NAVIGATING TOMORROW'S WATERS

The World of Autonomous Marine Vehicles

Photo courtesy of General Dynamics Mission Systems

HARWiN

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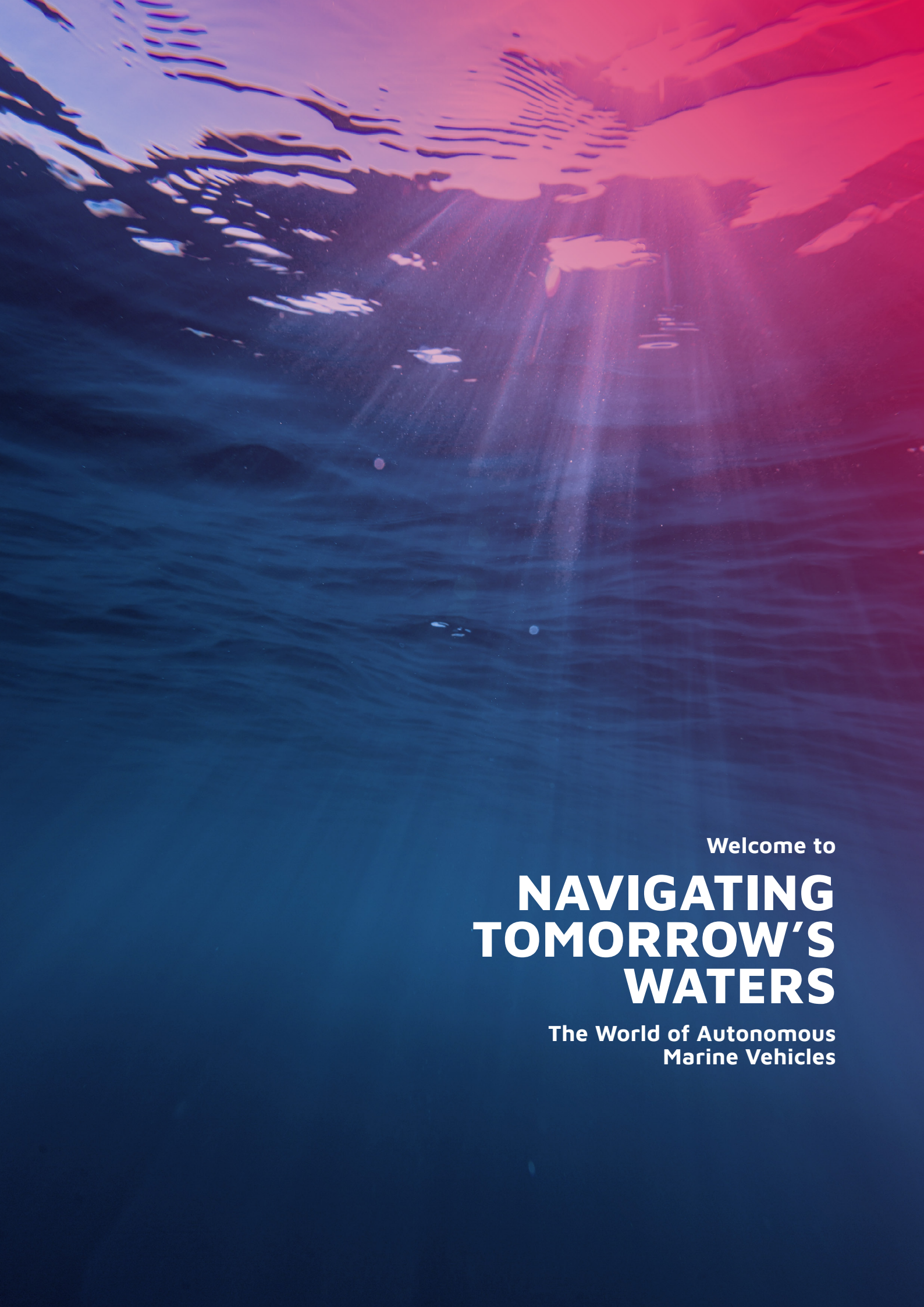


Welcome to

NAVIGATING TOMORROW'S WATERS

The World of Autonomous Marine Vehicles

0 INTRODUCTION

Welcome to Navigating tomorrow's waters: The world of autonomous marine vehicles, an in-depth ebook designed specifically for engineers seeking to unravel the complexities and opportunities presented by autonomous marine technology.

In this rapidly evolving era, the convergence of artificial intelligence, robotics, and maritime engineering has given rise to a new generation of intelligent marine vehicles capable of independent operation, revolutionising the field of maritime engineering.

The seas and oceans cover more than 70% of our planet's surface, holding an abundance of resources, from energy reserves to marine life. However, accessing these vast expanses has traditionally been a challenging and risky endeavour.

The advent of **autonomous marine vehicles (AMVs)** presents a groundbreaking solution, offering an array of possibilities and opening doors to exploration, conservation, and a range of commercial applications.

The engineering community plays a pivotal role in shaping the future of autonomous marine vehicles (AMVs) through their expertise, innovation, and problem-solving abilities. With this ebook, we aim to provide you with a comprehensive understanding of AMVs, their underlying technologies, and their wide-ranging applications across diverse industries.

