Technology Trends for Future Ships

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Instituto Superior Técnico, CENTEC

- ✔ The University of Lisbon and Instituto Superior Técnico (IST) were founded in 1911
- ✔ In 2013 the **Technical University of Lisbon** (from 1933) merged with the University of Lisbon taking the designation of **University of Lisbon** (50,000 students)
- ✔ IST is the **Engineering School (Faculty)** of the University of Lisbon
- ✔ IST has an academic staff of approximately 650 professors, about 13 000 undergraduate students, and 2,000 PhD students in 3 Campus: Alameda, Tagus Park, Sacavem
- ✔CENTEC is one Research Centre of IST with about 100 researchers

University of Lisbon Main Building

Instituto Superior Técnico Alameda Campus

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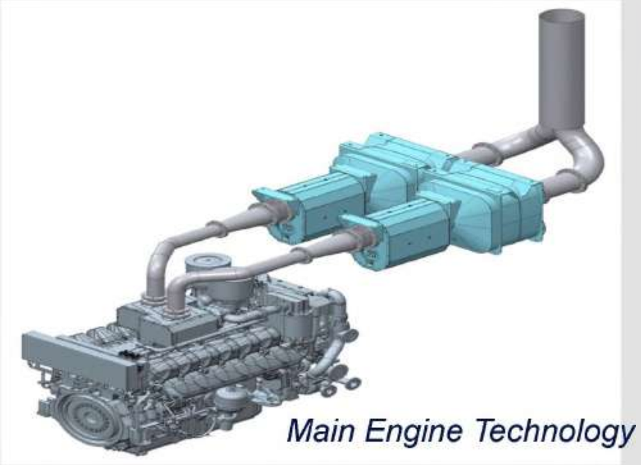
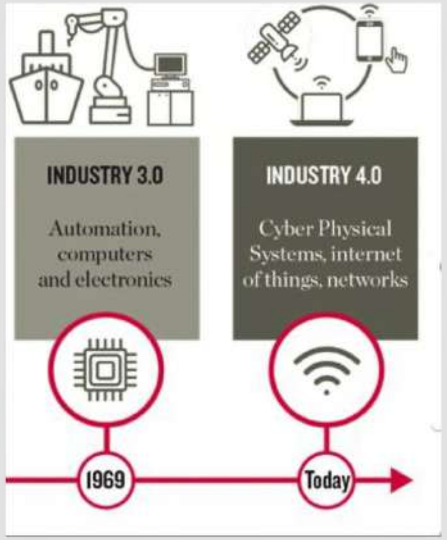
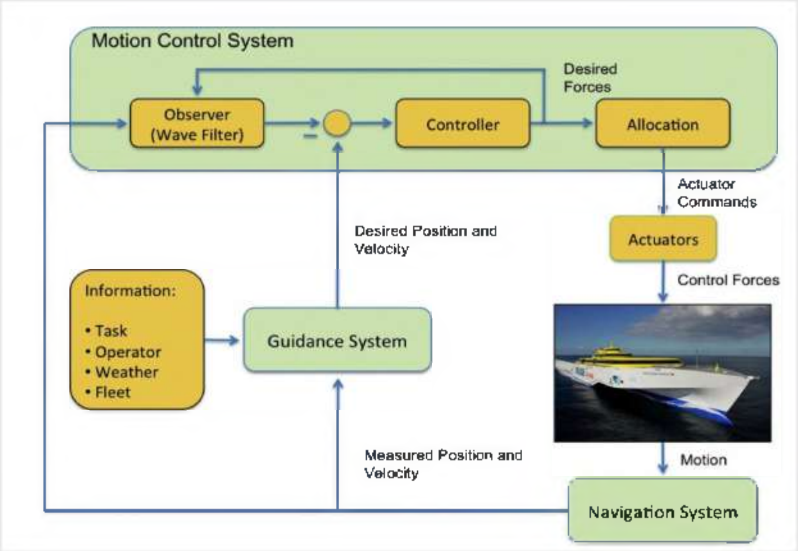


Main Engine Technology

Umanned Vessel control centre



Maritime 3.0 and 4.0



Autonomous Navigation System

Unmanned vessels

Energy transition in the Shipping Industry

GOALS

- Promote energy efficiency trough improved ship performance
- Reduce the greenhouse gas emissions, through technology and alternative fuels

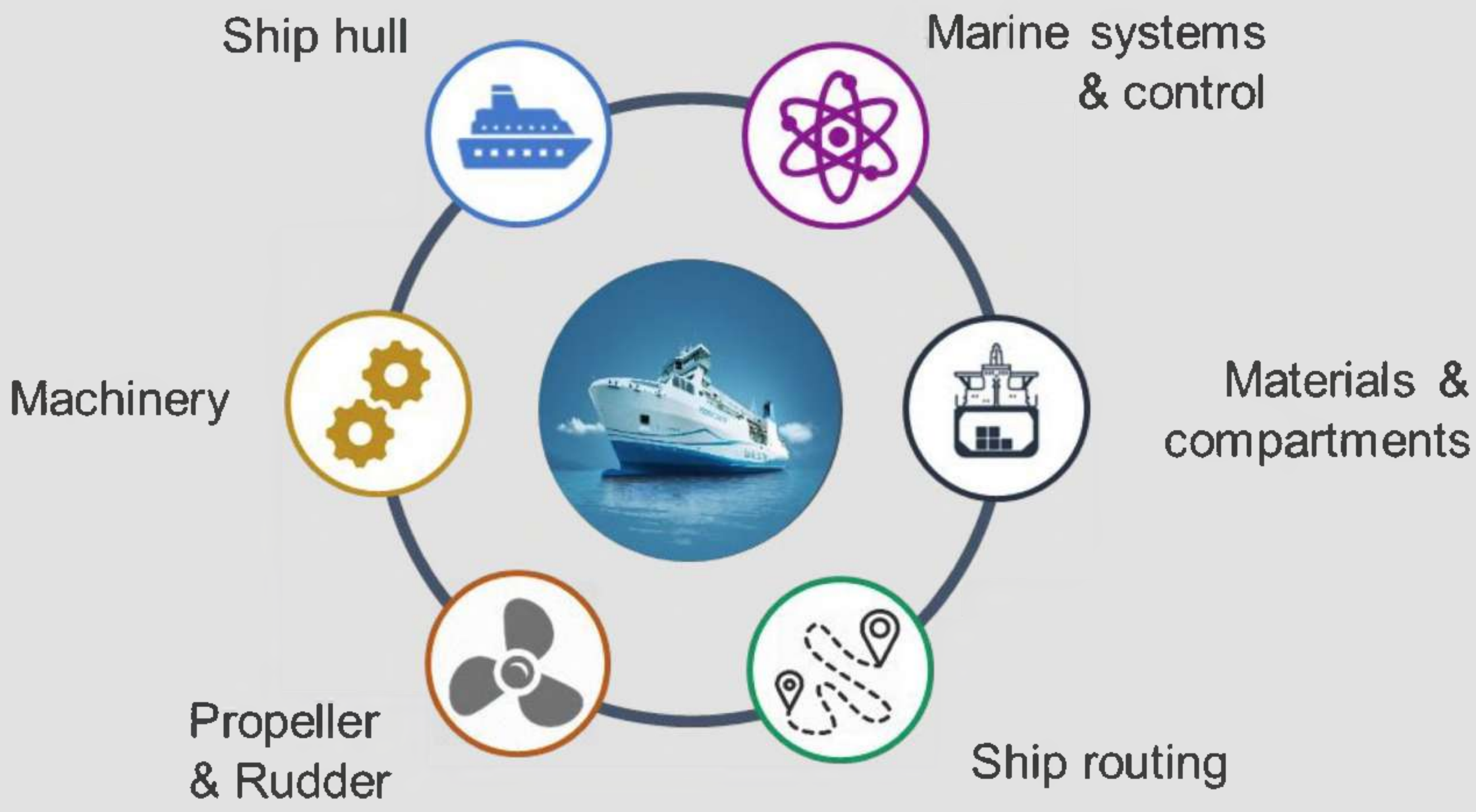
IMO provides

Regulations to reduce exhaust emissions

Indicators to monitor ship performance

Energy efficiency by improved ship performance

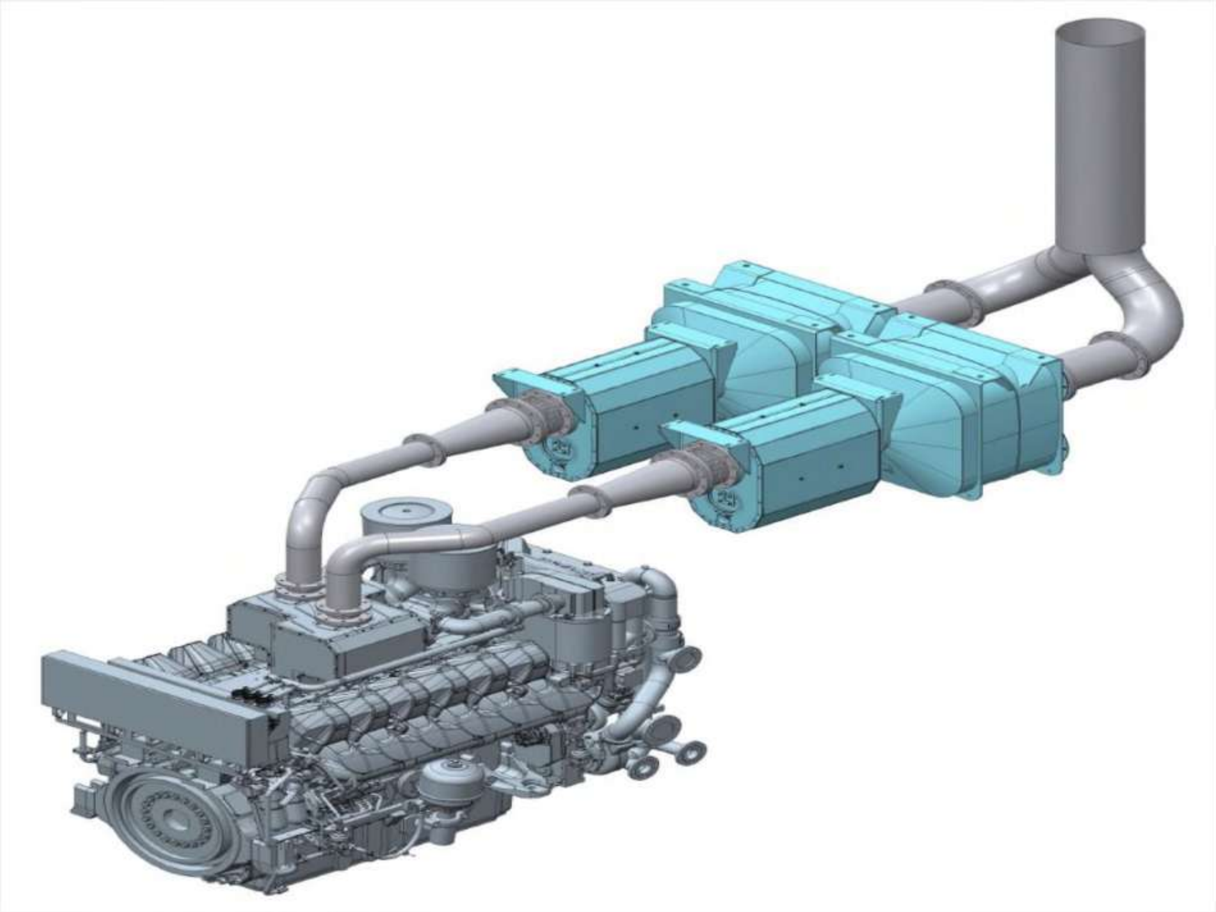
Ship performance improved by design and operational measures



Improved Main Engine Technology

Technology developments in:

- Turbocharger
- Intercooler
- Fuel injection system
- Variable valve timing
- Miller cycle
- Engine compression ratio
- Types of fuels



Ship Weather Routing System

Ship weather routing is a significant operational measure to improved energy efficiency of shipping

- A ship weather routing system is able to optimize the route between two ports minimizing fuel consumption, time of arrival and risk related with rough weather in a trade-off governed by the relative importance given to these goals by the Shipmaster.
- Ship responses are modelled for any sea-state
- Fuel consumption and emissions are calculated for any sea state
- It includes a ship route optimization system based on a robust multi-objective evolutionary algorithm
- The code modularity allows a great flexibility in the treatment of goals, objectives and input.

