Integrating Autonomy - Maintain, Launch, Execute and Recover

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Synopsis

In recent years, autonomy has been subject to significant interest and investment within the maritime industry. Several high-profile trials such as Unmanned Warrior 2016 and Autonomous Warrior 2018, have drawn attention to the rapidly emerging and advancing technology. Following the successful operation of 7 autonomous vessels during Unmanned Warrior 2016, L3 Technologies completed a series of demonstrations at Autonomous Warrior 2018. The continually evolving technology has enabled increasing complex autonomous operations to be trialled. This accessibility and enhanced capabilities have resulted in the increased adoption of autonomous vessel technology. Navies around the world have shown much interest in the enhanced military capability that autonomous vessels bring to the operational theatre. It is clear that the technology is available, and the demand exists, but integration into a modern operation warship poses an indisputable challenge? The operating cycle of an USV when hosted on-board a warship can be summarised as ‘Maintain, Deploy, Execute and Recover’. Understanding how the USV integrates into the mothership at each of these stages will increase the effectiveness and efficiency of operating the USV. To fully understand this all aspects of integration should be considered, people, processes and technical interfaces. Two key on-board systems that an autonomous vessel will need to interact with are the combat system and the IPMS. As autonomous technologies become more established and proven, the confidence gained will have implications for its possible implementation on larger vessels potentially leading to fully autonomous cargo ships and cruise ships.

KEYWORDS: Autonomy, Unmanned, Integration, IPMS, Combat System, Launch and Recovery

1. Introduction

In recent years, autonomy has been subject to significant interest and investment within the maritime industry. Several high-profile trials such as Unmanned Warrior 2016 and Autonomous Warrior 2018, have promoted massive interest in the rapidly emerging and advancing technology.

Following the successful operation of 7 autonomous vessels during Unmanned Warrior 2016, L3 Technologies then held a series of more advanced capability demonstrations at Autonomous Warrior 2018. Most recently, in support of the Defence Science and Technology Laboratory (Dstl), L3 Technologies operated a 9-metre (30ft) vessel outfitted with advanced, fully autonomous navigation capability for reconnaissance, interdiction and patrol tasks. The vessel, ‘MAST 9’ seen below in Figure 1, demonstrated COLREG aware collision avoidance, navigating waterways at speeds of up to 40 knots, for over 80 hours and successfully executing seven different task types. ASView, L3 Technologies’ proprietary autonomous control system, enabled remote mission commanders to track and follow target vessels for interdiction tasks. The vessel, designed and built by L3 Technologies, used radar to provide situational awareness and as a consequence, collision avoidance.

“The exercise successfully showcased an integrated system of systems approach to executing autonomous defence tasks with little or no human intervention,” added Ian Campbell, Defensive Surface Warfare, Platform Systems Division, Dstl.

Figure 1. An image of MAST 9 from Autonomous Warrior 2018

Author’s Biography
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Joe Chilcott BEng(Hons) MSc CEng L3 MAPPS Limited – Whilst working for L3 MAPPS Limited over the past 7 years, Joe has had a number of Engineering Roles, starting as a Software Engineer. He has developed a number of control systems for the Queen Elizabeth Class as well as working as the Integration Specialist for the platform. He is currently the Design and Technology Manager for L3 MAPPS Limited working on solutions for the business development team, including the Fleet Solid Support and Type 31e platforms.

ASView, L3 Technologies' proprietary autonomous control system, Figure 2, enabled remote mission commanders to track and follow target vessels for interdiction tasks. The vessel, designed and built by L3 Technologies, used radar to provide situational awareness and as a consequence, collision avoidance.