Chapter One will begin with an overview of the global maritime industry, highlighting the challenges faced by traditional vessel operations such as human error, high costs, environmental concerns, and limited operational capabilities. It explores how autonomous marine vehicles offer innovative solutions by leveraging artificial intelligence, robotics, and advanced sensing technologies to enhance efficiency, safety, and sustainability in various maritime sectors.

This market analysis will delve into the current landscape of autonomous marine vehicles, including the key players, their product portfolios, and technological advancements.

It provides a comprehensive evaluation of different types of autonomous marine vehicles, such as **unmanned surface vessels (USVs)**, **autonomous underwater vehicles (AUVs)**, and **autonomous ships.**

Chapter Two highlights autonomous marine vehicle's growing significance in various maritime sectors. It showcases the diverse range of applications, including offshore exploration, oceanographic research, maritime security, environmental monitoring, and more.

It explores the benefits offered by autonomous marine vehicles, highlighting their ability to enhance operational efficiency, reduce costs, improve safety by eliminating human error, and minimise environmental impact by optimising routes and reducing emissions.
It will also present insightful case studies and success stories showcasing the real-world applications of autonomous marine vehicles.

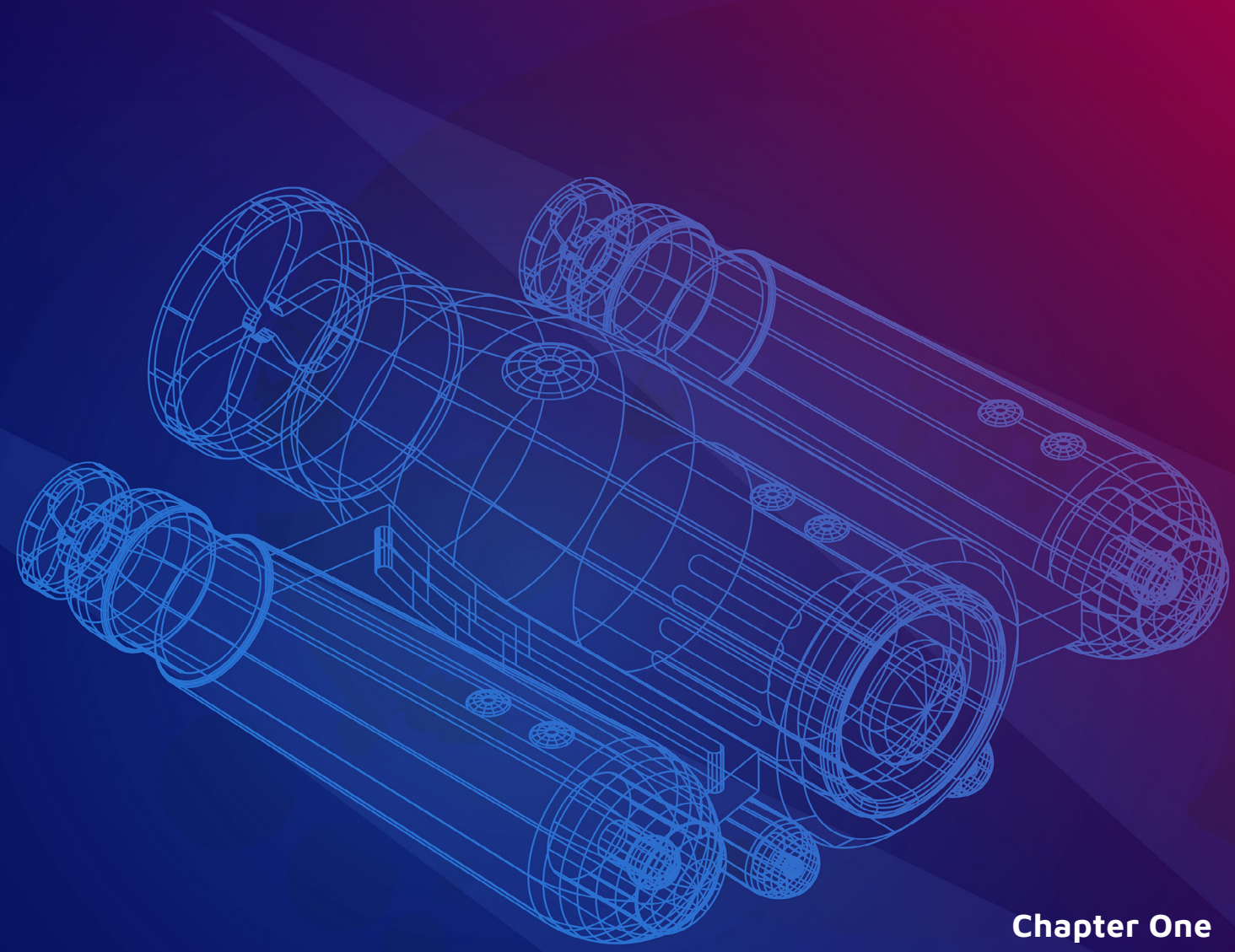
Chapter Three explores a real-world example of how an autonomous marine vehicle has revolutionised offshore operations, showcasing the transformative potential of these advanced technologies.