Vettor, R. and Guedes Soares, C. 2015; Multi-objective evolutionary algorithm in ship route optimization. Guedes Soares, C. & Santos T.A. (Eds.) *Maritime Technology and Engineering*,. London, UK: Taylor & Francis Group; 865-876.
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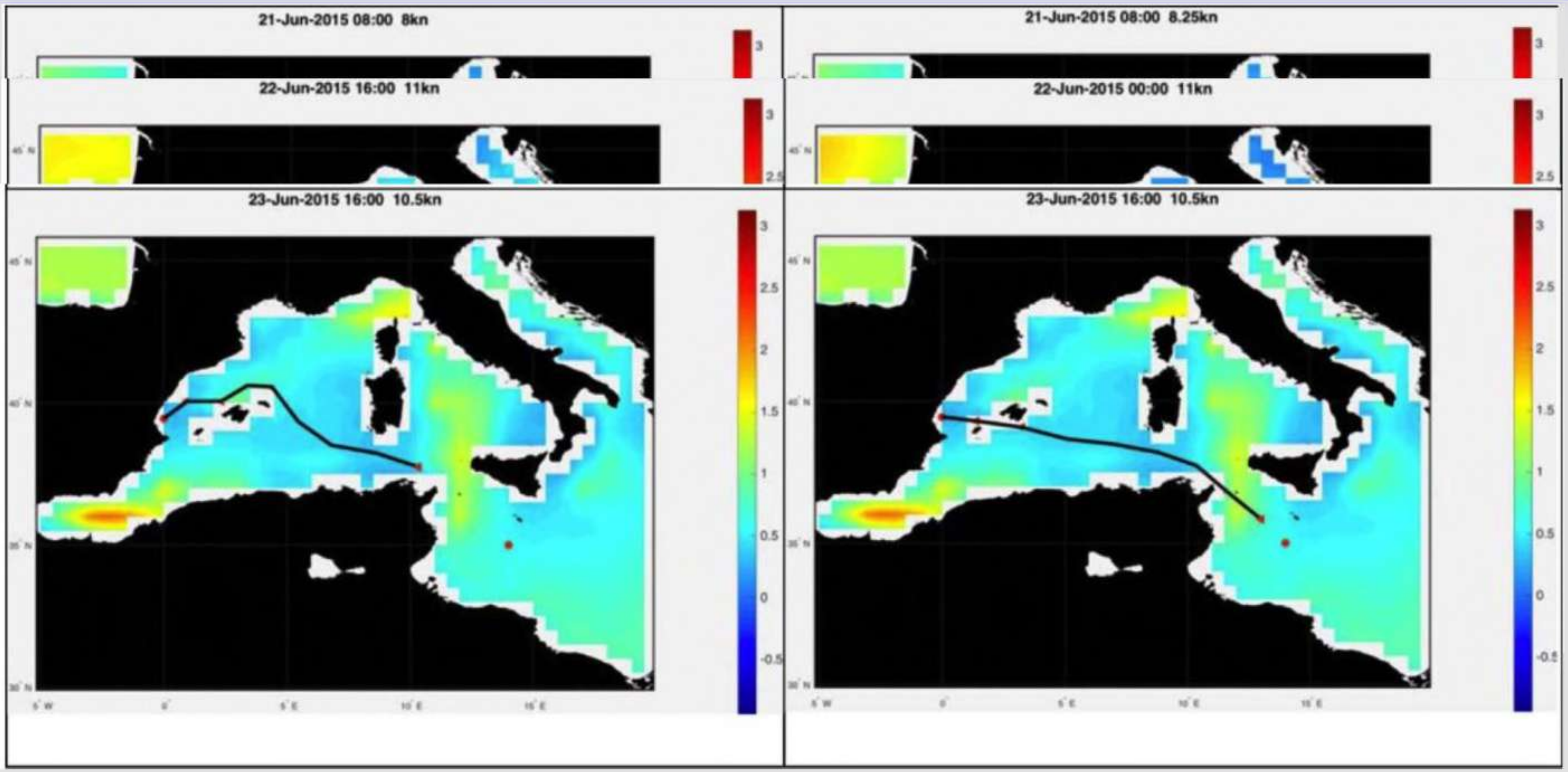
Prpic-Oršic, J.; Vettor, R.; Faltinsen, O. M., Guedes Soares, C. 2016; The influence of route choice and operating conditions on fuel consumption and CO2 emission of ships. *J. of Marine Science and Technology*. 21:434-457.

Ship Weather Routing System Example



Path for the Mediterranean transit of the fishing vessel selected with the two strategies: safest (left) and duration constrained (right).

Vettor, R. and Guedes Soares, C, 2016. Development of a ship weather routing system. *Ocean Engineering*, *123*, 1-14.
Vettor, R. and Guedes Soares, C. 2017. Characterisation of the expected wave conditions in the main European coastal traffic routes. Ocean Engineering. 140, 244-257.

Tools for Energy Transition to Green Shipping

LOGISTICS AND DIGITALIZATION	HYDRODYNAMICS	MACHINERY	FUELS AND ENERGY	AFTER TREATMENT MEASURE
Speed reduction Vessel utilization Vessel size Alternative routes	Hull coating Hull-form optimization Air lubrication Cleaning	Machinery improvements Waste-heat recovery Engine de-rating Battery hybridization	LNG, LPG Biofuels Electrification Methanol Ammonia Hydrogen Harvesting from the surroundings	Carbon capture and storage
>20%	5%-15%	5%-20%	0%-100%	>30%

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Green Navy Fleet

For the Navy, energy efficiency provides:

- **Combat advantage:**
  - Using energy efficiently enables to go farther, stay longer and deliver more firepower.
- **Strategic advantage:**
  - Using alternative fuels creates flexibility and contributes to global gas emission reduction.
- **Force protection advantage:**
  - Using energy efficiently reduces the need of fuel replenishment at sea and reduces the amount of time ships are tied to suppliers, reducing their vulnerability.

Energy Conservation Measures

- **Stern flaps:**
  - Modifies the flow field under the ship's hull to reduce drag and turbulence, thereby reducing overall hull resistance and saving fuel.

- **Shipboard energy dashboard:**
  - Provides real-time situational awareness of energy demand associated with specific equipment. This allows to minimize ship's energy consumption and increase its efficiency while meeting system performance and reliability.

- **Thermal management control system:**
  - Uses a centralized control system and smart programmable thermostats to provide appropriate heating and cooling for each compartment in ships.

Energy Conservation Measures

- **Bow bulb:**
  - Reduces fuel consumption by modifying the shape of the bow to reduce hull wave drag.
- **Combustion trim loop:**
  - Electronic controls which optimize fuel/air mixture to improve boiler efficiency and reduce fuel consumption.
- **Propeller coating:**
  - Reduces corrosion and accumulation of biofouling organisms that create drag.
- .

Energy Conservation Measures

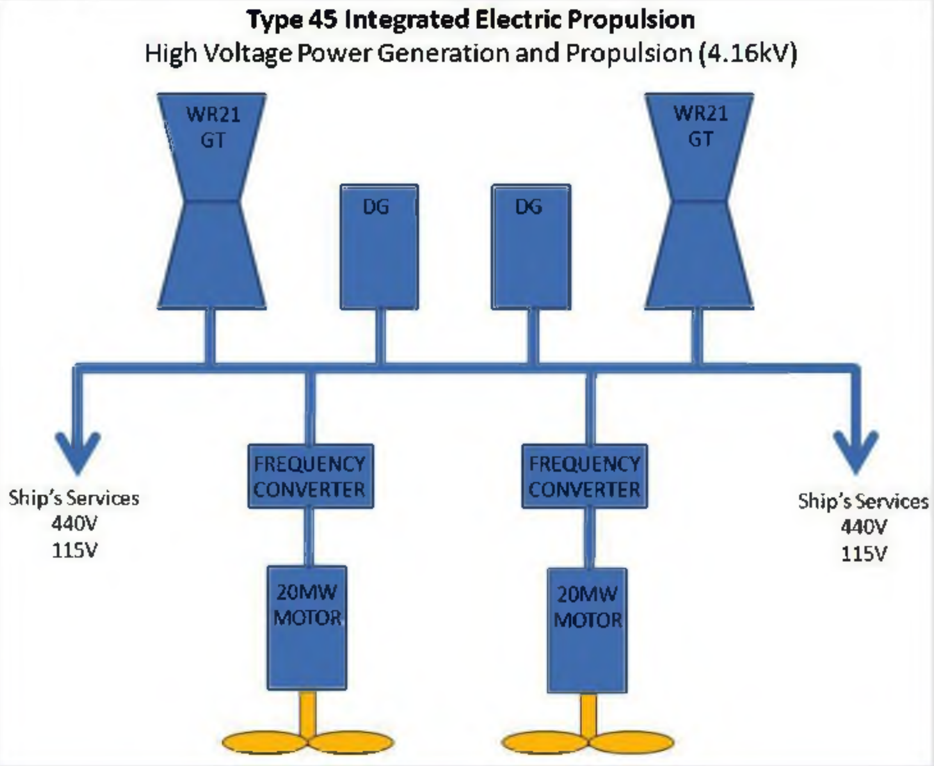
- **Effective propulsion systems:**
  - These systems have to satisfy speed and ship-service power requirements. Unlike commercial ships, naval ships operate in a variety of speeds and electric loads, making fuel consumption optimization challenging. (Pitch propeller can save up to 30% of fuel, thermal engine loading can be reduced, and acceleration time increased by 50%)

- **Waste heat recovery systems:**
  - Another way of ensuring optimum efficiency is to incorporate a waste heat recovery system such as an Organic Rankine Cycle (ORC) so that heat energy from the engines can be recovered. (increase in power output of about 10% and an expected Payback Time of less than 6 years).

Integrated electric propulsion

- **Integrated electric propulsion** (IEP) or **full electric propulsion** (FEP) or **integrated full electric propulsion** (IFEP) are arrangements of marine propulsion systems such that gas turbines or diesel generators or both generate three-phase electricity which is then used to power electric motors turning either propellers or waterjet impellors.

