Obstacle Avoidance Using Multi-Point Potential Field Approach for an Underactuated Flat-Fish Type AUV in Dynamic Environment

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Obstacle Avoidance Using Multipoint Potential Field Approach for an Underactuated Flat-fish Type AUV in Dynamic Environment

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Abstract: This paper presents a multipoint potential field method for obstacle avoidance of Autonomous Underwater Vehicles (AUV) in a 2D dynamic environment. In this method, an arc of predefined radius on a semicircle in the positive x-axis around the bow of an AUV is discretized into equiangular points with centre as the current position. By determining the point at which the minimum potential exists, the vehicle can be moved towards that point in 2D space. Here the analytical gradient of the total potential function is not calculated as it is not essentially required for moving the vehicle to the next position. The proposed obstacle avoidance algorithm is interfaced with the dynamic model of an underactuated flat-fish type AUV. The obstacle avoidance algorithm generates the path elements to the trajectory planner and the vehicle tracks the trajectory. The details of the algorithm and simulation results are presented.

Keywords: AUV, dynamic model, obstacle avoidance, potential field, trajectory planning.

1 Introduction

A great amount of research work has been carried out in the field of autonomous underwater vehicles (AUVs) over the last two decades. AUVs play a major role in exploration and exploitation of underwater resources [1]. But the development of guidance and navigation strategy in unknown dynamic environment is a major challenge for underactuated AUVs. An underactuated AUV cannot track a random path due to less controllable degrees of freedom (DOF) than movement DOF and hence the trajectory generation methods cannot be directly used to navigate it through unknown environments. Also, underactuated AUVs cannot take the “stop-then-turn-around” strategy like most autonomous ground vehicles [2]. Hence the real-time path planning and obstacle avoidance is a complex task in dynamic unknown environment. Road map, cell decomposition, optimal control and potential field methods are used for developing obstacle avoidance schemes. Among them potential field method is mostly used for obstacle avoidance due to its simplicity and computational elegance.

Artificial potential field method for obstacle avoidance was initially proposed by [3]. The potential field methods and their inherent limitations are discussed in [4]. A path planning method using virtual potential field concept for AUV is proposed in [5]. Several types of potential field method are presented in the past [6], [7], [8]. In most cases, the potential field methods are used for mobile robots. The potential of an obstacle is calculated at only one point and the gradient of the potential function is calculated analytically for driving the mobile robot. But the analytical gradient is essentially not required for moving the vehicle to the next position. In this paper, we propose a simple and improved obstacle avoidance strategy to address this. The obstacle avoidance can be improved by discretizing both the periphery of the obstacle and an arc of radius around the AUV into equiangular points. The potential fields due to each point on an obstacle can be calculated and integrated to obtain a strengthened potential field for that particular obstacle. By determining the point at which the minimum potential exists, the vehicle can be moved towards that point in 2D space. The developed algorithm is interfaced with the dynamics of AUV in order to study the performance of the algorithm and the response of the vehicle. The mathematical modeling of AUV is presented in Section 2 and the obstacle avoidance methodology is explained in the next section. Section 4 discusses the implementation of the developed algorithm with the vehicle dynamics and simulation results are presented in Section 5.

2 Mathematical Modeling of AUV

In order to simulate the system dynamics, the mathematical model of the AUV is developed. It is developed based on Newton-Euler's formulation. Two reference frames such as body-fixed frame {B} and inertial frame {I} are used to describe the kinematics. These frame assignments are shown in Fig. 1. It can be seen that, the origin of the body fixed frame coincides with the centre of the mass. The 6 DOF kinematic equation can be given as [9]:

$$\dot{\eta} = J(\eta)\nu \,, \tag{1}$$

where, $J(\eta)$ is the Jacobian transformation matrix and it can be gives as

$$J = \begin{bmatrix} J_1(\eta_2) & 0_{3x3} \\ 0_{3x3} & J_2(\eta_2) \end{bmatrix} \tag{2}$$

The dynamic equation of an AUV in 6 DOF can be given as [9]:

$$M\dot{\nu} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau \,, \tag{3}$$

where $M \in \Re^{6\times 6}$ is the inertia and added inertia matrix, $C(\nu) \in \Re^{6\times 6}$ is the coriolis and centripetal matrix including added mass terms. $D(\nu) \in \Re^{6\times 6}$ contains hydrodynamic damping and lifting forces and moments. $g(\eta) \in \Re^{6}$ is the vector of gravitational and buoyancy forces and moments. $\tau \in \Re^6$ is the vector of control input forces and torques in the body reference frame.

