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Review Article

A review of unmanned surface vehicle development

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Abstract

This paper provides a review of the development of unmanned surface vehicles (USVs). Their potential applications and developmental trends are also discussed. Based on active works in this fields, USVs may potentially be integrated into the existing force structures of manned ships, offering a cost-effective solution for performing various types of marine operations with minimal risk to the personnel.

1. Introduction

Unmanned surface vehicles (USVs) are marine crafts that are capable of unmanned operation. They have varying degrees of autonomy, ranging from remote controlled vehicles to ones that govern their decisions during the mission with minimal human intervention. The latter may be referred to as autonomous surface vehicles (ASVs). Since these unmanned marine vehicles can be remotely operated by pilots from safe locations, they are suitable for operations in dangerous areas, e.g., harsh environments, polluted areas, or nuclearcontaminated sites.

USVs have been reported as being used in military operations to detect and neutralise underwater mines; see **Figure 1** C-Sweeper (courtesy of ASV Global Ltd). Singer (2009) suggested using a USV for interrogating suspect crafts through a camera and loudspeaker-microphone system, with minimal risk to personnel.

The concept of force multipliers can be achieved by using multiple USVs simultaneously. For instance, a team of USVs may be equipped with sonar systems to search for and prevent possible underwater threats over strategic areas. This force multiplication is also highly beneficial for largescale ocean research, e.g., for environmental surveys (Sharma et al., 2013) and for collecting hydro-graphic data (Ferreira et al., 2009).

The rest of this paper is organised as follows. Section 2 provides key components for the autonomous operation of USVs. The developmental trends are discussed in Section 3. This is followed by conclusions in Section 4.

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Figure 1 C-Sweeper (courtesy of ASV Global Ltd).

2. Key common features

Since USVs are generic platforms, they may be designed to be equipped with different sets of sensors and actuators to suit different tasks. It is also typical to convert an existing manned craft into a USV (Manley et al., 2000). For USVs to work autonomously, they require a common basic navigation system that allows them to navigate from one point to another. The navigation system may be defined based on Fossen (2011) and consists of 3 interconnected modules (as shown in **Figure 2**). The modules are explained below.

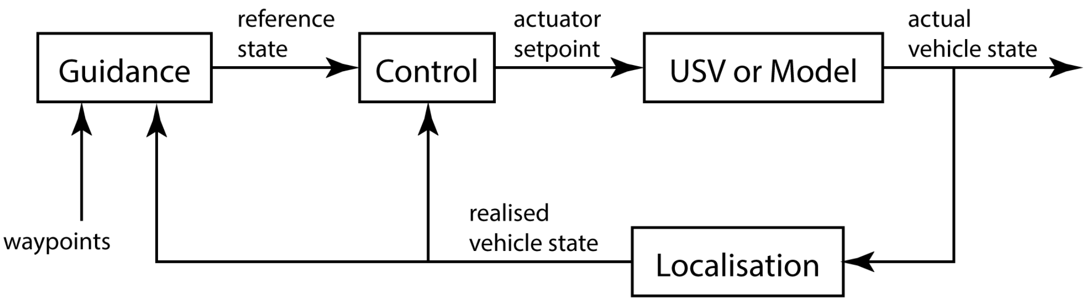

Figure 2 Navigation system.

2.1 Localisation

This module is dedicated to updating a vehicle's “pose” (composed of position and orientation). The position is obtained using the global navigation satellite system (GNSS) whereas the orientation is provided by the inertial measurement unit (IMU).

With real-time kinematic (RTK) technology, a centimetre-level positioning accuracy can be achieved. In this regard, 2 GNSS receivers may be fitted along the vehicle’s longitudinal axis at the extreme length. One stationary GNSS receiver is used as a base station to provide a position correction for those rover receivers. The vehicle’s heading is then inferred from the position difference between the 2 receivers on the vehicle. Such alternative heading information is very important when operating in areas with strong magnetic interference (for instance, near large metal ships) where the heading reference from the IMU is unreliable.