- It eliminates the need for clutches and reduces or eliminates the need for gearboxes by using electrical transmission rather than the mechanical transmission of energy,

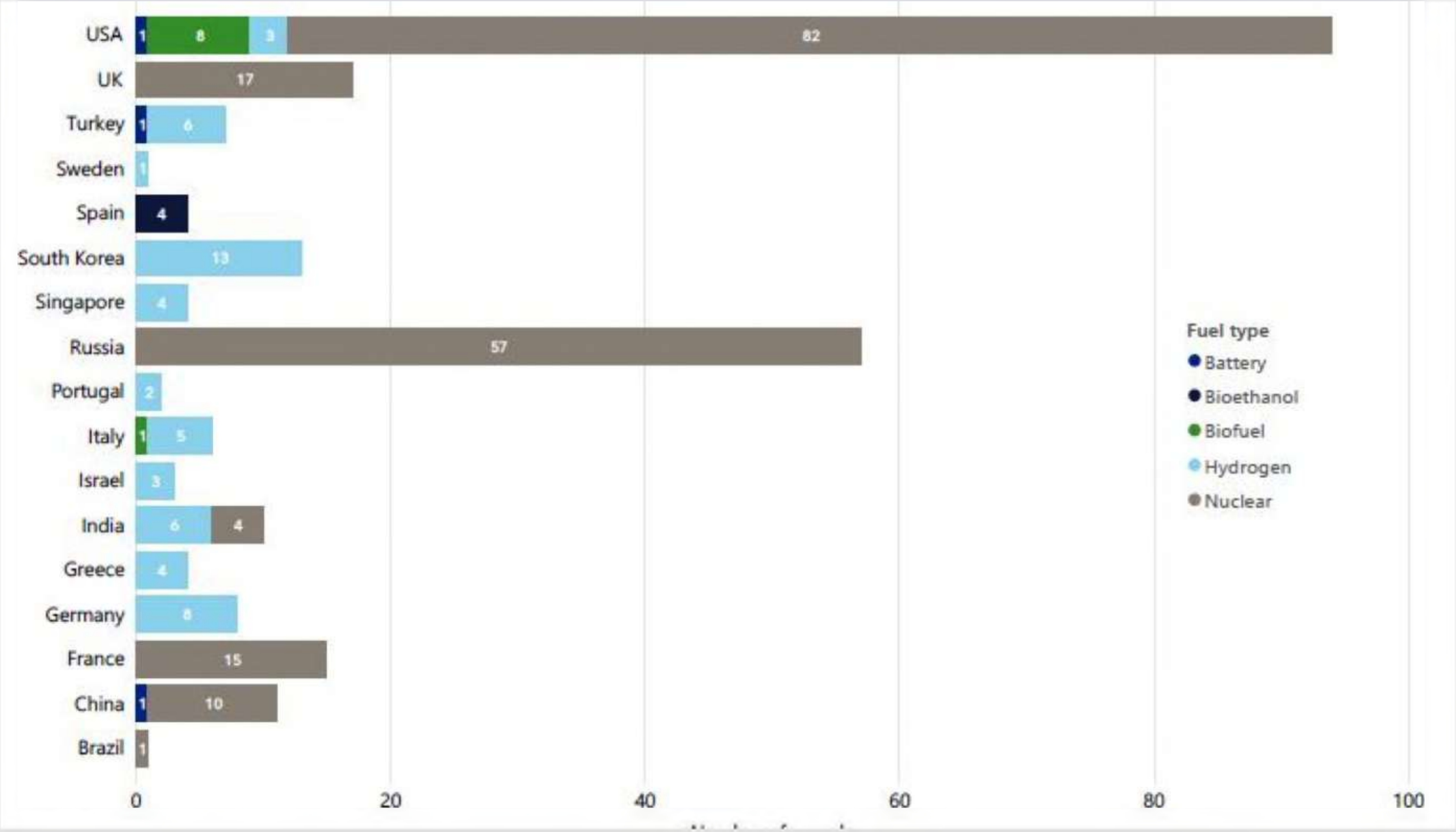


Alternative Fuels

- Alternative fuel includes nuclear power for carriers and submarines, and advanced biofuel.

- Certain biofuels have been certified :
  - "DROP-IN" FUEL
  - purchased at prices competitive with conventional fuels.
  - made from non-food feedstocks including fats, oils and greases, natural gas, coal and wood and plant fibers.

Alternative Fuels



Number of naval vessels that currently utilize alternative fuels in the navy across different countries based on information attained from open-source data

Ref: DnV Alternative Fuels for Naval Vessels, 2022

Technology Trends for Future Ships

- Energy Transition to Green Shipping
- **Digitalisation across the industry**

Digitalisation and Big Data

- **Big data** is the name given to the large volume of data both structured and unstructured that is generated in present days
- In the last decade data availability and usability have changed radically. The ability to store, combine, and analyse these data is now widely available
- The **main drivers** are:
- The price of sensors is falling rapidly and therefore the quantity of devices and equipment that can sense and log environmental factors has increased dramatically.
- The falling prices of processing power and storage space have resulted in the necessary computing power becoming affordable to many more persons
- The development of web technologies and the resulting explosion in social media has generated data about human interactions and interests
- Public institutions, governments, and private companies make datasets, application programming

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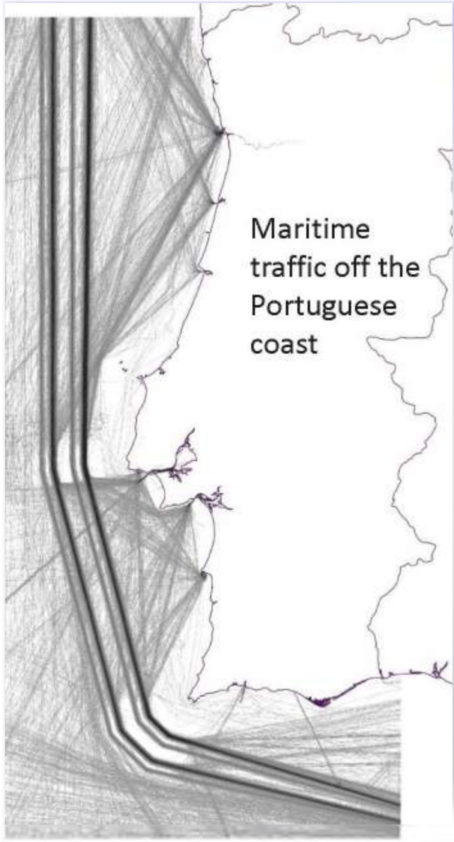
Big Data in the Shipping Industry

- Technical operation and maintenance
- Energy efficiency (cost and environment)
- Safety performance
- **Management and monitoring of accident and environmental risks in shipping traffic**
- Commercial operation (as part of a logistics chain)
- Automation of ship operations (long-term)

AIS data

- The Automatic Identification System (AIS) is an automatic tracking system used on ships and by vessel traffic services (VTS) for identifying and locating vessels.
- The IMO's Convention for the Safety of Life at Sea (SOLAS) requires AIS to be fitted aboard international voyaging ships with gross tonnage (GT) of 300 or more, and all passenger ships regardless of size
- AIS messages, transmitted using VHF radio waves, include: speed; position accuracy; latitude; longitude; course; heading; ship type; length; breadth;
- The AIS messages are transmitted every 2 to 10 seconds depending on the ship speed while underway
- AIS data has become an important source of information for studying maritime traffic and associated risks



Xu, H. T.; Rong, H., and Guedes Soares, C. 2019; Use of AIS data for guidance and control of path-following autonomous vessels. Ocean Engineering. 194:106635
Vitali, N.; Prpiæ-Oršiæ, J., and Guedes Soares, C. 2020; Coupling voyage and weather data to estimate speed loss of container ships in realistic conditions. Ocean Engineering. 210:106758 .

Maritime traffic risk assessment based on AIS data

The introduction of AIS has enabled the collection of large amounts of data on position, speed and course of the ships that have been used in several studies on marine traffic and associated risks, in particular:

- ✔ To characterize the patterns of the maritime traffic in coastal areas ("safe routes", future autonomous ship operations)
- ✔ To analyze routes associated with specific ports and across ocean maritime transportation;
- ✔ To route/ship trajectory estimation using physical or learning based models
- ✔ To develop models to assess maritime transportation risks, such as collision and grounding risks;
- ✔ For automatic detection of abnormal behavior of ships.

Rong, H.; Teixeira, A. P., and Guedes Soares, C. 2019 Ship trajectory uncertainty prediction based on a Gaussian Process model, Ocean Engineering, 182, 499-511.

Rong, H.; Teixeira, A. P., and Guedes Soares, C. 2020. Data mining approach to shipping route characterization and anomaly detection based on AIS data . Ocean Engineering . 198:106936

Rong, H.; Teixeira, A. P., and Guedes Soares, C. 2021; Spatial correlation analysis of near ship collision hotspots with local maritime traffic characteristics. Reliability Engineering and System Safety. 209:107463 .

Rong, H.; Teixeira, A. P., and Guedes Soares, C. 2022; Maritime traffic probabilistic prediction based on ship motion pattern extraction. Reliability Engineering and System Safety. 217:108061.

Big Data Challenges

- **Data swamping**: overwhelming amounts of raw data.
- **ICT infrastructure design aspects**
  - Where to store the raw data – on the vessel or onshore?
- **Data analytics**:
  - converting large amounts of raw data into actionable data suitable for automation or operational decision-making.
- **Data quality**:
  - ensuring the integrity and accuracy of the data. Access control and cybersecurity ensure that the data are protected
- **Lack of standards** for many aspects of the new ship connectivity

Cyber Security in the Shipping Industry

Information Technology

(Financial and reputation risks)

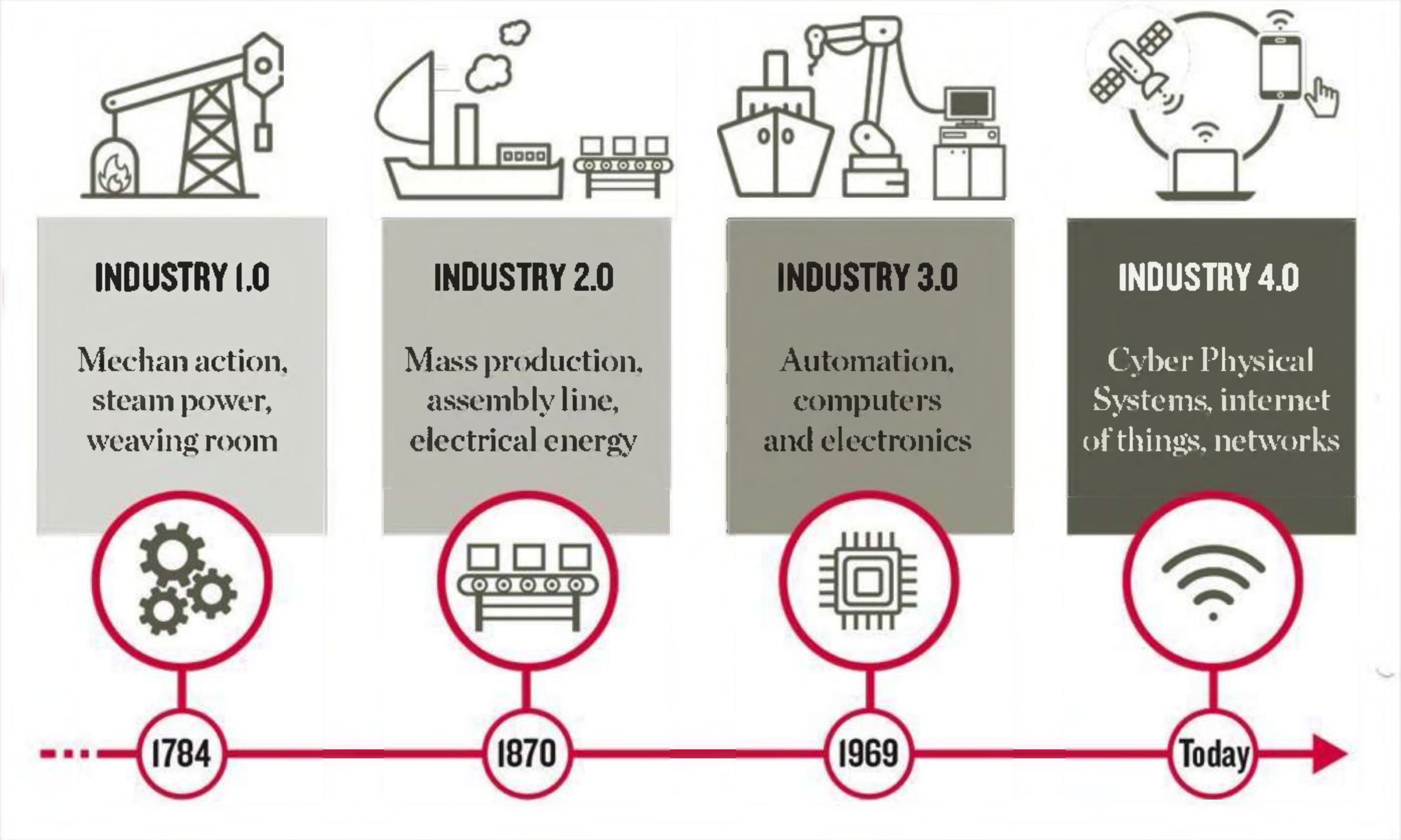
- IT networks
- Administration data, Email
- Spares management
- Electronic manuals
- Charter party, bill of lading