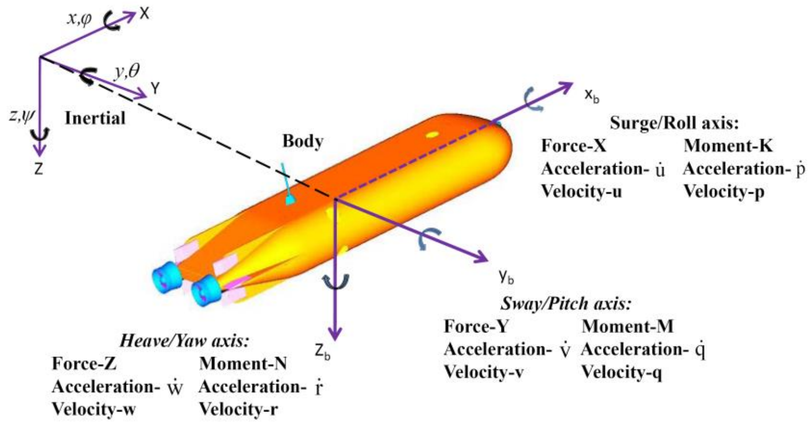

Fig. 1. Frame assignment of an underactuated flat-fish type AUV.

The AUV considered here for analysis has a length (L) of 4.5 m, width (b) of 1.46m and height (h) of 0.634m. The vehicle is underactuated i.e the number DOF is lesser than the number of actuators. It has two propulsion thruters and three vertical maneuvering thrusters. The various parameters of the vehicle that are used in the dynamic model are as follows: m=1462kg is the mass of the vehicle and I_x=498.63Nms^2, I_y=1850.34Nms^2 and I_z=2348.97Nms^2 are the moments of inertia about the body fixed x_b, y_b and z_b axes respectively. The centre of gravity vector (r_G) is (-22,0,0)mm, the centre of buoyancy vector (r_B) is (-22,0,-15)mm. The buoyancy force is 14391N. The detailed description of the vehicle parameters and their values can be found in [10].

3 Obstacle Avoidance by Multipoint Potential Field Method

The objective of the obstacle avoidance algorithm is to find an obstacle free path by avoiding the obstacles so that the vehicle can reach the desired goal position without collision. The main idea of the potential field method is to generate attraction and repulsion potentials for the target and the obstacles. The target has an attraction potential and the obstacles have repulsion potential. Here, multipoint potential field method is used for developing the obstacle avoidance algorithm. In this method, the total potentials are generated at multiple points. By determining the point at which the minimum potential exists among the total potentials, the vehicle can be commanded to that point. The proposed method has been developed for 2D dynamic environment. The methodology for the implementation of the obstacle avoidance algorithm is shown in Fig. 2. The following steps give the methodology of the obstacle avoidance algorithm. More details about the methodology can be found in [11].

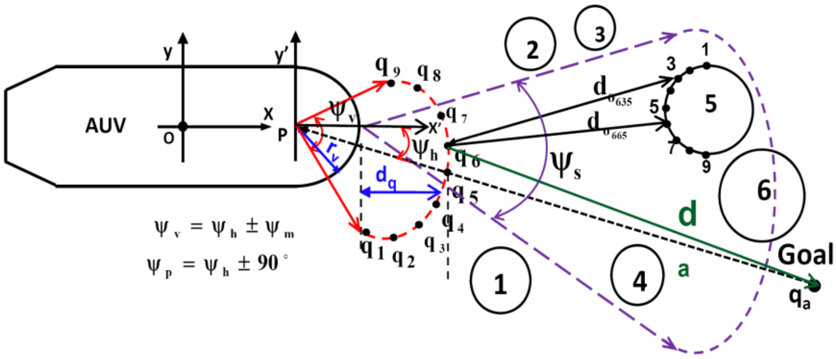

Fig. 2. Methodology for the implementation of 2D obstacle avoidance algorithm.

