Marine Autonomous Vehicles

Sakshi Singh
Department of Electronics and Communication Engineering
Faculty of Engineering, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India

***ABSTACT:** The need for robotic technology transfer from the research labs to civilian applications is now a big problem for the robotic community. In the marine robotics market, it is especially important to equip the robot with a safe and highly reliable Navigation Guidance and Control (NGC) system that allows the Unmanned Surface Vehicle (USV) to navigate safely even in the presence of human activities such as commercial and recreational traffic, swimming, rowers, etc. A crucial factor for successful autonomous navigation is the robot's ability to detect the existence of an unpredictable, potentially moving, obstacle well in advance. This role represents the base brick for developing smart enough collision avoidance systems to reactively detect unexpected obstacles and execute the appropriate avoidance maneuvers to prevent collisions in a safe manner. The present paper describes the design of an innovative sensor for the detection of obstacles, combining both passive and active optical devices and based on a new optronic system concept. It is designed specifically for collision avoidance tasks in marine environments, designed to be easily mounted on small to medium sized USVs. Its innovation lies in the interaction between the various integrated sensors, which are in fact completely decoupled. The paper presents together with the preliminary mechanical design, the functional architecture of the sensor for object detection. In addition, some experimental data collected by the sensor are reported, and some simulations are displayed, highlighting the system's ability to detect and correctly avoid both still obstacles and mobile obstacles passing through.*

***KEYWORDS:** autonomous underwater vehicle, marine robotics systems, underwater cultural heritage, underwater robotics, design work*.

INTRODUCTION

Autonomous Surface Vehicle (ASV) [1]is an intelligent robot that can carry various working devices to accomplish various river, lake, and ocean missions. This has broad applications in offshore mapping, meteorological tracking, hydrological assessment, and so on. Unmanned vehicles have benefits over manned vehicles in certain difficult and risky work conditions due to the reduced human costs and losses. The ASV can also be used as a bridge between Autonomous Underwater Vehicle (AUV) [2]and Unmanned Aerial Vehicle (UAV)[3], which plays a major role in the development of a hybrid unmanned vehicle team for coordinated missions. The implementation of single ASV, on the other hand, has its drawback, because single ASV is less expensive and more powerful than multi. In this case , multiple ASVs collaborating have more possible applications compared to single vehicles

Robotic technology is now mature enough to be employed effectively in civilian scenarios. This will produce a great profit in terms of both productivity and expense for the everyday efficient cycles. Obviously robots must guarantee very high standards of efficiency and protection in order to be used in environments that often anticipate the human presence[4].

More precisely, a reliable and efficient navigation guidance and control system is one of the key capabilities autonomous vehicles need to be equipped with within the marine and maritime context. In particular, for autonomous platforms to achieve reliability within complex environments, an efficient collision avoidance system is strongly needed. Examples of such scenarios (requiring safe interaction with human activities such as recreational and commercial traffic, swimmers, boys and other fixed facilities) are operations such as harbor patrols or area sampling[5].

An efficient unmanned vehicle must therefore detect unexpected obstacles in a reactive manner in order to execute the required maneuvers to avoid collisions safely. Apart from being robust and effective, a collision avoidance system should also be 'low-cost' and 'plug-and-play' (meaning highly integrated and lightweight, so that small-medium-sized robots can be installed on-board). The robotic community will benefit greatly from the availability of such a reliable low-cost and compact sensor, as effective and robust sensing is still an open question.

To order to provide a truly secure autonomous navigation, the vehicle must be able to identify the presence of a surfacing obstacle on its path, both to terms of distance and time, beforehand. Although fixed obstacles could pose a threat to the vehicle, they are only part of the issue. Even more dangerous are the moving obstacles, represented by small boats, canoes or swimming people. The vehicle itself poses a danger especially in the case of swimming people. Of this purpose, the obstacle detection sensor should have a field of view of 180 degrees, and a field of action of around 100 meters in order to allow the vehicle time to take the requisite safety avoidance maneuvers. This will enable the system to identify and avoid moving objects that can be found not only in front of it, but also laterally and potentially cross its path. In general, unmanned surface vehicles have a broad sensor endowment to achieve such outputs, such as a high number of fixed cameras (to cover the 180 degrees), X-band radar, and multi-beam laser. This approach, however, often results in a poorly integrated solution and a rather expensive and voluminous system that is not suitable for a small-medium-sized vehicle[6].

