Computer Technology Architecture for Platform Control and Supervision Systems on Military Ships

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Abstract
The present article puts forth a proposal for the design of a hierarchical architecture of computer technology for control and supervision systems in military ships. This architecture integrates Industry 4.0 technologies and industrial communication protocols. The objective of this initiative is to automate critical processes, including propulsion, power generation, and the monitoring of strategic sensors. This will enhance operational availability and reduce technological dependence. A systematic qualitative methodology is adopted, based on a review of the international, industrial, and military state of the art, with emphasis on the OPV (Offshore Patrol Vessel) units of the Colombian Navy. The analysis draws upon international experiences, success stories, installed national capabilities, and current limitations in standardization, interoperability, and sustainability of naval systems. The proposal is predicated on laboratory results obtained during two years of applied research and proposes a modular, scalable architecture model oriented towards real-time control. This analysis provides a foundation for assessing the viability of developing a national solution that would enhance technological sovereignty and facilitate the development of defense policies. The research under consideration herein highlights the experience of current constructions in national shipyards and compares current capabilities with international models. The end result of this comparison is that it lays the foundations for the development of a national strategic naval platform management system.

Keywords: Naval IT Architecture, SCADA Systems, Hierarchical Automation, Industry 4.0, Naval Platform Control.

INTRODUCTION

In the contemporary context of modernizing the armed forces, the integration of Industry 4.0 technologies in naval platforms signifies a pivotal strategic advancement, aimed at enhancing operational efficiency, sustainability, and technological autonomy. Modern military vessels, particularly the Colombian Navy's Exclusive Economic Zone (OPV) patrol boats, face the challenge of operating in complex environments where the availability of critical systems, such as propulsion, power generation, navigation, and tactical sensors, must be ensured with high levels of reliability and autonomy. However, many contemporary platforms possess independent, closed technological architectures that are significantly reliant on foreign manufacturers. This reliance imposes substantial limitations on their capacity to interoperate and evolve in accordance with national solutions. In light of this scenario, the necessity arises to devise a hierarchical technological architecture that facilitates comprehensive control and supervision of these platforms. This architecture should be predicated on principles of modularity, scalability, security, and real-time monitoring.

This research proposes a computer technology architecture that integrates standardized industrial protocols and SCADA solutions, specially designed for implementation in OPV units of the Colombian Navy. A comprehensive review of the current state of the art, both domestically and internationally, in addition to a meticulous examination of successful case studies and the technological capabilities currently available in national shipyards, has led to the identification of the primary obstacles concerning the fragmentation of systems, the dearth of data analytics, the protracted nature of repairs, and the absence of coherent policies for the management of operational information. The proposed model aims to address these limitations through a hierarchical approach to automation, compatible with contemporary architecture employed in industrial systems and adapted to the operational and logistical conditions of naval forces in defense scenarios.

The primary contribution of this proposal is the conceptualization of an integrated monitoring and control system for warships that ensures the capture, transmission, storage, and processing of data in an efficient, robust, and secure manner. The central objective of this study is the development of a solution that allows for informed decision-making in real time, enables predictive maintenance, anticipates critical failures, and contributes to the operational sustainability of the fleet. Furthermore, the value of this architecture as a foundational platform for the prospective integration of emerging technologies, such as artificial intelligence and machine learning, is underscored. Additionally, its capacity to scale to other categories of naval units and unmanned systems is highlighted in the literature (Dionysiou et al., 2021). This article presents the findings of two years of applied research involving laboratory tests and proposes a technical approach to enhance national technological autonomy in the military naval field.

The objective of the present study is to design a hierarchical technological architecture for the monitoring and management of critical variables and sensors in the Colombian Navy's patrol boat platforms located in its exclusive economic zone (OPV). The integration of Industry 4.0 technologies and secure industrial communication protocols is of the essence in order to guarantee the capture, transmission, storage, and subsequent analysis of data for operational decision-making, predictive maintenance, and the early detection of failures in hostile scenarios.

