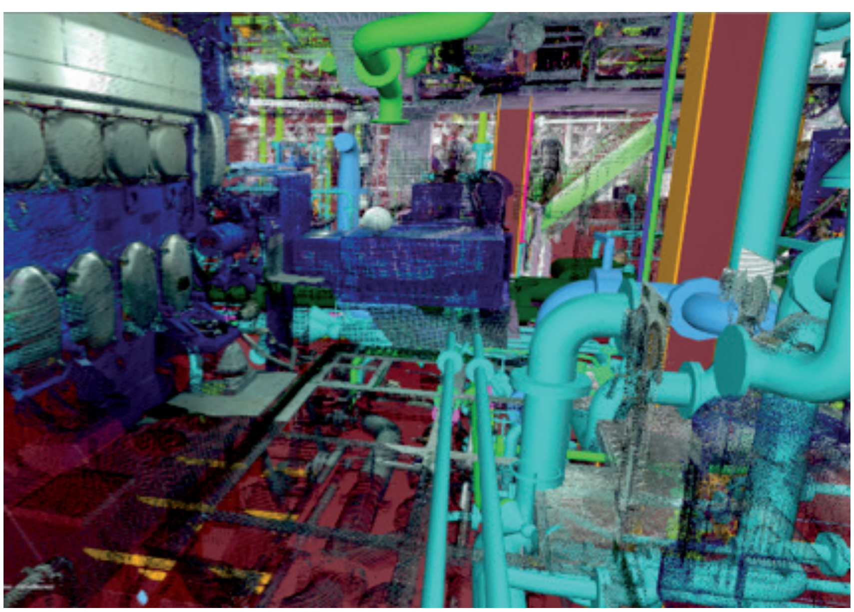
The objective of this article is to show how one of the technologies belonging to Industry 4.0, the Internet of Ships (IoS), can improve shipbuilding in the coming years. For such purpose, the implementation of this technology in ship design tools, also known by the acronym CAD (Computer Aided Design), has been studied over the last few years. Therefore, over the next few pages we want to explain how these design tools, used in shipyards all over the world, could improve in the near future.

As an introduction, we would like to analyze the current status of the functionalities that are currently being improved in CAD systems. E.g. in hull shape fairing or global shape modeling, complex surfaces could be transformed with excellent results, less interaction, high precision and full control. These techniques drastically shorten the design time, from days to minutes, obtaining excellent results *(Pérez & Alonso, 2015)*.

Another area of improvement concerns one of the most labor-intensive tasks in equipment design, the routing of piping, HVAC (Heat Ventilation Air Conditioning) ducts and cable trays. Automatic routing options minimize this time, but without reducing the robustness of the design. There are automatic routing algorithms, which provide simple solutions with material optimization. But the point is not just to consider existing elements for future routes; it is also necessary to assign priorities and eventually make automatic modifications to existing elements as a result of the incorporation of new ones. The complexity of the problem explains why a completely satisfactory solution for automatic routing does not yet exist. Current solutions provided by CAD systems solve partial problems, already offering significant support.

Another area where CAD development companies are very active is in Virtual Reality. The objective is to create a friendly environment for the user in order to review, audit, obtain metrics such as the progress of a project, etc. This type of model review process does not require the use of design tools, just a simplified tool that allows easy access (viewer). In Fig. 1, a 3D visualization model is reviewed on a mobile device, where authorized designers/ engineers could have all the project information. These browsers allow access to the reading of 3D information to load the component tree of the projects and obtain information about any part. Other basic tools available in these programs have different modes and commands, making it possible

Fig. 1. The future of naval design and the emergence of Industry 4.0 in the naval sector.



to measure distances or angles, create sections to access internal components, etc. The interface with the program is through a mouse, but Virtual Reality offers more possibilities, such as goggles or headsets.

Advanced browsers make it possible to incorporate human models to study ergonomic aspects, create highlights and textures for advanced renderings, component movements for simulations, etc. Browsers can connect to a project's database to access information in real time. Sometimes it is necessary to take information from an online database and if there is an Ethernet network through the shipyard, it is possible to implement a shared computer with a viewer to connect to a project. If there is no accessible database, users should be able to read files with the project information required for 3D product modeling and component data with optimal performance. Until now, it was common to implement viewers on laptops, because laptops are usually equipped with processors and graphics cards that allow navigating through the entire project. In recent years there has been a great advance in mobile devices such as tablets and smartphones. This hardware progressively incorporates new processors that enable improved graphics. On the software side, operating systems have been developed specially adapted for such devices (such as Android or IOS) that allow for interaction naturally through touch gestures.