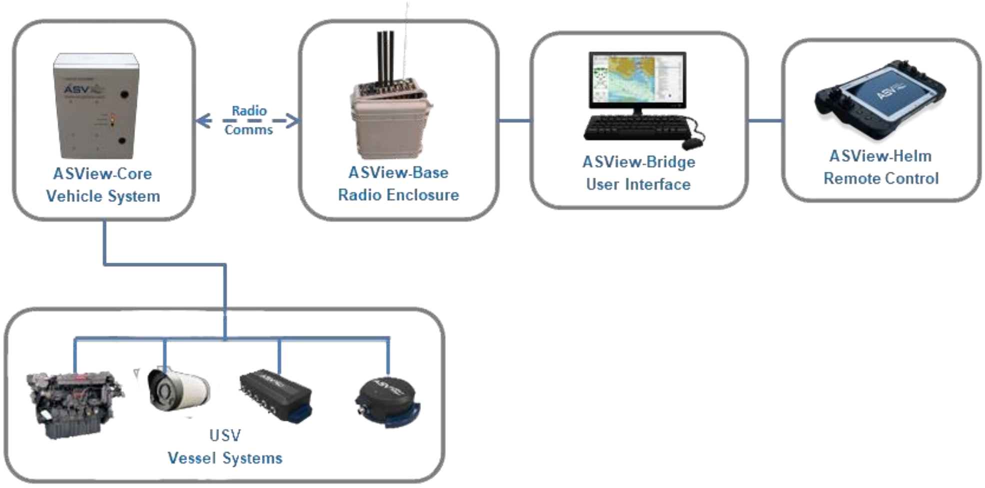

Figure 2. ASView System Components

The current operating philosophy of a USV is to operate as a standalone system for ship's crew. This is feasible for small USVs and short deployments. However, for larger USVs and enduring deployments an integrated solution will increase efficiency of operations. The aim of this paper is to consider how a medium sized USV could integrate into a mothership. This paper will review typical USV architectures, autonomy and current operating philosophy. The importance of considering the entire operating cycle and the challenge of fusing the Maintain, Launch, Execute and Recover stages on board an operational warship will be reviewed.

2. Autonomy

It is important to define the difference between automation and autonomy. An automated system is a system that performs repeatable tasks without human assistance, whereas an autonomous system performs in an uncertain environment and can resolve system failures without human intervention. For decades there have been automated systems available to aid and support operators. Only in recent years has the technology evolved and computing power available to make autonomous maritime systems a reality. The increased pace of change towards autonomous technology is due to multiple reasons.

- Personnel - A combination of shortage of skilled people in the maritime sector and their associated high through life costs. .
- Safety of personnel – Society's views on the value of personnel has changed significantly as well as the behaviours of our adversaries. This shift has put greater pressure on reducing loss of life and maximising the safety of personnel.
- Cheaper/ smaller vessels – Autonomous vessels do not need to support human life. There are no requirements for accommodation, domestic facilities, HMI operating positions and so on. This reduces the space and weight requirements resulting in a significantly smaller vessel than traditional manned vessels.
- Reduction in Human error and fatigue - Despite the high calibre of operators, human errors are inevitable. This is exacerbated by combat stress and long operational hours leading to fatigue. A machine cannot get tired or stressed and therefore has greater longevity.

Navies and industries throughout the world are investing in autonomous technologies to enable maintaining and/ or increasing capability while reducing associated costs. Examples of where unmanned surface vehicles can realise this benefit is through the ability to operate up to 24 hours a day with zero or minimal human intervention.

The continually evolving technology has enabled increasingly complex autonomous operations to be trialled, enabled by L3 Technologies' autonomous vessel systems being supplied to end-users with comprehensive training packages. The increasing accessibility and capability has resulted in increased adoption of autonomous vessel technology. Governments' worldwide and industry-leading commercial companies such as Ocean Infinity and Fugro are just some of the many companies investing in autonomous technology.

Globally, Navies have shown significant interest in the enhanced military capabilities that autonomous vessels bring to the operational theatre. This is a complex environment in which to integrate a new system such as a USV

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as considerations such as personnel, safety and are paramount. As stated by the Department for Transport (2019), "People remain at the heart of the maritime sector's journey towards maritime autonomy", putting more emphasis on the need to understand how autonomous systems will integrate within a ship, its operators and its processes.

The technology is available, and the demand exists, but integration into a modern operational warship poses an indisputable challenge.

The Royal Navy's announcement of 'NavyX', which is its new Autonomy and Lethality Accelerator programme [1], demonstrates the vision and commitment the Royal Navy is making to the development of autonomy and ensuring it is leveraged as a force multiplier. This programme emphasises the need for a step change in the pace of development and procurement of these systems. At the heart of this accelerator is the desire to create multi-disciplined collaborative teams from across industry and academia. Furthermore this emphasizes the need to look to the future and how the Royal Navy will employ these new capabilities and how they will be fully integrated in future capability solutions. Consideration is needed to determine how current processes and doctrine will be adapted to accommodate autonomous capabilities. From a technical perspective, how will these systems be developed, potentially pan industry and academia in such a way as to be interoperable and scalable for future enhancements? Finally, how will training for these systems be provided in a practical and cost effective manner? It is time to consider how unmanned and autonomous systems will be integrated into larger motherships.