Standard optronic systems for civil use which are normally equipped with infrared cameras and laser range finder (LRF) that reflect a potential solution, already available on the market. Unfortunately, none of them have proved capable of effectively solving the collision avoidance problem. The main problem is that such systems arise primarily for surveillance purposes, often supervised by a human operator, and are therefore not suitable for rapid scanning of a wide area. Second, all the sensors are housed on a single actuated head in those systems. This is an issue because the LRF has to remain fixed on the obstacle for a certain period of time in order to provide a accurate reading so, stopping cameras along with the LRF, the time to cover the 180 degrees is unacceptably high: a crossing obstacle, like a swimmer, will not be seen in time[7].

SYSTEM DESIGN

The proposed Obstacle Detection System is based on the optronic system's typical sensorial equipment, widely used for military and surveillance purposes. It uses a daylight camera[8], an uncooled infrared camera (IR), and a laser range finder (LRF) [9]with one beam. The innovation lies in how these optical sensors are implemented and how they communicate. The two cameras (representing the passive part of the system) are dedicated to determine two of the coordinates that characterize the obstacle’s position (azimuth and elevation), while the LRF (representing the active part) is responsible for computing the obstacle’s distance component Place. The basic idea is to use passive sensors to get a 180-degree panoramic view of the vehicle's surroundings as quickly as possible and in a continuous fashion and, in a second phase, exploit the LRF to inspect the obstacles to determine the distance coordinate. To reduce the recognition time, parallel execution of the two phases is convenient:

- The passive subsystem, with both cameras, is presented in permanent alternative movement spanning 180 degrees and creating a panoramic view; a list of candidate’s obstacles is compiled for each frame acquired by correct vision and data fusion algorithms. Any Name- Tified barriers are now only localized by azimuth and elevation coordinates;

- The list compiled by the passive subsystem is checked continuously by the active subsystem, which guides the laser beam to each obstacle throughout the list. In the neighborhood of such an obstacle the laser produces a point cloud thereby deciding the third coordinate of its location.

In order to execute the strategy mentioned above, it is clear that the passive and active subsystems must be mechanically decoupled and free to work independently from each other: while the panoramic view obtained by the two cameras is continuously designed to detect obstacles moving through, the laser will briefly stop the time required to create the cloud of points on each obstacle.

Thus, the sensor proposed is composed of two actuated heads which are integrated into a single pedestal to maintain a good level of compactness. In addition, the pedestal will be mounted on a gyro-stabilized base to balance the movement in the sea. The design of such a platform is not a key aspect of the proposed system so this paper will not discuss it.

MECHANICAL DESIGN

The pedestal’s physical realization is one of the project's most demanding issues. The goal of installing the device on a small autonomous marine vehicle involves a design that takes into account the ability to withstand external agents such as heat, salt spray and waves. This makes it difficult to adapt a complete mechatronic system consisting of electric motors, electronic components, and rotating shafts to the tightness and robustness needed.

Key points considered during the realization of the whole design are:

- Compatibility:

The pedestal dimensions are: Height: 449 mm, width: 259 mm, thickness: 249 mm. The system's total weight is about 6.5kg (excluding control electronics).

- Bottom cost:

The products used are not costly but they are robust. All the basic elements come from market for mechanics. With a lathe and a milling machine the machined elements can be realized in a few hours.

- Wetter-resistance:

The entire device is sealed to satisfy this requirement. All the flanges are realized using o-rings, and sealing rings are given to the rotating shafts. The link plug used is class IP 68.

- Lightness and ability to resist external loads from waves and vehicle movements:

The materials used are aluminum and Delrin to keep the pedestal light yet able to withstand external loads.

