Impact of Flinch Technology on Damage Control and Survivability

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Synopsis

When a mission critical naval vessel is operating in dangerous waters or in battle, amongst other things, the success of its mission is a measure of capability and availability of its Weapon Systems, Combat and Communications Systems, Battle Damage Control System (BDCS) & Situational Awareness, as well as, its ability to recover from unplanned incidents. The next Generation Integrated Platform Management Systems (IPMS) for Autonomous Ships with much reduced manning, dictates special considerations for autonomous control systems across the ship support systems and beyond without need for man-in-the-loop for decision making. This entails detailed analysis, vulnerability & recoverability assessments during target ship's basic design and the application of Artificial Intelligence (AI) where available. The optimum strategy involves consideration of distributed smart agent based control and monitoring systems that shall react rapidly to changes in operational demands and incidents without the need for man-in-the-loop, creating BDCS dynamic kill cards across ship subsystems and, extending the IPMS BDCS capabilities to Combat Management. The above gives rise to consideration of "Flinch Technology (FT)" [7]. It implies distributed smart agent based control systems that instinctively reacts to incidents for fast recoverability in the event of damage to supervisory control system (i.e. IPMS) and its related data communication network. This paper addresses the benefits that might be gained as a result of consideration of smart agent based control systems with no man-in-the loop involvement for decision making. Such technology solutions, empowered by Artificial Intelligence (AI) could be adopted in the future Autonomous Combatant Ships.

Keywords: Flinch Technology (FT); Battle Damage Control System (BDCS); Integrated Platform Management System (IPMS); Smart Valve; Autonomous Control System; Distributed Agent Based Control Systems, Autonomous Combatant Ships

1. Introduction

The demand for Autonomous Combatant Ships with reduced manning has resulted in consideration of smart strategies for reducing vulnerabilities, increasing survivability after incidents, application of smart sensors augmented with distributed autonomous control system agents and AI. Flinch Technology (FT) refers to the implementation of autonomous control systems agents that could react to unplanned incidents/weapon hit with little or no input from the ship crew to increase ship survivability as a result of improved functional and resources availability.

Authors' Biographies

Danielle Berenbaum BEng (Hons) currently works as a Junior System Design Engineer at L3 MAPPS UK based in Bristol. She completed her Bachelors degree in Aerospace Engineering and then joined L3 after graduating. During her two years at L3 she has completed placements in Software, Systems, Bids & Proposals and Hardware.

Dr. Reza Sahie-Pour Director of Marketing & Business Development at L3 MAPPS in Montreal, Canada. He obtained PhD in Control Systems and Monitoring (Durham), Masterss in Power Control systems (UMIST/Manchster) and Bachelors degree in Electrical Power Systems (Newcastle Polytechnic/Northumbria) in the UK, and has more than 30 years experience in control systems technologies through working at control systems suppliers in the UK and Canada as well as National Grid power utility company in the UK.

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The survivability and operability of a combatant ships mission critical systems and their related ship services after an incident or weapon hit is of paramount importance. By minimising damage through fast recoverability, the ship can continue functioning and therefore increase the chances of mission success. Mission success can be defined differently across ship and purpose, however some factors remain the same across the fleet; the Ship's crew, machinery and combat related subsystems should be protected regardless of operating conditions.

This paper presents how FT could be deployed across the ships fluid support systems, providing autonomous distributed automation independent of the IPMS in order to pre-empt potentially dangerous situations without the need for man-in-the-loop for decision making. FT reduces the time elapsed between the occurrence of a damage or failure and the point in which the problem is isolated and corresponding support system is reconfigured automatically to minimise damage or cascading failures. As such, FTs maximise the survivability of future autonomous ships with reduced manning.