3. Unmanned Surface Vehicles

An Unmanned Surface Vehicle (USV), also known as Autonomous Surface Vehicles (ASV), is a vessel which can operate on the water without the need for a human to be on board. As a crew is not necessary, USVs offer many advantages. For a USV to operate correctly in autonomous mode, there are several systems which need to work harmoniously together. The key systems within a USV are:

- The situational awareness system
- The communications system
- The autonomous control system
- The physical hardware

The situational awareness system is comprised of 'vision' sensors fitted onto the USV and can include optical cameras, infra-red and radar capabilities amongst others. A comprehensive and reliable situational awareness picture is critical to successful and safe conduct and is required to develop a truly COLREG compliant collision avoidance system. The communications system provides the link between the base station and the USV, communications bearers can include satellite, UHF, VHF, Wi-Fi and 4G. Both the range of communications and the rate of data transfer are dependent on the location of operation and the choice of communications bearer.

The autonomous control system receives inputs from all sensors and systems to inform decisions. This means both the situational awareness and communication systems feed into the autonomous control system, and vice versa. Principally the autonomous control system is responsible for the decision-making. This consists of the Last Response Engine, which makes the vehicle safe if higher levels of autonomy have failed to do so already. The collision avoidance system, which strives to determine a safe path for the vehicle to traverse, and the Control Plan which is a high-level mission system used to define mission objectives.

4. Current RN Operating Philosophy

The Royal Navy currently operates vessels with varying levels of automation and capabilities. Historically each function of the ship has been built and operated as a discrete system with specific SQEP to operate these systems. Numerous discrete systems cause the ship to be manpower intensive. Lean manning has continued to drive the requirement for more automation, as depicted in Figure 3 [2]. To continue on this path of growing automation, and autonomy, the availability and fusion of data on a ship is paramount. Therefore, integration of these systems is essential to ensure the availability of required data throughout all of the ship's functions. Project Nelson is "using Artificial Intelligence and data science to build a "Ship's Mind"" [3], this is an example of the paradigm shift towards integrated data platforms supporting data fusion.

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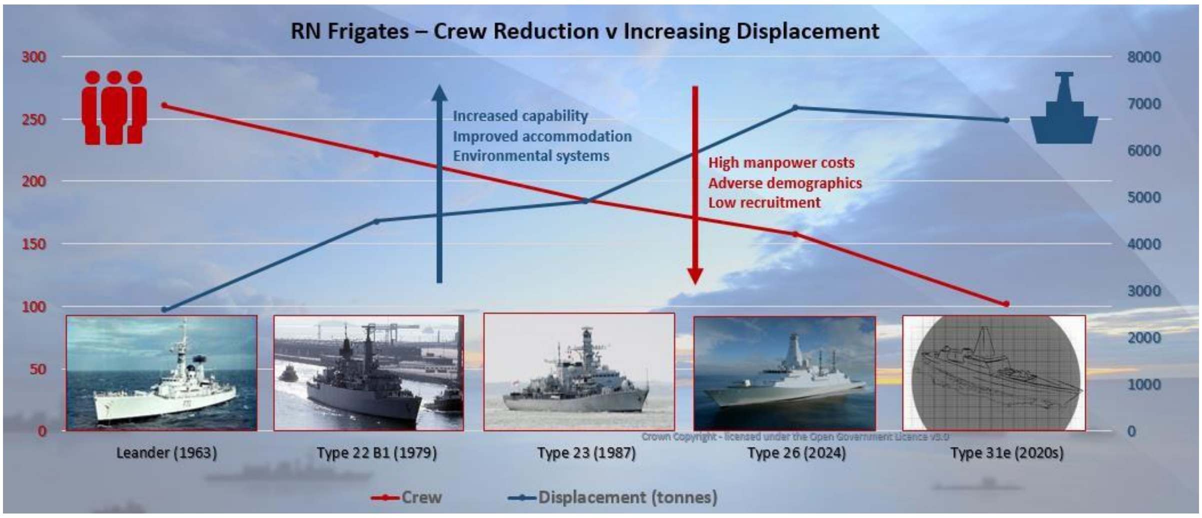


Figure 3. Manning vs Automation

Recently, there has been a desire to deliver versatile, capable and scalable vessels on tight budgets and schedules, personified perhaps in the T31e Programme. The question is therefore …'how do we provision for these cutting-edge technologies for future enhancements?' To do this we must have an appreciation of how these systems will integrate and operate.

