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NEXT GENERATION CONTROL ARCHITECTURES

Current generation control systems, including those aboard the "Smart Ships", place an ever-increasing amount of sensory information in front of the operator, and generally require sharply increased manning in case of control system malfunctions. Furthermore, there is a growing demand for reduction of the number of crewmembers on board a ship. The control system designer faces the challenge of designing a robust and increasingly autonomous automation system that is scalable and affordable. Research suggests these challenges will be met by three - tiered control architecture – a strategic layer that focuses on setting resource goals and priorities for machinery systems based on the ship's current mission. This will enhance the features of currently available systems by allowing direct addressing of any system component, sensor or actuator from anywhere in a vessel. This permits a system self-reconfiguration on failure or in case of damages to the segments of the system.

Future full integrated control and monitoring systems (FICMS) will be distributed systems that combine control and information functions under the umbrella of one overall management system. An open architecture with backward and forward compatibility provides improved through life support and reduces the risk of obsolescence. Generally, the technology to achieve the vision of an advanced FICMS is available today.

Keywords - *Integrated control and monitoring system, ships computerized systems, three - tiered control architecture*

1. INTRODUCTION

The last two quarters of the XX century has been marked by the achievements in automation of the marine technique and in control of operations for which this technique has been created [3, 7]. These achievements have confirmed their efficiency and viability. A further progress in this sphere is evident [4, 5].

A fully integrated control and monitoring systems (FICMS) offers immense benefits in on board and shore support to the vessel. On board a ship, the FICMS would undertake and manage all activities associated with the administration of the vessel, including stores and provisions management, work requests, logs, equipment tag outs and calling up and display of diagnostics, drawings and work procedures for engineering repair teams. The on-board engineering team could have access to shore support via direct satellite link in the unlikely event of a major breakdown while at sea. Prognostics and diagnostics as well as valuable back up histories and trends would be available from the Condition Monitoring Manager and Support Manager within the on-board FICMS to support the base maintenance team. This support vision also includes the possibility of equipment providers interrogating the performance of their products via the internet.

2. HISTORICAL PERSPECTIVE

The application of computers and computer networks to management systems has progressed rapidly since their introduction in the early 1970's [7]. Local control consoles utilized hard-wired logic to a large degree, but system wide monitoring and alarm functions were digital computer driven, with parameters collected and exchanged via a triply redundant, serial data bus. The next generation saw a much more extensive use of digital computers and ushered in the ship-wide, data multiplex system communications network in the late 1980's. Although touted as a ship-wide network, the data multiplex system generally served only engineering users: steering, machinery control, and damage control, with limited use for navigation signals. As technology improved and became more affordable, control system processing became more distributed, and communication networks became much more widely used.

Current network architectures, such as those found on the US "Smart ship" upgrades utilize a full mesh fiber optic LAN employing the ATM (Asynchronous Transfer Mode) protocol [3]. Traffic is separated between functional areas using virtual LANs, and bandwidth is high enough to accommodate both video requirements and real time monitoring and control [2, 5].

At the same time technology growth was enabling a dramatic change in the way shipboard control consoles communicated with each other, it was also enabling a major change in the manner in which sensor data was collected and processed, and commands delivered to actuators. Early automated systems had the user interface, processing electronics, signal conversion electronics, and the network interface all contained within a single console. This not only made the console a single point of failure, but also required that all sensors and actuators be hardwired to the console. As the computing and networking technology matured, it became cost-effective to move a portion of the electronics to "satellite" enclosures which were then networked together. In this system, the signal conversion electronics were moved from the main engineroom console to several remote units that were networked together. The operator interface, network interface, and the "intelligence" were still located in the main engineroom console. Continuing technology growth is making it affordable to distribute the "intelligence" function with the result that the main engineroom console will retain only the operator interface function, with all computing and signal/data conversion functions fully distributed, initially to remote or satellite enclosures, and eventually to individual or groupings of sensors and actuators.