. Flinch Technology is an area of interest that has been researched and investigated by a number of companies as discussed in papers on Intelligent Fluid Systems and Distributed Intelligent Networked Control Systems [2, 6, 10, 12]. These papers have focussed on more of a pre-emptive approach to coping with a leak or rupture, maintaining a computer based control and monitoring system, whereas this paper highlights a solution which eliminates the need for an additional layer of control. Not only this, but our approach removes the need for developing a scale model of the system, a common theme throughout the referenced papers, and replaces it with simulations for the necessary test and evaluations. Smart valves are a main focus of our paper, and we determine the optimum number and location of the smart valves which could lead to a higher availability, lower investment and lower maintenance costs. In the rest of this paper, references are made to sample FTs that could be considered for mission critical naval vessels, particularly for future remotely controlled unmanned/less manned Autonomous Naval Vessels

2. IPMS Configurations & Smart Agent Based Control Systems

The conventional IPMS is a fully integrated centralized supervisory control and monitoring system. Typical IPMS configuration is based on hierarchical or client-server architectures. In the former configuration, as in Figure 1, the IPMS control and monitoring software is distributed in consoles and in RTUs. In the latter configuration, generally a redundant pair of computer servers host the main software and database and provide input for the client workstations. Therefore, client-server configuration is less redundant than a hierarchical distributed control system configuration.

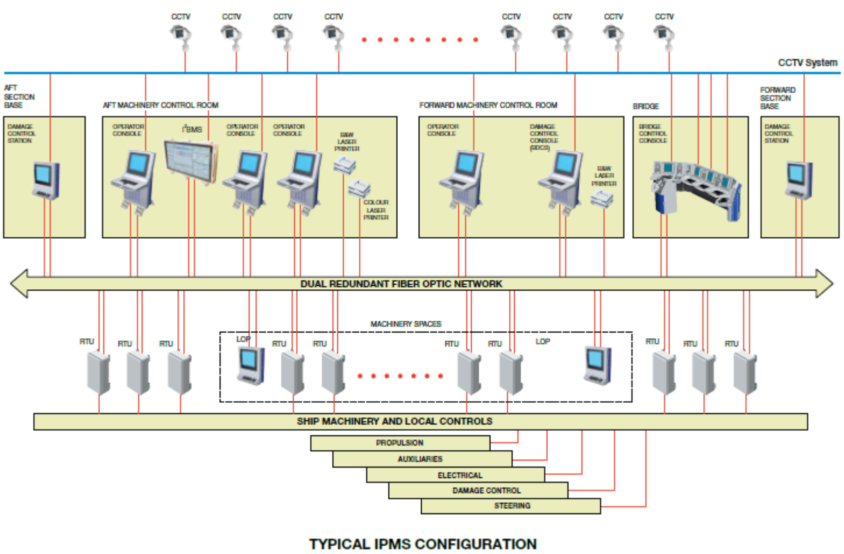

Figure 1 – Hierarchical Distributed Control System, typical for an IPMS Configuration

Considering conventional IPMS Architecture, in the event of a problem with the IPMS DAUs (RTUs/PLCs) or data communication network, control and monitoring of the affected ship support systems and main machinery will be lost. In the case of the radar and weapon systems, as an example, that rely on the Chilled Water System (CWS), the combat & communication systems may become inoperable in the absence of cooling water. Such situations could have undesired consequences in battle, but could be avoided through distributed agent based control system (Autonomous Control System) implementation as described in the below.

Unmanned/less manned future autonomous ships would require changes to conventional IPMS Architecture. The application of Artificial Intelligence software and intelligent sensors on autonomous vessels is unavoidable. This necessitates consideration of suitable Flinch Technologies that could best ensure reliable operations.

The implementation of an agent based distributed control system is nothing new. An agent based distributed control system is desired to overcome challenges with ship support systems when the interface between the supervisory control system and a given ship support system such as fuel system, Sea Water System, Fire Main system etc. is lost. The control system agent can be based on a robust autonomous system configuration that could detect loss of communication with the supervisory control system in order to facilitate local control and monitoring. Figure 2 illustrates configuration for CWS as an example of an agent based control system. However, while such distributed agent based configuration improves operations, they still rely on man-in-the-loop for control action and for decision making.

