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, L3Harris completed a series of demonstrations at Autonomous Warrior 2018. The continually evolving technology has enabled increasingly complex autonomous operations to be trialled. This accessibility and the 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 does integration into a modern operation warship pose an indisputable challenge? The operating cycle of an USV when hosted onboard a warship can be summarised as 'Maintain, Launch, 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 onboard 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, L3Harris 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), L3Harris 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. While navigating waterways at speeds of up to 40 knots for over 80 hours, this vessel successfully executed seven different task types. ASView, L3Harris' proprietary autonomous control system, enabled remote mission commanders to track and follow target vessels for interdiction tasks. The vessel, designed and built by L3Harris, also demonstrated collision avoidance through the use of radar to provide situational awareness.

"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

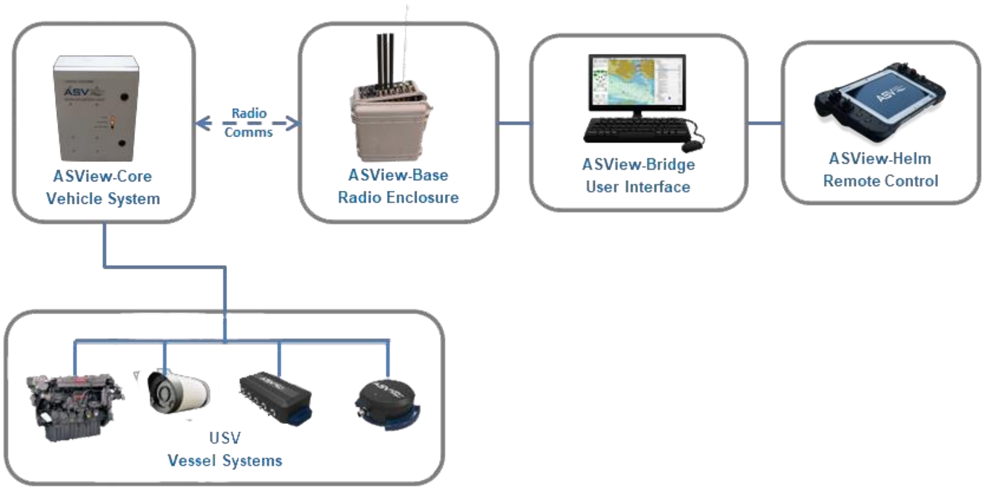


Figure 2. ASView System Components

The current operating philosophy of an Unmanned Surface Vessel (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 onboard 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, allowing computing power to become 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 the 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 USVs 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 allowed for increasingly complex autonomous operations to be trialled, which is enabled by L3Harris' 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. As the maritime environment is complex and dynamic, when integrating a new system such as an USV, considerations such as personnel, safety and policies 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 the industry and academia. Furthermore, this emphasizes the need to look to the future to see 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 doctrines will be adapted to accommodate autonomous capabilities. From a technical perspective, how will these systems be developed in such a way as to be interoperable and scalable for future enhancements? Potentially pan industry and academia. 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 Vessels

An Unmanned Surface Vessel (USV), sometimes also known as an Autonomous Surface Vessel (ASV), is a vessel which can operate on the water without the need for a human to be onboard. As a crew is not necessary, USVs offer many advantages. For an USV to operate correctly in autonomous mode, there are several systems which need to work harmoniously together. The key systems within an 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 input 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 vessel 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 vessel 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 had 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], which is an example of the paradigm shift towards integrated data platforms supporting data fusion.