Not only is affordability enabling distribution of the signal conditioning electronics, it is also contributing to a dramatic increase in the amount of data collected by the FICMS, with the result that more and more information is being presented to the engineering plant operators. Even though the displays are now graphical, making it easier for the operator to absorb or be cognitive of the information about the engineering plant. Although this movement towards highly distributed systems has been enabled by technology growth, it is being driven by "automated to reduce manning" initiatives, making the information overload problem even more critical [2,3]. An additional factor that must be considered when reducing the operator complement is that current systems rely on the operator to be the "backup" for the automation system in the event of failure due to malfunction or battle damage. Thus the next generation platform management system must begin to take on a portion of the operator workload and it must be so robust that it continues to provide the control and monitoring function even in the presence of damage or malfunction.

3. ADVANCED AUTOMATION DESIGN CHALLENGES

An automated system can be characterized by its logical organization and physical organization. The physical organization is the manner in which computing elements are distributed and interconnected. The logical organization is the manner in which information is processed. A given physical organization may support many different types of logical organizations, with some physical organizations more flexible than others. Despite this variety, however, most practical architectures are a hybrid of three logical types, namely: hierarchical, layered and distributed. Any particular logical organization exhibits more or less some combination of the characteristics of these types. For example, a distributed physical system consisting of discrete microprocessors, sensors and actuators interconnected over a network may be employed in a distributed parallel logical organization, a centralized hierarchical organization, or a hybrid of the two types. A centralized physical system with point-to-point connections to sensors and actuators, however, will support only a centralized logical organization. Hybrid physical organizations are also possible. Diagrams of the three major physical organizations are shown in figure 1.

Automation systems typically employ a hierarchical logical organization. The number of layers in the hierarchy varies and is often a matter of choice [7]. Higher levels of the hierarchy perform more general or deliberative tasks such as planning and sequencing. Lower levels of the hierarchy perform more reactive or autonomic tasks such as closed loop stability and set point control. Various groups have defined different hierarchical schemes but most system now use a loose 3 layer hierarchy. The top most level is often called the planning or strategic level and is responsible for mission based resource management, goal setting, priority assignment, operational scenario determination, and task sequencing. The middle layer is often called the tactical or coordination level, and is responsible for subsystem interaction, task and sensor fusion and priority and operational scenario implementation. The bottom layer is often called the execution or servo layer, and is responsible for low level tasks such as feedback control, subsystem control, data acquisition and actuation. Representative hierarchical control architecture is shown in figure 2. More recently, layered

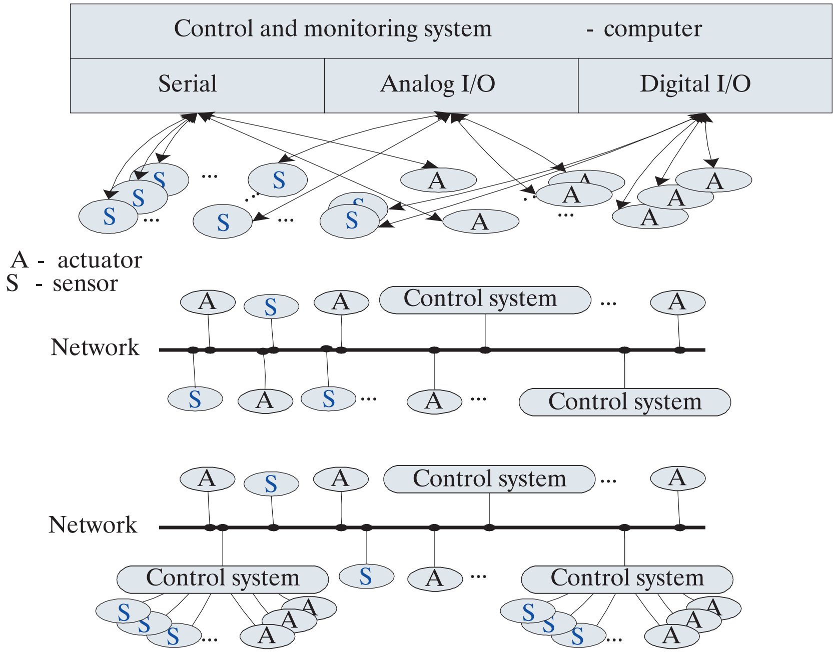

Figure 1: Diagrams of the three major physical organizations

logical organizations have become popular. A careful analysis reveals that layered control architecture can be characterized as a set of small hierarchical systems running in parallel with arbitration or task fusion to combine the parallel layers. A hybrid scheme employs layered control within each level of the standard 3 level hierarchy.