A vehicle's speed over ground may be inferred from the position information. The speed may be measured directly using a Doppler velocity log (DVL), but the seabed must be within tracking range of the sensor. Also, the same type of information from different sensors, as well as from a state estimator, may be combined, based on Kalman filter techniques (Han & Wang, 2012; Park et al., 2017), for example, in order to achieve a higher accuracy and provide more reliable navigation information.

2.2 Guidance

This module regularly determines a reference signal for the control system with respect to the prescribed waypoints and the current vehicle's pose. It may be broadly classified into 3 guidance scenarios (Breivik & Fossen, 2009; Bibuli et al., 2012).

The simplest scenario is called a pure pursuit guidance, in which the vehicle is tasked to reach a specified location (or to follow a target in the case of a moving waypoint) without any concern as to what path the vehicle may take. The USV may then be commanded to maintain its pose over the waypoint, which is known as a dynamic positioning. The next scenario is a path following guidance. This is where a spatial constraint is imposed in order to constrain the USV to navigate along a prescribed path, which is necessary in restricted water, e.g., in a river. The third scenario is a trajectory tracking guidance, which takes spatial and temporal constraints into consideration simultaneously. In this, the USV must not only transit along a given path but must also reach a given point at a specific time.

Trajectory tracking guidance is ideal for preventing a collision when operating in a dynamic environment with moving obstacles. However, path following guidance has been found to suffice for typical USV operation. The line-of-sight (LOS) guidance principle is normally used when implementing a path following system Caccia et al., 2008; Campbell et al., 2012). The LOS principle is illustrated in **Figure 3**; the USV is considered to be enclosed within a virtual circle with a fixed radius, called a LOS distance. A point where the circle intercepts with the path towards the target waypoint is called an LOS position. By following this point, the vehicle both converges to, and transits along, the path.

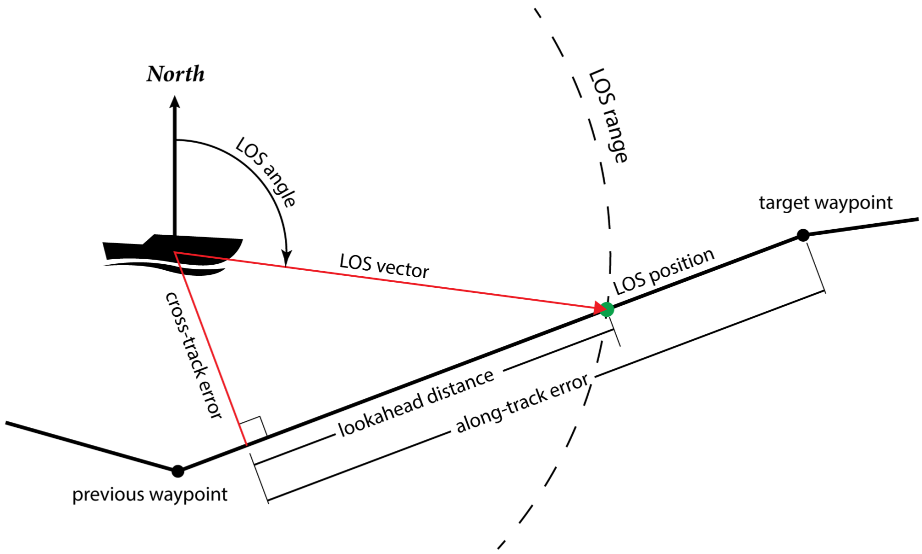

Figure 3 Line-of-sight guidance concept.

2.3 Control

The control module generates actuator set points that drive the USV's pose toward a reference from the guidance module. It has been reported that controlling only the surge and yaw dynamics of the vehicle are sufficient for horizontal-plane navigation (Bibuli et al., 2009). However, sway dynamics should also be considered to accurately perform a waypoint stabilisation or an autonomous docking (Park et al., 2017).

In practice, the surge and yaw degrees of freedom are decoupled into speed and steering subsystems, assuming that the 2 subsystems are not interacting with one another. A linear control technique is then developed for each of the 2 subsystems separately. Typical control approaches are, for example, a proportional-integralderivative (PID) technique (Demetriou et al., 2016), and a linear quadratic Gaussian (LQG) technique (Annamalai & Motwani, 2013).