- Discretize the arc of radius r around the AUV into N points $(q_i : 1 = 1,2,...N)$ over a range of interest defined by a span angle of ψ_v. Here $\psi_v = \psi_h \pm \psi_m$, where ψ_h is the heading angle of the vehicle and ψ_m is the maximum turning angle in horizontal plane (Refer Fig. (2)).
- Compute the attractive potential U_{att} at these points. The attraction influence tends to pull the vehicle towards the target position. The most commonly used attractive potential field is of the form [8]:

$$U_{att_{(i)}}(q) = \frac{1}{2}\xi(d_{a_{(i)}} + u)^2, \tag{4}$$

where $d_{a_{(i)}} = |q_i - q_a|$ is the distance between q_i th point around the vehicle and the goal point q_a. ξ is an adjustable constant. u is the forward speed of the vehicle.
- Define another region of interest to model the obstacles in the AUV path. This region is defined by the detection range and horizontal span of the sonar sensor. The obstacles with in this region are only selected. Obtain the location and size of the obstacle from the sonar data and discretize the semicircular area on the periphery of the obstacle that is facing the bow of the vehicle into K points $(p_j : 1 = 1,2,...N)$.
- Compute the repulsive potential U_{obs} at q_i due to the obstacle point p_j. The repulsion influence tends to push the vehicle away from the obstacles. The repulsive potential at q_i due to the obstacle point p_j is given as [8]:

$$U_{obs_{(i,j)}}(q) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{d_{o_{(i,j)}}} - \frac{1}{d_t}\right)^2 d_{a_{(i)}}^2, & if \quad d_{o_{(i,j)}} \le d_t \\ 0, & if \quad d_{o_{(i,j)}} > d_t \end{cases} \tag{5}$$

where $d_{o_{(i,j)}} = |q_i - p_j|$, is the distance between q_i th point around the vehicle and p_j th point on the periphery of the obstacle, d_t is the influence distance, η is an adjustable constant.

- Compute the actual repulsive potential U_{rep} at q_i due to the obstacle

$$U_{rep_{(i)}}(q) = \sum_{j=1}^{K} U_{obs_{(i,j)}}(q) \tag{6}$$

- Compute the total potential U_{tot} at each point around the vehicle. The total potential at a point around the vehicle is represented as a sum of attractive potential and all the repulsive potentials. Here the repulsive potential results from the superposition of the individual repulsive potentials generated by the obstacles.

$$U_{tot_{(i)}}(q) = U_{att_{(i)}}(q) + \sum_{m=1}^{R} U_{rep_{(i,m)}}(q), \tag{7}$$

where m=1,2…,R. R is the number of obstacles, $U_{att(i)}(q)$ represents the attractive potential and $U_{rep_{(i,m)}}(q)$ represents the repulsive potentials generated by the obstacle m. In this way, obtain the total potential for all the points around the vehicle and predict the next one step by determining the minimum potential U_{mintot}.

$$U_{mintot} = min(U_{tot}) \tag{8}$$

- Represent the minimum potential point in Cartesian space.
- Command the vehicle to the position calculated in the previous step.
- Repeat the above steps till the goal is reached.

4 Implementation of Obstacle Avoidance Strategy

The developed obstacle avoidance algorithm is interfaced with the dynamic model that was discussed in Section 2. In the outer loop, the user input and sensor data are fed to the obstacle avoidance algorithm. The inner loop consists of the AUV dynamics, a trajectory planner, a controller and actuators (thrusters and control planes). Figure 3 shows the Simulink model of the integrated system. The obstacle avoidance algorithm is executed at a time interval 'T' that is proportional to the velocity of the vehicle. Once the user inputs are given, this block gets the sensor data for every time, T and then it defines the next one-step position as path elements to the trajectory planner. The present positions are delayed and given as past input to the trajectory planner in order to calculate the desired yaw angle. Upon receiving the data, the desired trajectory is generated. As the forward speed of the vehicle is too slow and is taken as constant, a straight line trajectory in Cartesian space is implemented. The desired trajectory information is given to the PID controller and the controller outputs are shown in Fig.3. Finally, the manipulated variable (total force) is obtained from the actuator and is given to the vehicle dynamics. The blocks in the inner loop are executed with a time interval 't' of the step size specified in the solver. The current states of the vehicle are given to the controller and the obstacle avoidance algorithm till the vehicle reaches the target.