To this end, specific objectives have been delineated:

- To analyze the hierarchical levels of automation and monitoring in industrial systems, based on the automation pyramid, for their adaptation to the functional structure of the naval war platforms (OPV) of the Colombian Navy.
- Evaluate and select consolidated industrial technologies (SCADA, Profibus, Profinet, EtherCAT, local industrial networks and data acquisition systems) that ensure the robust and secure communication of large volumes of data in naval environments, aimed at monitoring propulsion sensors, power generation, navigation and mission systems.
- To propose a model of modular, scalable and hierarchical technological architecture that allows the collection, safe storage and efficient transmission of sensor data, enabling its use for predictive maintenance analysis, failure detection and real-time decision support in the OPV patrol boats of the Colombian Navy. The following text is intended to provide a comprehensive overview of the subject matter.

MATERIALS AND METHODS

This article adopts a systematic qualitative methodological approach, aimed at understanding the advantages and limitations of various hierarchical technological architectures applied to the monitoring, transmission, storage and analysis of sensory data on naval platforms of the Colombian Navy's exclusive economic zone (OPV) patrol boats.

The research is based on a comprehensive review of the state of the art at international, industrial and military levels, with a particular focus on naval platforms, maintaining as a framework of applications for surface warships. This review will allow the identification of hierarchical architectures for data capture and management, sensory acquisition systems, secure industrial communications networks, mass storage systems, predictive maintenance strategies, and early failure detection methods, as well as comparisons with solutions implemented by other navies worldwide.

The analysis developed in this article is based on the results of laboratory work carried out over two years, complemented by the findings of the technical proposal formulated. To this end, the following will be verified:

- Information on investments in sensory data monitoring architectures in naval environments, success stories in the implementation of data management systems in the last five years, current state of secure industrial communication technologies, capture of distributed sensors, signal processing and storage.
- Features of the most relevant control and supervision systems, including SCADA solutions, industrial communication protocols (Profibus, Profinet, EtherCAT), local industrial networks and cybersecurity standards applied to naval platforms.
- Problems associated with the lack of interoperability between systems from different manufacturers, the risks of vulnerability in naval communications, non-optimized maintenance costs, the prediction of failures based on historical data, and the unavailability times of critical systems on board.

In addition, a reflection is proposed on the feasibility of designing a modular, scalable and secure architecture for data management in OPV platforms of the Colombian Navy, highlighting its potential impact on the improvement of operational availability, the optimization of predictive maintenance, data-based decision-making, and the strengthening of national technological autonomy within the context of the Colombian naval industrial strategy.

The documentary review includes key articles by international experts in Industry 4.0, industrial automation, secure communications and databases for critical environments, through a systematic search in scientific databases such as Scopus, Web of Science and Google Scholar, focused on publications from the last five years. Both global technological trends and their applicability in the Colombian naval context are considered, highlighting the experience of the Colombian Navy shipyard in OPV platforms, contrasting it with technological solutions of international reference such as those implemented in frigates of German origin FS1500 acquired in the past by the Colombian Navy.

Research problem

Currently, control and supervision technology platforms on board warships face growing challenges arising from the need to operate in hostile environments and with high operational availability. In the particular case of the Colombian Navy, there are limitations in the standardization of systems, technological dependence on foreign suppliers, high maintenance costs, and low interoperability between critical subsystems such as propulsion, power generation, and strategic sensor monitoring. These problems negatively impact the efficiency and response capacity of naval units. Despite the advances of Industry 4.0 and the existence of hierarchical architectures and consolidated industrial protocols in other sectors, there is still no computer technology architecture specifically adapted to the functional, structural, and operational needs of Colombian warships. The absence of a modular, scalable solution oriented towards real-time supervision and control limits the development of its own capabilities in the naval sector.

Therefore, there is a need to design a hierarchical computer architecture that integrates industry-proven technologies, adapted to naval conditions, to automate and supervise critical processes, thus strengthening technological sovereignty and national strategic capacity.

Figure 1. Buque OPV ARC “20 de Julio”

Theoretical framework and review of the state of the art

In recent years, advances in robotics and automation have allowed systems to make certain decisions autonomously, significantly improving the visualization of information from sensors, the generation of control actions, as well as the issuance of alarms and warnings. All this has contributed to the optimization of operational processes, generating more efficient records and reports. In this context, the Colombian naval industry, through the shipyard, has taken as a reference various previous research on unmanned surface vehicles (USVs), with the aim of incorporating technologies associated with Industry 4.0.