The Queen Elizabeth Class aircraft carriers have demonstrated what can be achieved through collaboration across industry and a high degree of integration. Primarily this has supported lean manning requirements and enabled by a high degree of system integration, achieved through the use of a shared network environment entitled the Integrated Network Equipment (INE). The INE is a number of routers, access switches and network nodes interconnecting all of a ship's networks, thereby making the sharing of data between different systems far easier. This has enabled a number of holistic, command focused features within the Integrated Platform Management System (IPMS), such as capability reporting which enables ship's capabilities both combat systems, auxiliaries and power and propulsion systems to be assessed and prioritised in accordance with the current Command Aim. The capability reports are collated into the top 3 from each department eventually allowing the Command Advisor to focus the ship's efforts to support the Command Aim. This is a powerful feature which highlights the benefits of integrating data throughout the ship to provide a holistic picture for the command hierarchy. This pattern of integration and enhanced functionality must continue as is emphasised with the additions of new technologies such as Unmanned Surface Vehicles (USV).

There are still a great number of improvements to be made such as a data availability and integration. Historically systems on-board have been developed in a 'stove pipe' approach, making data integration and holistic analysis difficult. Recent developments in shared computing environments, show great promise as a common IT infrastructure throughout a ship, providing not just a shared network but multifunctional shared glass, virtualised PCs and Servers, network storage and associated services. There are two main stove pipes that must be considered in the context of this paper, focussing on the integration of a USV, the combat systems/weapons engineering team and the marine engineering team. The integration of a USV onto a ship requires input from both organisations because each will have a role in the operating cycle of the USV, covering maintenance, deployment, mission execution and recovery of the USV.

5. The Operating Cycle – Maintain, Launch, Execute and Recover

Maintain, Launch, Execute and Recover are the four stages making up the operating cycle that an autonomous vessel will go through whilst being hosted on-board a large mothership. Ensuring successful integration into an operational warship requires consideration of the people and processes interacting with the autonomous vessels at each stage.

Figure 4. The Maintain, Launch, Execute and Recover Concept Render

The two key on-board systems that an autonomous vessel will need to interact with are the combat management system (CMS) and the IPMS. These interfaces will be a mixture of live remote data links and hardwired links whilst stowed.

The integration of off board systems, such as USVs, into both the IPMS and the CMS, is a complex matter. As the unmanned surface vehicle moves through the different stages of its operating cycle, the system exercising primary control and monitoring will change, as indicated below:

1. Maintain Phase – IPMS is likely to have overall control and monitoring capability, allowing the engineering department to ensure the vessel is prepared to perform for the complete duration of its forthcoming deployment.
2. Launch Phase – At this stage the control of the vessel transfers from the IPMS to the CMS. The vessel has become an 'active' asset which the CMS will need to manage.
3. Execute Phase – During this phase the CMS will be overseeing the unmanned surface vehicle providing Command and Control (C2), setting goals to achieve. However, basic information on the state of the vessel will still be communicated to the IPMS to allow the engineering team to monitor and store operational health data for further analysis.
4. Recovery – Just like the launch phase, the CMS will have control of the vessel. However, once on board and the system is no longer 'active' the IPMS will re-gain control to prepare the vessel for the next mission.

Standardizing this operating model will create a standard interface for a USV allowing a mothership to interchange USV depending on operational requirements.

5.1. Maintain

The maintain phase focuses on ensuring the vessel is ready for operational deployment, this will involve running diagnostics, trending data from the autonomous systems. The larger USVs, currently around 12m as shown in Figure 4, which may be stowed on a mother ship are vessels in their own right, hosting relatively large equipment. Considering the equipment that the USV will likely be hosting, the maintenance process and the potential impact to the ship's trim and stability, it could be argued that the Marine Engineering department is best placed to take responsibility for the USV whilst stowed on the mother ship, supported by Mission System personnel. This is due to the USV having similar systems, propulsion, steering, and hydrostatic characteristics and supporting systems, all of which the Marine Engineer is most experienced with.