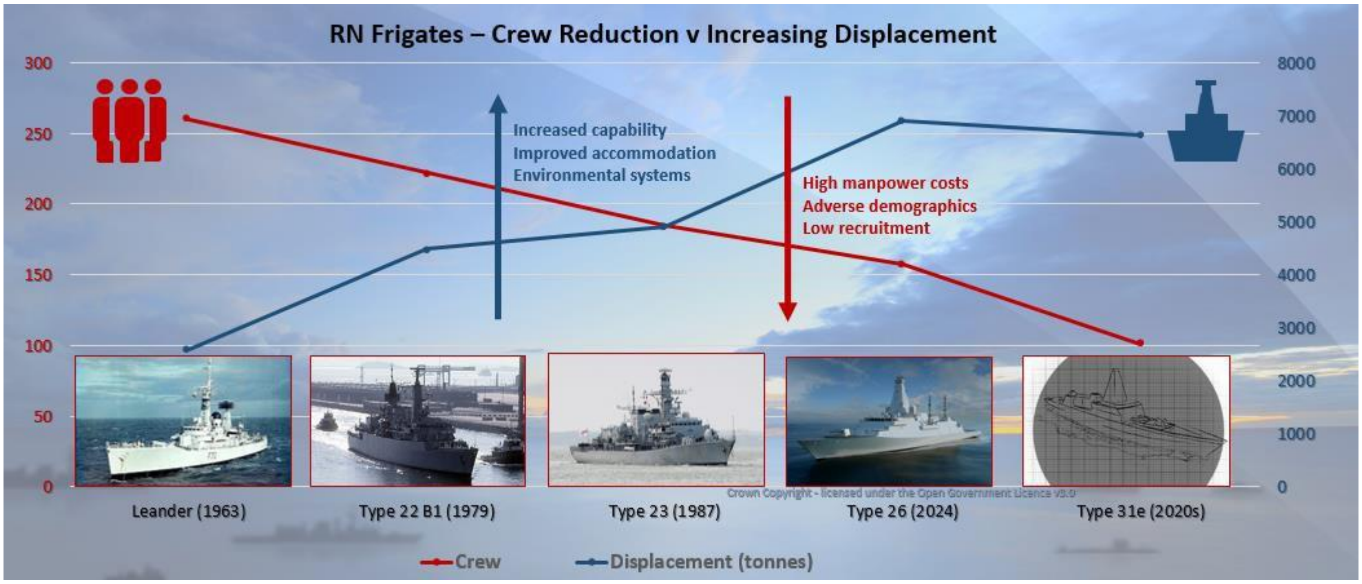


Figure 3. Manning vs Automation

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 collaboration has supported lean manning requirements, enabled by a high degree of system integration. This has been 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 the ship's capabilities, both combat systems and 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 USVs.

There are still a great number of improvements to be made such as data availability and integration. Historically systems onboard 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 an USV—the combat systems/weapons engineering team and the marine engineering team. The integration of an 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 (Deploy), Execute and Recover are the four stages that make up the operating cycle that an autonomous vessel will go through whilst being hosted onboard a large mothership (Figure 4). 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 onboard 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 offboard systems, such as USVs, into both the IPMS and the CMS is a complex matter. As the USV moves through the different stages of its operating cycle, the system exercises primary control and changes in monitoring, 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 becomes an ‘active’ asset which the CMS will need to manage.
3. Execute Phase – During this phase, the CMS will be overseeing the USV, providing Command and Control (C2) and 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 onboard, when 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 an USV allowing a mothership to interchange USVs, depending on operational requirements.

5.1. Maintain

The maintain phase focuses on ensuring the vessel is ready for operational deployment, which will involve running diagnostics and trending data from the autonomous systems. The larger USVs are currently around 12m, as shown in Figure 5, and can be stowed on a mother ship, which host 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 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. L3Harris Mine Countermeasures (MCM) Autonomous Vessel for Thales UK

To support the Marine Engineers maintaining the USV, there must be a data interface from the USV's onboard 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 detect alarm conditions and compare live data to benchmark data, as shown in Figure 6.