Focusing on the partnership between Harwin and VectorNav, this section delves into the journey of designing and deploying an autonomous marine vehicle, highlighting the components used and how Harwin has helped.

Chapter Four delves into the intricacies of designing autonomous marine vehicles, focusing on the key considerations and innovative solutions that contribute to their enhanced performance and safety.

By exploring the various technical aspects of these vehicles, the section provides valuable insights for engineers, researchers, and developers involved in the design and development of autonomous marine vehicles.

Through a comprehensive exploration of the engineering principles, historical context, technological advancements, and practical applications, we invite you to envision the vast potential and transformative impact that AMVs can have on our oceans and industries.



Chapter One

AUTONOMOUS MARINE VEHICLES

Market Analysis

1 MARKET ANALYSIS

The maritime industry is a vital sector for the global economy. Its importance was highlighted by the fallout from recent events like the Evergreen company's cargo ship blocking the Suez Canal and holding up global supply chains.

However, despite being a thriving, multi-national and multi-trillion-dollar industry, the maritime industry, like many others, has issues it needs to contend with. Aside from things like piracy, geopolitical tensions restricting access, and even a global pandemic halting shipping, many of its issues are perennial and are echoed by other sectors.

Staffing shortages is a pertinent problem, and as many ships are voluntarily signed up to a 'Safe Minimum Manning Certificate' to sail, should there not be enough crew then it's possible a ship may not be able to leave until that shortage on a particular ship is addressed.

Equally, as climate change becomes more of a concern for businesses and governments worldwide, environmental regulations are posing increasing problems for the maritime industry. The global maritime industry is estimated to account for around 2.2% of global carbon dioxide emissions annually, primarily coming from the burning of fossil fuels in ships' engines. To address this, the International Maritime Organisation agency of the UN has implemented regulations to limit sulphur content in marine fuels and has set targets to reduce greenhouse gas emissions from international shipping. This is forcing companies to reconsider how to power their fleet. This means building more ships or converting those already in the fleet to run on different fuels.

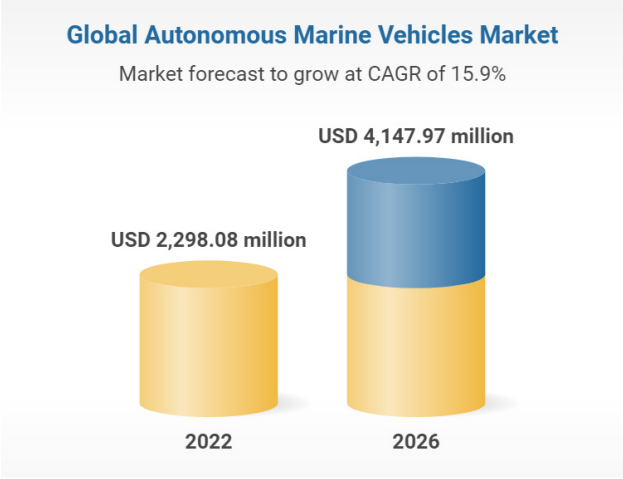
The existential threat of climate change also means more extreme, unpredictable weather and potentially more dangerous voyages. This risks both cargo and crew, and can raise costs of loss, and even the premiums to insure.

These issues, compiled with the relatively low profit margins the maritime industry runs on, the fuel costs, charter rates, vessel depreciation, maintenance expenses, and regulatory compliance costs means that cost saving is of major importance.

As companies look to improve their operations and remedy some of the issues listed above, we're seeing an increasing use of autonomous technology – and this is where autonomous marine vehicles come in.

Autonomous marine vehicles are robotic devices designed to navigate beneath or on the water's surface without the need for human intervention. The main types of autonomous marine vehicles are surface vehicles, otherwise known as unmanned surface vehicles (USV) or autonomous surface vehicles (ASV), and underwater vehicles, otherwise known as autonomous underwater vehicles (AUV), and they are normally involved in various applications like exploration, environmental protection and monitoring, search and salvage operations, and oceanography.

According to ResearchAndMarkets.com, the global autonomous marine vehicle market was predicted to grow from $1,994.26 million in 2021 to $2,298.08 million in 2022 at a compound annual growth rate (CAGR) of 15.2%. North America was the largest region in the autonomous marine vehicles market in 2022, with the Middle East coming up second. The market is now expected to grow to $4,147.97 million in 2026 at a CAGR of 15.9%.



Global autonomous vehicle market. Credit: ResearchAndMarkets.com

This growth is fuelled by an increase in hydrographic, oceanographic, and environmental surveys conducted worldwide. Hydrographic surveys involve the measurement and mapping of underwater features. The primary objective of these surveys is to generate navigational charts that are vital for ensuring the safe passage of vessels.

Conducting an oceanographic survey plays a crucial role in gaining precise knowledge about marine and freshwater environments, benefitting various areas such as port and harbour development, wastewater and industrial outfalls, power plant intakes and outfalls, and offshore disposals.