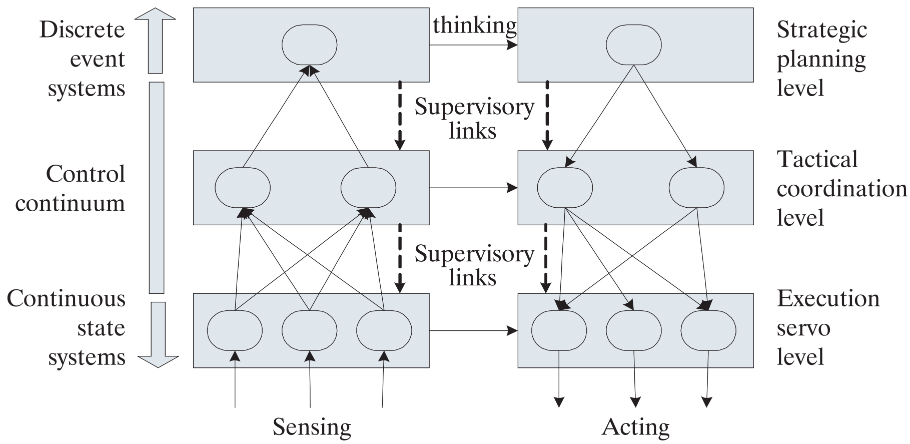

Figure 2: Representative hierarchical control architecture

The continuing distribution of signal conditioning electronics and intelligence functions from the early centralized architectures outward toward sensors and actuators has led to the development of component level systems. This physical organization has a high degree of distribution of simple computing elements most of team employed at the execution or servo layer. It is married to more sophisticated computing elements at higher logical levels in the system. However, as the computing power of embedded microprocessors increases, more and more middle and high level processing can be done by component level processors [1].

4. CHALLENGES DESIGNING CONTROL SYSTEMS

One of the biggest challenges to the control system designer to achieving advanced functionality in autonomous and semi-autonomous systems is complexity management. Many approaches will work up to a certain level of complexity and then fail due to lack of scalability or functionality; or the ability to practically test. One key to complexity management is dependency reduction; that is, reduce the number of dependencies between components in the system so that changes do not cascade to a point where the time and effort required making a change is prohibitive. Since dependencies arise from interaction or exchange of information and data between components of the system, the mechanism selected for information exchange will have the greatest effect on the number and type of dependencies. A dependency becomes a problem when there are changes, and changes arise from either changes in the mission or environment or the addition of new capability to the system. In the forme case, low complexity equals low maintenance and operations overhead and, in the latter case, low complexity equals low upgrade and lifecycle overhead.

In addition to dependency reduction, two other keys to complexity management are the degree of transparency in information transport and exchange, and the stage in the development process in which information exchange between components is fixed. Transparency refers to the amount of overhead and explicit details (dependencies) that must be kept track of by a component to exchange information with another. Can connections be changed without the components needing to know about the change? Information exchange between components is fixed when the data elements are "bound" to a computing node. Late or early binding refers to the point in the development and testing process when connections get fixed, such as compile time, load time, install time, or run time.

With this approach, each engineering subsystem (propulsion, electrical, fire main, fuel oil, compressed air, etc.) can be realized as a stand-alone autonomous control system consisting of a number of networked computing nodes.