The widespread use of these devices today has precipitated their use by software companies. Software developers have taken their time preparing targeted solutions, including those that allow us to have project plans or 3D models on smartphones or other electronic devices. In modern projects, there is a need for technicians to carry these devices to make them work better, with quick access to the 3D model of the project, with all the necessary part information and construction drawings. A wi-fi connection would make it possible to connect to a server to update information, mainly in files, such as: 3D models, classification or production drawings, among others. Another advantage of mobile devices is that the user interface can interact with the model or parts of the project using gestures, just as with smartphones. A browser evolution development line would incorporate augmented reality technology. It would be useful for production technicians to scroll through the project and point the camera of their mobile device at a particular component to get information from it and display the actual image of the same 3D design model. This is possible through the use of markers that allow the device to position itself within the project and also through the use of QR (Quick Response) codes.

CAD systems must handle the necessary information to create a collision-free design and to generate all production and assembly information, but not only this. The 3D model information is, at the same time, necessary for other activities and other departments involved in the construction of the vessel, such as planning, purchasing, outsourcing, accounting, etc. It is common for several designers to collaborate on the same project; therefore, it is necessary that the 3D model information be shared among them for reference. The paradigm of this problem appears when two or more designers collaborate on the same project, using different CAD tools. In this case, CAD systems must provide data exchange between them, leading to different degrees of integration, such as visualization, spatial integration and cross-manufacturing, depending on the characteristics and size of the information transferred from the 3D model. At the very least, it should be geometry and key attributes. A worldwide format for data transfer has not yet been found. Despite recognized international standards, in most cases we see dedicated formats or particular adaptations of standard formats. The transfer of 3D model information could result in a loss of performance due to the different geometric approaches to represent elements that exist in both CAD systems. In this case, special solutions must be adopted to minimize this impact.

Another milestone is the integration between different CAD systems and Product Lifecycle Management (PLM) tools, *e.g.*, the architecture-neutral FORAN Product Lifecycle Management (FPLM) tool. In this case, all information generated in FORAN can be transferred to a PLM and can be subject to all processes: control, configuration and release lifecycle and process management. FPLM consists of a number of tools and functions that allow bi-directional integration between different FORAN and PLM tool modules. The solution is based on standards such as XML, Web Services and Common Object Request Broker Architecture (CORBA). Fig. 2 shows an example of tool integration. Colors highlight parts or elements that will or will not be transferred to PLM.

There are many advantages of using CAD systems in shipbuilding: ease of design, speed of construction, use and reuse of information, etc. In the future, CAD tools are expected to advance further and enable greater information management and virtual access through smart devices. In general, CAD systems provide tangible benefits while optimizing the process, reducing design and production time and therefore costs.

What is IoT and how does it apply to the software world?

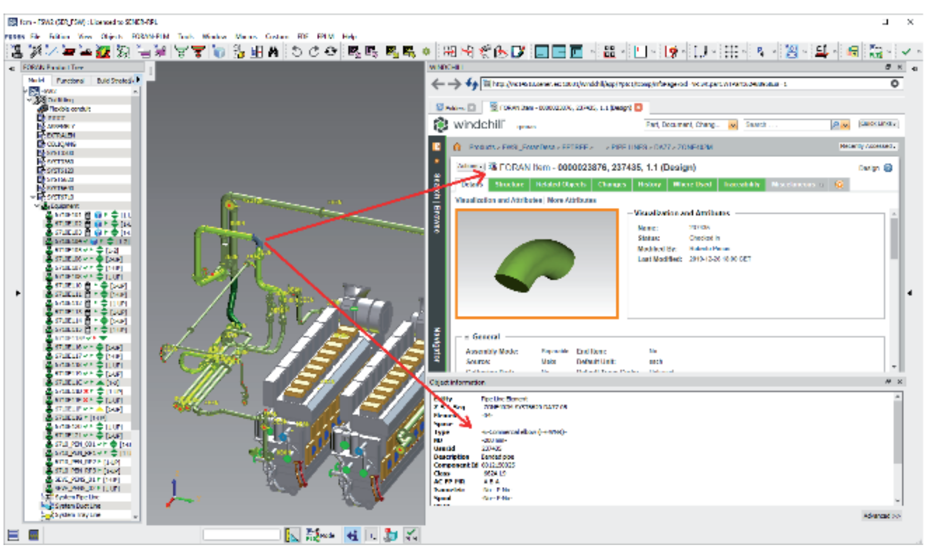
IoT is short for Internet of Things, which is known as the technology and process of connecting objects to the Internet. The goal is to make objects exchange data with the Internet and with each other *(Muñoz & Pérez, 2017)*.

