Documents

Alhattab, Y.A.[a b c] , Zaki, H.F.M.[a b] , Embong, A.H.B.[a b] , Abidin, Z.B.Z.[a b] , Faizabadi, A.R.[c] , Ibrahim, A.I.[a b]

Hybrid Vision System for Enhanced Situational Awareness in Unmanned Surface Vehicles: Decision-Level Camera-LiDAR Fusion With Supervised and Unsupervised Approaches

(2025) *IEEE Access*, 13, pp. 75618-75634.

DOI: 10.1109/ACCESS.2025.3562299

[a] International Islamic University, Department of Mechatronics, Kulliyyah of Engineering, Gombak, Kuala Lumpur, 53100, Malaysia
[b] International Islamic University, Centre for Unmanned Technologies (CUTe), Gombak, Kuala Lumpur, 53100, Malaysia
[c] Delloyd R&D (M) Sdn. Bhd, Department of Advanced Engineering, Selangor, Klang, 41000, Malaysia

Abstract
The integration of LiDAR and cameras with an efficient data fusion approach significantly improves Enhanced Situational Awareness (ESA) for small-sized Unmanned Surface Vehicles (USVs). This is critical for early obstacle detection, particularly when maritime obstacles are only 5 to 10 seconds away. This is important to ensure effective collision avoidance in regions without reliable Global Positioning System (GPS) and Automatic Identification System (AIS), while maintaining low computational requirements and real-time performance. This paper presents a system aimed at ESA using an unsupervised approach and a trained deep learning model to detect multiple maritime obstacles in denied GPS zones. The proposed system incorporates a technical mechanism that uses a compact hardware system with an integrated advanced computing module and sensors for small-sized USVs. It addresses the challenges of achieving peak performance on an edge machine learning computer integration to reduce computational overhead. Further, it minimizes temporal detection variations using sophisticated filters and clustering in dynamic maritime environments with synchronized LiDAR and camera data fusion. The detection model, trained using Maritime Federated Large Dataset (MFLD2), achieved over 99% operational accuracy with the proposed data fusion approach. The system's capacity to precisely identify obstacle location and distance is validated by experimental findings, enabling real-time situational awareness. © 2013 IEEE.

Author Keywords
collision avoidance; fusion system; Obstacle detection; situational awareness; unmanned surface vehicles

Index Keywords
Digital storage, Image coding, Image segmentation, Obstacle detectors, Risk assessment, Sensor data fusion, Unmanned surface vehicles, Unsupervised learning; Collisions avoidance, Decision levels, Fusion systems, Global positioning, Obstacles detection, Positioning system, Situational awareness, Surface vehicles, Unsupervised approaches, Vision systems; Global positioning system

References

- Bae, I., Hong, J.
  Survey on the developments of unmanned marine vehicles: Intelligence and cooperation
  (2023) *Sensors*, 23 (10), p. 4643.
  May

- Muhovic, J., Mandeljc, R., Bovcon, B., Kristan, M., Perš, J.
  Obstacle tracking for unmanned surface vessels using 3-D point cloud
  (2020) *IEEE J. Ocean. Eng.*, 45 (3), pp. 786-798.
  Jul

- Han, J., Cho, Y., Kim, J., Kim, J., Son, N.-S., Kim, S.Y.
  Autonomous collision detection and avoidance for ARAGON USV: Development and field tests
  (2020) *J. Field Robot.*, 37 (6), pp. 987-1002.
  Sep

- Faggioni, N., Ponzini, F., Martelli, M.
  Multi-obstacle detection and tracking algorithms for the marine environment based on unsupervised learning

(2022) *Ocean Eng*, 266.
Dec. Art.

- Huang, Z., Wang, Y., Wen, J., Wang, P., Cai, X.
An object detection algorithm combining semantic and geometric information of the 3D point cloud
(2023) *Adv. Eng. Informat.*, 56.
Apr. Art.

- Faggioni, N., Leonardi, N., Ponzini, F., Sebastiani, L., Martelli, M.
Obstacle detection in real and synthetic harbour scenarios
(2022) *Proc. Int. Conf. Modeling Simulation Auto. Syst.*, pp. 26-38.
Cham, Switzerland, Jan

- Kamsvåg, V.
(2018) *Fusion between camera and LiDAR for autonomous surface vehicles*,
M.S. thesis, Dept. Engineering Cybernetics, Norwegian Univ. Sci. Technol., Trondheim, Norway

- Sorial, M., Mouawad, I., Simetti, E., Odone, F., Casalino, G.
Towards a real time obstacle detection system for unmanned surface vehicles
(2019) *Proc. OCEANS MTS/IEEE SEATTLE*, pp. 1-8.
Seattle, WC, USA, Oct

- Clunie, T., DeFilippo, M., Sacarny, M., Robinette, P.
Development of a perception system for an autonomous surface vehicle using monocular camera, LiDAR, and marine RADAR
(2021) *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, pp. 14112-14119.
May

- Berg, J.V.D., Guy, S.J., Lin, M., Manocha, D.
Optimal reciprocal collision avoidance for multi-agent navigation
(2011) *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, pp. 1-8.
Jun

- Fiorini, P., Shiller, Z.
Motion planning in dynamic environments using velocity obstacles
(1998) *Int. J. Robot. Res.*, 17 (7), pp. 760-772.
Jul

