Heuristic Algorithm for Cooperative Motion Planning & Controlling of Unmanned Surface Vehicles

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Heuristic Algorithm for Cooperative Motion Planning & Controlling of Unmanned Surface Vehicles

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Abstract. From the past decades autonomous technology is growing significantly in all applications. In Marine applications, Unmanned Surface Vehicles (USV's) is emerging research technology. For this research mobile robotics motion, path planning technologies are adopted and extended. The objective of this paper finds out the shortest route and Collision free path between the two points at the dynamic environment in moving time using the proposed modified A* algorithm. The simulation of the proposed algorithm is using python - OpenCV.

1. Introduction

In automation technology is all over the world using engineering and science applications like automotive, robotics, software development, Medical and agricultural, etc. Initially, this technology was used remote controller with a human operator for controlling with the machine [1][2]. In WW-II time USV's are used for the removal of explosive things in naval mines. Later this technology is upgrading to Semi-autonomous and fully autonomous systems [3]. Present USVs are using for environment monitoring, research, commercial, surveillance, inspection and navigation, and mapping in naval operations [4][5]. USV's are classified from Submersible vehicles [6] and they are Autonomous underwater vehicles, Autonomous underwater gliders, and remotely operated vehicles. An overview of the simple functionality architecture of a USV is outlined in Fig 1.

Different types of USV's prototypes are explained in Table 1. Most of the USV's are using research and navy applications of surveillance of the environment and inspection only.[7]

2. Motion Path Planning Algorithms

In mobile robotics for motion path planning developed few algorithms based on robot application, local and global environment, and moving positions. USV's also the same as adopting A* algorithm and modifies for the shortest route and obstacle avoidance.

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Table 1. Different Prototypes of USV's.

S. No	Prototype Name	Manufacturing	Applications	Description
1	NOMARS[8]	DARPA ,US& 2020	Navy	Smaller watercraft operating
2	Large Unmanned Surface Vehicle [9][10]	US& 2020	Navy	Defense operations
3	MV Yara Birkeland	France[11][12] & 2019	Commercial	Port&.Industrial Operations
4	Sea Hunter [13]	DARPA , USA& 2018	Research	Detect diesel-electric submarines
5	USV Maxlimer [14]	British& 2018	Commercial	Crossed North sea and awarded Ocean Discovery X Prize
6	UAPS20 Unmanned Autopilot System [15]	Italy& 2016	Research	Autopilot system
7	Buffalo Automation [16][17][18]	New York& 2015	Commercial	Hazard identification and avoidance
8	Liquid Robotics [19][20]	US& 2013	Research	Guinness World Record awarded by a travelled longest journey by an autonomous
9	Scout (autonomous boat)[21]	Spain& 2013	Research	Research
10	Piranha Unmanned Surface Vessel [22]	Washington& 2010	Research	For manufacturing, this USV'S composite material was replaced by lightweight carbon-nanotube for less weight
11	ASW Continuous Trail Unmanned Vessel [23]	DARPA , US& 2010	Research	Detect diesel-electric submarines
12	Unmanned surface vehicle Piraya [24]	Sweden& 2009	Navy	Single operator control multiple USV's Pirayas
13	USV RSV (Marine Tech)	France& 2008	Research	Research
14	Fleet-class unmanned surface vessel [25]	US& 2008	Navy	Anti-submarine mission
15	Silver Marlin	Israel[26]& 2006	Navy	surveillance and reconnaissance
16	Protector USV [27]	Israel& 2005	Navy	surveillance and reconnaissance
17	Spartan Scout [28]	US& 2001	Research	Research
18	FL-boat [29]	German& 1911	Navy	Remote control

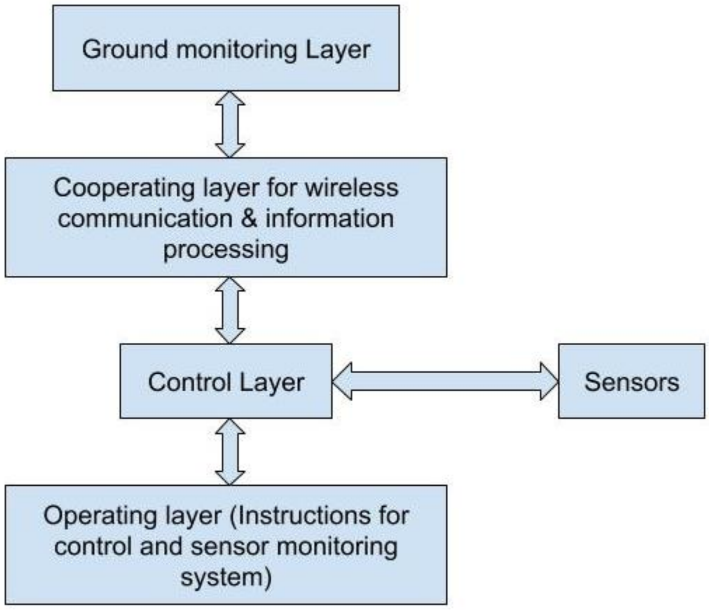

Figure 1. Simple functionality architecture of a USV's

A few USV's algorithms are shown in Fig 2. But basic and successful algorithms are Dijkstras and A* only.

