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Autonomous Underwater Transportation using Multiple HAUVs
F. U. Rehman, G. Thomas and E. Anderlini, University College London, UK

Though the underwater transportation is not an efficient mode of transportation due to the increased underwater drag resulting from higher density and viscosity of water compared to air, however, underwater transportation could be advantageous in certain circumstances such as to avoid detection of a military payload, to follow a shortest possible route or to get accuracy by avoiding interaction with the sea waves. This paper uses multiple Hovering Autonomous Underwater Vehicles (HAUVs) which operate at slow speeds but highly stable and accurate. The vehicles are considered rigidly connected to a payload via solid manipulators. To analyse the behaviour of the combined system, a nonlinear coupled dynamic model is developed using the Newton-Euler formulation keeping in consideration the inertia, Coriolis, hydrodynamic, hydrostatic and thrust terms. The hydrodynamic parameters are calculated using semi-empirical approach. The vehicles are neutrally buoyant, however, the difference between weight and buoyancy of payload is below the thrust limit of the vertical thrusters to enable motion of the system in every direction. Time-domain motion simulation is carried out for the combined system using the 4th order Runge-Kutta method. The system is found to be unstable due to the inconsistent operation of thrusters on individual vehicles to move the combined system in a specific direction. Therefore, a centralized control system is designed using PID controllers. A minimum snap trajectory is generated, and the control system is applied to follow it. At lower PID parameters, the trajectory is not followed as desired, however, it gets better at higher parameters.

Towards autonomous ships - Flag State involvement and regulatory aspects
C. Balls, Cayman Registry, UK

IMO interim guidelines for MASS trials – MSC.1/Circ.1604 – which makes clear that Flag States have prime responsibility for the safe operation of MASS. The four main pillars of Maritime Regulation are considered ; SOLAS; MARPOL; STCW; MLC.Other relevant conventions are; ILL; AFS; COLREG; BWM. There is currently a scoping exercise going on at IMO, however, the most relevant areas to autonomous ships would appear to be; SOLAS and COLREGS. STCW and MLC considerations will be very relevant during a transition to completely unmanned ships. Smaller vessels (especially under 24m L) are regulated to a lesser extent, although codes, such as the Caribbean Small Commercial Vessel Code, are intended to provide standards for Internationally trading small vessels and already mention some of the considerations for MASS. There already exists provision for Alternative Design, Exemptions and equivalences in various
conventions. Paper will explore, in more detail, some of the issues related to moving towards B0 such as; Single Man Bridge operations – have previously been proposed but did not receive sufficient support at IMO. Optical advances may make this more acceptable in the near future. Initially, one-man bridge – with the lookout replaced by sensors which could reduce the footprint of the bridge with improving aerodynamics and/or space utilisation. The bridge would be moved to somewhere else on board to free up space. This is the principal of the trials phase with Yara Birkeland. Eventually fully autonomous navigation decision making, but widespread use of this will be some time way.

Data Analytics to increase autonomy in ship systems
R. TAN Peihao, Defence Science and Technology Agency, Singapore

“There is a vast amount of data available on board vessels, which may prove overwhelming for operators to digest and analyse, especially during emergencies where less obvious critical components may be left out. Data analytics can be used in Fleet Management Systems (FMS) to autonomously examine system data, perform correlation, and present the analysis and system health in dashboards to facilitate decision-making by the ship commanding officer. Developed predictive models can also be used to pre-empt defects before they occur, allowing the system to be rectified before deployment, and allow spares to be provisioned for rectification at sea. In the future, improved comprehensiveness in ship system health assessment with data analytics could allow for controls to be automated based on system parameters, increase the autonomy of ship systems, and reduce the cognitive workload of operators.”