This type of research poses the challenge of identifying control and supervision architectures for both unmanned platforms and mother platforms or warships responsible for their management and operation. In this context, the importance of the industrial automation pyramid in naval environments is highlighted, fundamental to ensure real-time communications, reliable data acquisition and the need for technological standardization that guarantees interoperability and effective control in complex naval scenarios. In addition, it is essential that the information collected can be stored for offline analysis, thus contributing to the unit's logistics cycle (Cubides Garzón et al., 2024).

Naval platforms integrate a variety of communication systems, both wireless and wired. Among the former, there are navigation and communications sensor links (UHF/VHF radios, satellite communications, modem data link), identification systems (AIS and IFF) and global positioning (GPS). Surveillance sensors (navigation, surveillance and fire control radars) also employ wireless links. However, this article focuses on the internal communications of the ship, which are crucial for the control and supervision of the platform. These communications, predominantly wired and organized in local area networks, often consist of adaptations of industrial protocols for the naval environment. While the mechatronic equipment involved handles common variables such as power, level, temperature, pressure, and voltage, the diversity of protocols used poses challenges.

In the field of navigation, there are standards such as NMEA; however, in the context of industrial devices, networks such as PROFIBUS, Modbus, CAN, TCP/IP and EtherCAT are frequent, the implementation of proprietary protocols by numerous manufacturers introduces incompatibility problems and generates closed systems; therefore, it is essential that each nation, when developing its naval platforms, possesses the ability to control the hierarchy of supervision, control and data acquisition, regardless of the manufacturer or origin of the equipment and at the same time be able to guarantee the extraction of such data for further analysis (Tran et al., 2021).

The adoption of the Internet of Things (IoT) in the naval and military fields is a growing reality. In many scenarios, the secure integration of signals into control systems using low-cost hardware devices is required. This trend, currently called the Maritime Internet of Things (MIoT), facilitates communication not only between teams within the same naval platform, but also the exchange of information between autonomous vehicles such as unmanned aircraft (UAVs), unmanned surface vehicles (USVs) and unmanned underwater vehicles (UUVs). However, it is crucial to consider the inherent vulnerability of these communications to cyberattacks, jamming interference or spoofing. Despite these risks, the relevance of these technologies is undeniable due to their ability to simplify integrations, reduce costs, and offer robust operation in real time, making them a fundamental technological trend in the development of naval and military platforms; However, data acquisition for analysis and maintenance support cannot always be done by wireless transmissions on warships, first for security reasons, to avoid detection by the enemy through electromagnetic emissions and their corresponding electronic warfare measures, and second, to protect the reserve of tactical information. that could be used to sabotage naval operations (Kabanov et al., 2022).

Monitoring and control systems for naval platforms do not differ in essence from those used in industrial environments, such as factories and other critical infrastructure, including refineries and nuclear plants. These systems must be able to acquire data from multiple sensors and execute control actions through actuators, also incorporating advanced functionalities such as human-machine interfaces (HMI) that allow the operator to visualize the operation of the systems graphically and intuitively, as well as manage indicators, alarms, historical reports and network communications that integrate all devices.

In the case of Colombian shipyards such as COTECMAR, responsible for the design and construction of medium-sized warships, such as OPV (Offshore Patrol Vessel) units, it is common for these systems to be contracted abroad. This is due to the limited national capacity in the development of sensors, effectors and control consoles, which also includes on-board installation, generating a worrying loss of technological independence. These systems are usually closed solutions, designed to meet the customer's requirements, but with significant restrictions in terms of scalability, flexibility to integrate new hardware or software, and possibilities for future adaptation.

Aware of the limitations, the Naval Material Headquarters of the Colombian Navy (JEMAT) has identified the need to implement the monitoring of variables, sensors and actuators on naval platforms, in order to anticipate maintenance needs and optimize the use of economic resources allocated to this activity. For its part, COTECMAR has recognized the importance of strengthening national capacities in this area, which is why it has begun to promote research, development and innovation (R+D+i) projects, with the aim of creating, in the medium term, a national monitoring system for naval platforms.

In the last decade, SCADA systems have been the target of multiple cyberattacks. Depending on the level of process control compromised, these attacks can completely paralyze an industrial operation or, in the worst case, cause serious emergencies due to the loss of automated control. A recent example is the war between Russia and Ukraine, which has shown how cyberattacks targeting critical infrastructure such as nuclear plants, platforms and military equipment without the need to use conventional weapons.