Employing an ASV proves to be an efficient approach for carrying out hydrographic surveys, offering significant savings in terms of both cost and time.

Furthermore, the flexibility and convenience of autonomous marine vehicles enable rapid deployment to fulfil various survey needs, ranging from small-scale event surveys to extensive coastal surveys. A notable example is the autonomous hydrographic survey conducted by 4D Ocean, where the Channel Coastal Observatory (CCO) commissioned a seabed survey offshore of Hurst Spit, Western Solent. This survey utilised a SeaRobotics ASV 2.5, showcasing the capabilities of autonomous vehicles in the field.

The autonomous marine vehicle market is also witnessing an emerging trend known as maritime drone swarming, which enhances surveillance and investigation capabilities. Maritime drone swarms consist of a large group of underwater vehicles working together towards a specific objective. These drone swarms offer a diverse range of capabilities, particularly in defence applications, as they can conduct surveillance and investigation tasks while also implementing defensive or offensive countermeasures.

Through collaborative navigation, the swarm efficiently explores the underwater environment, utilising multiple sensing techniques to swiftly cover a broader area and construct a comprehensive map. An example of ongoing development in this field is the European Union's (EU) funding of the research project 'Ocean2020.' This project aims to integrate drones and unmanned submarines into swarms or fleet units, allowing for enhanced capabilities in maritime operations.

The autonomous marine vehicle market does face a significant challenge in the form of ship vulnerability to cyber threats resulting from automation. This is primarily due to the susceptibility of cyberspace and its related infrastructure to a wide array of risks stemming from cyber threats and attacks. The increased reliance on automation, which reduces the need for human intervention in ships and ports, escalates the potential for security breaches.

In a survey conducted by law firm Clyde & Co and the Institute of Marine Engineering, Science & Technology (IMarEST), it was revealed that more than two-thirds of marine industry executives worldwide expressed concerns about the increased cyber-security risks associated with unmanned/autonomous ships.

Major players in the autonomous marine vehicles market include ASV Global/ASV Unmanned Marine Systems, Atlas Elektronik, Teledyne Technologies, ECA Group, and SeaRobotics Corp.

Due to their potential applications, current and foreseen, the USVs and AUVs market has risen to a staggering worth despite only seeing real utility in recent years. Therefore, it's no surprise the market is projected to experience more significant growth.

Chapter Two

FROM CONCEPT TO REALITY

Application Focus

2 APPLICATION FOCUS

Innovations in AI, sensors, and even in materials, means that autonomous marine vehicles are beginning to blossom from concept, to prototype, to reality.

These autonomous marine vehicles, also known as unmanned or autonomous underwater vehicles (AUVs) or autonomous surface vehicles (ASVs), can help reduce costs and can also increase profit. The reduction of a human workforce means less overheads to pay salaries and even lower insurance costs. They are also generally more effective than a human in the task they carry out, due to the amount of sensors they use and the AI and machine learning that supports them.

Autonomous marine vehicles have a wide range of applications across various industries. Here are just a few examples:

Oceanographic research:
AUVs and ASVs are used for collecting data and conducting research in oceanography. They can be equipped with sensors to measure water temperature, salinity, dissolved oxygen levels, and other important parameters. These vehicles can gather data over extended periods, covering large areas of the ocean and providing valuable insights into marine ecosystems, climate patterns, and ocean behaviour.

Offshore industry support:
Autonomous marine vehicles are utilised in the offshore industry for various purposes. They can inspect and monitor offshore oil and gas infrastructure, including underwater pipelines and platforms, for maintenance and safety purposes. AUVs can also perform subsea inspections, identifying potential issues and reducing the need for human divers in hazardous conditions.

Search and rescue operations:
Autonomous marine vehicles are valuable tools in search and rescue operations. Equipped with advanced sensors and imaging systems, they can aid in locating missing persons, downed aircraft, or sunken vessels. These vehicles can quickly cover large areas, operate in harsh conditions, and provide real-time data to rescue teams, enhancing their efficiency and effectiveness.

Military and defence applications:
Autonomous marine vehicles have applications in military and defence operations. They can be used for surveillance and reconnaissance missions, monitoring maritime borders, and gathering intelligence. Additionally, they can support mine countermeasures by detecting and neutralising underwater mines without risking human lives.

Underwater inspections and maintenance:
AUVs are employed for inspecting underwater infrastructure such as bridges, dams, and underwater cables. They can assess the structural integrity, identify damage or corrosion, and provide valuable data for maintenance and repairs.

These applications are not just hypothetical, plenty of operations are being carried out with AUVs and ASVs. Here are some notable examples:

FlatFish – pipeline inspection

Shell's FlatFish vehicle for autonomous pipeline inspection

For Shell, autonomous marine vehicles are enabling the company to change the concept of operations for all offshore facilities, including traditional oil and gas as well as offshore wind and carbon capture and storage facilities.

In the 1970s, underwater maintenance and construction work was primarily conducted by human divers. However, as the offshore industry expanded to deeper waters, exceeding

depths of 150 metres, the conditions became too hazardous for human divers. As a result, autonomous vehicles emerged as the standard solution.

