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TOWARD A MULTI-AGENT SYSTEM FOR MARINE OBSERVATION

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Developing a robust obstacle avoidance module is a foundamental step towards fully autonomous unmanned surface vehicles. Until now, most marine vehicles traverse following waypoints paths, usually GPS-based, totally unconcerned about possible collisions. In this paper, a combined system integrating autonomous flying and surface vehicles is suggested as solution to the path planning problem.

Keywords: Path planner; unmanned surface vehicle; unmanned aerial vehicle; obstacle avoidance

1. Introduction

Marine vehicles represent one of the three categories of the mobile robotics namely sea, ground and aerial. This type of vehicle can be also further distinguished in *unmanned surface vehicles (USVs)* and *unmanned underwater vehicles (UUVs)*.

An increasing interest in USVs has been expressed by the military community, expecially for those situations such as for force protection, surveillance, mine warfare and so on. Multiple platforms were developed and deployed in the last 20 years[1] such as the *Spartan* USV developed by the US Space and Naval Warfare System Center in San Diego, the *Delfim* and *Caravela* developed by the Portuguese Dynamical Systems and Ocean Robotics laboratory,[2] and finally the *Springer* developed by the University of Plymouth.[3]

Most of the vessels cited are dual-purpose vehicles, i.e., they can be driven by humans, on-board or remotely, but also in an unmanned mode. In this way their capabilities are augmented and extended in an affordable and low-risk manner.

To navigate in a fully autonomous way the presence of an *obstacle avoidance module* is required to move the unmanned vessel from the actual track to another one if an immediate collision is expected, and then take it back on the previous one towards the goal pose.

The scope of this paper is to suggest the integration of an unmanned aerial vehicle (UAV) together with an USV in a single system, augmenting the overall awareness about the environment in which both vehicles are located, to address in an easier way the path planning problem for autonomous vessels.

The structure of the paper is divided as follows: in Section 2 the necessity of having a robust path planner will be discussed, whilst Subsections 2.1 and 2.2 will illustrate how a global and a local path planners could be implemented. Section 3 describes cooperative works realized integrating heterogeneous platforms in a single system, and in Sections 4 and 5 conclusions are discussed.

2. Path Planner

Having a virtual representation of the environment in which a robot is located is a key point to plan a path for moving autonomous vessels. As described in Section 1, the path planner module is usually divided in two sub-components: the global path planner (GPP) that aims to find a path from the actual pose of the robot to a goal one, while the local path planner (LPP) tries to avoid moving obstacles close to the robot.

In the following subsections the most recent path planners used in marine robotics, to guide autonomous vessels on the sea surface among other marine crafts and moving hazards, will be described.

2.1. *Global Path Planner*

GPP has to continuosly adapt the already existing path to new long-range obstacles. In Larson *et al.*[4] the path planners use a bidimensional (2D) map created by discretising the environment each cell is assigned a value representing its probability of being occupied or not. Stationary and moving obstacles are processed and added to the map. The A* search algorithm was chosen as the search technique and an obstacle proximity cost was added to prevent the USV to move too close to the obstacles.
To avoid moving ones, safe velocity ranges are determined using the *velocity obstacles* (VO) method: a velocity space v-θ grid (where v denotes the USV

speed and θ is the heading angle) is constructed as decision space, obstacle are expanded by the vehicle size and the USV is assumed as a point. To avoid collision, its velocity has to lie outside the VO; if the obstacle change velocity or direction, a replanning with the new informations is performed. In the case that a collision cannot be avoided, the path planner creates a *projected obstacle area* (POA) (Figure 1) is created for each obstacle and the path planner plans a new safe route. A POA represents the area a moving obstacle will occupy in the future and it has to be recalculated for every path segment because an obstacle can represent a threat more than once.

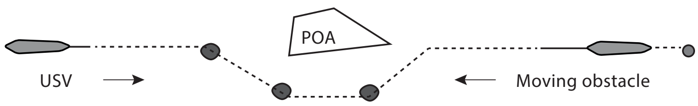

Fig. 1. The USV has to avoid the obstacle coming ahead passing port-to-port its projected obstacle area.