These events have shown that attacks follow a systematic and hierarchical approach, starting at the lowest levels of the automation pyramid, until reaching and neutralizing higher-ranking systems. Against this backdrop, it is essential to have a robust communications network, a clear and well-structured design architecture, as well as applying lessons learned to strengthen the resilience of systems. In addition, it is necessary to adopt redundancy strategies in the event of possible failures and to develop specialized software that is not only oriented to process control, but also to the detection and mitigation of intrusions in SCADA networks.

Therefore, the submission of variable monitoring data for analysis should be handled with the highest level of restriction, as it could reveal to the enemy the operational status of the units or expose their vulnerabilities (Olasya et al., 2025)

In recent years, integrated platform management systems (IMS) have revolutionized the automation and control of sensors and actuators on warships. These systems provide a common, flexible, and scalable architecture for various naval platforms, centralizing key functions such as power generation, auxiliary machinery, fault control, navigation, monitoring, and alarms. Crucially, they facilitate the generation of preventive and corrective maintenance reports. In the Royal Netherlands Navy, the implementation of SIGP optimizes the performance of warships, including weapons control, and lays the groundwork for the future integration of artificial intelligence into data analytics to improve predictive maintenance and logistics. A significant advantage of SIGPs lies in their ability to integrate not only the aforementioned sensors, but also other vital systems of the ship, such as the combat system and the integrated bridge, leading to a reduction in navigation personnel and, in the context of warships, a greater survivability in the face of hostilities; however, the ability to transmit data remotely for supervision and logistical support is not contemplated, but the combat and maintenance cloud respectively is defined, which not only allows all the events on board the ship to be reproduced with high fidelity; it has also been successfully implemented to update systems by identifying errors; on the other hand, some records have also made it possible to focus on erroneous manipulations by operators and calibration problems (Kamstra, 2025)

On naval platforms, such as merchant ships and oil tankers, solutions based on the Internet of Things (MIoT) have already been widely implemented. These technologies allow the control of multiple pieces of equipment through wireless data links, making it possible to collect information in real time at a single monitoring point. This facilitates the early detection of faults, the verification of the proper operation of the systems, and the optimization of maintenance processes. In addition, some of these platforms occasionally operate with subordinate surface vehicles or submarines, with which they must communicate at short distance. In these cases, MIoT allows efficient and low-cost communication links to be established.

Although these implementations represent the state of the art in automation, control and robotics, their adaptation in military environments involves significant challenges, mainly related to cybersecurity vulnerabilities, impersonation risks and, above all, threats derived from electronic warfare. The challenge lies in developing secure implementation strategies, which allow taking advantage of these technologies without compromising operational integrity, and staying ahead of trends in monitoring, supervision and control systems, as fundamental support for predictive maintenance, fault detection and incident prevention (Lazakis et al., 2016).

In various home automation applications, the concept of telematics has been incorporated, which allows large volumes of data to be managed for efficient control and monitoring. One of the main contributions in this field has been the use of radio frequency technologies, which enable the transmission of data in an efficient and reliable way, thus facilitating the remote monitoring of variables of interest. The evolution of home automation has allowed its progressive migration towards applications on land, naval and aerial platforms. As highlighted in the literature, this transition has opened the door to advanced maintenance strategies, such as intelligent failure prediction, thanks to the use of big data systems that allow large volumes of information to be analyzed. These advances make possible systematic scheduling of real-time monitoring, implementation of predictive analytics, and decision support in naval operating environments (Palem, 2023).

Reproducing failures or stimulations of a system is a perpetual challenge, whether through the application of identical explanations of its operation or the replication of an error. In naval systems, both sensors and actuators frequently render reproduction of failures impossible under all conditions. In recent years, digital twins have gained traction in naval applications. This theoretical framework enables the reproduction of dynamic and static behaviors, as well as the relevant specifications of the system. It facilitates the execution of functional tests and the modeling analysis of errors or failures in a controlled, efficient, and economical manner (Zocco et al., 2023).