Figure 5. L3 Technologies Mine Countermeasures (MCM) Autonomous Vehicle for Thales UK

To support the Marine Engineers, maintaining the USV, there must be a data interface from the USV's on board systems to IPMS. This data interface will provide health and diagnostic data for processing and analysis. Analytics such as that provided by an Enhanced Health Monitoring system can be used to analyse, detect alarm conditions and compare live data to benchmark data, as shown in Figure 5,

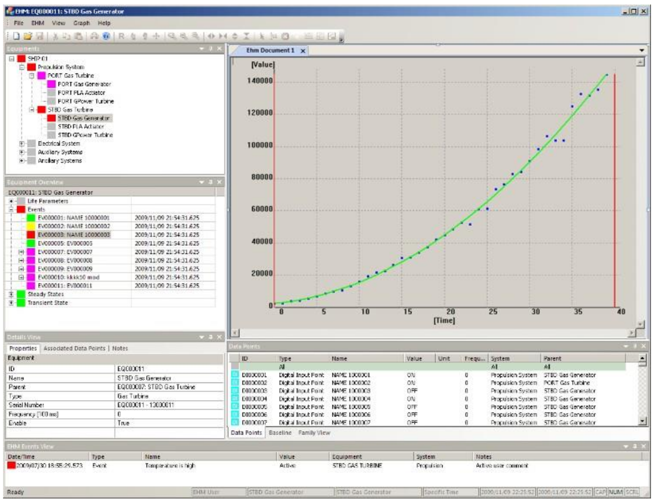


Figure 6. L3 Enhanced Health Monitoring

AI techniques can be used to identify 'unknown unknowns', determining patterns and trends which would be almost impossible for a human to spot. The Enhanced Health Monitoring system could incorporate such trends for predictive maintenance, enabling equipment defects to be rectified prior to occurring, thereby maximising the availability of the USV. To achieve predictive maintenance, a great deal of data needs to be collected and analysed, emphasising the importance of integration and accessibility of data for the development of future capabilities.

There are numerous other tools and features within IPMS that add value and capability if a simple interface exists between the stowed USV and IPMS. For example, a recent feature of IPMS is the development of auto prioritisation of ship defects to support the mission intent / command aims. With the USV providing health data to IPMS the potential defects that occur on the USV can be prioritised to reflect and observe the ship's context and current command aim, respectively.

5.2. Launch

Launching an unmanned surface vehicle from a mothership is a complex operation which requires a number of considerations. First and significant within the defence sector, is the challenge of fitting a launch system into a typically small and cramped mission bay. Secondly there is the logistical challenge of having so many individual moving parts in one system, potentially operating in hostile conditions. The unpredictability of wave patterns, particularly in high sea states, makes it difficult to securely latch the USV with the launch and recovery system without causing any damage. There are then further constraints on the design of the system imposed by the restricted space in the mission bay. Finally, there is the concern of control of the system moving from the IPMS to the combat management system as the unmanned surface vehicle moves from the maintain phase to the launch phase.

In the near future there will be multiple off board capabilities hosted on board a mothership, spanning across air, surface and sub-surface. Managing numerous separate, disparate systems and ensuring the correct information is fed into both the IPMS and the combat management system allowing them to make decisions and plan missions will be difficult. The challenge here is ensuring that all involved parties receive the same real time information simultaneously avoiding poor decisions being made based on outdated information. Secondly, with the vast amount of data being collected and distributed on a USV it is important to ensure that the user is not overloaded with unimportant information. A potential solution to this is to set boundaries on the information sent by the USV, meaning that unless information is outside the safe boundaries the operator does not need to know what the readings are.

It is proposed that upon completion of the Maintain phase when the unmanned surface vehicle is ready for deployment, the engineering department ‘activate’ the vessel so that is appears on the combat management system as an available asset to use for planning and executing missions. This will rely on a connection between the IPMS and the combat management system