Operation (onboard)Technology

(Life, property, environment risks)

- Navigation and communication
- Propulsion, Thrusters and Steering
- Power generation and Auxiliary systems
- Watertight integrity and Fire Detection
- Ballasting

Maritime 4.0 shapes the digital shipyard of the future



Maritime 4.0 shapes the digital shipyard of the future

- The automated integration of real data into decision making.
- The adoption and implementation of connected technologies for design, production and operation.
- Reduction of vessels' environmental impact, related to production, operation and disposal, including emissions, underwater noise and material utilization.
- Affordable and sustainable operation.
- Reduction of risk, increasing safety and security.

Maritime 4.0 shapes the digital shipyard of the future

- The transformational technologies that are an essential part of industry 4.0, from AI and machine-learning to 3D printing and digital twins, will play a defining role in maritime 4.0 strategies, and taking advantage of these technologies requires digital transformation.

- In 2017 the UK Royal Navy announced project NELSON, specifically designed to deliver digital transformation across the service.

- The US Navy has its Naval Operational Business Logistics Enterprise (NOBLE) project, which will eliminate over 700 database servers and consolidate over 23 currently isolated application systems.

Technology Trends for Future Ships

- Energy Transition to Green Shipping
- Digitalisation across the industry
- **Intelligent Ship Technology**

Intelligent Ship Technology

- **Intelligent Technology** exists to some degree in all ships nowadays
- **Increasing Intelligent Technology** provides the transition to autonomous vessels
- **Automated and Autonomous** ships represent different levels of control
- **Automation** means that a task that has been executed formerly by a human is being executed by a technical system instead.
- **Autonomy** is the ability of a system to make its own decisions and to adapt to the circumstances to achieve the overall goal of the system. This is achieved without additional decisions or input from supervising agents. An autonomous system is automated. However, an automated system is not necessarily autonomous.
- **Levels of automation**, refer to the degree of automation. This implies a certain degree of independent decision making to achieve an overall mission goal. For example a ship may still be manned, while the bridge or the machinery is unmanned.

Present Intelligent Ships

Present Intelligent Ships include several systems:

- Navigation systems, including electronic charts, global positioning systems (GPS), and dynamic positioning systems (DPS)
- Radar and automatic identification systems (AIS)
- Communications systems, including radio communications (terrestrial and satellite) and data communications (broadband, Voice over IP, internet access and e-mail)
- Integrated bridge systems
- Control systems for the wide range of electro-mechanical systems

Evolution of Intelligent Ships

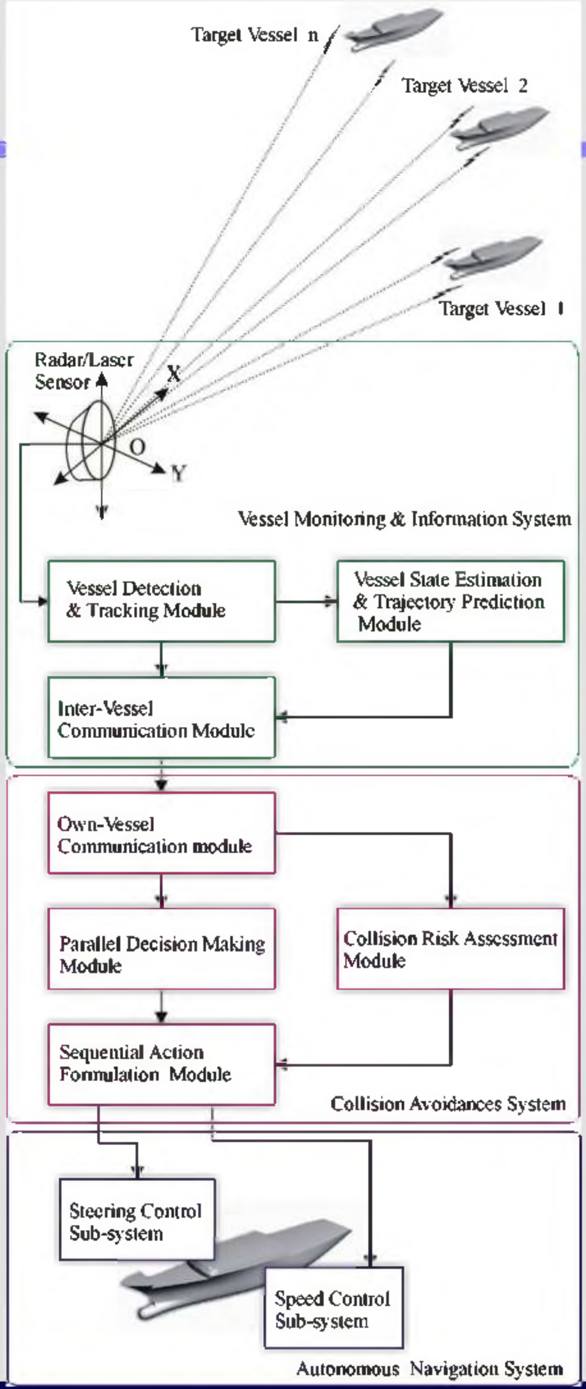
Increased intelligence in ships requires technological and organizational measures:

- integrating systems
- interconnecting system through computer networks
- creating layers of embedded or application software that separate the operator and the ship
- shifting the operator's perception of the ship and its environment, to one defined by human-machine interfaces
- changing the role of the operator to a manager of many linked, complex systems
- enhancing the ability and efficiency of the crew, or changing the organisation of work

Intelligent Navigation System

An Intelligent Navigation System consists of three main systems:

- **Vessel Monitoring & Information System (VMIS).**
  Detection and tracking of vessels and its states estimation and navigational trajectory prediction.
- **Collision Avoidance System (CAS).**
  Parallel collision avoidance decision making and sequential collision avoidance action formulation.
- **Autonomous Navigation System (ANS).**
  Course and speed control systems for a vessel.



Perera, L. P.; Oliveira, P., and Guedes Soares, C. Maritime Traffic Monitoring based on Vessel Detection, Tracking, State Estimation, and Trajectory Prediction. Transactions on Intelligent Transportation Systems (IEEE). 2012; 13(3)1188-1200.

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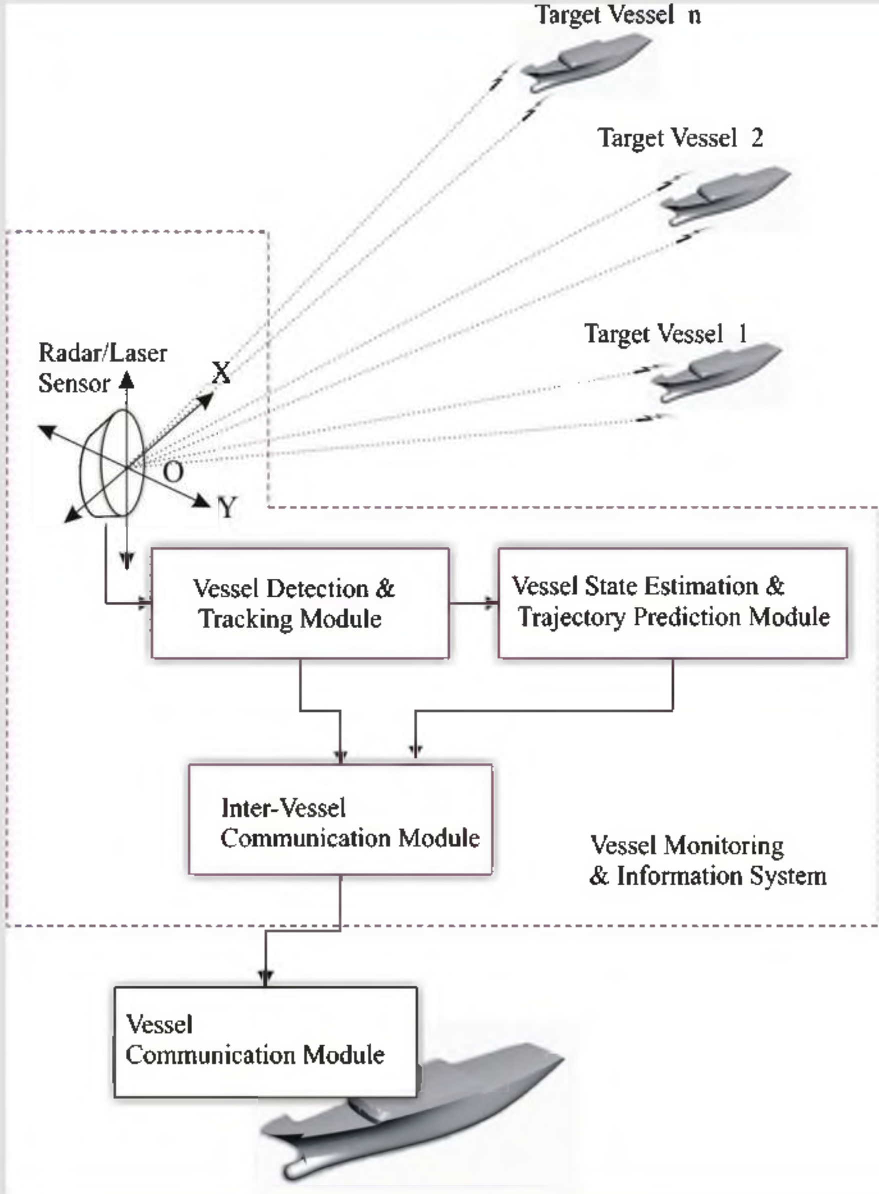
Vessel Monitoring & Information System

VTMIS consists of three main modules:

- **Vessel Detection & Tracking Module:** Artificial neural network based vessel detection and tracking.
- **Vessel State Estimation & Trajectory Prediction Module:** Extended Kalman filter based vessel state estimation and its navigational trajectory prediction.
- **Inter-Vessel Communication Module:** Estimated vessel state information distribution among vessels.