Passive System

This system is characterized by a degree of freedom (vertical rotation) required for panoramic motion of the TV and IR. The selected motor allows a trapezoidal or triangular intermittent movement to be realized in about 1.4 seconds within an angular range of 180. The pan mechanism is pretty simple: a watertight box containing the two cameras is formed. The box is mounted on a rotating shaft on two angular contact ball bearings which guarantee good stability and angular accuracy. The box’s movement is driven by a brushless high performance motor that is rigidly connected to the shaft. The entire machine is fixed onto the main structure with a bolted flange.

Active System

The active system is a liberation mechanism (pan and tilt) of two degrees. The pan system is the same as the one used for TV and IR pan: brushless motor, shaft, and ball bearings with angular contact. In this case the shaft is attached to a fork on which to install the tilt mechanism. The last one uses a second brushless motor to realize the movement from the horizontal position between 15 to 15 degrees. The engine is enclosed in a weathertight box containing both the laser and the Risley-prism scanner.

Part of the mechanical analysis focused on the design of such a scanner which is an optical beam steering mechanism centered on a couple of separately driven rotating wedge-shaped prisms. Depending on the rotation velocity ratio between the two wedge-shaped prisms, different scan patterns can be obtained using this kind of scanner. A "flower" scan pattern is obtained with a positive ratio whilst a "spiral" scan pattern is obtained with a negative ratio. The closer this ratio is to 1 the denser the resulting scanning figure is but it also requires more time to complete a pattern.

The goal of the design was to develop a modern, small, and ultra-compact scanner that could be used with most commercial LRF. The adopted solution consists of two twin mechanisms, driven by two brushless motors. Everyone mechanism is implemented by enclosing a prism between the two ends of a double flanged bush. The flange is effectively inserted inside a thin ball bearing's inner ring. One of the bush's flanges is connected to a ring gear driven by a cogwheel directly connected to a tiny brushless motor in diameter. Within the watertight chamber the two elements are locked, containing the two engines, the laser and the tilt motor.

The active subsystem is equipped with a pulsed time-of - flight LRF and has the task of providing the distance portion to the location of obstacles the passive element recognizes. Many of the lasers widely used in mobile robotics, though fitted with a linear scanning system, have a maximum range of approximately 30 meters on non-reflective targets; thus, they can not be used in this situation. Therefore it was agreed to use a more powerful laser with a single beam capable of detecting obstacles at distances of more than 100 meters needed by the application in order to provide a good return from obstacles; this however leads to a rather collimated laser beam (about 2.0 mrad). As the divergence is much lower than the cameras' vertical FOV, the active subsystem is fitted with an elevation degree of freedom with a stroke of 15 degrees, in addition to the horizontal degree of freedom, to guide the beam in any location framed by the cameras. It should be remembered that the extremely small size of the beam requires extremely high accuracy of the laser's line of sight. A small error in the positioning of the pedestal or in the detection of obstacle positions (performed by the passive subsystem) may cause the beam to not point exactly to the obstacle, resulting in a miscalculation of the distance.

A laser scanning subsystem with the task of creating a point cloud in the neighborhood of the selected obstacle has been introduced to overcome this problem. In this way the laser covered space area is increased along with the likelihood of detection. Risley-prism scanner, a system for optical beam steering based on a few rotating wedge-shaped prisms, has been agreed to employ. Compared with the predominantly diffused Palmer scanners (based on mirrors), this sort of system is very lightweight. It has a low inertia moment, no cantilevered elements and thus creates fewer mechanical movements during the scanning process.

An ad-hoc, very compact scanner with a 2 degree beam deviation is currently under development. Another key parameter for dense coverage of the scanning area is the laser firing rate. With a high firing rate, the scanning pattern can be done quicker, without any holes in the scan. A trade-off was reached to match the firing rate, capability ranging, size / weight, power consumption and cost. The selected LRF in a compact form factor (140 mm 90 mm 60 mm 0.8 Kg) is capable of 2000 pulses per second and consumes less than 5 W during operations. The laser beam has a 905 nm wavelength, and a 1.7 mrad separation. It is capable of measuring distances of up to 300 m on natural surfaces and up to 3000 m on reflectors, under strong atmospheric conditions.