Specific implementations, such as monitoring a propeller engine on a ferry to measure all its variables: fuel consumption, turning frequency, temperature, pressure, etc. allowed to carry out analysis based on wear which allowed to conclude the maintenance planning, the reduction of frequency of intervention and the unnecessary accumulation of spare parts in the warehouse, all this thanks to the remote monitoring, simulation and diagnosis of all the electronic variables that could be acquired from the marine engine. This type of application confirms the need to do this with all the equipment on a naval platform and even more so with the relevance and importance of a warship (Bukovac et al., 2025)

During the development of the theoretical framework, it has been shown that naval platforms, and particular warships, require updating and standardization in their systems of supervision, control and continuous monitoring of operational variables. These capabilities are essential to enable early failure analysis and maintenance prediction. The literature reviewed shows technologies that allow these objectives to be achieved, highlighting the current trend towards the use of artificial intelligence for data analysis and the advantages derived from the implementation of electronic and communications systems. However, as the author of the analyzed article points out, a significant gap persists in the in-depth knowledge of warships that prevents the effective implementation of predictive maintenance based on real data. This limitation affects the ability to anticipate damage to critical systems such as propulsion, the electrical system, the hull or auxiliary systems. The article confirms the urgent need for the Colombian National Navy to advance in the design and implementation of systems that allow the monitoring, storage, and analysis of this vital information (Kalafatelis et al., 2025).

Identifying a single target actor for the integrated platform control and supervision system is complex. Depending on the focus of the literature, it could be considered that this type of system is especially relevant for maintenance personnel; in other cases, its usefulness for logistical personnel is emphasized, or it is even suggested that its greatest impact falls on the combat unit, the engineering personnel on board and the commander of the unit himself. However, from a holistic perspective, it is evident that all actors benefit equally, since the common goal throughout the value chain is to keep the combat unit operational at the lowest possible cost and in the shortest time. The article, developed by the Spanish Navy shipyard, highlights the importance of systems engineering to integrate statistical, geometric and dimensional reduction models in the analysis of the entire naval platform, which is key to ensuring the sustainability of the ship's life cycle (Michelena et al., 2023).

It has been pointed out that there are multiple software solutions for the acquisition and control of platforms, as well as various communications and data acquisition subsystems. The technological advantages derived from the standardization of industrial networks, both for sensors and actuators, are also highlighted. However, integrating all these elements into a single monitoring, transmission and storage system – initially for the museum ship and later for the entire fleet – requires a specific and tailor-made software solution.

Previous research has shown that true technological independence is achieved when, using standardized systems, a functional and hierarchical supervisory tree is built. The tools and conclusions derived from this article constitute key recommendations for the design of an integrated platform supervision system for warships of the Colombian Navy (Dionysiou et al., 2021).

RESULTS AND DISCUSSION

During the development of this scientific article, the ARC ship "20 de Julio", an oceanic patrol vessel with an exclusive economic zone (OPV-80), built by the Colombian Navy shipyard under a design license from the German shipyard Fassmer, has been considered as a case study. This unit represents a significant advancement in the country's shipbuilding capabilities, integrating multiple propulsion, power generation, automation, and monitoring systems within a modular and flexible platform, suitable for patrol, surveillance, and humanitarian support operations.

Figure 2. ARC OPV Engine Room "20 de Julio"

The ARC "20 de Julio" is equipped with two Wärtsilä 6L26B2 main engines and two Wärtsilä 12V26 auxiliary engines, capable of propelling the ship at speeds of up to 21 knots. The propulsion system includes controllable pitch thrusters and a 280 kW bow pusher, which gives it high maneuverability. As for the power supply, the ship has three main generators of 360 kW and an emergency generator of 105 kW, all operating at 440 V and 60 Hz, ensuring redundancy and continuity in the operation of the critical systems on board.

The integration of these systems within the bridge and the main console was carried out by the Colombian Navy shipyard, which assumed the responsibility of assembling and incorporating the subsystems. Although the exact communication protocols used have not been publicly disclosed, it is inferred that common technologies are used on naval platforms such as Ethernet and Modbus, in an environment that includes centralization of information and control of operational parameters. This integrated architecture allows monitoring of the condition of the propulsion plant and auxiliary systems.

Figure 3. OPV ARC "20 de Julio" Engineering Console

The most outstanding features of the design include its ability to adapt to different missions through a modular approach, as well as its speed, maneuverability, helicopter flight deck and low radar profile. However, it also has some limitations such as the technological dependence on international manufacturers for spare parts, as well as the need for highly trained personnel to operate and interpret the integrated systems, which raises operating and maintenance costs.