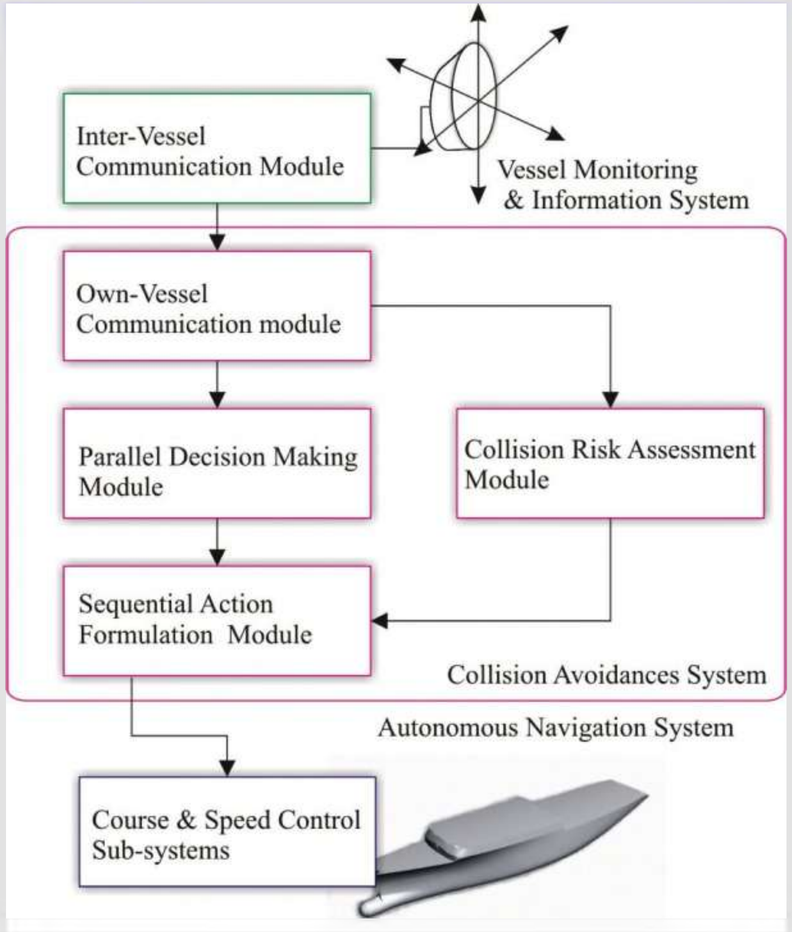
Perera, L. P.; Carvalho, J. P., and Guedes Soares, C. Intelligent Ocean Navigation and Fuzzy-Bayesian Decision-Action Formulation. Journal of Oceanic Engineering (IEEE). 2012; 37(2)204-219.



Collision Avoidance System (CAS)

CAS consists of four main modules:

- **Own-Vessel Communication Module:** Vessel state information collection.
- **Parallel Decision Making Module:** Fuzzy logic based collision avoidance decision making process.
- **Sequential Action Formulation Module:** Bayesian network based sequential collision avoidance action formulation process.
- **Collision Risk Assessment Module:** Relative Course-speed vector and Time and Place until collision estimation.



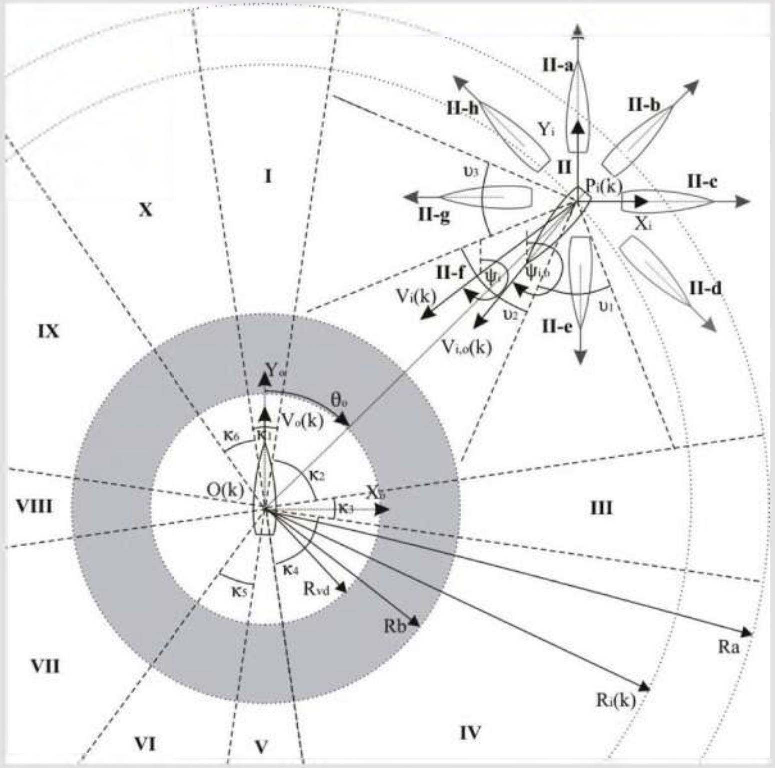
Perera, L. P.; Carvalho, J. P., and Guedes Soares, C. 2011; Fuzzy-logic based decision making system for collision avoidance of ocean navigation under critical collision conditions. Journal of Marine Science and Technology. 16(1):84–99.

Perera, L. P.; Carvalho, J. P., and Guedes Soares, C. 2014; Solutions to the Failures and Limitations of Mamdani Fuzzy Inference in Ship Navigation. IEEE Transactions on Vehicular Technology. 63 (4): 1539-1554

Collision Avoidance Module

Fuzzy logic based parallel decision making process

- The experienced **helmsman actions** in ocean navigation can be simulated.
- **Fuzzy rules** are formulated with respect to the **COLREGs** rules and regulations and expert knowledge on Ocean Navigation.
- Three **distinct situations** involving risk of collision, **Overtaking, Head-on and Crossing**, highlighted by the COLREGs.



Mathematical Foundation

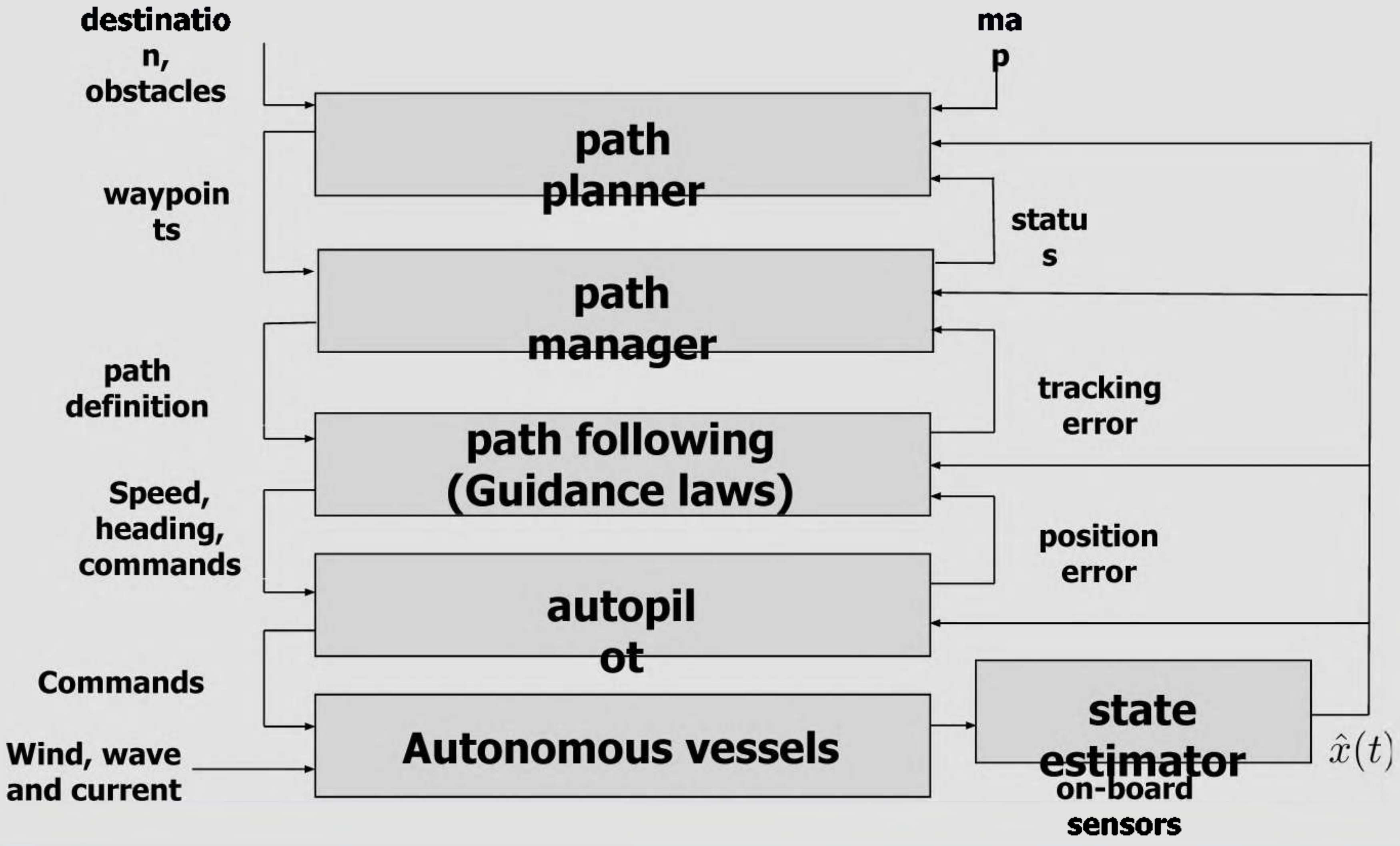
- Own Vessel domain
- Target vessel Range : 3 Regions.
- Own vessel collision regions: 10 regions.
- Target vessel orientation: 8 divisions.
- Relative course-speed vector conditions

Perera, L. P.; Carvalho, J. P., and Guedes Soares, C. 2011; Fuzzy-logic based decision making system for collision avoidance of ocean navigation under critical collision conditions. Journal of Marine Science and Technology. 16(1):84–99.

Zhang, J. F.; Zhang, D.; Yan, X. P.; Haugen, S., and Guedes Soares, C. 2015; A distributed anti-collision decision making formulation in multi-ship encounter situations under COLREGs. Ocean Engineering. 105:336-348.