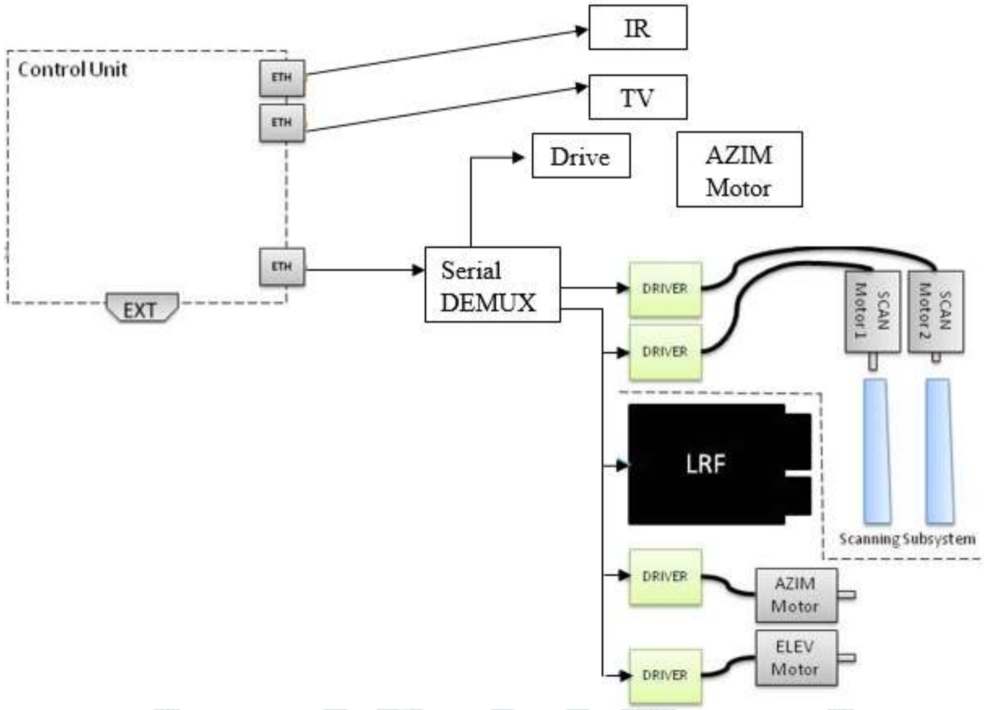

Figure 1: Portrays the General Conceptual Functional Architecture

Exploitation

The mechanical realization of the pedestal is under way at the current stage of the work; however some preliminary data on the functioning of the selected sensors were collected. Additionally, some preliminary simulations were conducted on the integration of the anti-collision sensor with the vehicle's guide collision avoidance algorithm.

Early Experimental Information

Some preliminary results on behavior of the IR camera and LRF within a real marine environment are shown in this section. It was noted as a first result how an accurate adjustment of the false color image in IR can facilitate subsequent processing. Figure 8 shows the same adjusted image with two sets of different parameters. The snapshot, taken at night, refers to a 19 meter long distance swimmer (measured by the laser).

To this end, an ad-hoc image processing algorithm is currently being developed and tested, specifically designed for IR images. It essentially analyzes the shape of the equalized image histogram to dynamically define a threshold for fake-color adjustment that enables a simulated image to be displayed. Starting with such an image, the location of the target can be detected with good mental accuracy with simple contour-finding feature and blob analysis techniques, and will be given in further works.

Note that the coast, visible in the distance behind the different detected vessels or buoys, is a disturbance to the algorithm, as it is not easy for even a human eye to distinguish between image portions that correspond to either obstacles or coast. A horizon line detection strategy will be applied to eliminate this effect, as suggested above.

Finally, as far as the LRF is concerned, it was noted that its reading is very robust and repeatable, but it is strongly influenced by the reflectivity of the target material for distant objects in particular. Also the LRF has shown good robustness to the sea glitter, showing no echoes with a significant intensity of return.