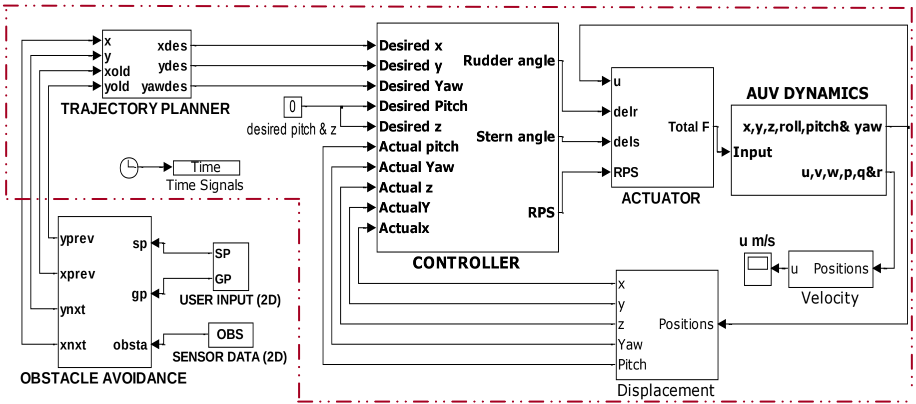

Fig. 3. Simulink model of the integrated system.

5 Simulation Results

In order to verify the performance of the proposed method, numerical simulations are performed. The obstacles in circular shape of various sizes with random velocities are taken. The forward speed *(u)* of the vehicle is fixed to a constant value of 1m/s. It is assumed that the velocity of the obstacle is lesser than the velocity of the vehicle. As the environment is a 2D space, the pitch and depth values are taken as zero. Simulations are carried out for two different cases.

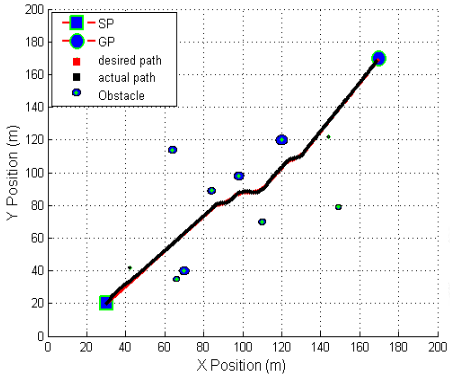

Fig. 4. 2D scenario of the multipoint potential field method in static environment.

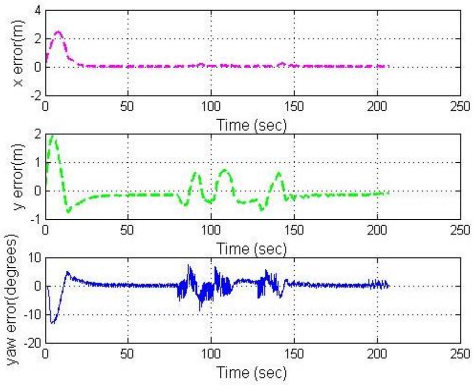

Fig. 5. Tracking errors in 2D static environment.

In case-1, static obstacles are only considered with the given starting and goal point of (30,20) and (170,170) respectively. The results of the simulation are presented in Figs. 4 and 5. It has been observed from Fig.4 that the obstacle avoidance algorithm is able to find a collision free path by avoiding the obstacles and the vehicle is able to track the path. The corresponding tracking errors are shown in Fig.5. The vehicle reached the goal point with the position errors in surge and sway axes of 0.05m, -0.1m respectively and a yaw error of 3^{o} which are in the acceptable limits.

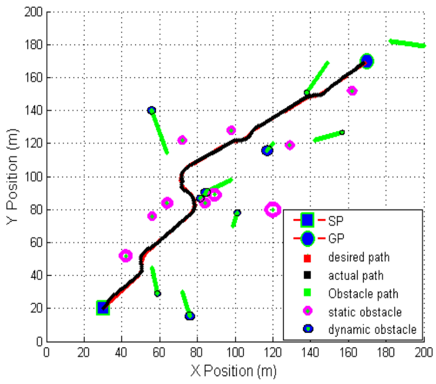

Fig. 6. 2D scenario of multipoint potential field method in dynamic environment.