- Snape, J.
Directional optimal reciprocal collision avoidance
(2014) *Proc. Robot., Sci. Syst. (RSS)*,

- Mohanan, M.G., Salgoankar, A.
A survey of robotic motion planning in dynamic environments
(2018) *Robot. Auton. Syst.*, 100, pp. 171-185.
Feb

- Thompson, D.
(2017) *Maritime object detection, tracking, and classification using LiDAR and vision-based sensor fusion*,
M.S. thesis, Dept. Mechanical Engineering, Virginia Tech, Blacksburg, VA, USA

- Chen, Z., Huang, T., Xue, Z., Zhu, Z., Xu, J., Liu, Y.
A novel unmanned surface vehicle with 2D–3D fused perception and obstacle avoidance module
(2021) *Proc. IEEE Int. Conf. Robot. Biomimetics (ROBIO)*, pp. 1804-1809.
Sanya, China, Dec

- Zhang, Q., Shan, Y., Zhang, Z., Lin, H., Zhang, Y., Huang, K.
  Multisensor fusion-based maritime ship object detection method for autonomous surface vehicles
  (2024) *J. Field Robot.*, 41 (3), pp. 493-510.
  May

- Solheim, M.
  (2022) *Integration between LiDAR-and camera-based situational awareness and control barrier functions for an autonomous surface vehicle*,
  M.S. thesis, Dept. Engineering Cybernetics, Norwegian Univ. Sci. Technol., Trondheim, Norway

- Yao, Z., Chen, X., Shi, C.
  Research on surface environment perception via camera-LiDAR sensor fusion
  (2023) *Proc. 6th Int. Conf. Artif. Intell. Big Data (ICAIBD)*, pp. 895-899.
  May

- Lidar, I.V.
  (2024) *Velodyne HDL-32E Datasheet*,
  Accessed: Jun. 8, 2024. Online.

- (2023) *Zed 2I Camera*,
  Accessed: Jun. 8, 2024. Online.

- Yigzaw, S.
  An analysis and benchmarking in autoware
  (2023) *AI and openpcdet LiDAR-based 3D object detection models*,
  M.S. thesis, Dept. Electrical and Computer Engineering, Univ. Waterloo, Waterloo, ON, Canada

- Jocher, G., Chaurasia, A., Stoken, A., Borovec, J., Kwon, Y., Fang, J., Michael, K., Skalski, P.
  (2022) *ultralytics/yolov5: V6. 1—TensorRT, TensorFlow edge TPU and OpenVINO export and inference*,
  Zenodo, Geneva, Switzerland, Feb

- *Downsampling a Pointcloud Using a Voxelgrid Filter*,
  Accessed: Nov. 23, 2023. Online.

- Rusu, R.B.
  Semantic 3D object maps for everyday manipulation in human living environments
  (2010) *KI-Künstliche Intelligenz*, 24 (4), pp. 345-348.
  Nov

- Alhattab, Y.A., Abidin, Z.B.Z., Faizabadi, A.R., Zaki, H.F.M., Ibrahim, A.I.
  Integration of stereo vision and MOOS-IvP for enhanced obstacle detection and navigation in unmanned surface vehicles
  (2023) *IEEE Access*, 11, pp. 128932-128956.

- Rachman, A.
  3D-LiDAR multi object tracking for autonomous driving
  (2017) *Maritime Mater. Eng. (3mE)*,
  M.S. thesis, Fac. Mech, Delft Univ. Technology, Delft, The Netherlands

- Lin, T.-Y., Maire, M., Belongie, S., Hays, J., Perona, P., Ramanan, D., Dollár, P., Zitnick, C.L.
  Microsoft COCO: Common objects in context
  (2014) *Proc. 13th Eur. Conf. Comput. Vis.-ECCV*, pp. 740-755.
  Zurich, Switzerland, Jan

- Prasad, D.K., Rajan, D., Rachmawati, L., Rajabally, E., Quek, C.
  Video processing from electro-optical sensors for object detection and tracking in a maritime environment: A survey
  (2017) *IEEE Trans. Intell. Transp. Syst.*, 18 (8), pp. 1993-2016.
  Aug

- Shao, Z., Wu, W., Wang, Z., Du, W., Li, C.
  SeaShips: A large-scale precisely annotated dataset for ship detection
  (2018) *IEEE Trans. Multimedia*, 20 (10), pp. 2593-2604.
  Oct

- Accessed: Jun. 15, 2023. Online.

- (2024) *Nvidia Jetson Xavier Series*,
  Accessed: Jun. 8, 2024. Online.

- Benjamin, M.R., Schmidt, H., Newman, P., Leonard, J.J.
  Nested autonomy for unmanned marine vehicles with MOOS-IvP
  (2010) *J. Field Robot.*, 27 (6), pp. 834-875.
  Oct

- Yu, X., Wang, Y.
  A time dimension-added multiple obstacles avoidance approach for unmanned surface vehicles
  (2022) *Ocean Eng*, 252.
  May Art.

Correspondence Address
Embong A.H.B.; International Islamic University, Gombak, Malaysia; email: ehalim@iium.edu.my

Publisher: Institute of Electrical and Electronics Engineers Inc.

ISSN: 21693536
Language of Original Document: English
Abbreviated Source Title: IEEE Access
2-s2.0-105002830303
Document Type: Article
Publication Stage: Final
Source: Scopus