FlatFish is an autonomous underwater vehicle designed specifically for conducting close inspections of pipelines and structures. Its primary purpose is to visualise and provide a comprehensive understanding of anomalies present in these underwater systems. Equipped with high-resolution 3D imaging capabilities and precision optics that accurately capture natural colours, FlatFish enables remote operators to identify even the smallest dents and imperfections in the infrastructure being inspected.

The project, which was developed in partnership with SENAI CIMATEC, offers the potential to significantly reduce the expenses associated with subsea inspections and data collection.

REMUS – scanning the Titanic
A more recent project comes from the Woods Hole Oceanographic Institution (WHOI) who have developed REMUS (Remote Environmental Monitoring UnitS). REMUS is a widely used AUV and has been employed for various purposes, including mapping the Titanic wreck.

Using deep-sea mapping technology, a 3D view of the sunken ship has been created, providing a 'drained-water perspective' of the wreck. Over 200 hours were dedicated to surveying the entire wreckage, capturing an immense number of images totalling over 700,000 from every angle to construct an accurate 3D representation.

The full-scale digital scan of the Titanic is considered a significant step toward evidence-based research.

Bluefin-21 – search and rescue
The Bluefin-21 from Bluefin Robotics is a versatile and modular autonomous unmanned underwater vehicle designed to accommodate multiple sensors and payloads simultaneously. With its substantial energy capacity, it can perform extended operations even at considerable depths.

It gained attention during the search for Malaysia Airlines' Flight 370. It was deployed to scan the seafloor in the Indian Ocean to locate the missing aircraft wreckage. Using side scan sonar, the Bluefin descended to a depth of between 4,000 and 4,500 metres, approximately 35 metres above the ocean floor.

Saildrone – hurricane monitoring
Saildrone designs and operates a fleet of wind-powered ASVs for various applications. Its vehicles have been used to gather data on ocean acidification, study marine mammal populations, monitor fish stocks, and collect meteorological and oceanographic data.

More recently, the ASV has been used to collect data and video where it's never been collected before – inside a hurricane. In July 2021, NOAA (National Oceanic and Atmospheric Administration) and Saildrone collaborated to deploy a fleet of five Explorer USVs. These USVs were specially equipped with robust 'hurricane wings' that were specifically designed to withstand extreme conditions, including winds exceeding 90mph and waves surpassing 50 feet in height.

The mission's objective was to gather measurements of near-surface atmospheric and upper-ocean parameters. These measurements aimed to calculate the energy and momentum exchanges occurring between the atmosphere and ocean in both the presence and absence of hurricanes. The data collected would provide valuable insights into the impact of ocean-atmosphere interaction on hurricane intensity and aid in enhancing hurricane prediction models.

As technology continues to advance and the capabilities of autonomous marine vehicles improve, their use is expected to grow even further. Their potential to revolutionise industries, enhance data collection and analysis, and contribute to our understanding of the marine environment makes them a valuable asset in various sectors.

Chapter Three

VECTORNAV & HARWIN

REDEFINING INERTIAL NAVIGATION PERFORMANCE

Case Study

3 CASE STUDY

Founded in 2008, VectorNav Technologies began with the idea that its expertise in aerospace guidance, navigation, and control could be applied to the latest advancements in inertial and GNSS technology, resulting in products that achieve high performance in the smallest possible footprint.

VectorNav products integrate gyroscopes, accelerometers, and magnetometers with GNSS receivers, which undergo a robust calibration process to account for error in bias, scale factor, misalignment, and gyro g-sensitivity. The data produced by the calibrated sensors is then passed through VectorNav's proprietary navigation algorithms to deliver a highly accurate position, velocity, and attitude solution.

VectorNav has gained experience in numerous applications spanning navigation of the deep ocean to the stratosphere. The company's products are used in everything from autonomous vehicles (underwater and surface), UAVs, and self-driving cars.

Product overview

VectorNav's product range includes Inertial Measurement Units (IMUs), Attitude and Heading Reference Systems (AHRS), GNSS-Aided Inertial Navigation Systems (GNSS/INS) and Dual GNSS/INS featuring an integrated GNSS-Compass.

The first product to be launched was the VN-100 surface mount device (SMD) in 2009. The VN-100 is a miniature, high-performance IMU and AHRS. Combining 3-axis accelerometers, gyros, and magnetometers, a barometric pressure sensor and a high-speed processor, the VN-100 provides high-rate, calibrated IMU data and a real-time 3D attitude solution that is continuous over the complete 360° of motion.

VN-100

To facilitate development and testing, the VN-100 is available in a rugged 'plug and play' version. Enclosed in a clamshell precision anodised aluminium enclosure, the VN-100 Rugged offers additional protection of the internal inertial sensors and electronics.

In 2012, VectorNav launched the VN-200. The VN-200 is a miniature, high performance GNSS/INS that combines 3-axis gyros, accelerometers and magnetometers, a high-sensitivity GNSS receiver, and advanced Kalman filtering algorithms to provide optimal estimates of position, velocity, and attitude.

