2017-05-08

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http://hdl.handle.net/10026.1/8717

COMPIT'17: 16th International Conference on Computer and IT Applications in the Maritime Industries

Path Planning of an Autonomous Surface Vehicle based on Artificial Potential Fields in a Real Time Marine Environment

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Abstract

With growing advances in technology and the everyday dependence on oceans for resources, the role of unmanned marine vehicles has increased many a fold. Extensive operations having naval, civil and scientific applications are being undertaken and demands are being placed on them to increase their flexibility and adaptability. A key factor for such vehicles is the requirement for them to possess a path planning subsystem. Most path planning techniques are implemented in self-simulated environments. This study accounts for the use of artificial potential field in path planning of an autonomous surface vehicle (ASV) in a real time marine environment. Path cost, path length and computational time are described to ensure the effectiveness of the motion planning.

1. Introduction

Advanced electronic navigation has become an irreplaceable guide to navigate marine vehicles around the globe. A detailed classification of marine vehicles can be found in Fig. 1. ASVs are marine vehicles having small displacement of less than 1 tonnes. An ASV has several applications from ocean surveying to military intelligence gathering which lead to the requirement of safe navigation through obstacles of various shapes and dimensions such as boat, shoreline and docks. These applications require reactive computation of the path based on the rapidly changing conditions.

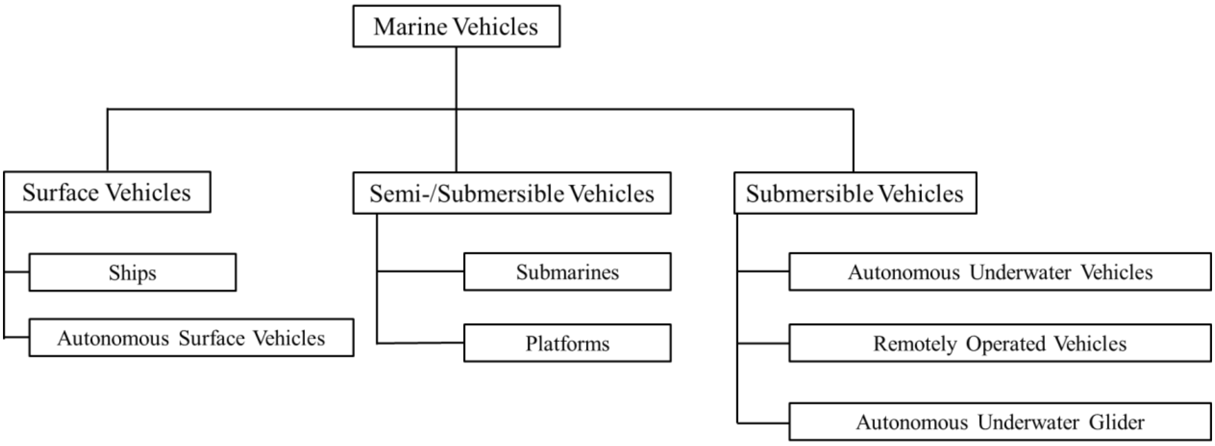

Fig.1: Classification of marine vehicles (Source: *El Hawary (2008)*)

A variety of approaches have been developed and applied in marine navigation in recent years. In ASV navigation, there are two kinds of path planning approaches adopted, namely, reactive and deliberative. Reactive approaches are used where the environment is partially unknown while deliberative approaches are used where the marine environment is completely known. The classification of reactive and deliberative approaches can be seen in Fig. 2.In this paper, an effort has been to use a reactive approach, namely, an artificial potential field (APF) approach in the path planning of an ASV in a practical marine environment. The main scholarly outcome of this study is to understand the effectiveness of the performance of a reactive approach in a practical marine environment in terms of path length, path cost and computational time. Until now, such approaches have been tested in self-simulated environment. This study makes an effort in direction of developing a reliable path planner which can cope with real time constraints of an ASV.