A Review on Digitalization of High Speed Craft
A. Dashtimanesh, Estonian Maritime Academy, Tallinn University of Technology, 11712, Tallinn, Estonia
J. A. Mehr, Australian Maritime College, Australia
S. Tavakoli, The University of Melbourne, Australia

Golbal demands for cleaner and more environmental friendly ships has led to dramatic changes in the industry. Digitalization is part of the solution. Recent autonomous ship market analysis shows that during past years, the main focus has been on digitalization of larger ship types such as tankers and container ships. Although several autonomous high-speed crafts (HSCs) have been developed, there are only a few studies on digitalization of HSCs. Because of the nature of HSCs and its applications in a large variety of activities such as fishing, leisure, patrolling and rescuing, it seems that HSCs cannot be fully autonomous. However, there are a number of systems and subsystems that can be digitalized onboard of HSCs. Moreover, new technologies may be implemented on HSCs that leads to improving both fuel efficiency and Safety. In fact, partial automation segment has been taken into account for the largest share of the autonomous ships market in 2018 due to the increasing demand for automation systems in commercial and naval ships. Therefore, it will be reasonable to tackle digitalization of HSCs by partial automation. The current paper aims to study the literature related to digitalization of HSCs and performs a study on various parts of small HSCs that can be digitalized. This paper also discusses the related challenges and opportunities. The concluding remark answers these questions that what the future trends will be, which systems may/can be digitalized on HSCs and what the effects of digitalizion on HSCs operation are.

Possible COLREGs Failures in Autonomous Ship Navigation
L. P. Perera, UiT The Arctic University of Norway, Norway

Autonomous ship navigation in a mixed environment, i.e. remote-controlled, autonomous and manned vessels are interacting, is considered in this study. In general, these vessels can have various encounter situations and adequate knowledge on such situations should be acquired by the same to take appropriate navigation actions. That has often been categorized as situation awareness and appropriate tools and techniques to improve the knowledge on such ship encounter situations should be developed to avoid possible ship collision and near-miss situations. The collision risk assessment can play an important role in situation awareness due to the same reasons and that information can eventually be used towards the respective collision avoidance actions.
Ship collision avoidance is regulated by the International Regulations for Preventing Collisions at Sea 1972 (COLREGs) in open sea areas and additional local navigation rules and regulations can be enforced especially in confined waters and maritime traffic lanes. However, these collision avoidance actions will be interpreted by both humans as well as systems in future vessels, therefore adequate understanding on situation awareness should be achieved to overcome possible collision or near-miss situations. This study focuses on identifying such challenges in future ship navigation in a mixed environment and possible solutions to overcome ship collision and close encounter situations due to the respective collision avoidance actions that are taken by onboard humans as well as systems in future vessels. Furthermore, additional regulatory modifications that should be introduced to improve the safety of future ship navigation have also been considered under this study.

Autonomous Ship: Manoeuvring, Control and Navigation in Laboratory Environment
A. C. Dubey, V. A. Subramanian, P. Krishnankutty, Indian Institute of Technology Madras, India

The development of the autonomous ship needs prior knowledge of the hydrodynamic motion behavior and stability in external wave conditions. Such studies can be classified under the two main areas of i) Sea keeping ii) and Maneuvering. Both studies involve knowledge of stability, motion and control. Knowledge of ship steering dynamics is required to evaluate the manoeuvrability and for the design of the autopilot and navigation system. This paper presents the study of the control, navigation and communication protocol in the laboratory environment by simulating different ship manoeuvres, in calm and wave conditions, using free running ship model. The developed autonomous on-board system equipped with main computer, suitable electronics, sensors, data acquisition system and Wi-Fi based communication system. The Wi-Fi based communication between shore station and the ship model facilitates the user to access the data over any web browser making it independent of operating system and enables to do Internet of Things (IOT). Various steering control designs such as PID, LQR and adaptive steering controllers are simulated and compared on a mathematical model obtained from standard manoeuvring tests. A range-based navigation technique by fusing the on-board sensor and range measurement from other ship models is investigated to enhance the capability of the autonomous ship towards group control. A preliminary physical simulation in the laboratory environment is performed to verify the communication protocol and the model response in different wave conditions.