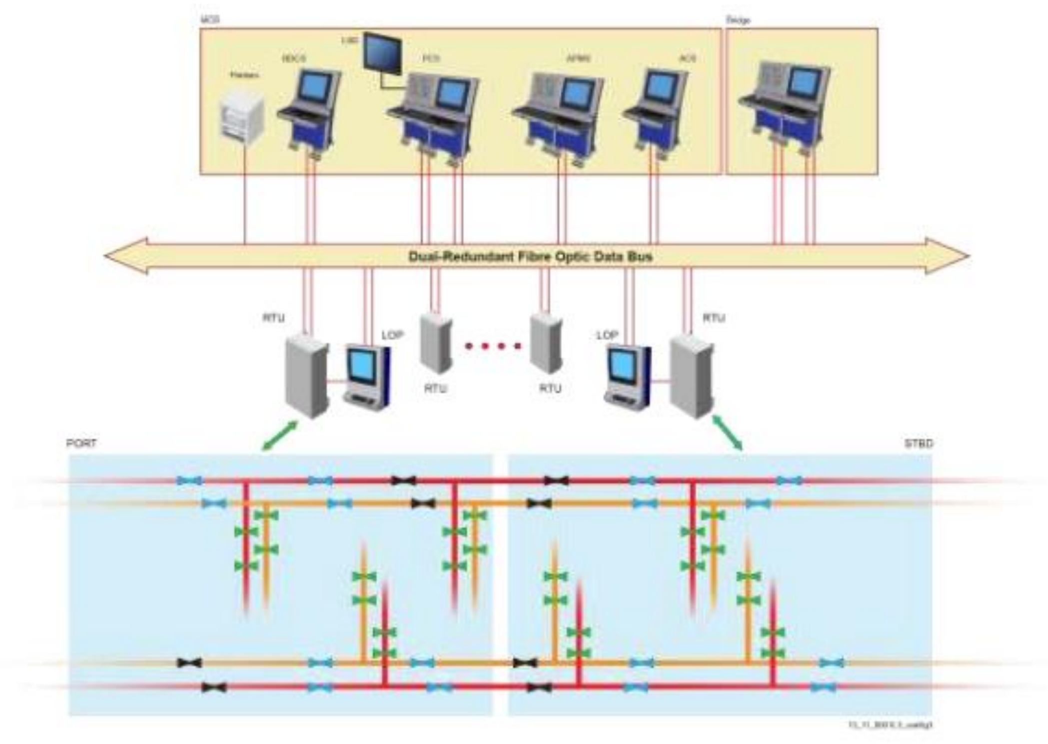

Figure 2 - Distributed Agent Based Control System for Chilled Water System

The above could be improved by removing/reducing the presence of man-in-the-loop through the application of appropriate Flinch Technology to CWS or other fluid support systems onboard the ship as described in the rest of this paper. In contrast to previous work in this area, the approach by L-3 MAPPS removes the need for additional embedded networks or computer based control systems for control and monitoring. In addition, by adopting the proposed solution, there is no need for constructing a model of the target subsystem (such as the CWS). Detailed simulations are used to determine the number and location of smart agents and, through simulations, various faults can be analysed to create robust algorithms tailor made for target ship systems.

3. Application of Flinch Technology to Fluid Support Systems

As described in the previous section, an autonomous distributed agent based control system on its own is insufficient for making decisions without the presence of man-in-the-loop. Smart software and hardware configuration is needed to overcome the above in a modern ship to ensure availability of mission critical systems, such as weapon systems, in the event of damage to support the system (in this case the CWS). In this section, application of FT to CWS is presented. Similar solutions could be applied to all fluid systems such as the fuel system, sea water system, Fire Main System (FMS), etc. The above includes Smart Valves/Actuator units equipped with intelligent software that removes the need for man-in-the-loop for decision making.[11]

Smart Valves include two pressure transducers, programmable control logic hardware and software that is generally embedded in the associated actuator or externally in close vicinity of the desired valves, and could include an embedded data communication fieldbus for faster response time. They could detect and isolate the affected pipes much quicker than through conventional IPMS or manually by the ship crew. Without requiring operator input, the valves could put measures in place to stabilise the situation, isolate the problem, realign, reconfigure and resume normal operations in less than 3 minutes. This should be compared with conventional IPMS implementations where the above involves man-in-the-loop and could take more than 30 minutes; thereby causing total loss of cooling resource and inoperability of the weapon systems and Radar. The cost of loss of equipment, complete or partial ship hull structure and human lives under such circumstances is obvious.