To fully support the desired reduction in manpower, though, the FICMS must be "aware" off the ship's current mission, knowledgeable regarding the various resources required of the engineering plant to support the mission, and able to prioritize the resource needs of various shipboard equipments involved in responding to the ship's mission. In current generation ships, the context knowledge is based on sensor system input from both threat sensors (radar, visual,..) and damage sensors (fire, flooding, etc.) the context is based on doctrine (refined by ship system status) and resource needs are based largely on reactive measures. Most of these steps can be automated by capturing operator decision making criteria and current doctrine using artificial intelligence techniques. Such a system could be referred to as a context based resource management system, where the context is the ship's current mission or mission mix, and the resources are electrical power, propulsive thrust, chilled water, compressed air, etc. Meeting the challenges represented by this vision will require such techniques as redundant sensing of selected parameters, fusion of sensory inputs, new control algorithms that are capable of intelligent processing in the absence of complete information, and a degree of robustness not yet seen in shipboard controls.

4.1 System robustness

Extensive use of automation can bring significant improvements in system safety. By removing the notoriously unreliable "man in the loop", both system performance and function reliability improves. Safety design principles such as segregation of control and protection functionality, diversity and redundancy can be incorporated into the FICMS design so that high integrity functions may be allocated to FICMS. This may entail the use of triple modular redundant (TMR) or even quadruple modular redundant (QMR) system architectures to function at the control level. The systems are designed from the outset to maximise th potential benefits brought by FICMS and automation. In order to reduce human error, FICMS will check command requests against a rule base, with cause effect analysis and subsequently advise the operator in order to reduce human error.

An often asked question is "What happens if a computer fails?" By distributing the intelligence of the entire system outward toward individual components, each of the computing nodes is responsible for a relatively small portion of the overall control and monitoring function. Therefore, if a processor fails, only a small portion of the system's functionality is lost. Even with this high distribution of function, loss of a critical computing node or sensor could result in an inability to execute a particular control algorithm. The solution in this case is to either utilize redundant sensors or actuators, or incorporate data fusion into the design. Data fusion is best defined as making decisions based on several pieces of information that are dependent parameters but that are based on data from separate sources. For example, if it is necessary to determine if an engine is in the operating state, an algorithm might use engine as a determining parameter. Utilizing data fusion techniques, input data would be supplemented by fuel pressure (from an engine driven pump) and exhaust temperature so that one of the sensors could fail without losing the ability to determine engine state. These three signals are from three independent sensors, on three independent processors, in three physically separate locations. The system can lose two out of the three parameters and still be able to make the correct decision. This decision making technique is applied as much as possible in the lower level automation algorithms.

4.2 Open system architecture to enable multi-vendor solutions

Technology will not necessarily be costly – consumer electronic equipment becomes more reliable with increased functionality, yet with a decreased cost year on year [1]. Reduced manning alone is a big cost saver. Rate of technology change is always difficult to manage, but at least with the adoption of open system architectures and fully backward and forward equipment compatibility for FICMS, upgrades will be more cost effectively engineered into the vessel. Open system architecture will allow upgrades trough boat life without costly re designs and re engineering, thereby evading obsolescence. Chosen suppliers will be committed to full forward and backward compatibility.

4.3 Communications survivability

One of the biggest challenged to the automation designer is the network architecture layout. This function determines how many local rings to create in the network and how many processors should be on each ring. By analyzing the number of signals and periodicity, the designer can predict the bandwidth utilization on each of the rings (also called subnet). For small system this can be done by hand. Larger systems, however, will need a computerized design tool that optimizes network connections based on specified criteria. This tool allows the designer to trade off survivability and cost in the design based on criticality of the signals/processors and the cost of additional hardware [1, 8].

4.4 Model based plant and system monitoring to permit prognostic and diagnostics

The engineering operators will be advised of any impending problems using the prognostic and diagnostic capability of Condition Monitoring (CM) and be guides as to what corrective action to take. Advanced prognostics and diagnostics capabilities utilise an online Condition Monitoring System. This is likely to be a model based rather than a complex rule based solution that will enable a much more efficient handling of plant and system condition monitoring. The main source of prognostic and diagnostic information is provided to engineering personnel by the Condition Monitoring System that is constantly on-line. The engineering personnel evaluate this information and make a judgement on whether to take remedial action to maintain the vessel capabilities. However, it is accepted that detection reliability must be high to be effective [8].