Autonomous Navigation System (ANS)

Control Architecture for an Autonomous Navigation System



Autonomous Navigation System (ANS)

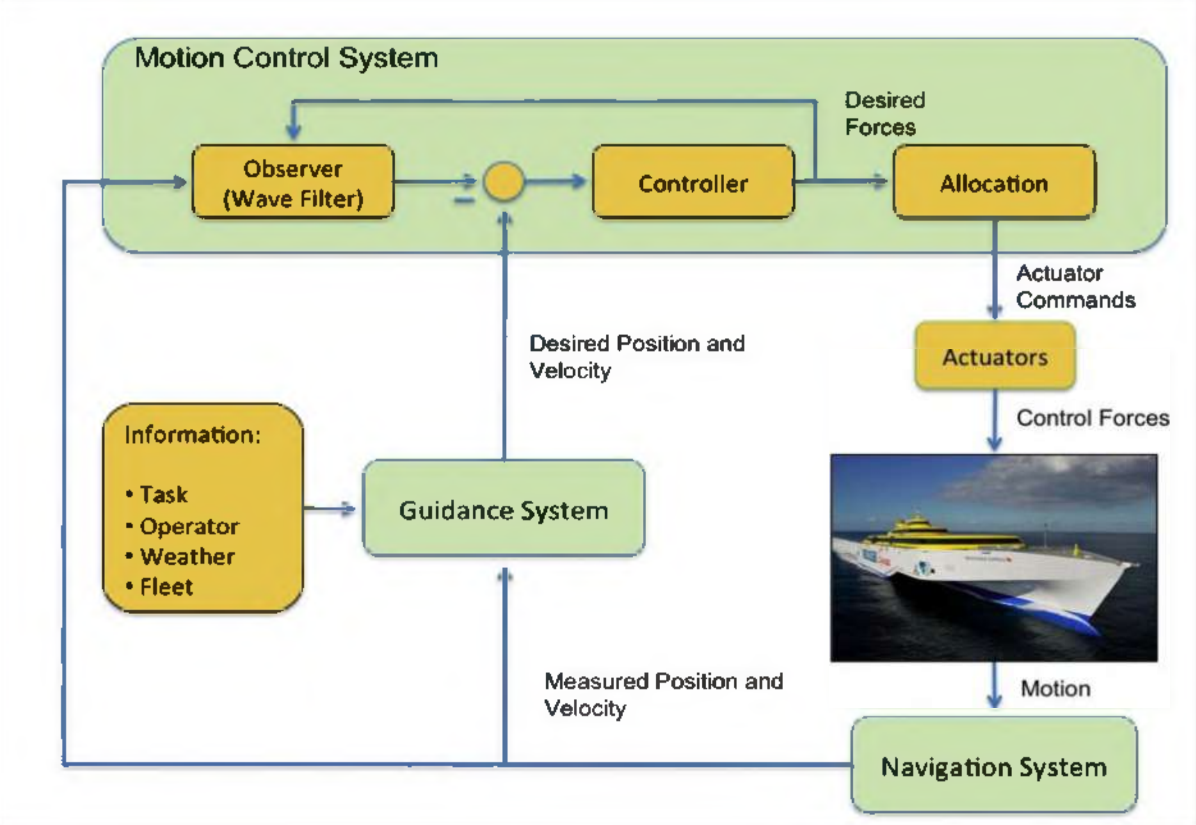
Guidance is the action that continuously computes the reference (desired) position, velocity and attitude of a marine craft to be used by the control system

Guidance* and *control systems consist of:

- ✔ An attitude control system
- ✔ A path-following control system

Basic **attitude control** system: heading autopilot, while roll and pitch are regulated to zero or left uncontrolled.

The **path-following** controller keeps the craft on the prescribed path with some predefined dynamics, for instance given by a speed control system.



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Technology Trends for Future Ships

- Energy Transition to Green Shipping
- Digitalisation across the industry
- Intelligent Ship Technology
- **Unmanned and Autonomous vessels**

Unmanned Surface Vessels

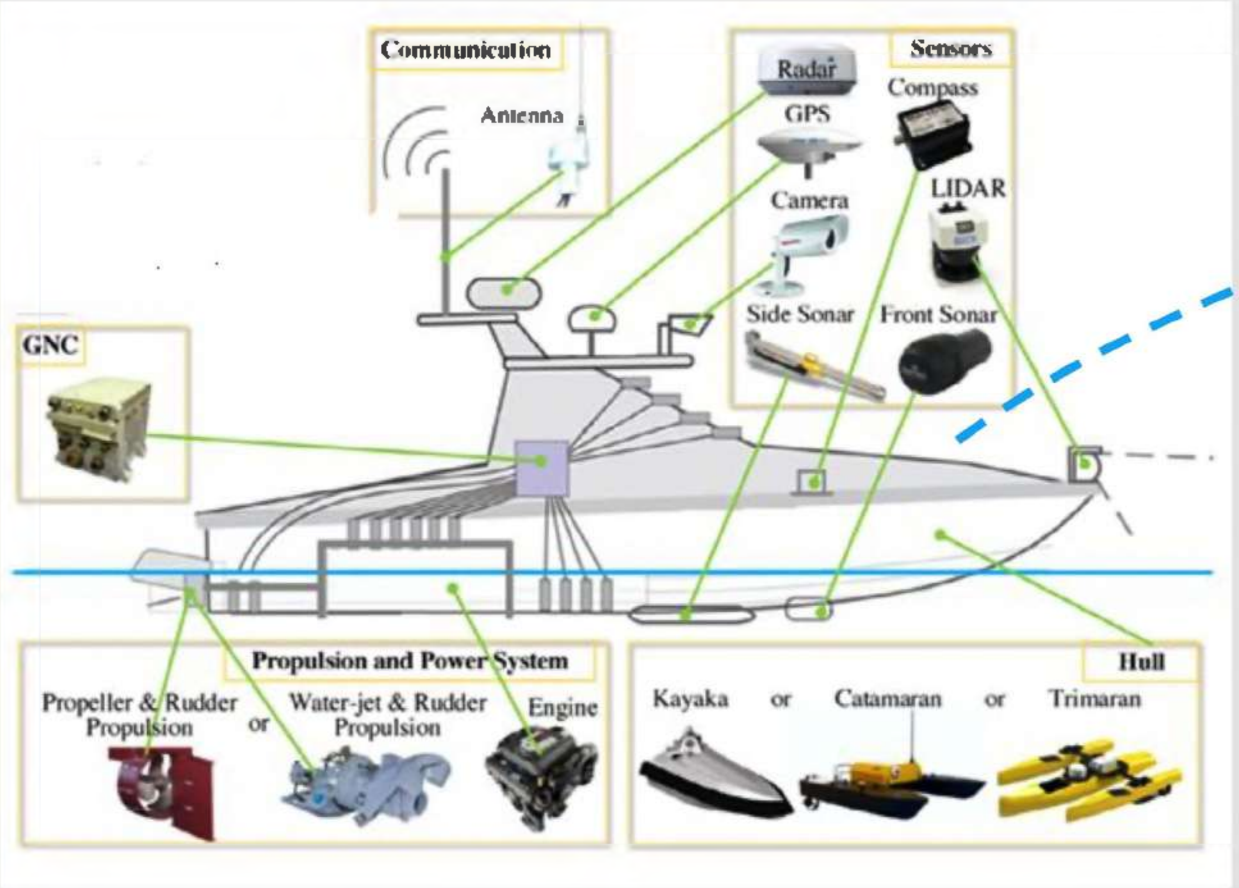
The concept of USV can be found even earlier than World War II, where the Canadians developed the COMOX torpedo in 1944 as a pre-Normandy invasion USV designed to lay smoke during the invasion

For military uses, USV can be particularly suitable for long-duration missions that might tax the physical endurance of onboard human operators, or missions that pose a high risk of injury, death, or capture of onboard human operators—so-called “three D” missions, meaning missions that are dull, dirty, or dangerous.

For example, Port, harbor, and coastal surveillance, reconnaissance and patrolling; search and rescue; anti-terrorism/force protection; mine countermeasures; remote weapons platform; target drone boats

Fundamental architecture of a typical USV

- Hull and auxiliary structural elements
- Propulsion and power system
- GNC (Guidance, navigation and control) systems
- Communication systems
- Data collection system
- Ground station



Development of USVs and applications

- In 1950's **minesweeping** drones gained much attention in the US Navy. A remotely controlled 23-ft fiberglass hull, powered by a V-8 inboard gas engine was used as a minesweeper south of Saigon, during Vietnam War.

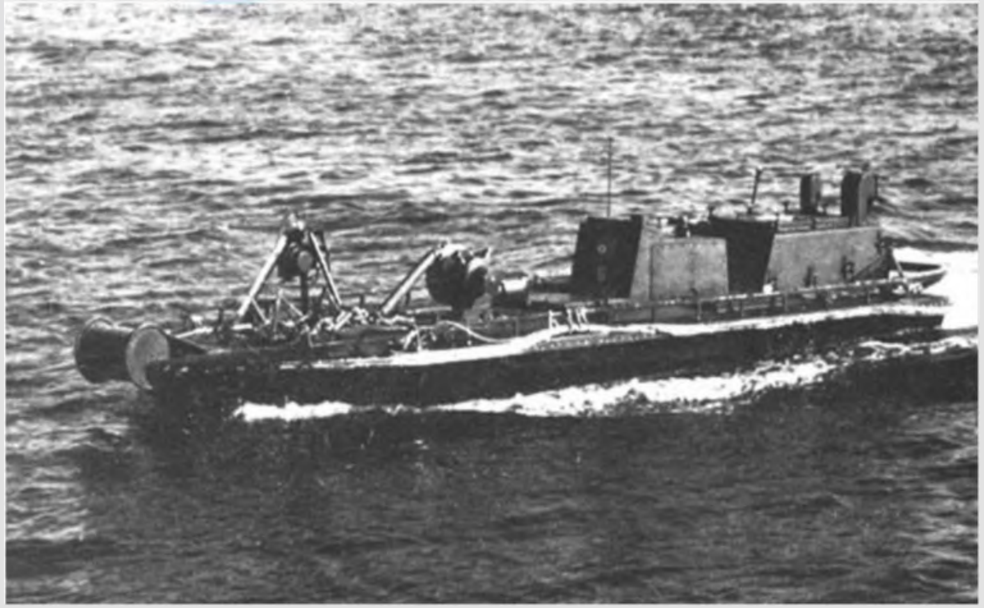


Fig. Minesweeping Drone (MSD)

Fig. RMOP in the Persian Gulf

- In 1997, a Remote Mine hunting Operational Prototype (RMOP) operated for 12 days in mine hunting operations during the SHAREM 119 exercise.

Development of USVs and applications

- The most designs of USV were developed for **reconnaissance and surveillance** missions with the development of the Autonomous Search and Hydrographic Vehicle (ASV) were planning hull with high speed like Owl MK II which are a Jet Ski chassis equipped with a modified low-profile hull for increase stealth and payload capability.

OWL MK II

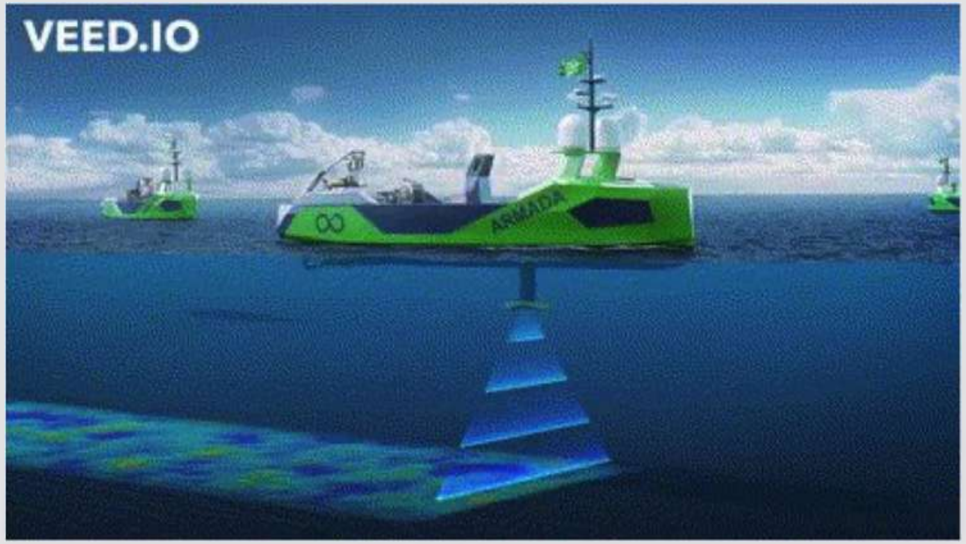
H-class uncrewed surface vessel (USV) by SEA-KIT

- SEA-KIT International revealed its new H-class unmanned surface vessel (USV) for ocean survey, with a design that focuses on hydrography and environmental data collection.