Casalino *et al.*[5] suggests an approach based on the *visibility graph* concept. A visibility graph is a graph of intervisible locations: for each couple of point visible one from each other, a straight line connecting them and not passing into an obstacle is drawn.
The first step is to transform the obstacles into polygons. At this point the Dijkstra's Algorithm is applied between the starting point and the goal one to find a safe trajectory not intersecting any of the obstacles.

A totally different approach has been developed in Xie *et al.*[6] The authors take inspiration from the concept of *artificial potential field* (APF): in order to define a safe path leading the USV far from obstacles and to the goal, APF combine the repulsion potential field of obstacles and gravitational potential field of targets.
The improvement introduced by the authors to the traditional approach consists in a regulatory factor that, in the presence of an obstacle, controls attraction for decreasing as a linear factor and repulsion as a higher-order function. In this way, situations as local minimun or destination unreachable are addressed while the craft is able to avoid obstacles smoothly and reach the goal.

2.2. *Local Path Planner*

One example of a LPP is given in Kuwata *et al.*,[7] in which the authors suggest an algorithm able to avoid moving hazard while respecting the COLREGS (for COLlision REGulations) as shown in Figure 2 for overtaking, head-on and crossing situations. In the situation in which a USV overtakes a slow traffic boat, it must guarantee enough space to the overtaken vessel. In the case the USV and the traffic boat are moving one toward each other, both vessels should deviate toward their right. Otherwise, if a traffic vehicle is traversing from the right, the vessel with the other on its right side must give away.
The developed algorithm works in this way: first the *closest point of approach* (CPA) between the vessel and possible obstacles is calculated; then, the best COLREGS rule is applied; once the constraints set of VO and COLREGS are generated, a cost for each v_i and θ_j ammissible is generated and the (v_i, θ_j) pair with the minimum cost. At this point, the velocity value is sent to the controller.

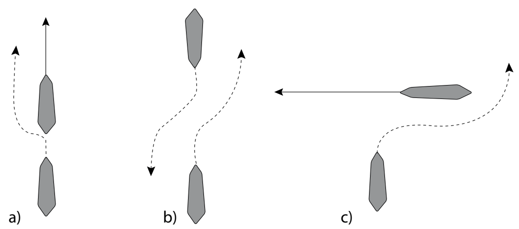

Fig. 2. Ruled defined to avoid collisions for overtaking (a), meeting (b), and crossing (c) obstacle.

In Casalino *et al.*[5] a new reactive path planner based on the *bounding box* concept is described. A bounding box of a track is defined as the rectangle area the autonomous vessel should avoid in order to not crash against the moving object. The algorithm proposed integrates the four bounding box's vertixes with the vehicle actual position S and the local goal G in a graph. Then the solution is any path from S to G. Since the authors did not consider any kinematic constraints of the USV, the work suffers from sub-optimality.
Based on the A* search algorithm, the node with the smallest utility function f is selected and removed from the *openset* at each iteration. The search procedure is interrupted if the goal can be reached without collision;

otherwise the vertexes intercept positions is calculated for each obstacles and check if this path is collision free with *ray tracing* techinque. If so, this node is added to the openset and the entire procedure is reiterated.

In their successive work,[8] the authors present a refinement of this algorithm introducing a *safety* bounding box in addition to the original collision one. All the computations are now performed against it; after entering the safety box, the USV must leave it without intercepting the main diagonals. In this way it is ensured that the vehicle moves doen not cross the collision bounding box.
In this way the computed path will be very robust to changes in speed and heading of the obstacle.

In Blaich *et al.*[9] a modification of the A* algorithm that address velocity variations and different turning circles is proposed. Initially a map with data coming from a laser finder is built and the obstacles contours are extracted. In parallel, a *multi object tracker* (MOT) for moving objects is adopted.
The A* algorithm is modified adding to the cost function a penalty representing the amount of path skipped during the evasion manoeuvre. In this way the algorithm make the USV to go back to the original path after the deviation. The kinematics of the USV has to be considered to address the feasibility of the path: therefore velocity and time are added to the search space, in order to allow changing velocities and the minimum turning circle.