The IoT concept was born at MIT's Au-to ID research center in 1999 after extensive research into the radio frequency identification of objects (known as RFID), which is Kevin Ashton's main idea. The idea of the research was to identify all objects and all people in some way, allowing some of the objects to exchange data with others via the Internet. Object identification was the prerequisite for IoT.

Humans interact with objects in a more or less direct way. But if objects are allowed to interact with each other, objects themselves may exchange data for their own needs. This would create a network of smart objects that can interact independently in the context of their mission. This network is known as IoT. The intelligence property of objects or devices need not be complex and exhaustive. For example, a refrigerator would require a way of measuring the elements so as to obtain information and recharge it when its charge is below threshold. These examples clearly show what device intelligence is.

In order to achieve connectivity, certain requirements must be met, including unique identification. But most importantly, it is necessary to determine whether the object is connected to the global network. The object will be related to its mission, but it will also be related to its needs so that it can fulfill its mission.

Fig. 2. Select an item in CAD scene and directly show simultaneously the item data in CAD and PLM.



Object connectivity requires various technical properties: hardware, connection method, and software. Hardware are physical devices that are intelligent, software are intelligent programs for the object, and the connection method is the way in which objects can communicate through physical or virtual devices (*e.g.*, radio frequency, wireless, etc.). Obviously, this is a very simple description of connection, but it is enough to illustrate the components involved in this concept.

The following four aspects can identify whether a product is connected to the IoT:

- Be able to control the use and operation of the product or object.
- Be able to be remotely operated or appropriately designed for use.
- Be able to predictively diagnose, repair or improve its performance.
- Any combination of the above.

There is enormous growth potential in this area and it can induce extraordinary potential economic growth. The McKinsey Global Institute report entitled "Disruptive Technologies: Breakthroughs that will transform life, business and the global economy" *(McKinsey, 2013)* concludes that the economic impact of IoT in 2015 has a potential annual growth of $2.7 to $6.2 billion. It further predicts that 80%-100% of the manufacturing market will use IoT applications with an economic impact of $0.9-2.3 billion *(McKinsey, 2015)*.

All economic sectors will be affected by this revolution. It will undoubtedly be the world of software and it will also be the case for shipbuilding. The vessel itself and all its elements will be linked to the connection, which can be done with this technology, opening up an extraordinary field.

The meaning of objects in IoT should not be limited to just physical objects. The concept can be extended to those programs called "virtual objects" that do not have a physical element. Therefore, we can know what the programs for IoT should be. And in particular, how should programs in the IoT world be oriented?

The origin of IoT can be found in the programs themselves. When a program suddenly stops working and indicates that there is a problem and if we want to transmit the diagnostic information to the supplier. This is an emerging IoT, although in this case it requires user acceptance. At other levels this acceptance is configurable and will be automatic.

These concepts can be applied not only to objects and devices, but also to CAD programs.

The Internet of Ships

According to the latest Juniper Research report, the number of connected devices in 2021 will reach 46 billion *(Muñoz & Pérez, 2017)*. As a comparison, this is a 200% increase vs. 2016. Many more will come, very quickly, and it looks like 2021 will be the year when 5G will definitively take off. This revolution, which started a few years ago, has aroused enormous interest in all industries and in some of them it is already operating with apparent normality.

The deployment of 5G networks will have a great effect on high-end IoT applications linked to robotics and automation, virtual and augmented reality, and artificial intelligence. Today it is difficult to buy appliances and household items that do not have an Internet connection.

From the Internet of Things Solutions World Congress in Barcelona, major Internet of Things trends include attempts at format simplification, Artificial Intelligence, Edge Computing and Digital Twin.

In this context, the question is how the shipping industry is adapting to this revolution. Is it possible that this traditional and conservative sector will move towards this technology?

Sea transport is facing a new scenario; Covid-19, even with IMO (International Maritime Organization) recommendations, has affected the sector. The changes in the creation of global value chains make the concept of IoT gain importance, and the result of this scenario will be the significant advancement of the digital era in this sector.