The smart valve detects rupture conditions when the pressure falls below a set limit [5]. This would trigger control action on controllable valves based on the requirements of the end-user/design authority. Approximately 1 second after detecting the fault conditions, the valve identifies this fault as a rupture and proceeds to close valves surrounding the failure, starting from those furthest away from the fluid source or based on the desired requirement. In some cases, the end user may require to shut down all valves and let the operator decide to open the required valves. In other implementation, based on design phase simulations and tests, predefined valve operations could be deployed.

Optimum strategy is to remove the requirement for crew involvement in decision making and for control action. In such implementations, there is need for the inclusion of intelligent software that could detect, isolate, reconfigure and realign the target system without man-in-the-loop. The time taken by the applicable FT for performing all the above actions is less than 3 minutes. When you compare this to if the rupture had been identified and isolated manually by an operator, this could have taken 10+ times as long.

To determine which valves should open after the initial path that closes various valves, and to realign the affected system to ensure supply to critical loads without the man-in-the-loop involvement, requires intelligent proven software. The above, as already developed and tested by L3 MAPPS, involves consideration for fluid hydrodynamics based on combined flow and pressure measurements.

During the Royal Navy's QEC Aircraft Carrier sea trials, a scenario was encountered in which the use of Flinch Technology could have proved invaluable and possibly improved the response time to the situation. This event was documented in the television show, Britain's Biggest Warship [1]. During the initial dry cruise in which QEC relied upon its own power for a week in order to test systems before leaving the dock, one of the fluid systems suffered a leak and water began leaking into the High Voltage compartment. Previous ships had not featured compartments on board with such a high voltage present, so the increased risk of potentially lethal electrocution was new to personnel. The leak was identified quickly, however isolation was not done as efficiently as possible, with the leak spreading to another compartment before it was contained. The presence of Smart Valves could have meant a reduction in the time taken for identification and isolation of the rupture. The risk associated with this leak on the QEC highlights how invaluable quicker reaction times could be to preserve the ship and all its personnel.

Notwithstanding the above case, loss of cooling agents such as chilled water due to structural damage or weapon hit, could directly impact the operation of the weapon system on board a combatant ship. Pipe damages in fuel system or fire main system can also have consequences if ship crew have to rely on manual operations.

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Therefore, initial investment cost of implementation might easily overcome mission challenges when a ship is in battle or during unplanned incidents. The control logic for restoration and realignment after the initial detection and isolation of the damaged pipes could be discussed with ship design authority and based on the design authority/End-User's doctrine, the required intelligent software could be modified.

Not only could Smart Valves be invaluable in the event of a pipe leak or rupture, but they could also be utilised to monitor target system's performance during normal operation. The valves provide local leakage, pressure and flow information to a network or central control system such as the IPMS, which enable a better understanding of how each valve performs under normal conditions.[9] This data could then be analysed and used for maintenance corrections and to improve efficiency by calculating how much fluid is being used and how much is actually needed to maintain required conditions. By application of AI and consistently measuring pressure and flow, the valves might build a picture of the normal conditions to expect. Once unusual data is detected, usually due to a leak or rupture in the piping, the valve could act accordingly to isolate the problem through reconfiguration of valve status and begin the predetermined sequence of events to recover the system as efficiently as possible.

Determining the sequence of events during detection, isolation and reconfiguration, requires a thorough analysis of the survivability requirements of the ship, full understanding of the types of failures that could occur, and knowledge of the architecture and characteristics of each fluid system. Each ship will have unique priorities for its survival, in which other systems will be sacrificed to ensure the maintained functionality of others when in battle or damage conditions.

Research carried out by L3 MAPPS concluded that a TOTS – Triple Offset Torque Seated (Valve) with a long pattern would be suitable for many Smart Valve applications.[13] The long pattern provides various benefits to the configuration. These include the capability to replace gate valves in line, which enables two pressure transducers to be included, one from upstream of the valve seat, and one from downstream of the valve seat, and creates a design which is lower in weight, lower in cost and easily automated.[4] The control logic and communications interface would depend on the application and location intended for that specific valve.

Figures 3 depicts the agent based control system architecture that could be considered by the ship design authority. The same configuration could be used for all fluid support systems onboard a target ship.