Simulations

In the simulative campaign, in the presence of an obstacle the vehicle is required to follow a predetermined path. The total field of view (not shown in the figures) consists, as already mentioned, of the panoramic view obtained by putting all instant fields of view side by side. The following simulations were conducted using a geometric approach, which associates a probability of detection with the obstacle when the obstacle sensor is in sight for at least 5 scans. As the estimated distance decreases the probability increases. Two cases were considered for the simulations: a stationary obstacle on the road, and a moving obstacle crossing the track.

In the case of a moving obstacle, note that if the vehicle were limited to looking just in front of it, the incoming threat would not have been detected. Alternatively, the proposed sensor allows it to detect an obstacle from the earliest stages of motion. Once in the proximity of the obstacle, the avoidance maneuver starts and ends as soon as the obstacle emerges from sight.

CONCLUSION

In conclusion, within marine applications, the proposed system of obstacle detection is strongly needed in order to significantly increase the reliability and robustness of USVs in relation to the work environment.

The sensor's great advantages and innovation are the 'plug-and - play' feature that makes such a system very convenient to use: its compactness allows it to be mounted on board small and medium-sized vessels, thus addressing and suiting a wide range of marine vehicles. In addition, its low-cost peculiarity helps make it ideal for a wide range of boats, from research-devoted platforms to commercial vehicles. The first results, as already suggested, are very promising, both in terms of simulations and early experiment data. In addition, simulative tests demonstrated the effectiveness of the vehicle guidance and collision avoidance algorithm, which always managed to elude obstacles identified by the anti-collision system.

Finally, in a real world, the early collected experimental results demonstrated the feasibility of obstacle detection. This demonstrated the great potential of detecting specific obstacles with a very high probability of detection, and further stressed the essential role of such an advanced sensor.

REFERENCES

[1] K. Kritayakirana and J. C. Gerdes, "Autonomous vehicle control at the limits of handling," *Int. J. Veh. Auton. Syst.*, 2012, doi: 10.1504/IJVAS.2012.051270.

[2] J. J. Leonard and A. Bahr, "Autonomous underwater vehicle navigation," in *Springer Handbook of Ocean Engineering*, 2016.

[3] F. Mancini, M. Dubbini, M. Gattelli, F. Stecchi, S. Fabbri, and G. Gabbianelli, "Using unmanned aerial vehicles (UAV) for high-resolution reconstruction of topography: The structure from motion approach on coastal environments," *Remote Sens.*, 2013, doi: 10.3390/rs5126880.

[4] A. Sorbara, A. Odetti, M. Bibuli, E. Zereik, and G. Bruzzone, "Design of an obstacle detection system for marine autonomous vehicles," 2015, doi: 10.1109/OCEANS-Genova.2015.7271716.

[5] A. Sorbara, E. Zereik, M. Bibuli, G. Bruzzone, and M. Caccia, "Low cost optronic obstacle detection sensor for unmanned surface vehicles," 2015, doi: 10.1109/SAS.2015.7133652.

[6] O. Yalcin, A. Sayar, O. F. Arar, S. Apinar, and S. Kosunalp, "Detection of road boundaries and obstacles using LIDAR," 2014, doi: 10.1109/CEEC.2014.6958546.

[7] B. Bovcon, R. Mandeljc, J. Pers, and M. Kristan, "Improving vision-based obstacle detection on USV using inertial sensor," 2017, doi: 10.1109/ISPA.2017.8073559.

[8] S. Han, Y. Matsushita, I. Sato, T. Okabe, and Y. Sato, "Camera spectral sensitivity estimation from a single image under unknown illumination by using fluorescence," 2012, doi: 10.1109/CVPR.2012.6247752.

[9] Y. Liao, L. Huang, Y. Wang, S. Kodagoda, Y. Yu, and Y. Liu, "Parse geometry from a line: Monocular depth estimation with partial laser observation," 2017, doi: 10.1109/ICRA.2017.7989590.