Development of USVs and applications

- Ocean Infinity, a U.S. based marine survey firm developed the world's largest fleet of unmanned surface vessels, Armada
- The vessels will be able to perform offshore data acquisition and intervention in both shallow and deepwater operating regions. The vessels will use a range of underwater platforms, including remotely deploying autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs).
- The first Armada vessel was delivered in 2021 and, along with the remainder of the fleet, will be controlled and operated by experienced mariners via satellite communication from onshore control facilities in Austin, Texas, and Southampton, England.

Fig. Armada by Ocean Infinity



Development of USVs and applications

- The SAM 3 (Self-Propelled Acoustic Magnetic Sweep) is an unmanned surface vehicle developed by SAAB Kockums that can conduct minesweeping operations via remote control or autonomously. The length of catamaran-hulled USV is 14.4 m and it can be disassembled and transported in a 40 foot shipping container.

Fig. . SAM 3 developed by SAAB Kockums

- Raytheon demonstrated the Demo Unmanned Single-Sortie Mine Sweeping for Navy at ANTX 2019.
- Once the sonar detects a possible sea mine, an expendable semi-autonomous mine neutralization unmanned undersea vehicle will be launched into the water from an A-size sonobuoy launcher on the USV, and starts a search track and detonate the mine with a charge.

Fig. Demo Unmanned Single-Sortie Mine Sweeping

Development of USVs and applications

- The Silver Marlin USV developed by Israel is supplied with communication systems and **weaponized** with remotely controlled weapon base beside mission duration capabilities up to 36 hours

The primary application of Silver Marlin USV include surveillance, harbour security, mine sweeping, anti-terrorist warfare, pollution assessment and reconnaissance.

- Israel developed another unmanned remotely controlled surface craft called the Protector characterized by manoeuvrability, stealthy and its ability to perform critical missions with undetected human risks

Fig. Silver Marlin USV

Fig. Rafael's "Protector USV"

Development of USVs and applications

- In 2021, the Republic of Singapore Navy (RSN) deployed new Maritime Security Unmanned Surface Vessels (MARSEC USVs) to complement manned vessels in patrolling and securing Singapore's waters.

- In 2021, Turkey launched the first Armed Unmanned Surface Vehicle (AUSV) program

AUSV is the first prototype platform of the "ULAQ" line, which successfully destroyed the target by firing guided missiles for the first time in the world from an Unmanned Surface Vehicle and completed all tests including the firing tests with the 12.7mm weapon system.

Fig. Singapore Navy's maritime security unmanned surface vessels during sea trials

Fig.Turkey`s First Indigenous Armed Unmanned Surface Vehicle "ULAQ"

Development of USVs and applications

- In March, 2021, The UK Royal Navy officially welcomed a new unmanned surface vehicle (USV), Madfox, into service. Royal Navy experimentation division NavyX will test the Madfox USV while also examining how the vessel can be utilised across a range of military operations including surveillance and force protection.

- In 2022, The French Navy has taken delivery of the lead example of a new type of unmanned surface vehicle (USV) developed under the service's Future Mine Warfare System (SLAM-F) program.

The 12-metre-long USV can be remotely controlled from shore or another vessel, though it can be programmed to sail through pre-determined waypoints. Operations are possible even under conditions of Sea State Four.

The first USV will undergo further testing. The French Navy expects the system to achieve initial operational capability by 2024.

Fig. Madfox in UK Royal Navy

Fig. Artemis USV in French Navy

Development of USVs and applications

- Swedish Navy Tested Saab Enforcer III Unmanned Sea Vessel (USV). It is a converted Combat Boat 90, equipped with navigation and communication systems, sensors, cameras and lasers for navigation.

It is an exceptionally fast and agile boat that can execute extremely sharp turns at high speed. Its lightweight, shallow draught, and twin water jets allow it to operate at speeds of up to 40 knots (74 km/h) in shallow coastal waters.

- In June, 2022, China's first domestically developed 200-ton-class USV, characterized by its capabilities in stealth and far sea operation, has wrapped up its first autonomous sea trial.

The vessel has a length of more than 40 meters and a trimaran design. It has a top speed of more than 20 knots, can carry out tasks undersea state 5, or rough waves, and can sail safely undersea state 6, or very rough waves.

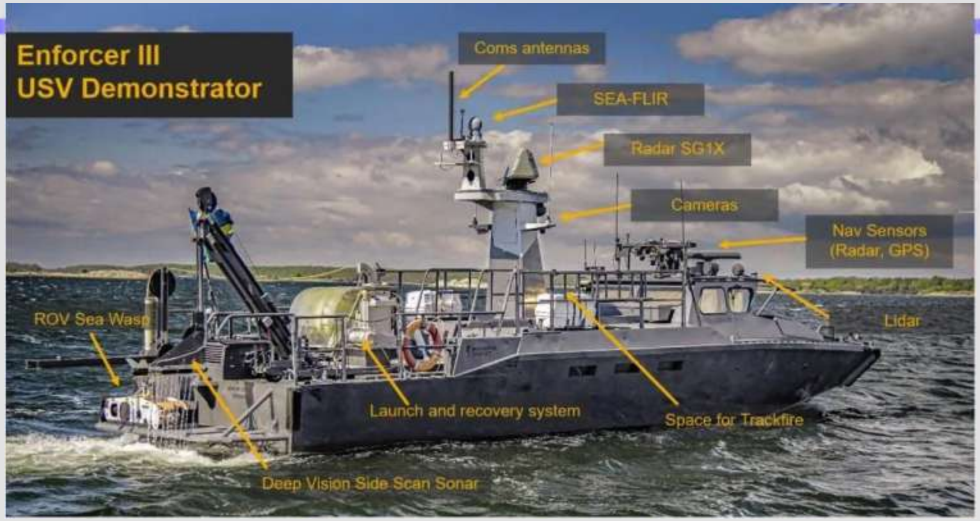


Fig. Swedish Navy Tests Saab Enforcer III Unmanned Sea Vessel (USV) During Exercise

Fig. First Chinese 200 ton-class USV

Development of USVs and applications

- According to the US Navy's proposed Fiscal Year 2023, the US Navy wants to develop and procure three types of large **unmanned vehicles** (UVs) called:
  - Large Unmanned Surface Vehicles (LUSVs),
  - Medium Unmanned Surface Vehicles (MUSVs)
  - Extra-Large Unmanned Undersea Vehicles (XLUUVs)
- The Navy wants to acquire these large UVs as part of an effort to shift the Navy to a more distributed fleet architecture.

Sea Hunter MUSV

LUSV Prototype in 2020

Currently, the MUSV and LUSVs prototype has been delivered to the US Navy and tested, Such as, sea hunter MUSVs, Nomad and Ranger LUSVs

Overlord USVs Ranger & Nomad on the West Coast

LUSV Prototype in 2020

Development of Swarms of USVs and applications

- Currently, the swarms of Unmanned Surface Vessels are used for complex tasks in large ocean areas, such as seabed surveying, maritime search and rescue, material transportation, and target protection.
- Since it is difficult to rely on one single USV to complete the task, multi-USV cooperatives can be a good solution to the problem.
- Compared to a single unmanned surface vehicle (USV), the multi-USV system has numerous advantages, such as high robustness, fault tolerance, good adaptability, and high efficiency of task execution.
- A typical coastal defence scenario with multi-USV cooperation is presented in the Figure

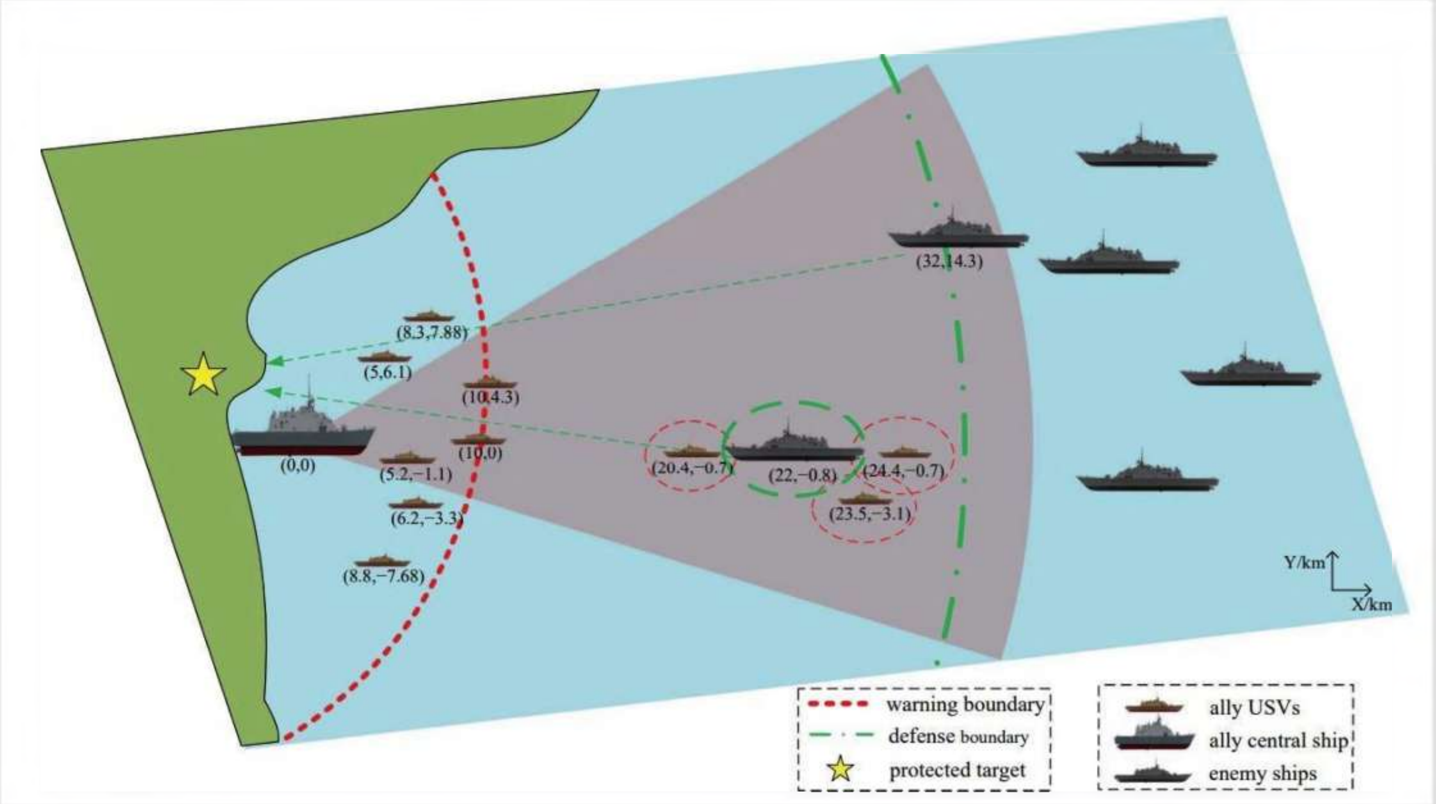


Figure A typical coastal defence scenario with multi-USV

Development of Swarms of USVs and applications

- In June 2020, XOCEAN completed a wide area bathymetric survey in the eastern Irish Sea. Multiple USVs were used to complete the 422km2 survey in depths ranging from 10m to 30m. Survey activity was carried out in a variety of conditions up to Sea State 5.
- During June, XOCEAN completed the survey of 37 wind turbine foundations on the 576 MW Gwynt Y Môr offshore wind farm on behalf of Innogy Renewables UK, and high efficiency of task execution.