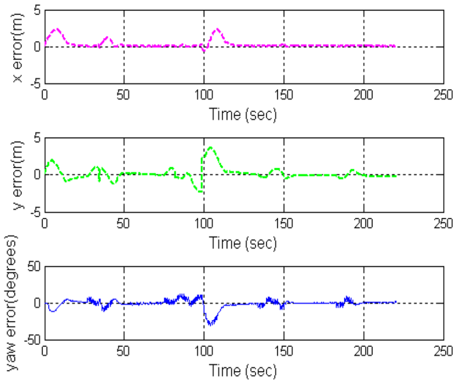

Fig. 7. Tracking errors in 2D dynamic environment.

In the next case, both static and moving obstacles at various locations are considered. The starting and goal points are taken as in the previous case and the results are shown in Figs. 6 and 7. It has been seen from Fig. 6 that the obstacle avoidance algorithm is able to generate a smooth path by avoiding both static and moving obstacles. As the path elements are generated at every 1s and the trajectory is planned for every 1m, the minimum potential is calculated based on the current position of the moving obstacles at every 1s. It is found that the vehicle is able to follow the desired path at a safe distance from the moving obstacles. The vehicle reached the goal point at t=220s with negligible position and orientation errors as shown in Fig. 7.

6 Conclusions and Future Work

An obstacle avoidance algorithm using multipoint potential field approach for an underactuated flat-fish type AUV is developed by improving the basic potential field approach. Both static and dynamic environments in 2D space are considered. The simulation results show that the algorithm helps the vehicle to avoid the obstacles and reach the target successfully. It has also been observed that the tracking errors are very minimal and the path generated by the method is smooth. Hence it can be said that the proposed algorithm is simple and appropriate for real-time implementation. In order to implement the developed obstacle avoidance algorithm for real-time applications, hardware in the loop (HIL) simulations will be carried out to validate the algorithm. The proposed algorithm is being improved to address the issues of local minima as well as dynamic environments in 3D space. The results will be presented in the near future.

References

1. Repoulias, F., Papadopoulos, E.: Planar Trajectory and Tracking Control Design for Underactuated AUVs. J. Ocean Eng. 34, 1650--1667 (2007)
2. Xu, H.L., Feng, X.S.: An AUV Fuzzy Obstacle Avoidance Method under Event Feedback Supervision. State Key Laboratory of Robotics, Shenyang Institute of Automation, China (2009).
3. Khatib, O.: Real-time Obstacle Avoidance for Manipulators and Mobile Robots. Int. J. Robotic Research. 5, 90--98 (1986).
4. Koren, Y., Borenstein, J.: Potential Field Methods and their Inherent Limitations for Mobile Robot Navigation. In: IEEE Conference on Robotics and Automation, pp. 1398--1404 (1992).
5. Fu-guang, D., Peng, J., Xin-qian, B., Hong-jian, W.: AUV Local Path Planning Based on Virtual Potential Field. In: IEEE International Conference on Mechatronics and Automation, pp. 1711—1716. Niagara Falls, Canada (2005).
6. Khosla, P., Volpe, R.: Superquadric Artificial Potentials for Obstacle Avoidance and Approach. In: IEEE Conference on Robotics and Automation, pp. 1778--1784. Philadelphia, PA (1988).
7. Kim , J.O., Khosla, P.K.: Real-time Obstacle Avoidance using Harmonic Potential Functions. IEEE Trans. Robot. Automat. 8, 338--349 (1992).
8. Ge, S.S., Cui, Y.J.: New Potential Functions for Mobile Robot Path Planning. In: IEEE Trans. Robot. Automat. 16, 615--620 (2000).
9. Fossen, T.I.: Guidance and Control of Ocean Vehicles. John Wiley and Sons Ltd., Chichester (1994).
10. Asokan, T.: Mathematical Modeling and Simulation of Autonomous Underwater Vehicle, Technical report, Department of Engineering Design, Indian Institute of Technology Madras, Chennai, India (2007).
11. Saravanakumar, S., Asokan, T.: Waypoint Guidance based Planar Path Following and Obstacle Avoidance of Autonomous Underwater Vehicle. In: 8th International Conference on Informatics in Control, Automation and Robotics, pp.191—198. Noordwijkerhout, The Netherlands (2011).