Figure 4. OPV ARC "20 de Julio" control panels

Regarding the monitoring and historical control of maintenance, this type of vessel depends on the periodic manual rounds recorded by the operators in which the values are taken directly from the indicators and are later entered into computer tables, however this manual method does not guarantee adequate integrated logistical support, because there are errors due to typing and lack of synchronization in the food vision of the database and on All because it takes a very long time to register, digitize and then process, a process that is also manual and does not generate any automatic recommendation metrics, much less in real time. This type of methodology only serves to generate statistics and support for corrective maintenance and does not offer any preventive anticipation.

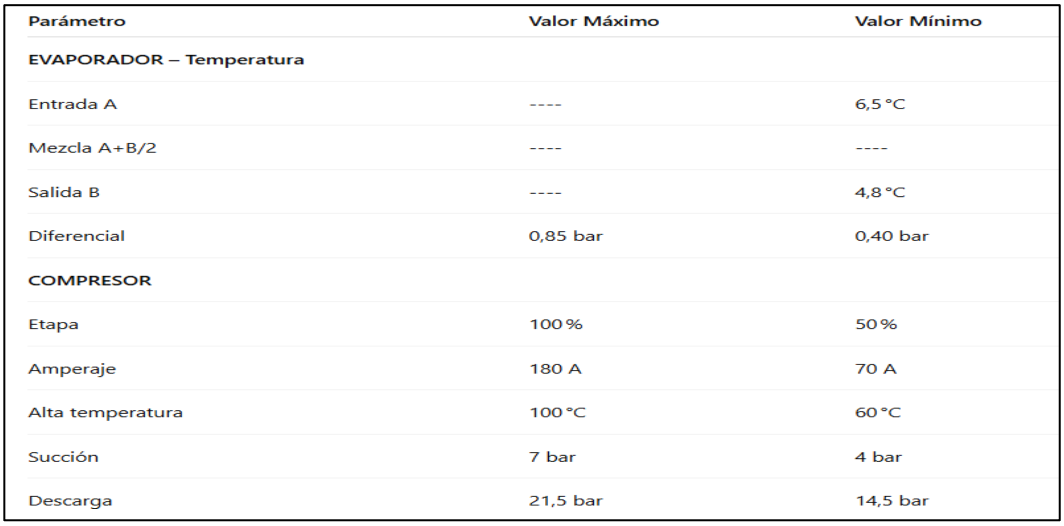
Additionally, the integrated bridge system for this type of units is isolated and does not share information with the other systems of the ship such as the bridge or the weapons system, which is a great weakness for a warship since in hostile situations total integration allows better decisions to be made to repel combat and sustain itself in the confrontation.

Figure 5. Identification of the current problem

Once the current architecture of an engineering console on board ships has been identified, it is observed that the lack of system integration, the multiple brands hardware and software architectures, with closed communication protocols and exclusive manufacturers, a high technological dependencies without data analytics, which cause high costs of implementation, updating and support, with long repair times, it is possible to identify that it is necessary for the Colombian Navy for its warships to implement a better method of data acquisition, supervision and control, management and support to the planning of resources with data analysis

Eliminating workbooks, operation records, equipment history and manual maintenance record sheets, turning towards modernity with electronic integrated equipment that has online and real-time support expenses.

Table 1. Example of data logging of on-board equipment OPV unit



Parámetro	Valor Máximo	Valor Mínimo
EVAPORADOR – Temperatura		
Entrada A	----	6,5 °C
Mezcla A+B/2	----	----
Salida B	----	4,8 °C
Diferencial	0,85 bar	0,40 bar
COMPRESOR		
Etapa	100 %	50 %
Amperaje	180 A	70 A
Alta temperatura	100 °C	60 °C
Succión	7 bar	4 bar
Descarga	21,5 bar	14,5 bar

The following diagram shows the approach of 5 levels of hierarchy for a proposal for control, supervision and subsequent management of information and maintenance analysis, not only of an OPV type unit, but a scalable system for all ships of the national navy that allows true logistical support, anticipation of information, failures and the future use of artificial intelligence methodology for analysis.