However, a linear controller will only work optimally within a small range of operating conditions in which the dynamics model is linearised; the control performance may significantly degrade when the operating conditions (e.g., vehicle draft) change enormously. To this end, multiple linear controllers may be developed to cover the possible range of conditions, and the gain-scheduling technique (Bibuli et al., 2009) may then be adopted to link these controllers together into one control system. Alternatively, a robust control performance may be achieved by employing nonlinear control techniques, such as local control network (Sharma et al., 2012) or fuzzy logic (Majid et al., 2015).

3. Developmental trends

Existing USVs have varying degrees of autonomy. At the most basic level, USVs are manually controlled, with continuous input from the operator. These remote-controlled USVs have already demonstrated their potential for commercial use, offering a cost-effective solution for inspecting bridge footing with sonar systems, for example; this is illustrated in **Figure 4**.

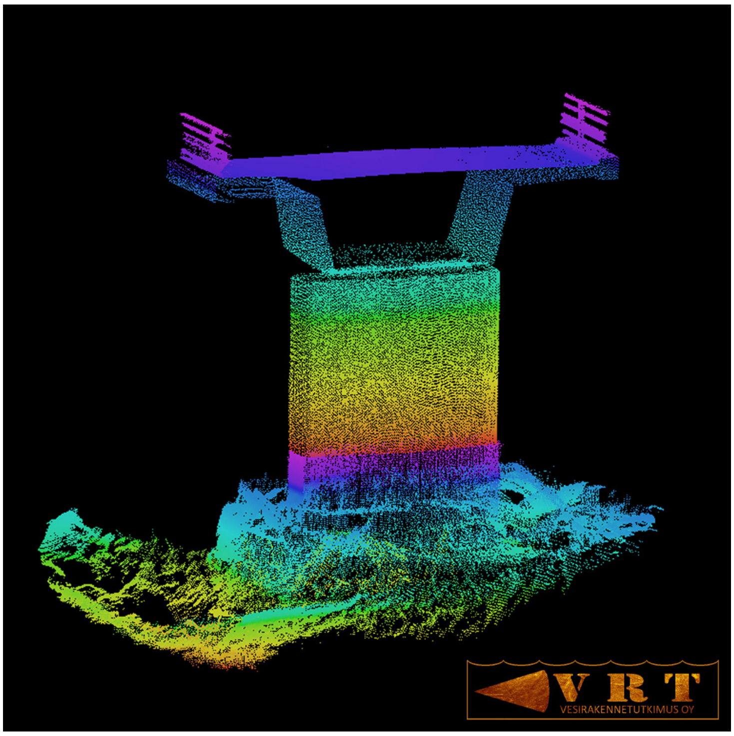

Figure 4 Bridge footing inspection with multibeam sonar (courtesy of Kongsberg Maritime Ltd).

Using the navigation system discussed in the previous section, USVs are capable of performing basic waypoint navigation autonomously. Thus, an operator can control multiple USVs simultaneously. In this regard, a series of waypoints that reflects the task is assigned to each of the vehicles; the human pilot monitors the mission outcome and interacts if required. This concept provides a forcemultiplier solution for a large-scale task. The trend also covers the development of mission control software that allows the operator to work only on a mission level. By highlighting areas of interest and areas to be excluded (e.g., areas containing obstacles), the dedicated mission control software then interprets the mission into tasks and optimally assigns these tasks to available vehicles, as seen, for example, in the ASView Control System by ASV Global Ltd.

Collision avoidance is also an active field of research. It helps to reduce the workload for humans when operating in unknown and/or dynamic environments, as well as to prevent collisions between vehicles autonomously; obstacles may be detected and identified using a camera and a LIDAR, for example (Park et al., 2017). A collision avoidance algorithm then processes information and guides the USV away from potential harm or plans a collision-free path (Benjamin et al., 2006; Naeem et al., 2012; Tam & Bucknall, 2013). The collision avoidance algorithms are typically based on the COLREGs, which are international regulations for preventing collisions at sea, defined by the International Maritime Organisation.