Remote Region Search & Rescue Response - do Autonomous, Remotely Controlled, and Optionally Manned Vessels have a Role to Play?
J. Dalziel, R. Pelot, Dalhousie University, Canada

The technology supporting Autonomous and Remotely Controlled vessels has developed rapidly in recent years. These vessels are becoming much more capable, safe, and affordable. In addition, the Regulatory Regime is evolving to sanction their operation.
Unmanned Surface Vessels (USVs) are already under evaluation, and in service, for military and oceanographic / survey applications. Unmanned vehicles, land and air, are making inroads into Search and Rescue (SAR) response.
USVs could play a significant role in Maritime SAR response, particularly by providing SAR resources in locations where these would otherwise not be available. Many nations, such as Canada, the United States, Russia, New Zealand, Australia, Chile and many others, are responsible for large Search and Rescue Regions (SRRs). Many of these Regions include large areas with low traffic densities, but which are remote from rescue resources.
Building on previous presentations over the past three years to the World Maritime Rescue Congress (2019), RINA Surv 9 Conference (2018). Transport Canada MASS Workshop (2018) and others, this presentation explores how USVs could fulfill roles in an integrated SAR response system for Remote Regions. It will outline relevant Unmanned / Autonomous technologies, their advantages and disadvantages, operational and technical hurdles and solutions. In particular, it will explore SAR resource needs, and provide a Cost-Benefit analysis, and one or more Case Studies where these technologies could improve the rescue response, potentially saving lives and reducing environmental pollution risks.

The Effect of Sea Currents on Autonomous Underwater Transportation using Multiple HAUVs
F. U. Rehman, G. Thomas and E. Anderlini, University College London, UK

This paper focuses on the effect of sea current on autonomous underwater transportation using multiple vehicles. A nonlinear coupled dynamic model is developed to resemble the actual system of multiple Hovering Autonomous Underwater Vehicles (HAUVs) connected to a payload through solid manipulators. The Coriolis terms are included for the rigid body mass and added mass, to get the effect of the rotation of the body-fixed frame about the earth fixed frame. The hydrostatic parameters are calculated from weight and buoyancy of the individual bodies, whereas, the hydrodynamic parameters are calculated using the semi-empirical approach. The thrust allocation matrix is developed by taking the effect of all the thrusters installed on the contributing HAUVs. All the parameters are taken about a combined centre of body i.e. the centre of the payload, to get benefit from the geometric properties. Time-domain motion simulations are initially carried out without any external disturbances to verify the motion responses at different thrust inputs. Sea current effects are then included at different velocities. At low sea current velocity, the disturbances to the motion response are small which are reasonably adjusted by the application of PID controllers in 6DOF. However, at higher current velocities, the effects are massive which requires higher PID gains.

Numerical and experimental results towards the design and development of a novel variable buoyancy system for autonomous underwater vehicle
T. Brijkishor, Indian Institute of Technology Madras, India

Autonomous Underwater Vehicles/ Gliders (AUVs/Gs) are applicable for the underwater survey both in coastal area and deep sea without human intervention during their operations. However, their high energy consumptions required by the AUVs' thrusters for their maneuverability adversely affect their performance and endurance, etc. Herein, we present numerical and experimental results towards the design and development of a novel variable buoyancy system for autonomous underwater vehicle. Our design idea is 'Pump Driven Variable Buoyancy System (PDVBS)' and our results show that it is an energy efficient system for an excellent maneuverability. We focus especially on the vertical motion, forward and heave motion of the vehicles. Detailed performance analysis is presented along with the integration of the PDVBS with AUV's design. Results are presented for the design of 5 kg buoyancy +-B capacity with a diaphragm type PDP at maximum buoyancy change rate of 4.0 kg/min.