The new social distancing and prevention measures in the face of Covid-19 make it essential to use all the technology that we have adopted in recent years: cloud computing, collaboration tools (such as videoconferencing software, project management, chats), remote computer access and device synchronization, VPN and mobile-first applications.

There is already evidence that the shipbuilding industry is no stranger to these developments and is already connecting some ship components to the Internet, as shown in Fig. 3.

Just as there is a smart home or smart phone, there are new smart boats that are equipped with a network of sensors that capture a variety of voyage information, including:

- Location.
- Weather.
- Ocean current.
- Status of onboard equipment.
- Cargo status.

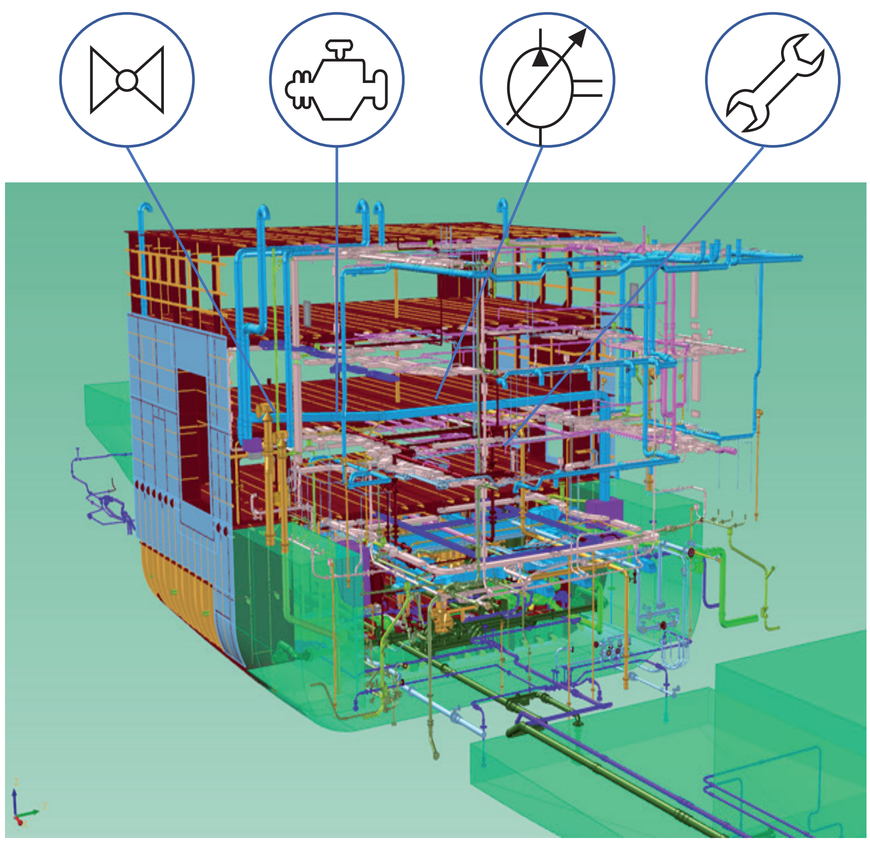
Ship owners can monitor the ship's status in real time and perform analysis on historical and current data to make decisions to operate more efficiently, saving time and fuel.

Sensors and technologies facilitate the introduction of new applications at sea, such as energy distribution, water control and treatment, real-time monitoring of equipment...

Sensors that, for example, collect air quality information and are connected to an Artificial Intelligence system that can turn HVAC systems on and off as needed.

The aim is to take advantage of this technological revolution by also acting in the design and production phases in order to build efficient, safe and sustainable vessels.

Fig. 3. Representation of a 3D model with access to the different components of the ship connected to IoT.



In a decentralized industry such as the naval industry, where engineering and production are often in different locations and where critical decisions cannot wait, the Internet of Ships (IoS), or the connection of critical components in ship design/construction, is beginning to loom as something the industry cannot afford to ignore. The idea is to monitor all those parts where early detection of situations allows us to make the right decisions.

In this sense, having sensors during the early stages of ship construction allows us to identify whether the ship's construction is completely in accordance with the design we have created with CAD. Whether we can reduce materials or use another one, if we have to adjust something according to naval architecture calculations...

Continuous monitoring with a ship design CAD, such as FORAN, will allow for cost reduction, error avoidance and real-time decision making from the shipyard, design offices or remote locations.

Today, CAD solutions such as FORAN can be used in pocket-sized tools, becoming an indispensable ally in this new technological revolution (see Fig. 4).