It also includes the lowest level not only with equipment technology and devices integrated in isolation but also control system with standard but common communications designed and developed by the Naval Technological Development Center (CEDNAV), installed on board all ships of the navy that allow efficient maintenance distributed control systems that achieve that in case of loss of control loops the devices can have actions of local execution.

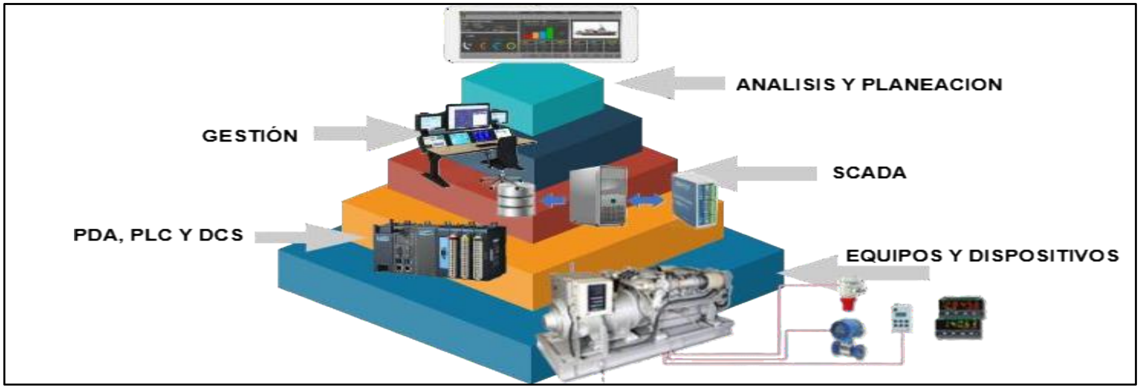


Figure 6. Proposal of the Hierarchy of control and maintenance analysis

DISCUSSION

As evidenced in the images of the ship's engineering control console, the integration of the sensors was carried out through a classic configuration, based on analog needle-type indicators (dashboard) that locally show the status of the monitored variables. This approach, although functional in real time, does not allow the storage or export of data for later analysis. As a result, historical synchronization with other variables and sensors on the ship is impossible, limiting the ability to correlate events or disturbances in an integral way. In other words, although the integration is technically adequate, its nature is local, isolated and dependent on the physical presence of a trained operator, without offering automatic recommendations in operational situations or emergencies.

The analysis of the control system and sensor integration reveals a strong technological dependence on manufacturers, both in the sensing and actuation components and in the visualization and communication elements. The equipment was not selected, designed or integrated by the Colombian shipyard; instead, the integration was limited to connecting the devices in the way established by the vendor. This generates a rigid architecture, without the possibility of centralizing data or commands under unified protocols adapted to the needs of the Colombian National Navy. Additionally, redundancy is compromised, since the systems work point to point (sensor-indicator-actuator), which implies that in the event of the failure of any of these elements, the original manufacturer must be resorted to for replacement. Since most of these brands do not have local production or representation, delivery times can exceed three months, without considering the administrative processes of contracting, importation and nationalization.

In contrast, the image below shows a communication loop scheme based on the DDS (Data Distribution Service) protocol, which allows data networks to be standardized in accordance with NATO interoperability recommendations. This type of open architecture facilitates total integration between the platform's subsystems, favoring scalability, redundancy and interoperability between naval units. In addition, it provides a solid basis for the design of the Colombian Navy's own systems, allowing greater control over the functional architecture and reducing external technological dependence.