3. Multi-Agent Systems

In the last decade UAVs have obtained a growing interest thanks to the reduction of production costs together with the easiness to use. Big efforts in the research has been done, expecially in the fields related to computer vision and reconnaissance, but the most fascinating aspect of this new technology is the possibility to integrate it in heterogeneous systems with other different platforms. In fact, it is difficult for one single vehicle to accomplish complex task due to its limited sensor capabilities or dynamic constraints. The integration of different vehicles can solve this problem but introduce the need for an additional common communication layer.

Until now, multiple temptatives towards an Air-Ground Cooperation has been done. In this scenario, Unmanned Aerial Vehicles (UAVs) are combined with Unmanned Ground Vehicles (UGVs) such that the complementary skills of each vehicle can compensate the limitations of the others and the final system can accomplish the mission with higher efficency.

Among the developed applications, Michael *et al.*[10] illustrates how a team of UAVs and UGVs can provide the 3D map of the three top floors of an earthquake-damaged building. Other examples of mapping missions can be found in Forster *et al.*,[11] Kim *et al.*[12] and Hsieh *et al.*[13]

Another interesting mission is the one called *cooperative navigation*, in which the UAV acts as an added vision sensor[14] providing to the land robots informations related to normal or negative obstacles, such as holes and cliffs, in order to navigate safely. The same task has been addressed in Choi *et al.*[15] and Vandapel *et al.*[16]

In Harik *et al.*[17] a new object transportation scheme based on aerial and ground cooperation is described. A drone is responsible to guide a set of UGV, aligned in a predefined formation, in an industrial contex. Waypoints provided by the UAV are sent to a leader ground robot, while the others use a vision tracker to keep a safe distance one to each other following the leader.

4. Discussion

In this Section an integration with a UAV is proposed as solution to the path planning problem for USVs.

The images acquired with the UAV can be processed with diffent tools (i.e. openCV, Matlab or machine learning algorithms) and the world model is created as an occupancy grid in which obstacles are enlarged by a factor depending on the size of the robot used to prevent it crashes against them. Once world model is realised and the CPA and projected obstacle area of every obstacle are calculated, an implementation of A* can be used to find a safe path connecting the actual pose of the robot and the goal one. If this lies outside the map, a temporal goal can be assumed as the projection of the goal on the upper limit of the map.

The innovation of using a flying robot instead local cameras is represented by the flexibility of using it: instead of cover only a limited range, it can allow to look far from the USV and therefore prevent unusual trajectory of moving hazard in advance, as shown in Figure 3. On the other hand there are some disadvantages to face while using this interesting platform, like the subject to wind currents and the battery consumption.

From a pratical point of point, in situations in which the UAV is responseless (e.g. due to network issues or battery empty), the cameras (mono or stereo) mounted on the vessel allow it to continue the task even in the absence of the GPP, acquiring the proper data for creating a local area model used by the LPP.

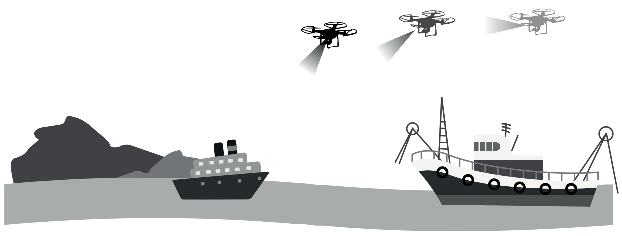

Fig. 3. Cooperation between an UAV and a USV.

5. Conclusion

In this paper a review on previous path planners for USVs has been provided. Among the other techiniques, a new multi-agent system based on the cooperation with an UAV is proposed to augment the overall awareness of the environment, in order to take care of possible hazards and plan a safe path for the vessel.

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