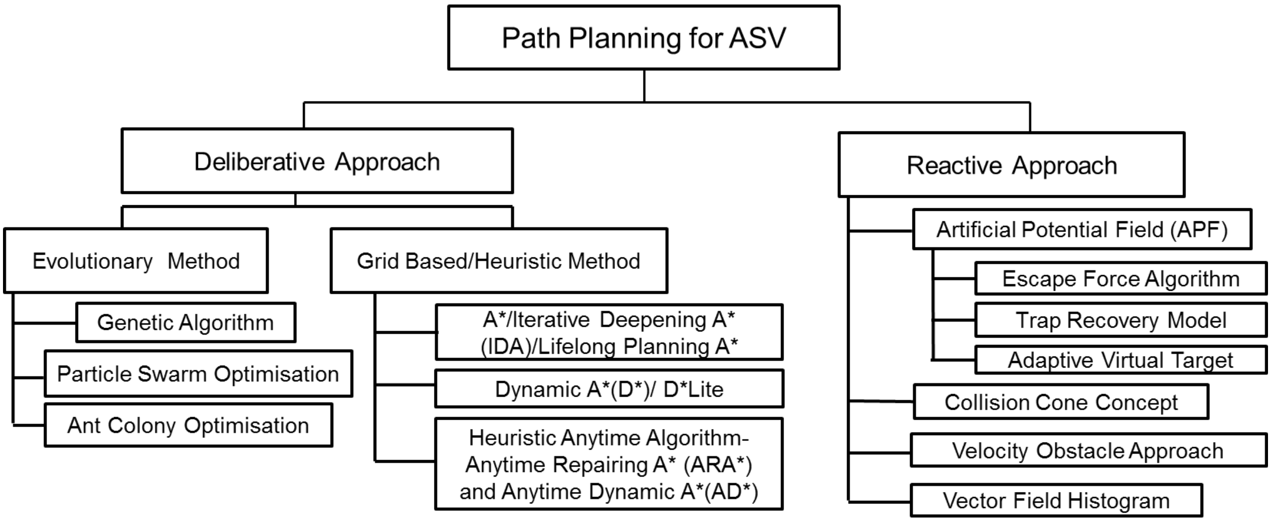

Fig.2: Path planning approaches for an ASV

The plan of the paper is as follows. Section one gives an introduction to the ASV path planning and the major outcome of the present study is outlined. Section two gives an overview of the literature pertaining to APFs in path planning of mobile and marine robots. Section three provides a brief overview of the APF and discussion pertaining to its applicability within the stated problem of ASV path planning. Section four presents the results of the ASV navigation using an APF approach. Conclusions and future work of the study are presented in the final section.

2. Literature Review

In robotics, various reactive approaches such as; Collision Cone Concept (*Chakravarthy and Ghose (1998)*), Velocity Obstacle Approach (*Fiorini and Shiller (1998)*), Vector Field Histogram (*Borenstein and Koren (1991)*) and APF (*Khatib (1986)*) has been proposed. As most of the robotics problem is real time, the need to have a very fast and simple motion planner is evident. The simplicity enables fast development and deployment of a robot, whereas the computationally inexpensive nature allows the algorithm to be implemented in robots with minimum sensing capabilities. APF is one of the simplest methods, and the method is capable of autonomously moving a robot in realistic obstacle framework.

After APF was introduced by *Khatib (1986)*, many researchers have attempted to improve the APF, which suffers from trap situation in local minima, oscillations in narrow passage and goals non-reachable with obstacles nearby (GNRON) (*Koren and Borenstein (1991)*). *Ge and Cui (2002)* included velocity terms for target and obstacles within APF to compute potential to correct the problem of GNRON. *Baxter et al. (2007, 2009)* used APF for multiple robots in order to correct the sensor errors. *Tu and Baltes (2006)* used a fuzzy approach within APF to solve the problem of oscillations within narrow passage. *Fahimi et al. (2009)* used the concept of fluid dynamics within APF to correct the issue of a trapped situation in local minima.

Until now in the literature, very few studies associated with the path planning of ASV have made use of the APF in a practical marine environment. Most of these studies have been conducted in self-simulated environment. The present paper makes an effort to understand the effectiveness of APF in path planning of ASV in a practical marine environment.

3. APF: Concept and Methodology

APF solves the problem assuming all obstacles are a source of repulsive potential, with the potential inversely proportional to the distance of a robot from the obstacle while the goal attracts it by applying an attractive potential (*Kala (2016)*). The derivative of the potential gives the value of the virtual force applied on the robot, based on its movement (*Kala (2016)*). The motion is completely reactive in nature. A schematic of the APF is shown in Fig. 3.