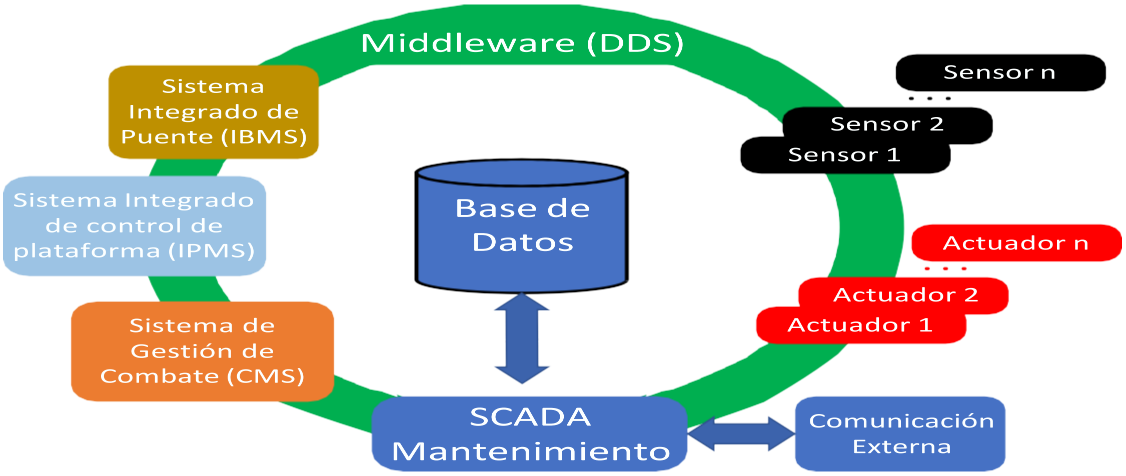


Figure 7. Proposal for a SCADA communication system on warships.

The Naval Technology Development Centre has assumed leadership in promoting strategic processes related to the automation and control of naval platforms. In particular, all the progress made to date in the Colombian Integrated Platform Control System (SICP-C) project has been made possible thanks to the sponsorship of the Francisco José de Caldas Fund. This investment has been designed not only to strengthen the development of applied engineering capabilities, but also to consolidate the country's defense industrial and technological base. In this sense, the project seeks to promote the creation and maturation of its own technologies, both in hardware and services, that strengthen the Colombian industry and reduce its dependence on international suppliers.

Finally, the fundamental purpose of an integrated platform control system is to enable the continuous and structured extraction of operational data from all subsystems of a warship, in real time. This information, when properly processed and analyzed, enables the generation of detailed maintenance reports – both individually and collectively – optimizing the logistical and technical management of the units. In this way, it is possible to anticipate operational needs and significantly reduce the costs associated with corrective maintenance, providing efficiency and sustainability to the operation of the Colombian National Navy.

CONCLUSIONS

It was possible to develop a detailed conceptual design for an integrated system of supervision and control of data from sensors and actuators installed on naval platforms, specifically oriented to warships of the Colombian Navy. The design includes robust mechanisms for the secure storage of information, guaranteeing its traceability, integrity and correct identification.

Likewise, an efficient architecture for data transport was defined, aligned with the current cybersecurity and cyberdefense standards applicable to tactical units. The design incorporates specific measures to mitigate vulnerabilities associated with electronic warfare, such as the possible disclosure of the ship's operational position.

The chronological and structured consolidation of all the captured variables – both individual and correlated – is proposed, which will allow statistical analysis, derived variables to be generated, operational patterns to be identified and predictive models aimed at preventive maintenance and strategic decision-making in real time to be enabled.

This first phase of the project focused exclusively on the conceptual and functional design of the system, not including the manufacture or experimental validation of an on-board prototype. Therefore, there is still no empirical evidence in real operating conditions.

During the analysis of the state of the art and based on surveys applied to commanders of operational units and personnel of the General Staff of the Naval Force, the need to restrict the use of GPS geolocation data was identified as a critical limitation, due to the risk of being electronically compromised or poorly managed, which could affect the safety and success of naval operations.

In a second stage, it is planned to implement the system on an OPV (Exclusive Economic Zone Patrol Vessel) type vessel, integrating it with the on-board SCADA. It is planned to transmit the data through tactical links, such as LinkCo, to a command-and-control center on the ground, where information from multiple units will be centralized for processing and analysis.

The project also contemplates the incorporation of artificial intelligence (AI) and machine learning tools that allow the generation of automatic maintenance recommendations, as well as corrective action plans systematized and prioritized according to criticality.

It is expected that this system can be scaled up and implemented on other platforms of the National Navy, including ground vehicles, aircraft and unmanned units, adapting to different operational environments, and consolidating a comprehensive real-time monitoring and control solution.

Finally, the project seeks to develop digital twins of the entire naval platform, including its sensors and actuators, to virtually reproduce its behavior, validate implementation solutions and simulate failures in controlled environments. This not only optimizes maintenance management but also constitutes a key tool for the technical and operational training of crews.

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Conflict of interest

The authors did not declare any conflict of interest.

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