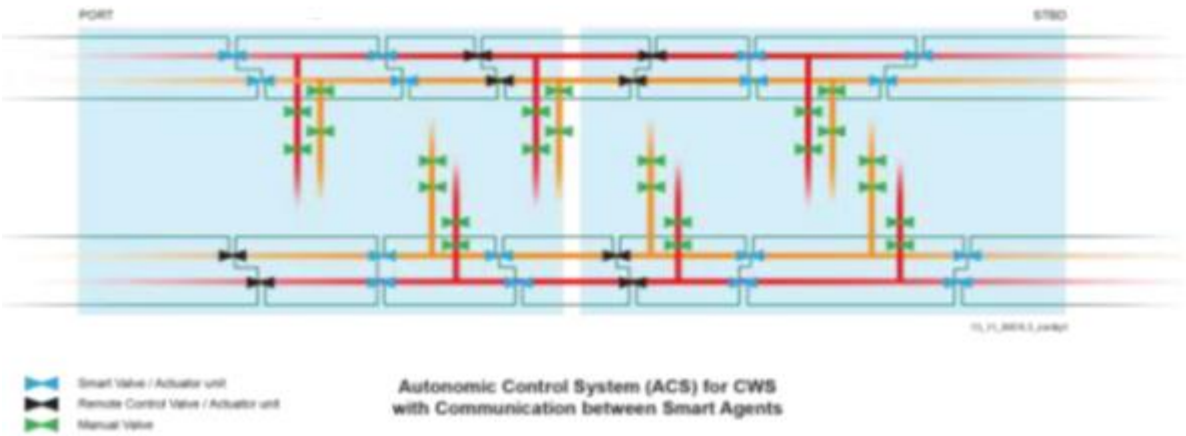

Figure 3 – Example of Flinch Technology Design Applied to Chilled Water System, with the Smart Valves shown in blue

4. Damage Situation

The benefits of Smart Valves become obvious when one compares the consequences between a rupture which has been identified and isolated automatically, and when the operator does this manually.

Looking at the case without the application of FT, a simulated system for a given vessel suggested that after three minutes, if there has been no manual intervention to isolate a rupture, the expansion tanks will fully drain.

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Within five minutes, still without any manual response, it is highly probable that damage will occur in critical components of the ship due to the lack of chilled water keeping the temperatures within a functional range. With ships becoming more automated, there are less personnel stationed around the ship, especially under normal operating conditions, making it highly possible that a leak could go undetected for 5 five minutes or more.

Warships typically take at least 20 minutes to recover from damage caused to a ship's CWS. However, if the expansion tank empties, a feasible scenario, the ship could actually take over 90 minutes to recover. In this time, vital combat systems, communications equipment, and other essential electronic systems will overheat due to the lack of chilled water, causing them to shut down after only a few minutes. As soon as these systems become compromised, the ship's mission, defence capabilities and personnel are at risk.

Unfortunately, the above situation can in no way be considered as a worst-case scenario, as it is likely that weapon hit inflicted on the ship also could damage the data network in that area. This network would otherwise be the normal method of communication between the valves and a control system that would be used to isolate the damaged area of the CWS. Without this network, the system isolation cannot be achieved via the ship's central control system or by remote control, causing further system deterioration. Therefore, an autonomous control system must be adopted that will not rely on communications with a central control system such as the IPMS. To further optimise the response time, the Smart Valves will be interfaced with each other through a separate fieldbus network. Under normal (intact) conditions, control and monitoring will be done at the supervisory level (IPMS). Under damaged conditions, such as loss of the IPMS main data communication network, the valves will take corrective actions.

5. Considerations During Ship Basic Design

To optimise the benefits associated with Smart Valves, it is important to consider including these designs early in the life cycle, from ship design rather than trying to implement them further down the line. Too often, the naval industry focusses on establishing remote control and building upon that, where a 'prevention is better than a cure' approach should be adopted instead. Nonetheless, the implementation of Flinch Technology as presented in this paper could improve ship survivability during ship life cycle.

Installing Smart Valves is a simple process that does not require much more effort in terms of design or build. When designing the fluid systems throughout the ship, whether this be fuel or chilled water for example, selected regular valves could be replaced by Smart Valves. Detailed simulations performed by L3 MAPPS identified the optimum number of Smart Valves and their location in a target ship. As the sensors and shut off technology is all contained within the valve or its vicinity, they could easily be installed.