Since USVs are capable of both radio and acoustic transmissions, they may be used as communication hubs for network systems between air, sea, and underwater environments, as well as for aiding underwater navigation (Manley, 2008; Manley & Hine, 2011; German et al., 2012). Furthermore, USVs may be designed to operate at sea for months, if not years (Manley & Hine, 2011; Tsourdos e al., 2014; Bowker et al., 2016). Based on these factors, support ships for marine operations may be required only for vehicle launch and recovery, with the rest of the missions being executed and monitored from a ground control station over satellite communication. Using this concept, the cost of extended period operations could reduce significantly. Pearson et al. (2014) presented a concept for deploying and recovering an autonomous underwater vehicle (AUV) from a USV. This concept eliminates the support ship from the AUV launching and recovering process, hence making operations more cost-effective.

4. Conclusions

Unmanned surface vehicles (USVs) are typically compact in size when compared with manned vehicles with equivalent mission-related functionality. This is because USVs do not need extra spaces to accommodate systems or items to facilitate human needs. Also, USV development is tending towards increased autonomy levels and vehicle capability. With suitable mission control software, only one human pilot is required for controlling a fleet of USVs. In this regard, significantly less capital and operational costs are required for these unmanned vehicles. Using USVs as an alternative to manned vehicles can help increase the cost-effectiveness of marine operations while avoiding putting personnel at risk.

References

Annamalai, A. S. K., & Motwani, A. (2013). *A Comparison between LQG and MPC Autopilots for Inclusion in a Navigation, Guidance and Control System*. Marine and Industrial Dynamic Analysis, School of Marine Science and Engineering, Plymouth University, pp. 1-19.

Benjamin, M. R., Curcio, J. A., Leonard, J. J., & Newman, P. M. (2006). Protocol-based COLREGS collision avoidance navigation between unmanned marine surface craft. *Journal of Field Robotics, 23*(5), 333-346.

Bibuli, M., Bruzzone, G., Caccia, M., & Lapierre, L. (2009). Path-following algorithms and experiments for an unmanned surface vehicle. *Journal of Field Robotics, 26*(8), 669-688. doi:10.1002/rob.20303

Bibuli, M., Caccia, M., Lapierre, L., Bruzzone, G. (2012). Guidance of unmanned surface vehicles:

Experiments in vehicle following. *IEEE Robotics & Automation Magazine, 19*(3), 92-102. doi:10.1109/MRA.2011.2181784

Bowker, J. A., Townsend, N. C., Tan, M., & Shenoi, R. A. (2016). *Experimental analysis of submerged flapping foils; implications for autonomous surface vehicles (ASVs)*. Proceedings of the IEEE Monterey on OCEANS 2016 MTS. Monterey, CA, USA, pp. 1-10. doi:10.1109/OCEANS.2016.7761324

Breivik, M., & Fossen, T. I. (2009). *Guidance Laws for Autonomous Underwater Vehicles*. In: Inzartsev, A. V. (Ed.). Underwater Vehicles. InTech. doi:10.5772/6696

Caccia, M., Bibuli, M., Bono, R., & Bruzzone, G. (2008). Basic navigation, guidance and control of an unmanned surface vehicle. *Autonomous Robots, 25*(4), 349-365. doi:10.1007/s10514-008-9100-0

Campbell, S., Naeem, W., & Irwin, G. W. (2012). A review on improving the autonomy of unmanned surface vehicles through intelligent collision avoidance manoeuvres. *Annual Reviews in Control, 36*(2), 267-283. doi:10.1016/j.arcontrol.2012.09.008

Demetriou, G. A., Hadjipieri, A., Panayidou, I. E., Papasavva, A., & Ioannou, S. (2016). *ERON: A PID controlled autonomous surface vessel*. Proceedings of the 18th Mediterranean Electrotechnical Conference. Lemesos, Cyprus, pp. 1-5. doi: 10.1109/MELCON.2016.7495463

Ferreira, H., Almeida, C., Martins, A., Almeida, J., Dias, N., Dias, A., & Silva, E. (2009). *Autonomous bathymetry for risk assessment with ROAZ robotic surface vehicle*. Proceedings of the OCEANS 2009, Bremen, Germany, pp. 1-6. doi:10.1109/OCEANSE.2009.5278235