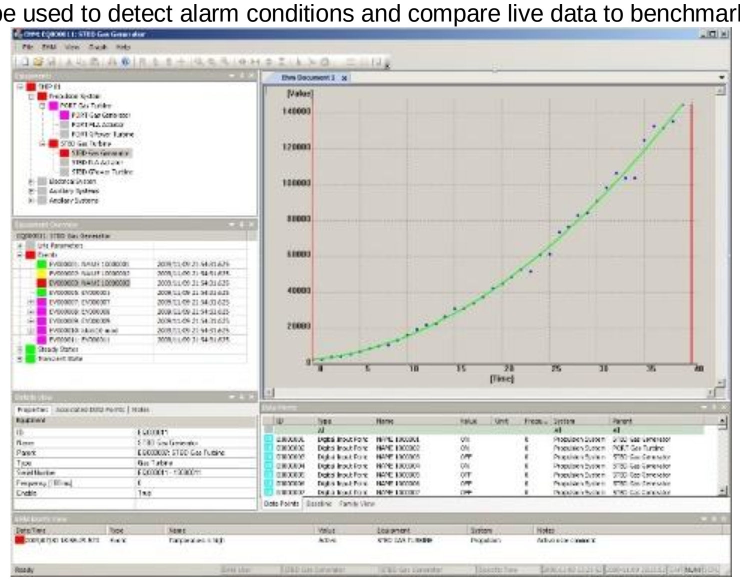


Figure 6. L3Harris Enhanced Health Monitoring

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 and thereby maximising the availability of the USV. To achieve predictive maintenance, a great deal of data needs to be collected and analysed, with emphasis on 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 USV from a mothership is a complex operation which requires a number of considerations. First, and most significant within the defence sector, is the challenge of fitting a launch system into a typically small and cramped mission bay. Second, 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 CMS as the USV moves from the maintain phase to the launch phase.

In the near future, there will be multiple offboard capabilities hosted onboard a mothership, spanning across air, surface and sub-surface. It will be difficult to manage numerous separate, disparate systems and ensure the correct information is fed into both the IPMS and the CMS, allowing them to make decisions and plan missions. The challenge here is ensuring that all involved parties receive the same real time information simultaneously, avoiding the possibility of poor decisions being made based on outdated information. With the vast amount of data being collected and distributed on an 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 USV is ready for deployment, the engineering department can 'activate' the vessel so that it appears on the CMS as an available asset to use for planning and executing missions. This will rely on a connection between the IPMS and the CMS.

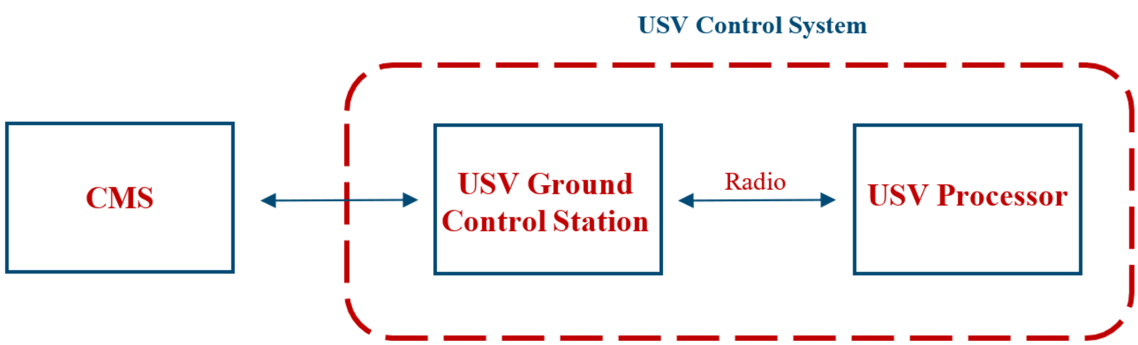
5.3. Execute

During the execution stage, both the IPMS and the CMS will be fed information from the USV. 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 CMS 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

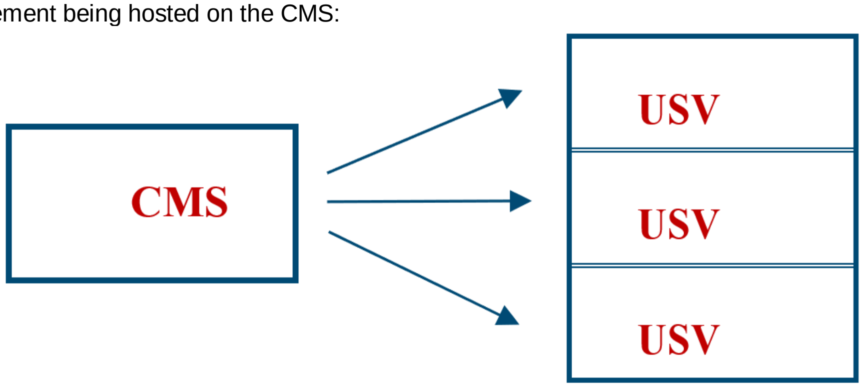
The control system supplied with the L3Harris USV is based on a Service- Orientated Architecture. The interaction between the CMS and the USV is outlined in the diagram below:



This architecture allows the CMS to send commands to the USV's ground control station, which then converts the message to a format readable by the USV processor.