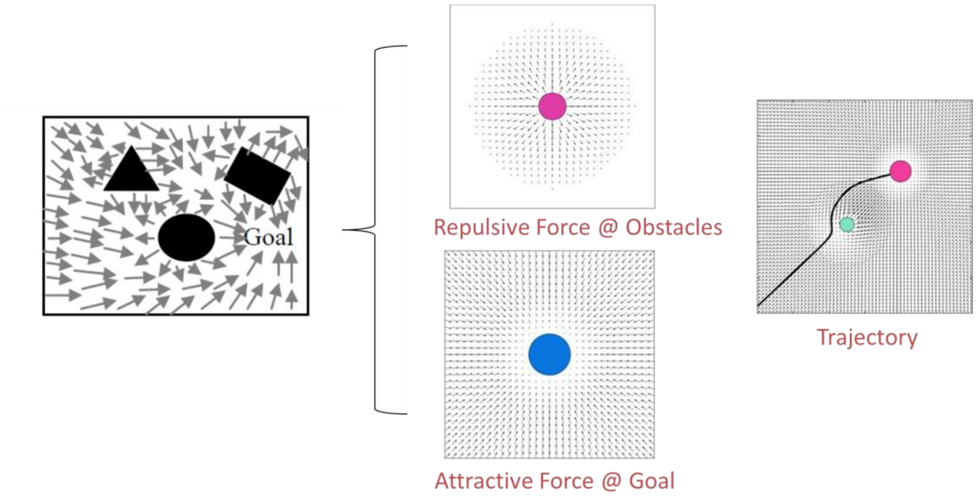

Fig. 3: Schematic of the APF

3.1 Attractive Potential

The attractive potential is applied by a single goal to direct the robot towards itself. The attractive potential is directly proportional to the distance between the current position of the robot and the goal. This causes the potential to tend to zero as the robot approaches the goal and hence it slows down as it approaches the goal (*Kala (2016)*). The potential in this study is taken as, quadratic potential, represented in Eq. (1)

$$U_{att}(x) = \frac{1}{2} k_{att} \|x - G\|^2 \tag{1}$$

where, x is the current position of the robot and G is the goal. $\|.\|$ is the Euclidean distance function and k_{att} is the proportionality constant, whereas the degree is taken as 2.

The driving force is a vector whose magnitude is measured through the derivative of the potential function and direction as the line which maximizes the change in potential, which is given by Eq. (2)

$$\begin{aligned} F_{att}(x) &= \nabla U_{att}(x) = k_{att} \|x - G\| . u(x - G) \\ &= k_{att} \|x - G\| \frac{(x - G)}{\|x - G\|} \\ &= k_{att}(x - G) \end{aligned} \tag{2}$$

Where, *u()* is the unit vector.

3.2 Repulsive Potential

The repulsive potential is applied by obstacles which repel the robot coming close and repelling it to avoid collision. The potential is inversely proportional to the distance so that potential tends to infinity if robot comes near obstacle leading to repulsion. Obstacles at a certain distance d^* are considered in modeling the potential (*Kala (2016)*).

The repulsive potential is given by Eq. (3).

$$U_{rep}(x) = \begin{cases} \frac{1}{2} k_{rep} \left(\frac{1}{\|x - o_i\|} - \frac{1}{d^*} \right)^2 & if \ \|x - o_i\| > d^* \\ 0 & if \ \|x - o_i\| \leq d^* \end{cases} \tag{3}$$

Where, x is the current distance of the robot and o_i is the position of the obstacle. $\|.\|$ is the Euclidian distance function and k_{rep} is the proportionality constant, whereas the degree is taken as 2.

The repulsive force is given by Eq. (4), which is a derivative of the repulsive potential

$$\begin{aligned} F_{rep}(x) &= \nabla U_{rep}(x) = -k_{rep} \left(\frac{1}{\|x - o_i\|} - \frac{1}{d^*} \right) \frac{1}{\|x - o_i\|^2} u(x - o_i) \\ &= -k_{rep} \left(\frac{1}{\|x - o_i\|} - \frac{1}{d^*} \right) \frac{1}{\|x - o_i\|^2} \frac{(x - o_i)}{\|x - o_i\|} \\ &= -k_{rep} \left(\frac{1}{\|x - o_i\|} - \frac{1}{d^*} \right) \frac{(x - o_i)}{\|x - o_i\|^3} \end{aligned} \tag{4}$$

where, *u()* is the unit vector.