Challenges of mission planning for collaborative maritime autonomy
S.R.Turnock, H.S.Hoang, E.Rogers, S. J. Johnston, J.Downes, University of Southampton, UK
B.Pritchard, Thales, UK

It is expected that that a key part of a future with ever increasing use of maritime autonomous systems will require collaborative and integrated working. How approaches to such collaborative working can be developed and tested was part of Integrated Mission Management System 2019 (IMMS2019) project. The immediate objective was to demonstrate the ability to use a single mission management system to control a fleet of heterogenous autonomous platforms whereby their collaborative mission could be planned, verified and delivered. In order to challenge the various spatial-temporal-energetic-communication-environmental constraints when operating such a fleet, real-world demonstration trials were carried out in Plymouth sound deployed from the Thales Marine autonomy centre at Turnchapel wharf. The trials were focussed on ensuring that the control of the mission was secure and robust and that the need for human intervention was minimised. The trials were based on use of a 12 m rib that acted as the mobile command centre, a C-CAT3 Autonomous surface vessel, a fixed wing autonomous aircraft, and a pair of EcoSub autonomous underwater vehicles.
The proposed paper will describe the development of a series of software-based systems to create and plan missions, to validate that mission constraints at the planning stage are not violated and to provide real time monitoring capability of the performance of each vehicle. The use of the actual maritime environment helped expose the practical issues that such vehicle-vehicle collaborations face alongside the practical issues of ensuring that all vehicles were operated safely and could not pose a hazard to other marine or air traffic.
The successful completion of the trials provided essential information into how such collaborations can be best executed alongside invaluable lessons as to how existing platforms need to enhance their interoperability and in particular, robustness of communications and mission plans.

MARLab: Data Support for UK Design and Testing of MASS
R. Blazejczyk, Solis Marine Consultants, UK

The UK continues to lead within the international Maritime Autonomous Surface Ships (MASS) industry with a significant number of companies, universities and other institutions either researching, developing, building, regulating, operating or in some other way supporting their adoption. The Maritime and Coastguard Agency, in collaboration with the Department for Transport and the National Oceanography Centre, are delivering a project to support the UK's smart and autonomous vessel industry.
This paper summarises the work carried out in the past 12 months to examine how data gathered and held by the government can support the design and testing of autonomous marine systems in the UK. The work has been conducted by a team of naval architects and data specialists at Solis Marine Consultants and Maritrace who have developed an online data sharing portal to make around 20 different data sets available to access by MASS developers and operators for mission planning and operation in the test site of Portland Harbour. Data sets include AIS, bathymetry, meteorological data, vessel movements and a hydrographic data.

Paving the Way towards Autonomous Shipping development for European Waters - The AUTOSHIP project
G. Theotokatos, V. Bolbot, E. Boulougouri, University of Strathclyde, UK

Paving the way towards the development of the next generation autonomous ships (NGAS), innovative initiatives are required. This presentation describes the AUTOSHIP project developments. AUTOSHIP is a €27M budget EU funded project with a duration of 42 months started on 1st June 2019, aiming at building, testing and operating two remotely autonomous vessels; in particular, a Short Sea Shipping (SSS) cargo vessel and an Inland Waterways (IWW) barge. The AUTOSHIP consortium gathers technological excellence, market and industry knowledge and the necessary know-how to analyse and define the extended framework related to NGAS adoption and acceptance. Technology packages and key enabling technologies, including shore control centres, autonomous navigation, docking and mooring technologies, intelligent maintenance, operation and safety based on AI tools, communication technology enabling a prominent level of cyber security, will be developed and experimentally validated targeting both retrofitting of existing vessels and new ships design. Thorough regulatory, societal, economic, (cyber)security and safety analyses will be performed, thus leading to a roadmap, methodologies and standards for future adopters and developers. A proposal to IMO for amending and improving the existing regulatory framework is planned, duly motivated by the two full-scale demonstrators development and testing. AUTOSHIP targets the commercial use of the first R&A vessels by the end of 2022. In fact, the involved shipping companies will employ the AUTOSHIP demonstrators into operation as precursor of their new fleets. Moreover, the project will upgrade and exploit new tools like simulators and decision support tools for operators training, cost assessment and optimisation of the NGAS. Finally, the environmental and socio-economic aspects of the autonomous shipping transportation scaled up at a global level will be thoroughly investigated quantifying environmental impact, modal-shifts from road to water, jobs shifting towards higher-skills positions, social costs of future scenarios, new business cases.

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