However, data management is only one side of the IoS coin. Energy efficiency is also a fundamental aspect in new devices that connect to the network. But IoS does not only cover the design or production stages of the ship, once the sensors are on the components which information we want to monitor, we can obtain information throughout the life of the ship.

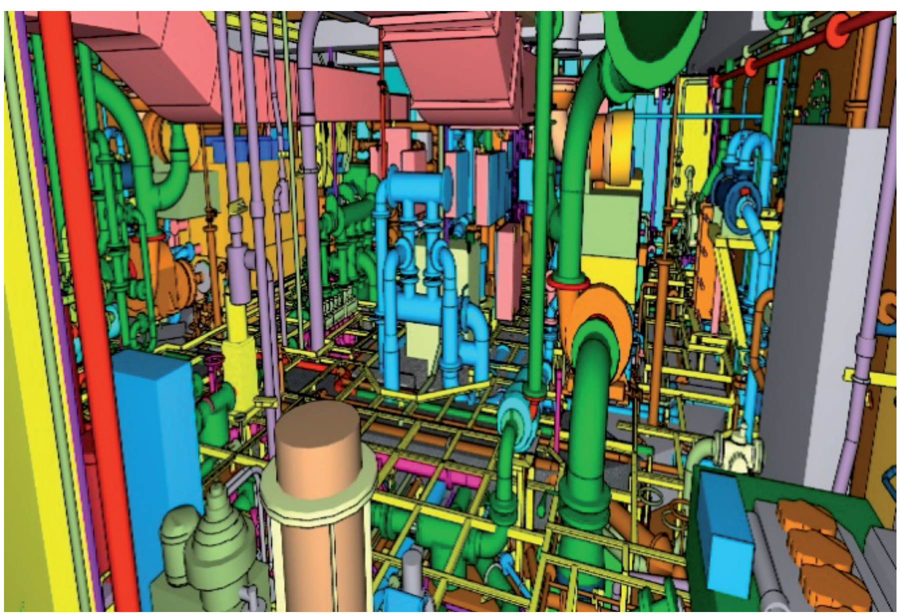
IoS is presented as a solution capable of detecting when a component of a vessel is close to failure and must be replaced, when we must take the vessel to be repaired, when we have to repaint, when corrosion has reached a certain limit... and all using our pocket-sized tool and with enough time in advance to avoid late or unexpected actions.

IoS comes to this sector to ensure a profitable production, a safe, efficient and sustainable process for all types of vessels, fishing vessels, tugboats, tankers, cargo ships, ferries, dredgers, research vessels...

The IoS in a shipbuilding CAD environment

How could this revolution affect the world of shipbuilding? Could we consider the IoS concept? Ship projects are developed with CAD platforms, but every day we seek comprehensive product

Fig. 4. 3D model in a virtual handheld solution such as tablets or smartphones.



development that involves the entire Life Cycle of vessels. We seek to integrate the CAD system with the PLM and to be able to conceive from the PLM the whole design and at the same time control the production and include the use of the vessel.

The PLM can contain information on all the ship's systems and also on all its components. If the components are designed for IoS, they will have a technology that will enable sharing their status, diagnostics, functionality with the PLM system that distributes the initial design.

The PLM can use this information to know if they are working properly or if we can improve their performance. It is also possible to identify whether the equipment needs to be maintained or needs to be replaced because its life is ending or because it is malfunctioning. It will be possible to determine and evaluate its performance by comparing it with other similar components or by comparing it in different operating periods. It will also be possible to know how its performance affects the operation of the entire product, *e.g.*, the vessel. In addition, if the connection of objects is made with their PLM, it would be possible to record their history, track changes, and know what their function or performance is after scheduled maintenance is performed.

In the case of a vessel, this connectivity will extend to its commercial activity, to act autonomously in the operating conditions. A commercial vessel can transmit its sailing status, cargo status, merchandise to be unloaded or reloaded.

All this means an enormous amount of information to manage and analyze. New programs must be developed to achieve the greatest use of that information, so that, in this way, the design of the ship can be improved from real design information and can be maintained by itself, there being a connection with this enormous existing information in the cloud and thus create a method in which objects can achieve a certain intelligence. The growth of IoS is linked to the increase of information and Big Data management, with the exception that IoS somehow identifies information, direction and order for a specific purpose, while the concept of Big Data is more generic.