3.3 Resultant Potential

The resultant potential is given by sum of attractive and repulsive potential. This final force is henceforth, the derivative of the resultant potential. This is given in Eq. (5).

$$\begin{aligned} U &= U_{att} + U_{rep} \\ F &= \nabla U = \nabla U_{att} + \nabla U_{rep} = F_{att} + F_{rep} \end{aligned} \tag{5}$$

3.4 Methodology

In the present study, APF is used for ASV navigation within a practical marine environment i.e. Portsmouth Harbour having a start and goal point as shown in Fig. 4.

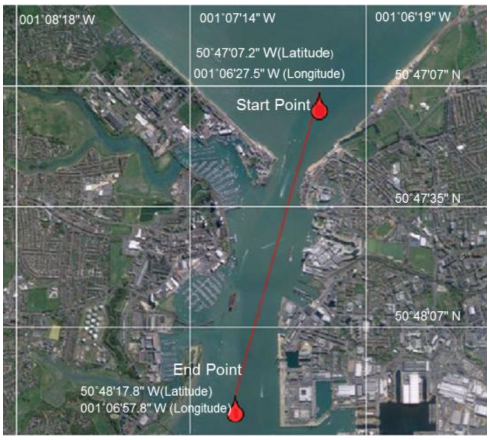

Fig. 4: Simulation area- Portsmouth Harbour (Source: *Google Maps*)

A binary map of 800 x 800 pixel grid resolution (shown in Fig. 5) is taken into account with a ASV available from Plymouth University named, *Springer*, being considered in terms of kinematic constraints for the purpose of path planning. Parameters used in APF for path planning of *Springer* are shown in Table I. *Springer* is shown in Fig. 6.

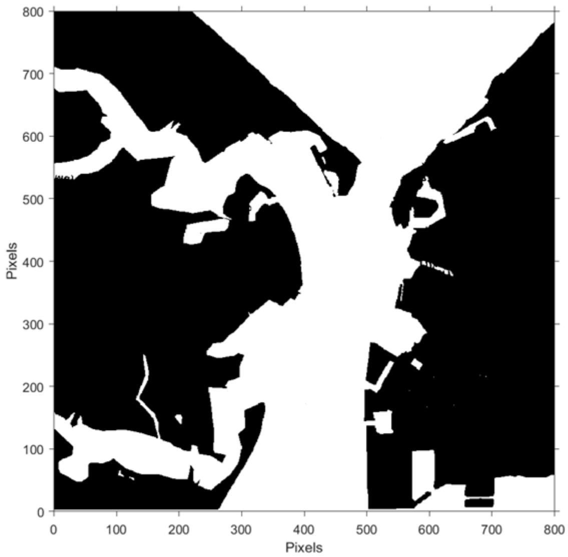

Fig. 5: Binary map of the simulation area (1 Pixel = 3.6 m)

Table I: Parameters used in APF for path planning of *Springer*

Parameters	**Values**
Attractive Potential Scaling Factor (k_{att})	300000
Repulsive Potential Scaling Factor (k_{rep})	300000
ASV Size	4 m (Length); 2.3 m (Breadth) [Size of *Springer*]
ASV Speed	4 m/s [Maximum speed of *Springer*]
Safety Distance from Obstacles (d^*)	30 pixels
Maximum Turn Rate	10 pi/180˚
Initial Heading of ASV	-pi/2

Fig. 6: The *Springer* ASV

4. Results

Evaluation of the APF performance for ASV path planning in terms of path length, path cost and computational time is described in Table II. Simulation records movement sequences of the ASV within map. Fig. 7 shows the sequence of ASV motion from start to goal point at different time of the motion. The overall trajectory shows that such algorithm is efficient in generating safe path for ASV in a practical marine environment.