4.5 Advanced logistics support using the internet

The internet will be used for advanced logistics support, subject to firewalls and arrangements. The Support Manager will have a stores inventory with location from scanning system when carried on board. There are many options to reduce workload in this area including the use of standard interchangeable units, stores ordering over internet, and a direct link into manufacturers spares ordering system via the internet. An ideal of this arrangement is achieving the goal of zero maintenance at sea [2,4]. Performance degradation may prove to be acceptable, and when at sea advice would be from base port via the support contractor, through satellite and internet. Shore base staff should do all the base port maintenance.

The stores inventory is to be subject to auto tagging, resulting in not only inventory levels, but also usage rates being available on demand. This could be achieved with the use of wireless hand-held or fixed tagging devices used within the stores to track inventory and record usage. The immediate benefit of this is an instantaneous awareness of stock of provisions and the rate of usage.

5. CONCLUSIONS

Future full integrated control and monitoring systems (FICMS) will be distributed systems that combine control and information functions under the umbrella of one overall management system. An open architecture with backward and forward compatibility provides improved through life support and reduces the risk of obsolescence. A future FICMS will have an advanced Human Machine Interface (HMI) using direct voice input into a wearable computer. This wearable computer transmits via a wireless link the single commands to the FICMS to initiate a functional sequence of events. Self-healing control systems and plant are essential to ships [2]. Generally the technology to achieve the vision of an advanced FICMS is available today [1]. Use of an extensive condition monitoring fit, perhaps model based, will enable early diagnosis and prognosis of any impending problems with the platform systems and plant [5].

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Sažetak

BUDUĆE GENERACIJE UPRAVLJAČKIH ARHITEKTURA

Sadašnji sustavi upravljanja, uključujući i one na "pametnim brodovima" najčešće operateru daju veliku količinu informacija putem senzora i općenito zahtijevaju znatnu ručnu manipulaciju u slučaju neispravnosti sustava. S druge strane stalno se zahtijeva smanjivanje broja članova posade tako da se projektanti sustava upravljanja suočavaju s projektom robusnog sustava upravljanja koji će se moći nadograđivati i koji će imati mogućnosti održavanja od strane srednje sposobnog prosječnog mornara. Istraživanja sugeriraju da se ovi izazovi mogu postići korištenjem troslojne upravljačko-nadzorne (TUN) arhitekture. Na osnovnoj razini je izvedbeni dio koji je odgovoran za izvođenje upravljačkih zadataka i sadrži razne autonomne podsustave. Na srednjoj razini donose se taktičke odluke i koordinacija autonomnih podsustava i ova razina je zadužena za implementaciju upravljačkih scenarija. Na gornjoj razini imamo razinu planiranja i donošenja odluka, kako dodjeljivati resurse, prioritete i zadatke, odnosno kako određivati slijed izvođenja upravljačkog scenarija. TUN arhitektura se može ostvariti poboljšanjem karakteristika sustava koji su sada na raspolaganju i koji imaju mogućnost izravnog adresiranje bilo koje komponente sustava, osjetnika ili aktuatora iz bilo kojeg mjesta na brodu. Ovo će omogućiti samorekonfiguraciju sustava nakon greške ili u slučaju oštećenja dijela sustava.

Budući potpuno integrirani sustavi upravljanja i nadzora imat će visoku razinu distribuiranosti kombiniranu s novim upravljačkim algoritmima koji su sposobni obavljati inteligentnu obradu u odsutnosti dijela informacija. Nadalje, pristup otvorene konstrukcije dozvolit će da se koristi oprema od drugog dobavljača gdje je potrebno primijeniti standard otvorne konstrukcije, sa svrhom da se tako smanje efekti zastarijevanja. Općenito, tehnologija za postizanje naprednog potpuno integriranog sustava upravljanja i nadzora je na raspolaganju u današnje vrijeme.

Ključne riječi: *integrirani sustav upravljanja i nadzora, brodski računalni sustavi, troslojne upravljačke arhitekture*

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