The possibilities are countless, but the principle is the same. It should start at the initial design. It is necessary to consider what is needed to properly fulfill the mission of the atomic elements. These requirements must be configurable in the initial design from where they will be extended to the relationships between each of them with other entities. CAD is one of the first steps, because that's where the concept of each component begins to be systematically collected. Therefore, it is necessary to use CAD tools for IoS design.

IoS and CAD systems

Engineers design ships according to the requirements of the ship owner and Classification Societies, but some materials change due to new regulations applied during the time of ship design, lack of availability of materials or obsolete materials.

In all these cases, the Storage Control System (SCS) software should help design teams easily identify unsuitable materials in 3D modeling, reducing the cost derived from this problem by highlighting them.

For the pre-selection of materials in the equipment, smart tools connected to the SCS software can count the required materials based on the smart piping and instrumentation diagrams (P&IDs) that use the required materials in this 2D design.

These diagrams can have two design phases, basic and detailed, the first is applied in the first steps of the project and represents the main requirements and accessories of the equipment, but the second, applied in 2D or directly in 3D generates more accurate information. Electrical and electronic systems are based on the same principles, and CAD should help designers avoid design problems and interference.

In the case of the main structure, this design is made directly in 3D, in CAD software, avoiding delays in the steel work of the blocks and sub-blocks into which the entire ship is divided.

In this case, the selection is made based on the shipyard's standard scrap percentage and the required material, based on the quality, thickness and surface required.

The SCS software should have a bi-directional connection with the CAD system to feed the catalog components, reducing the waiting time for designers to use it, and when the systems/structure are mature enough, feeding the SCS software with all the materials used/required to issue the pertinent orders.

Finally, information maturity is a decision by the team design leader that requires human interaction and, based on CAD tools such as design rules and self-checking, can be done easily and quickly.

Materials should be collected, from CAD by maturity level, added to the ERP/PLM to control the workflow in the workshops and counted in the SCS software to help people in the purchasing department issue orders.

This is based on full interoperability between systems, all of them working as a single system.

The material in workshops can also be labeled, coded and stored for further production steps, which allows the CAD system to lock down items making them non-editable, and the PLM/ERP advances in the workflow, to trigger the next production step and the SCS software to add a new material into the production system.

IoS as IoT organs of vessels

By dividing each system into autonomous, self-regulating and interrelated IoT cells or Ship System (SB) IoT cells, overall system failures are reduced and problems in other parts of the ship that are not directly related to the system are avoided. Cooling systems can be divided into SB cells as follows, for example:

- Seawater suction.
- Main pumping group.
- Secondary/auxiliary/emergency pumping group.
- Main engine circuit.
- Discharge of seawater.
- General System Control (CGS).

Each SB generates inputs for other parts of the system, and at a global level, it can group all parts of the system in the engine control room, where the CGS easily displays the status of each cell and, also, some data can be distributed to the main control bridge console.

In this way, each CGS represents an organ of the vessel, as a summary of all the cells of the system represented by their shared information.

Each organ has a relationship with the others through the CGS. Continuing with our example, the total failure of the cooling system can communicate with the fuel and lubricant system, stopping the main engine to avoid a major problem. As well as with the main bridge to give an alarm, send a report to the ship owner and communicate via GPS (Global Positioning System) with the nearest port.

Based on all this information, the engine room engineers can start the repair process or wait if the problem cannot be solved with the tools and materials on board.

Extending the biological concept of system to the vessel, any system directly or indirectly related to propulsion can be an IoS System that groups all these organs to produce a single action on the vessel.

The creation of larger groups makes it possible to classify errors, problems and also improves maintenance, as each simplification requires a shorter list of spare parts.

The last organ is represented by the ship's brain, this is the main CGS that retrieves information from all IoSs, its organs and SB.

Conclusions

The recent emergence of Internet of Things (IoT) technologies in different industries has led shipyards around the world to be interested in applying the same technology to the naval industry, and this application has been called the Internet of Ships (IoS). IoS is the application domain of IoT in the naval industry, and refers to the network of smart and interconnected objects, which can be any physical device or infrastructure associated with a shipyard, a vessel, a port or sea transport itself, with the aim of significantly driving the naval industry towards an improvement in terms of safety, efficiency and environmental sustainability. This article provides a comprehensive review of the IoS paradigm, its key elements and main features. In addition, the state of the art has been reviewed for emerging applications, including improvements in CAD ship design tools. Finally, the open challenges presented and future opportunities for naval research, safety, ship data collection, management and analysis provide a roadmap towards the full application of IoS in the naval sector.

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