It is essential that the control system supplier interacts with the ship design authority in order to simulate the target system. This is essential to determine the location and number of desired Smart Valves. During the design of the applicable autonomic control software, different strategies for the implementation of the required hardware and software might be sanctioned with the ship design authority. The Simulation software will be used for assessing various vulnerabilities in the target subsystem too. This enables the designers to perform contingency analysis to determine prespecified configurations based on various ruptures in the piping system. Such assessments are needed during ship design phase or during the ship life cycle when considering the deployment of Smart Valves.

6. Other Examples of Flinch Technology

In this section, examples of Flinch technologies that could best suit new generation of combatant ships are presented.

An example of FT is the use of intelligent valves in the Fuel System, Sea Water System and FMS. In collaboration with the valve and actuator supplier, the intelligent software could be installed in the actuator's related digital cards or in a separate unit in the vicinity of the valve.

Figures 3 illustrates the architecture that could be considered by the ship design authority/End-User for Chilled Water System. In this architecture, there is no communication between smart valves or between the autonomous CWS agent and the IPMS. In this case, the complete system is segregated with the embedded ability to make autonomous decisions.

Flinch Technology is not limited only to the application of intelligent valves or the fluid systems. The principal of creating intelligent systems that could put into place preventative measures automatically rather than reactive measures, much quicker than any operator could, has the potential to establish smarter and more maintainable ship designs in the future. Not only does this new way of approaching system design help reduce damage and support the survivability of the ship and its crew, but it also contributes to the ever increasing demand for lean manning on board.

The rise in number of complex systems and the reduction in funding available for operating and maintenance of a ship, calls for a more streamlined and efficient approach to manning, with big reductions being demonstrated under normal operating conditions. One of the many benefits of Flinch Technologies is the ability to monitor a system without requiring input from the operator or even the IPMS, which means less need for constant attention on certain systems under normal operating conditions. [3]

Flinch Technologies also include consideration for smart sensors and the application of AI for improved condition assessment, rule based diagnostics and prognostics for improved maintenance management system, maintenance advisory, voyage fuel advisory and fuel saving strategies, etc. As an example, smart image processing of CCTV or other cameras images could detect fire, smoke or flooding in a ship and based on an intelligent agent based distributed control system it could executed control sequences to take necessary actions to minimise damage to ship equipment of risks to crew.

In the absence of a modern control system and survivability oriented designs, ships rely on the reactions of operators to minimise the consequences of damage incidents. However, creation of shipwide dynamic kill cards based on detailed simulation of vulnerability and survivability assessments at subsystem levels during the ship's initial design phase and, the application of an advanced BDCS augmented with distributed smart control system agents, can result in rapid detection, isolation and recovery from damage.

Intelligent autonomous control systems empowered with AI software could be deployed for managing ballast and deballasting, propulsion and electrical control systems functions. Based on preliminary assessments by L3 MAPPS, by applying AI to autonomic control systems it may be possible to remove the need for certain hardware and control logic that currently is needed for deployment on valve/actuator units. The BDCS capability could be extended to execute dynamic kill cards for mission critical ship systems beyond the machinery and damage control related equipment in order to improve ship survivability under security threat or various incidents without the inclusion of man-in-the-loop. Such FTs augmented with Artificial Intelligence will be desired for the future autonomous naval vessels. Smart sensors and software could react to operational demands or incidents based on preprogramed control sequences logic and AI. FT could also include software analytics for assessing integrated images from all installed cameras onboard a target vessel in order to assess, detect and execute preprogrammed control sequences based on optimum data fusion. These could include detection of fire, smoke, flooding incidents, intrusion and other security risks and threats and the execution of appropriate dynamic kill cards without the involvement of ship crew or with their minimum involvement. Figure 5 [8] shows potential for further data fusion where consideration of suitable FTs could further improved ship performance and survivability with minimum manning requirements.