VN-200

Shortly after, in 2014 the VN-300 was launched. The VN-300 is a miniature, high-performance Dual Antenna GNSS-Aided Inertial Navigation System that combines MEMS inertial

sensors, two high-sensitivity GNSS receivers, and advanced Kalman filtering algorithms to provide optimal estimates of position, velocity, and orientation. By utilising two separate GNSS receivers and antennas, the VN-300 enables accurate heading measurements without reliance on vehicle dynamics or magnetic sensors, providing unmatched performance under both static and dynamic conditions.

VN-300

A perfect partnership

For all three of these products, VectorNav required a high-quality connector. The company underwent a rigorous process of evaluation, considering numerous connectors, but all failed to meet performance requirements. That was, until Harwin's Datamate connector was tested.

The Datamate connectors provide an extremely flexible interconnect solution which is ideally suited to a wide variety of challenging environments. In fact, it is the connector range of choice in many demanding applications on land, sea, and air.

Very high levels of reliability are vital for VectorNav's Rugged range as these types of applications are subject to high loads of shock and vibration, and wide extremes of temperature. Datamate connectors feature a proven 4-finger contact design that maintains electrical contact through high vibration and shock, and the connector series is rated between -55 to 125°C.

VectorNav's customers connect to the unit by way of a cable harness, and under high vibration, cables can cause additional load on the connection, forcing it to work loose and separate. VectorNav mitigates this risk by using connectors fitted with jack-screws, which securely lock the connectors together. VectorNav also provides 'pigtail' cable assemblies ready-made and available off-the-shelf to ease integration into the end-user's system.

On the cable side specifically, VectorNav chose Harwin's extended rear-wall connectors. This allows the addition of a back-potting compound which reduces stress on the cable crimp and adds strain relief to the overall assembly – increased safety and reliability in the field.

Another benefit of the Datamate system is the connector's compact footprint. This allows VectorNav's sensor unit to maintain a low profile and physical space which is hugely important to end-users looking to reduce size and weight.

"The VN-200 provided the best attitude performance and exceeded all expectations of what could be achieved in our high vibration environment, even outperforming larger, more expensive systems," said Monica Rodriguez, R&D Communications Manager at Hydra Technologies.

Finally, given the nature of their devices, it was of paramount importance to VectorNav that the connector must have a low magnetic impact, so as not to affect the magnetic compass, something that can be an issue with some high-reliability alternatives.

Chapter Four

GETTING THE CONNECTION RIGHT

Technical Focus

4 TECHNICAL FOCUS

When designing autonomous marine vehicles (AMV), engineers need to consider several technical aspects to ensure their efficiency, safety, and effectiveness. These include things like path planning and control, communication systems, power and energy management, redundancy, and safety, as well as component selection.

Autonomous vehicles, as the name suggests, do not have any human intervention, so when things go wrong, it's very hard to recover them. Therefore, the components within these vehicles need to be as reliable and durable as possible.

Connectors play a vital role in the design and operation of AMVs. They serve as the interface between different electrical and electronic components, facilitating connectivity, signal transmission, power distribution, and data exchange.

Why is it important to choose the right connector?

Firstly, connectors ensure reliable electrical and data connections between various onboard systems. With an array of sensors, cameras, navigation equipment, and communication devices, AMVs require a robust and secure network to transmit signals and data. High-quality connectors guarantee stable and uninterrupted connectivity, minimising the risk of signal loss or data corruption, thus enhancing the overall performance and safety of the vehicle.

Secondly, connectors enable modularity and flexibility in AMV design. These vehicles often undergo upgrades, modifications, or maintenance activities to adapt to changing environmental conditions or mission requirements. Connectors simplify the integration and disconnection of different modules or components, allowing for easy replacement, repair, or addition of equipment. This flexibility significantly reduces downtime and maintenance costs, ensuring efficient operation in the field.

Moreover, connectors in AMVs must withstand harsh marine conditions, such as saltwater exposure, temperature variations, and mechanical vibrations. They need to be highly durable and resistant to corrosion and environmental contaminants. By employing robust connectors specifically designed for marine applications, the risk of electrical failures, system malfunctions, and safety hazards can be minimised, enhancing the reliability and longevity of autonomous marine vehicles.

Lastly, connectors play a crucial role in ensuring interoperability among different systems and devices onboard AMVs. These vehicles often collaborate with other platforms, such as satellites, remote control centres, or manned vessels, to exchange information or coordinate operations. Standardised connectors facilitate seamless integration and interoperability, allowing for efficient communication and data sharing, enabling AMVs to operate effectively within a larger ecosystem.

The design challenges

More often than not, connectors are the last thing designers think to consider.

One of the biggest challenges is finding connectors that actually fit as AMVs often have limited space for onboard equipment and subsystems. Not only that, but these vehicles are often taken apart to be retrofitted and refined so it's important that they not only fit but that they are easy to fit and maintain.