Parameters	Value
Path Length	3.075 Km

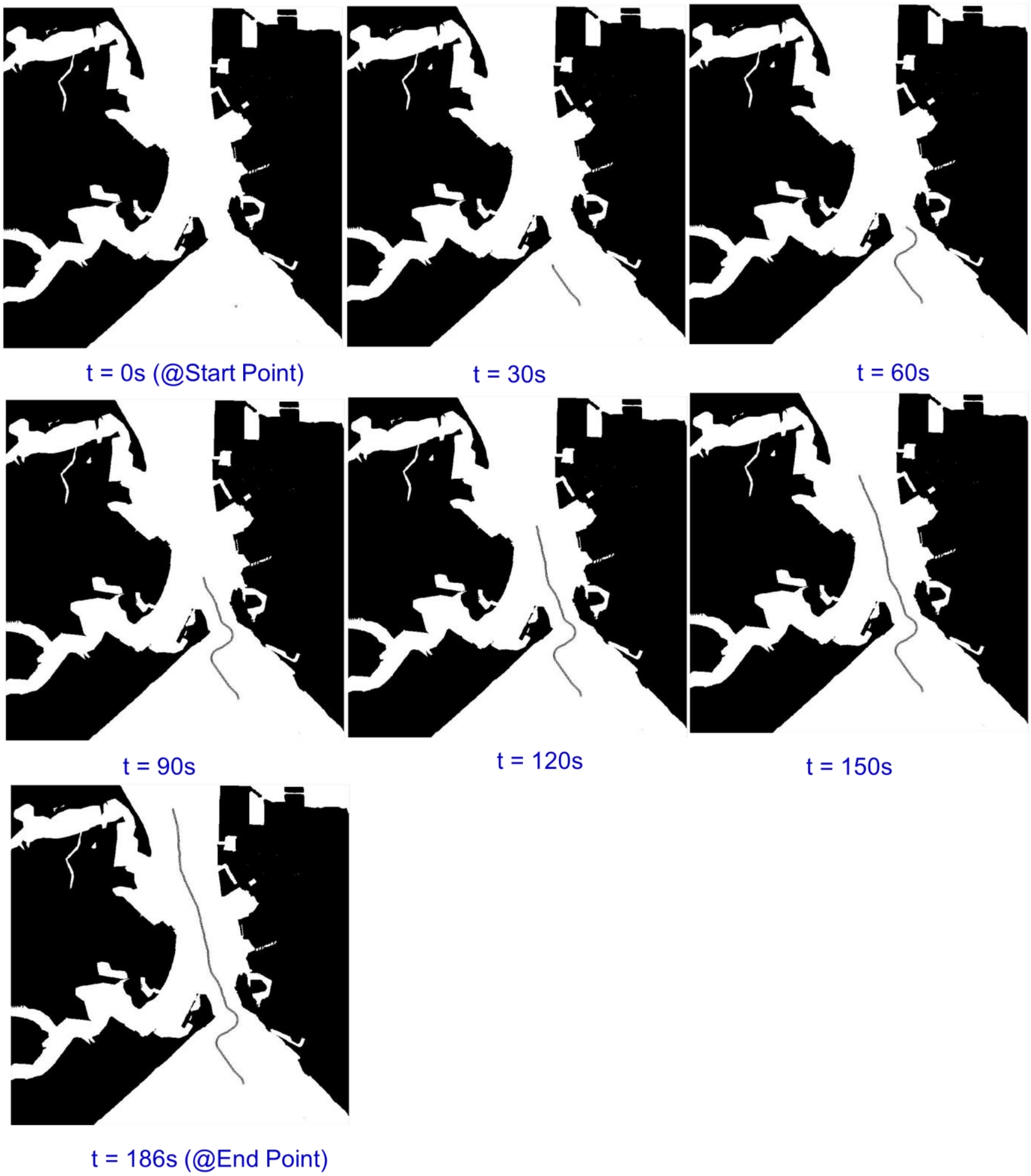

Fig. 7: Sequence of ASV motion from start to end point

Path Cost (1 Pixel = £20)	854.315 Pixels
CPU Time	32.608 s

Table II: Performance of APF in *Springer* navigation

Table II shows that ASV is able to find a safe trajectory of length 3075 m within 32.608 s which means, less than 1 second is required by ASV to find a path of 1m. This leads to the fact that real time implementation of such algorithm is possible within a practical marine environment. Since the APF is a parameter dependent algorithm, there is a need to find right set of parameters for different case scenarios.

5. Conclusions and future work

The paper introduced and discussed APF algorithm for ASV path planning in a practical marine environment. The algorithm is found robust in terms of computational time and real time implementation in a static environment and can be extended in a dynamic environment. Furthermore, international collision avoidance regulation COLREGs can be incorporated within the algorithm to make it suitable for maritime manoeuvring.

APF and its several variants have been widely implemented in path planning of mobile robotics for safe navigation. Although, conventional APF is prone to several disadvantages but recent variants of APF take care of those infelicities. For future work, this can be extended towards navigation of multiple ASVs. This will help in increasing autonomy of ASVs, which is the goal of the future research in ASV navigation.

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