Fig. Unmanned Seabed Survey of Offshore Wind Farm

Fig. Multi-USV for bathymetric survey

Development of Swarms of USVs and applications

- iXblue's DriX USV, along with its efficient launch and recovery system, is a seasoned asset in the environment of supervised autonomy. DriX offers outstanding seakeeping and speed capabilities. It is a versatile and efficient USV that can host a wide range of payloads and that offers optimum conditions for high quality data acquisition in both shallow and deep waters.
- In the right video, the two DriX USVs were remotely operated from the inshore Control Center near Paris. The both USVs can be conducting surveys in two different locations, embarking different payloads and using different survey navigation software.

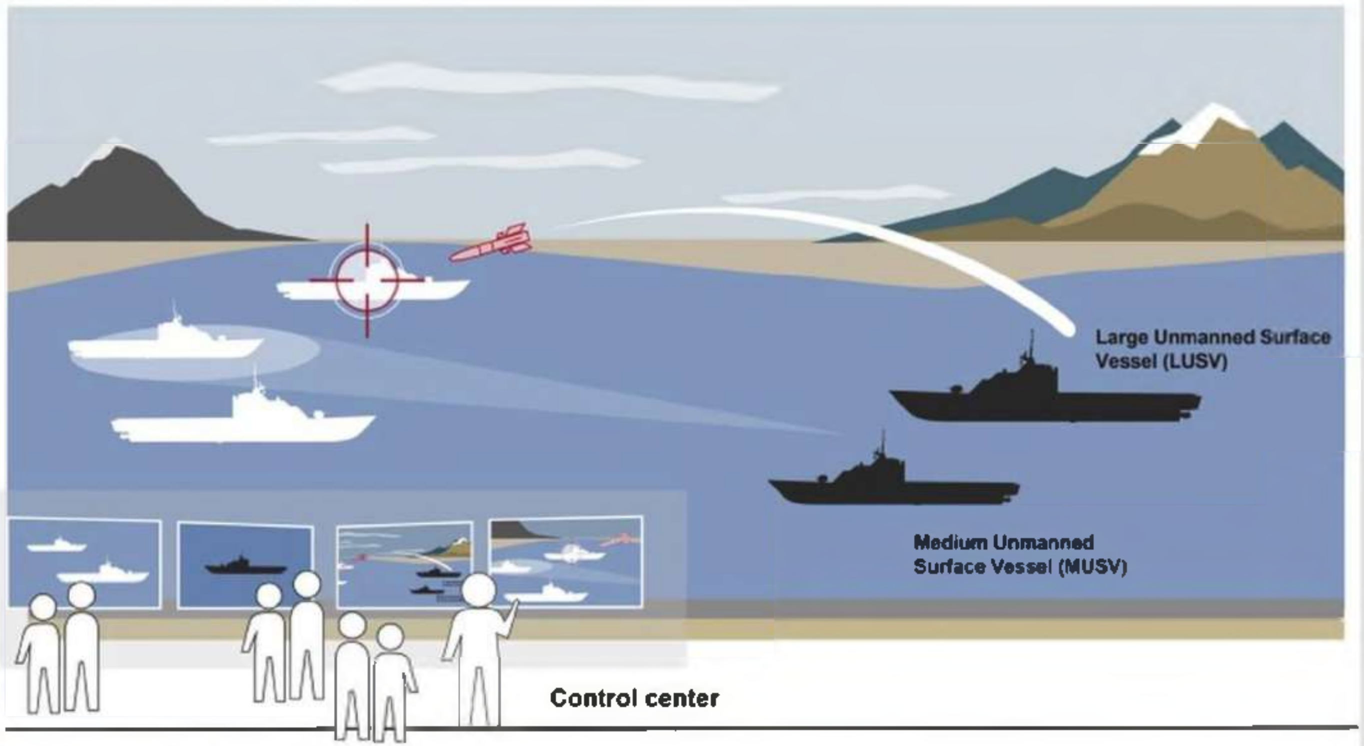
Fig. iXblue's DriX USV

Fig. Multi DriX USV

Development of Swarms of USVs and applications

- U.S. Navy is developing unmanned surface and undersea drones to augment the fleet of the future, the information technology and artificial intelligence that will drive these platforms remains a work in progress.
- A Government Accountability Office image shows how Navy unmanned surface vehicles will contribute to the fight of the future. (GAO)

Figure 3: Notional Uncrewed Surface Vessel Operational View



Source: GAO analysis of Navy documents. | GAO-22-104567

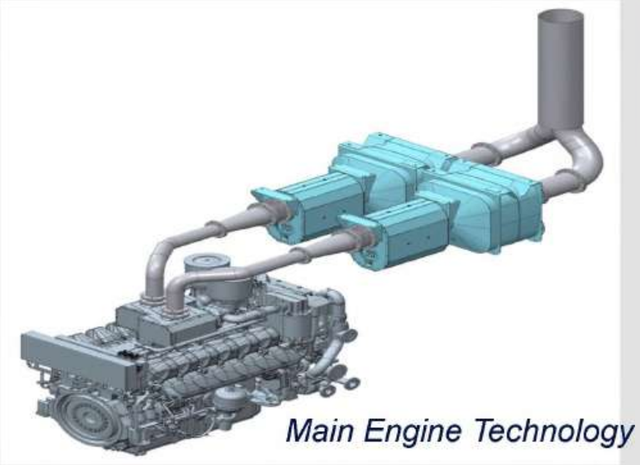
Figure 1: Selected Navy Uncrewed Maritime System Prototyping Efforts

Vehicle	Acquired by	Notable demonstrations/events	Prototype quantity	Potential missions
Sea Hunter/Seahawk Medium Displacement Unmanned Surface Vessel  Source: U.S. Navy/Petty Officer 2nd Class Thomas Gooley. | GAO-22-104567	Defense Advanced Research Projects Agency/Office of Naval Research	• June 2018 naval exercise with a reconnaissance payload • September 2020 exercise incorporating advanced autonomy and perception • April 2021 exercise with classified payload	2 delivered 0 planned	• Support MUSV and LUSV development
Overlord Unmanned Surface Vessel  Source: U.S. Navy/Institute | GAO-22-104567	Department of Defense Strategic Capabilities Office /Uncrewed Maritime Systems Program Office	• October 2020 and April 2021 mostly autonomous transits from Gulf Coast to West Coast for both available prototypes • December 2020 naval exercise with electronic warfare payload	2 delivered 2 scheduled for delivery by fiscal year 2023	• Support MUSV and LUSV development
Large Unmanned Surface Vessel (LUSV)  Source: U.S. Navy | GAO-22-104567	Uncrewed Maritime Systems Program Office	• September 2019, Navy awarded six conceptual design studies worth $42 million • Following fiscal year 2021 budget, the Navy decided to delay procurement	0 delivered Plan to transition program to major capability acquisition	• Surface warfare
Medium Unmanned Surface Vessel (MUSV)  Source: U.S. Navy | GAO-22-104567	Uncrewed Maritime Systems Program Office	• In July 2019, Navy awarded a $35 million fabrication contract to L3 Harris, with delivery expected in the second quarter of fiscal year 2023	0 delivered 2 planned Up to 7 on contract	• Multi-mission asset due to interchangeable payloads, such as surveillance and electronic warfare
Snakehead Large Displacement Unmanned Undersea Vehicle (LDUUV)  Source: U.S. Navy | GAO-22-104567	Uncrewed Maritime Systems Program Office	• Initiated in 2012 as an acquisition program, but designated an accelerated research and development effort in 2017 • Government-led prototype to be delivered in fiscal year 2022 • Request for proposal for two industry prototypes issued in 2021	1 under construction 2 planned in short term	• Multi-mission asset due to interchangeable payloads, such as surveillance and electronic warfare • Planned to launch from a submarine
Orca Extra Large Unmanned Undersea Vehicle (XLUUV)  Source: U.S. Navy | GAO-22-104567	Uncrewed Maritime Systems Program Office	• March 2017, Navy awarded a $274 million contract to Boeing • First XLUUV delivery delayed approximately 21 months until September 2022 due to ongoing production issues	0 delivered 5 under construction Up to 4 on contract Plan to transition program to major capability acquisition	• Modular payloads for seabed warfare

Source: GAO analysis of Navy documents. | GAO-22-104567

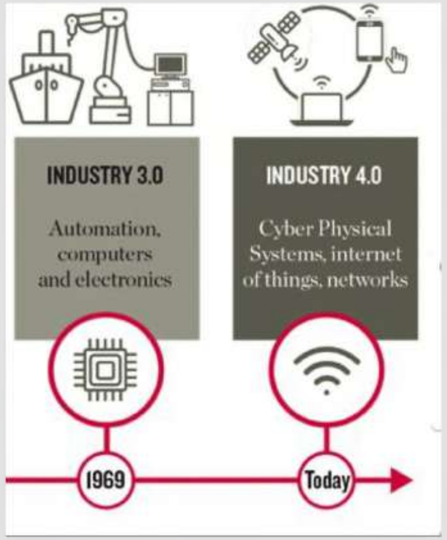
Conclusion

1. Energy Transition to Green Shipping
2. Digitalisation and Big Data
3. Intelligent Ship Technology
4. Unmanned and Autonomous vessels

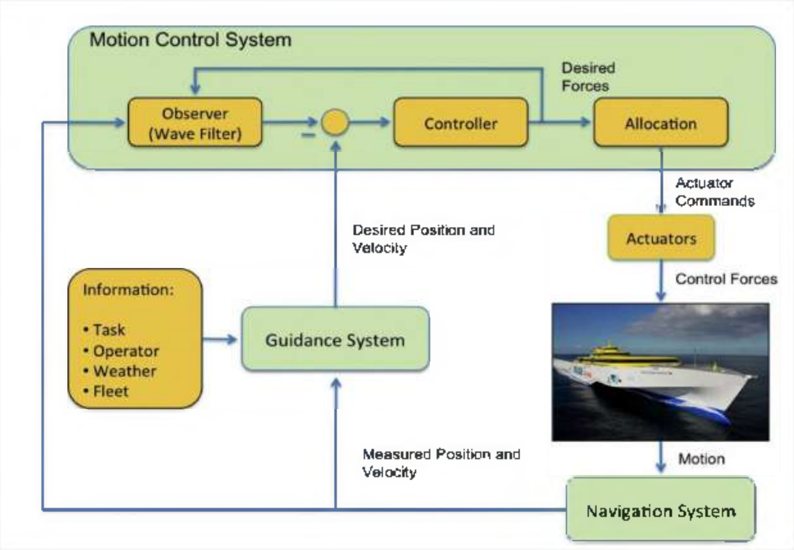


Main Engine Technology

Umanned Vessel control centre



Maritime 3.0 and 4.0



Autonomous Navigation System

Unmanned vessels

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Thank you for your attention

Technology Trends for Future Ships

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