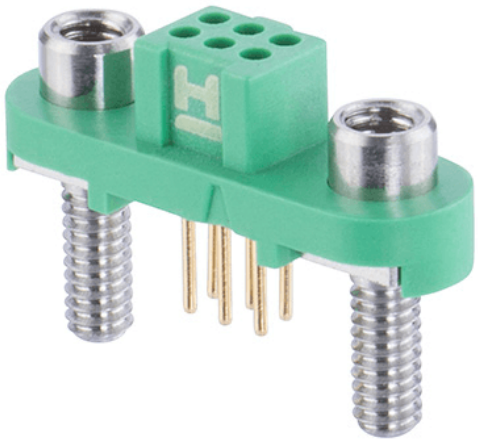
After struggling to find connectors that actually fit, it's not until the final design is complete that they realise they aren't getting enough reliability or durability. As discussed above, AMVs operate in challenging and often remote environments, where accessibility for repairs or replacements is limited. Therefore, the connectors should be designed to withstand mechanical vibrations, shocks, and other physical stresses encountered during operations.

Introducing Harwin's HRi range

High-reliability (Hi-Rel) interconnect solutions from Harwin are suitable for critical applications where high performance and assured dependability are vital.

The portfolio includes the compact and lightweight Gecko, high-density Datamate, M300, and the high-power Kona series. The products in this portfolio can assist designers in overcoming some of those challenges mentioned earlier.

Space and weight:
Gecko delivers a pin spacing of 1.25mm with up to 50 contacts per connector. This design means that G125 connectors achieve up to 45% space saving and up to 75% weight saving over other high-performance connectors.



Gecko

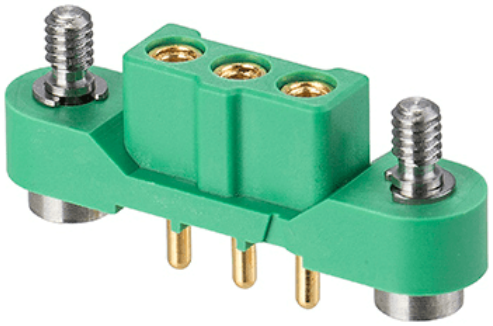
The electrical contact is at the heart of Gecko's performance. Machined contacts are manufactured from solid material, giving them high mass and good electrical performance. The contacts are also gold plated to ensure the lowest possible electrical resistance and high reliability. This construction means that the current rating of the contact is 2 Amps when a connector is fully powered.

Datamate is also small. At just 2mm pitch, with a particularly compact height profile, it fits into spaces other connectors in this class would struggle to accommodate. It is also lightweight but strong. The choice of materials and design means there is no added bulk.

Shock and vibration resistance:

Kona

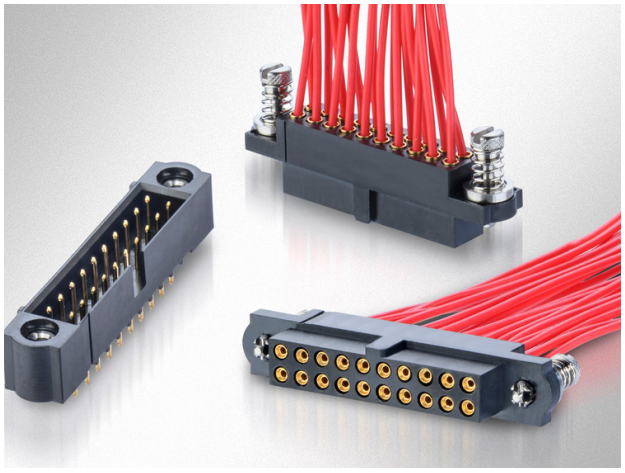
With a maximum voltage rating of 3kV, and a working temperature ranging from –65°C to +150°C, Kona connectors are suitable for deployment in the most difficult of applications environments. These components can handle vibrational forces of 20G for a period of 12 hours. The 6-finger Beryllium Copper contacts prevent any interruption in connectivity.



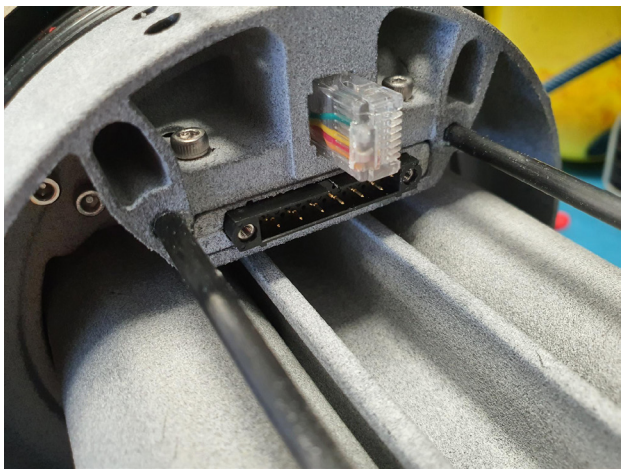
M300

The Gecko and M300 feature a 4-finger patented contact design to maintain electrical contact through high vibration and shock and Datamate has been tested to 10G and 20G vibration tests, and 100G shock (sudden stop).