5.3. Execute

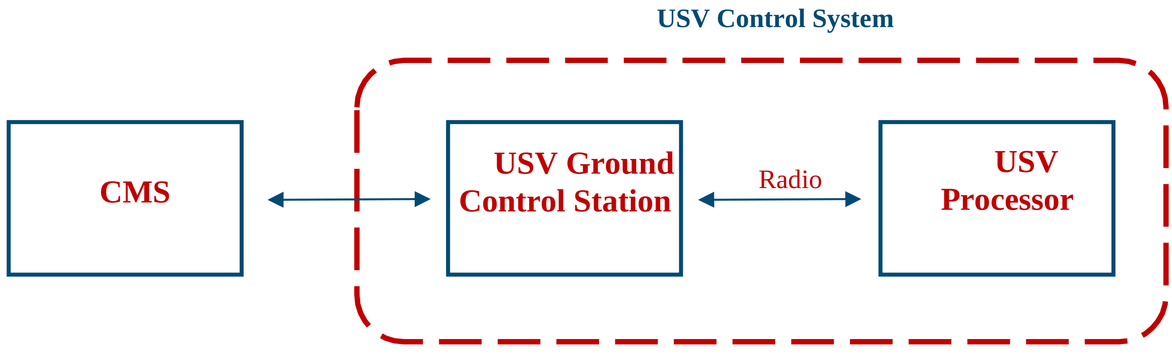
During the execution stage, both the IPMS and the combat management system will be fed information from the unmanned surface vehicle. The vessel will report back to the operations centre via the capability reporting feed on the progress of the mission and any required/useful mission specific information to the combat management system to inform future command decisions. Additionally the USV will report health monitoring information to IPMS allowing the engineering team to prepare for necessary preventative or corrective maintenance on completion of the mission.

To reduce the amount of data being transferred back to IPMS the system can set safe operating parameters. This means only data which falls outside of these parameters will be passed over the data link, thereby reducing the amount of data and bandwidth required.

5.3.1. Controlling a single USV through the CMS

The control system supplied with the L3 Technologies unmanned surface vehicle is based on a Service-Orientated Architecture

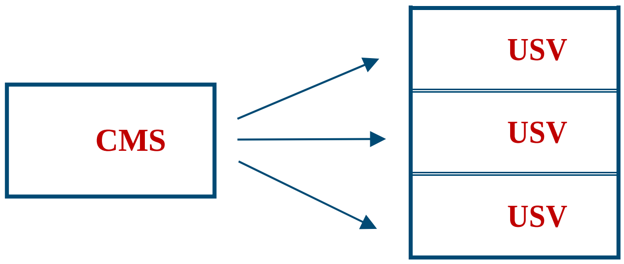
The interaction between the CMS and the unmanned surface vehicle is outlined in the diagram below:



This architecture allows the CMS to send commands to the unmanned surface vehicle’s ground control station which then converts the message to a format readable by the unmanned surface vehicle processor.

5.3.2. Controlling a squad of USVs through the CMS

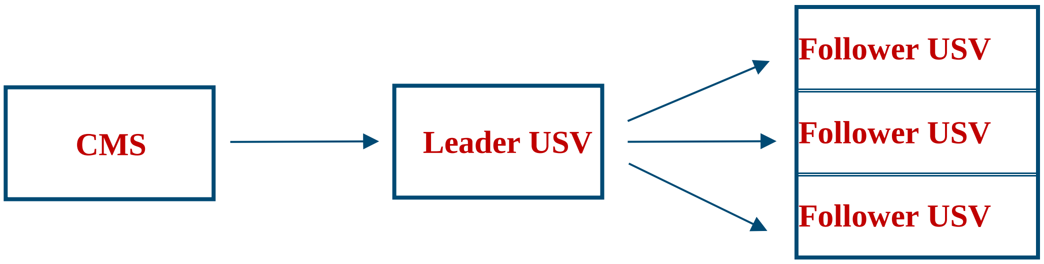
Controlling a squad of USVs could be done in a number of different ways, firstly the combat management system could communicate with the USV individually, the squad planning element being hosted on the CMS:



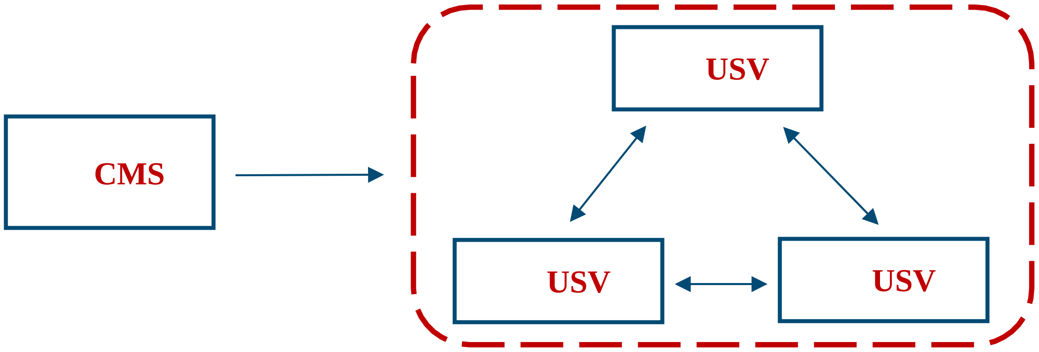
The above scenario would work well when the off-board systems are within good communications range of the mothership. Once out of communication range, the behaviour of the USV will be dependent on the autonomous control software. An example behaviour could be that the USV returns to the last known location where it was receiving communications, known as the Last Response Engine.