5.3.2. Controlling a squad of USVs through the CMS

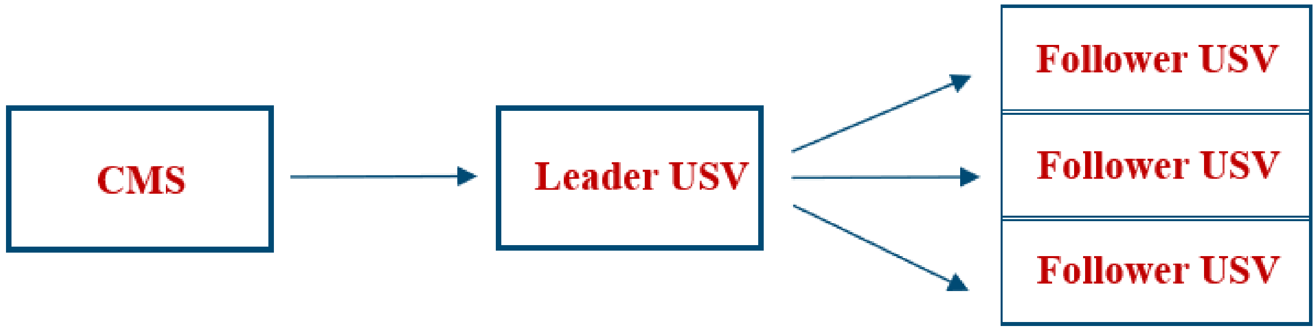
Controlling a squad of USVs could be done in a number of different ways. First, the CMS could communicate with the USV individually with the squad planning element being hosted on the CMS:



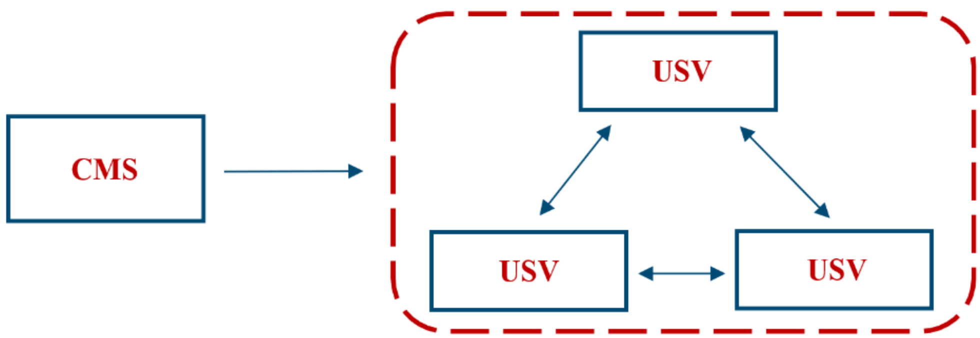
The above scenario would work well when the offboard systems are within a good communication range from the mothership. Once out of the communication range, the behaviour of the USV will be dependent on the autonomous control software. An example behaviour could be that the USV returns to the last known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

The next two proposed architectures would suit a situation where the offboard systems were further afield from the mothership. This is because there would be less information to be sent between the mothership and the offboard systems.

One of the offboard 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 CMS 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.



Alternatively, there could be negotiation 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.

5.4. Recover

Recovery of an autonomous vessel is one of the biggest challenges for maritime autonomy across industry and is preventing a 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 offboard 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 upgrades. The lifespan of an USV is around 10 years, much shorter than the lifespan of a mothership which is 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 offboard systems increase in the near future, the integration of these systems needs to be carefully considered. The solution will be based on previously independent and unconnected systems that worked 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 and potentially lead 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, raising a question of how we can integrate people and processes into/surrounding the autonomous vessel. This is the beginning of a journey with many challenges ahead.

8. Conclusion

Successful integration of an offboard 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, operating 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 that 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 integration of an 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 an USV is captured in four phases—Maintain, Launch, Execute and Recover. By considering the stages that an USV goes through, all of the stakeholders can be engaged, and interfaces can be 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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