Assembly and maintenance:



Datamate 101Lok reduces mating/un-mating times when assembling high-rel connectors



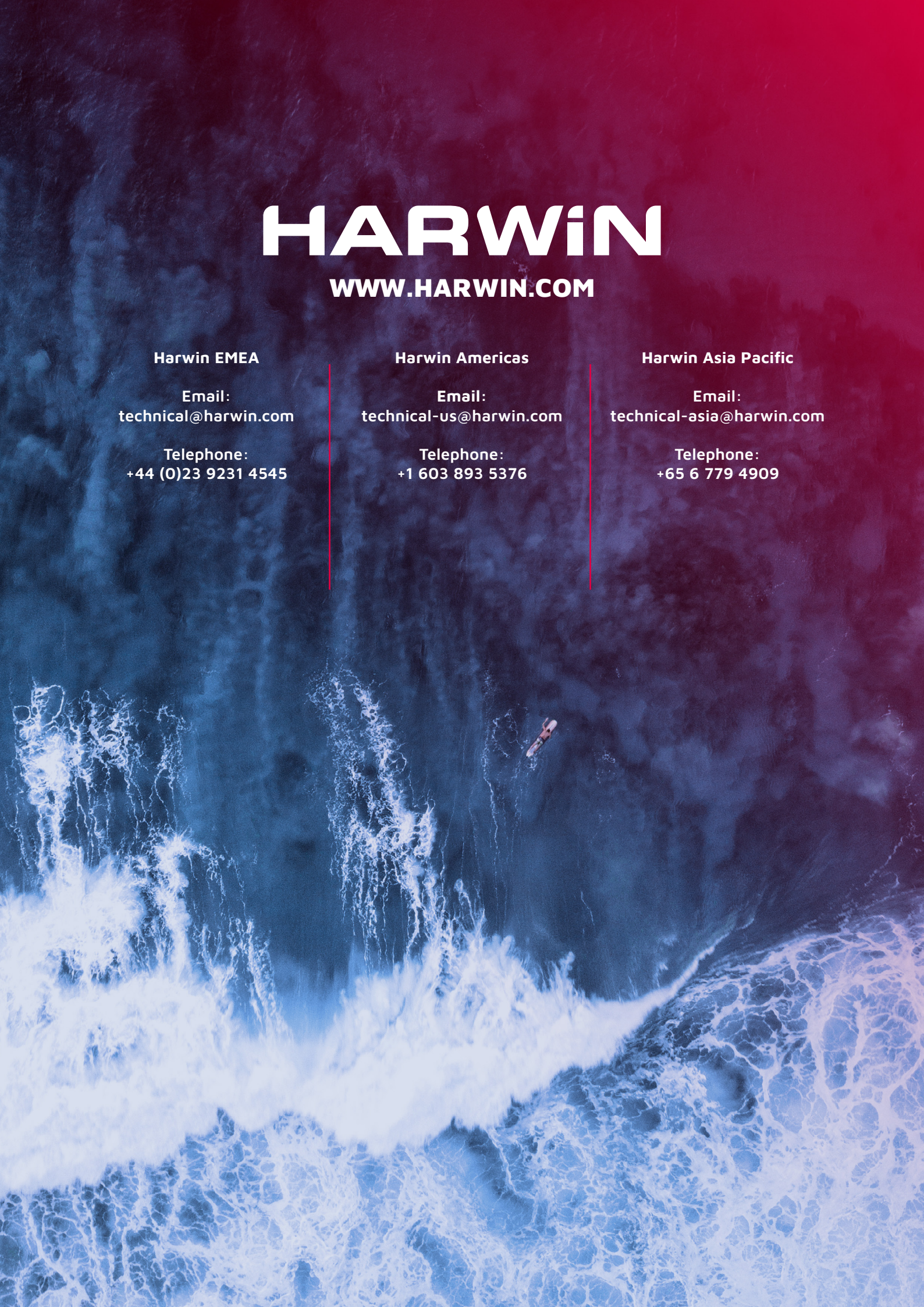
To stop damage to the pins when removing its autonomous submarine's nose cone, ecoSUB Robotics fitted it with guide-pins to prevent misalignment

Designers can cut their assembly time using the 101Lok feature of the Datamate connector series. These use specially designed-hardware tensioned by a coil spring to reduce the time required to mate the connector halves. This is ideal for those users that are seeking a faster means of assembly, whilst ensuring complete security of the retention device. This novel locking feature is also ideally suited to Harwin's mixed technology Datamate Mix-Tek connectors, and also the Datamate Trio-Tek range where high production volumes demand minimal assembly costs.

Datamate connectors require only a simple 'quarter turn' – actually 101 degrees – to ensure complete security of the retention device. The spring tensioning also helps resist vibration in rugged environment applications. These connectors are designed to be very easy to use and require no special tooling. Harwin's Datamate connectors are chosen because they are very rugged and highly resistant to shock and vibration.

Sometimes, designers can experience misalignment during connection – this is especially true if parts are constantly removed. Removable parts can be connected with mechanical guides built into the panels and the housing, this reduces the amount of misalignment that takes place, and the guide-pins can assist with the final connection.

In summary, connectors are crucial components in AMVs, ensuring reliable electrical connections, facilitating modular design, simplifying maintenance and troubleshooting, providing environmental protection, enhancing safety, enabling standardisation, and addressing space and weight constraints. Their proper selection, quality, and design are essential to the overall performance, functionality, and longevity of AMVs.



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