Fossen, T. I. (2011). *Handbook of Marine Craft Hydrodynamics and Motion Control*. Chichester, UK: John Wiley & Sons. doi:10.1002/9781119994138

German, C. R., Jakuba, M. V., Kinsey, J. C., Partan, J., Suman, S., Belani, A., & Yoerger, D. R. (2012). *A long term vision for long-range ship-free deep ocean operations: Persistent presence through coordination of autonomous surface vehicles and autonomous underwater vehicles*. Proceedings of the 2012 IEEE on OES Autonomous Underwater Vehicles. Southampton, UK, pp. 1-7. doi:10.1109/AUV.2012.6380753

Han, S., & Wang, J. (2012). Integrated GPS/INS navigation system with dualrate Kalman Filter. *GPS Solutions, 16*(3), 389-404. doi:10.1007/s10291-011-0240-x

Majid, M. H. A., & Arshad, M. R. (2015). *A fuzzy self-adaptive PID tracking control of autonomous surface vehicle*. Proceedings of the 2015 IEEE International Conference on Control System, Computing and Engineering. George Town, Malaysia, pp. 458-463. doi:10.1109/ICCSCE.2015.7482229

Manley, J. E. (2008). *Unmanned surface vehicles, 15 years of development*. Proceedings of the OCEANS 2008. Quebec City, QC, Canada, pp. 1-4. doi:10.1109/OCEANS.2008.5152052

Manley, J., & Hine, G. (2011). *Persistent unmanned surface vehicles for subsea support*. Proceedings of the Offshore Technology Conference. Houston, Texas, USA, pp. 1-8. doi:10.4043/21453-MS

Manley, J.E., Marsh, A., Cornforth, W., & Wiseman, C. (2000). *Evolution of the autonomous surface craft AutoCat*. Proceedings of the OCEANS 2000. IEEE, 2000. pp. 403-408. doi:10.1109/OCEANS.2000.881292

Naeem, W., Irwin, G. W., & Yang, A. (2012). COLREGs-based collision avoidance strategies for unmanned surface vehicles. *Mechatronics, 22*(6), 669-678. doi:j.mechatronics.2011.09.012

Park, J., Kang, M., Kim, T., Kwon, S., Han, J., Wang, J., Yoon, S., Yoo, B., Hong, S., Shim, Y., Park, J., & Kim, J. (2017). Development of an unmanned surface vehicle system for the 2014 Maritime RobotX Challenge. *Journal of Field Robotics, 34*(4), 644-665. doi:10.1002/rob.21659

Pearson, D., An, E., Dhanak, M., Ellenrieder, K. V., & Beaujean, P. (2014). *High-level fuzzy logic guidance system for an unmanned surface vehicle (USV) tasked to perform autonomous* *launch and recovery (ALR) of an autonomous under-water vehicle (AUV)*. Proceedings of the 2014 IEEE on OES Autonomous Under-water Vehicles (AUV). Oxford, MS, USA, pp. 1-15. doi:10.1109/AUV.2014.7054403

Sharma, S. K., Sutton, R., Motwani, A., & Annamalai, A. (2013). Nonlinear control algorithms for an unmanned surface vehicle. *Proceedings of the Institution of Mechanical Engineers Part M: Journal of Engineering for the Maritime Environment, 228*(2), 146-155. doi:10.1177/1475090213503630

Sharma, S., Naeem, W., & Sutton, R. (2012). An autopilot based on a local control network design for an unmanned surface vehicle. *The Journal of Navigation, 65*(2), 281-301. doi:10.1017/S0373463311000701

Singer, P. W. (2009). *Wired for War: The Robotics Revolution and Conflict in the Twenty-first Century*. Penguin Press.

Tam, C., & Bucknall, R. (2013). Cooperative path planning algorithm for marine surface vessels. *Ocean Engineering, 57*, 25-33. doi:10.1016/j.oceaneng.2012.09.003

Tsourdos, A., Oh, H. N. H, & Savvaris, A. (2014). Development of collision avoidance algorithms for the C-Enduro USV. *IFAC Proceedings Volumes, 47*(3), 12174-12181. doi:10.3182/20140824-6-ZA-1003.02362