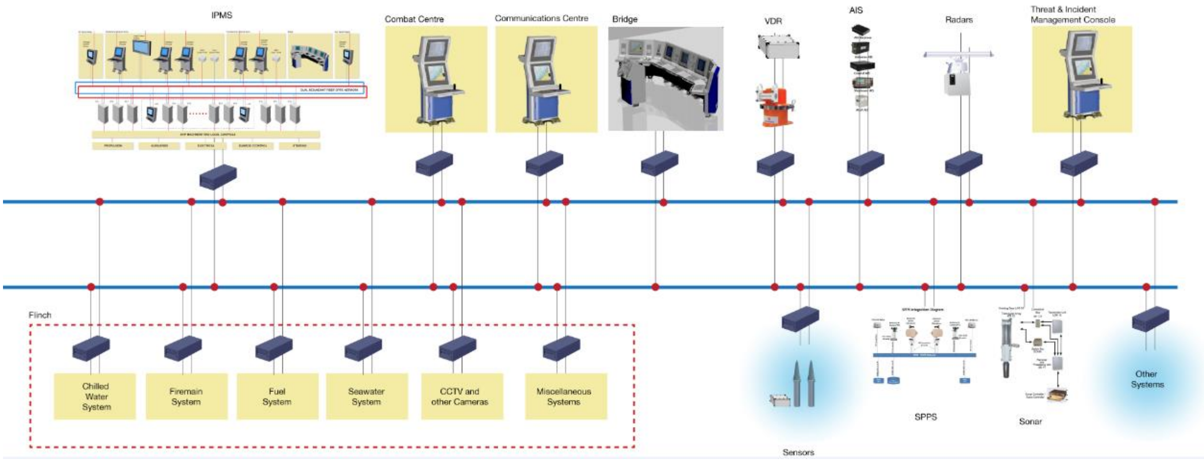

Figure 5 – Smart Systems & Sensors Integration possibilities onboard ship beyond IPMS e.g Threat and Incident Management Console

7. Conclusions

Flinch Technologies offer great potential for improving the capabilities of existing and future naval vessels. Various options exist which could positively impact the survivability and damage control capabilities of both existing and future marine vessels. These options include implementing intelligent sensors and agents as an integral part of a conventional IPMS or as an autonomous control system, creating a more sustainable and efficient condition for operation.

Considering the limitations of conventional control systems as well as the future needs of autonomous naval vessels, there is support for using Flinch Technology on board the not only Naval Combatant ships but also on mission critical commercial ships such as cruise ships. Smart agents could improve ship survivability and also offer a solution to the demand for reduced manning. They could also contribute to reducing the strain on operators and maintainers throughout the lifetime of the vessel, during normal and damage operating conditions, and could increase the chances of maintaining critical systems. By drastically reducing the time between failure, isolation and system recovery, the level of cascading damage could by kept to minimum. Critical systems remain protected and functional whilst fluid systems are maintained through the carefully configured closure of valves around a failure.

Notwithstanding the above, the implementation of Flich Technology demands appreciation of the complexities involved in concept developments, integrations with supervisory control systems and other shipboard systems as applicable and the development of robust, tested and proven algorithms with higher degree of reliability. Subsystems detailed simulations during concept development as well as close cooperation with shipbuilder's design authorities during the basic ship design phase is an integral part of such implementations, during which the End-Users could clearly specify the involvement of control systems speciallists.

The future unmanned vessels and Autonomous Naval Ships would require the application of Flinch Technologies. L3 MAPPS, as a lead control system supplier for naval vessels, has already developed and tested certain FT capabilities, including Autonomous Control System augmented with an in-the-house developed intelligent software for deployment on conventional valve/actuator units to empower them as intelligent agents and, is actively pursuing the integration of intelligent sensors and AI to its advanced IPMS.

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10. Glossary of Terms

ACS	Autonomous Control System
AI	Artificial Intelligence
BDCS	Battle Damage Control System
CWS	Chilled Water System
DAU	Data Acquisition Unit
FMS	Fire Main System
FT	Flinch Technology
HMI	Human Machine Interface
IPMS	Integrated Platform Management System
LOP	Local Operator Panel
QEC	Queen Elizabeth Carrier
RTU	Remote Terminal Unit
TOTS	Triple Off-Set Torque Seated (valve)

11. Figures

All figures have been produced by L3 MAPPS.