The next two proposed architectures would work better if the off-board systems were further afield from the mothership. This is because there would be less information to be sent between the mothership and the off-board systems.

One of the off-board systems could be nominated as the Lead USV, which would be 'smarter' than the others. This USV would receive the aim of the mission from the combat management system and would then issue individual missions to the squad of Follower USVs. In this scenario the planning would be carried out on the Lead USV.



Finally, there can be negotiate tasking between USVs where a mission is sent to the whole squad and they negotiate between themselves about how to achieve the mission in the most efficient way.



Throughout the above scenarios there will also have to be health information fed back to the IPMS – this could be done either via the USV directly or fed from the CMS to the IPMS using the communications links already established between the USV and the CMS.

5.4. Recovery

Recovery of an autonomous vessel is one of the biggest challenges for maritime autonomy across industry and is preventing wider uptake of this technology. Innovative autonomous launch and recovery solutions are currently subject to significant investment. This makes achieving the full operating cycle of an autonomous vessel being completely unmanned a real possibility in the near future.

During the recovery stage, much like the launch stage, the control of the process will fall under the CMS remit. However, it would be very advantageous to maintain a link with the IPMS during this phase of the operating cycle.

Some advantages of maintaining a link with the IPMS include:

- Utilising the functionality of the mission bay cameras to aid in the recovery process
- A wireless link to IPMS when the USV is being launched / recovered to update the operator on the status of the USV during that phase of the operating cycle

6. Next steps

For successful integration of off board systems across all domains and manufacturers, there is a need for a standard USV to CMS / IPMS interface. Not only is this in keeping with the current trend towards open architectures but it will also allow for the inevitable rapid pace of technological change and associated capability upgrade.. The lifespan of a USV is around 10 years, much shorter than the lifespan of a mothership which can be between 30 and 50 years. Having a defined standard interface will allow different systems to be modular, interchanged and updated multiple times during the lifespan of a mothership.

As the uptake of autonomous and unmanned off board systems increases in the near future, the integration of these systems needs to be carefully considered. The solution will see previously independent and unconnected systems having to work together seamlessly and simultaneously.

7. Future Trends

The future of autonomy is far broader than the topics covered within this paper. The technologies being developed to optimise autonomous vessels will have other applications for the operations of the support vessel. As autonomous technologies become more established and proven, the confidence gained will result in larger vessels, potentially leading to fully autonomous cargo ships and cruise ships. The path to this vision has been set out in the Maritime 2050 Route Map [4]. As this vision becomes a reality, USVs will naturally grow in size, complexity and capability, it will then be a question of how we integrate people and processes into and surrounding the autonomous vessel. This is the beginning of a journey with many challenges ahead.

8. Conclusion

Successful integration of an off board autonomous vessel into a mothership's platform management system will rapidly increase the effectiveness and uptake of this technology across defence and commercial sectors. Currently, autonomous vessels are treated as a separate component, operated independently from the mothership. However, platform-wide integration will allow the USV to be incorporated into the operating doctrine just as any other system in the mothership. This will ensure the USV capability can be kept in a high readiness state for use by the ship's command.

As discussed throughout this paper, the successful of integration of a USV into a mothership is not just a technical challenge, the personnel, processes and policies must be considered and developed in parallel. The operating cycle of a USV is captured in four phases, Maintain, Launch, Execute and Recover. By considering the stages that a USV goes through, all of the stakeholders can be engaged, interfaces refined and enhanced to optimise the solution.

A Royal Navy vessel has two main information components that the USV operating cycle will interface with, the CMS and the IPMS. To ensure a smooth operation between the two a common computing environment and infrastructure is essential. An integrated approach will allow for much more scalability such as the handling of squads of autonomous vessels operated from a central control point on the mothership or even interchanging multiple USV depending on mission objectives.

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