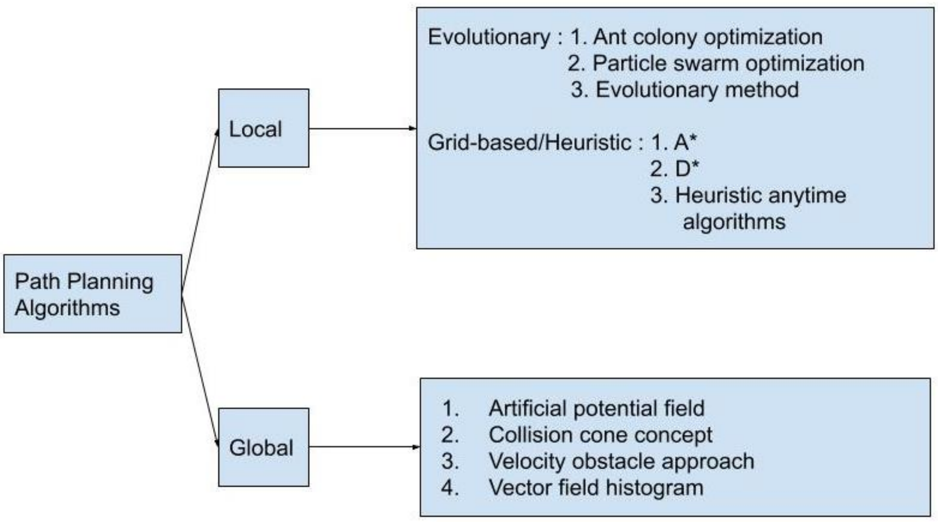

Figure 2. Classifications of Path Planning algorithms

- Ant Colony Optimization (ACO): It was first presented by Marco Dorigo during the 90's in his Ph.D proposal. This calculation is presented dependent on the rummaging conduct of a subterranean insect for looking for a way between their state and source food. At first, it was utilized to tackle the notable mobile sales rep issue. After ward, it is utilized for taking care of various hard improvement issues [31].

- Particle Swarm Optimization (PSO): The PSO calculation look through the space of a target work by modifying the directions of individual operators, called particles, as the piecewise ways shaped by positional vectors in a semi stochastic way. The development of an amassing molecule comprises of two significant parts: a stochastic segment and a deterministic segment. Every molecule is pulled in toward the situation of the current worldwide best and its own best area ever, while simultaneously it tends to move haphazardly..
- Evolutionary algorithms (EA): It frequently performs well approximating answers for a wide range of issues since they in a perfect world don't make any suspicion about the basic wellness scene. Methods from transformative calculations applied to the displaying of natural development are commonly restricted to investigations of micro evolutionary cycles and arranging models dependent on cell measures. In most genuine utilizations of EAs, computational intricacy is a forbidding element.
- A* Algorithm: A* is a calculation that is broadly utilized in path finding. The calculation productively plots a walk able way between various hubs, or focuses, on the diagram. A non-proficient approach to discover a way on a guide with numerous obstructions, path finding from directs A toward B can be troublesome. A robot, for example, without getting a lot other direction, will proceed until it experiences a hindrance, as in the way discovering guide to one side underneath. In any case, the A* calculation brings a heuristic into a standard diagram looking through calculation, basically preparing at each progression so a more ideal choice is made. With A*, a robot would rather discover a way in a manner like the graph on the privilege beneath.

  $$f(n) = g(n) + h(n)$$

  Where,
  f(n) = total estimated cost of path through node n
  g(n) = cost so far to reach node n
  h(n) = estimated cost from n to goal
- Dijkstra's Algorithm: Dijkstra's Algorithm works by visiting vertices in the chart beginning with the item's beginning stage. It at that point over and again analyses the nearest not-yet-inspected vertex, adding its vertices to the arrangement of vertices to be inspected. It extends outwards from the beginning stage until it arrives at the objective. Dijkstra's Algorithm is ensured to locate a most brief way from the beginning stage to the objective, as long as none of the edges have a negative expense.
- Heuristics: Utilizing a decent heuristic is significant in deciding the presentation of A*. The estimation of h (n) would in a perfect world equivalent the specific expense of arriving at the objective. This is, nonetheless, unrealistic on the grounds that we don't have the foggiest idea about the way. We can, nonetheless, pick a technique that will give us the specific worth a portion of the time, for example, when going in an orderly fashion without any obstructions. This will bring about an ideal exhibition of A* in such a case.
- Artificial Potential Field: A potential field is any physical field that complies with Laplace's condition. Some normal instances of potential fields incorporate electrical, attractive, and gravitational fields. A potential field calculation utilizes the counterfeit possible field to control a robot around in a specific space. For USV's, we believe a space to be partitioned into a network of cells with hindrances and an objective hub. The calculation doles out a fake expected field to each point on the planet utilizing the potential field capacities which will be portrayed further in the clarification. The robot reproduces from the most noteworthy potential to the least potential. Here, the objective hub has the most reduced potential while the beginning hub will have the greatest potential. Henceforth, we can say that the USV's moves from most minimal to the most noteworthy potential.

- Vector Field Histogram: Another method snag shirking technique for versatile robots has been created and executed. This strategy, named the vector field histogram (VFH), licenses the recognition of obscure snags and dodges impacts while at the same time guiding the versatile robot toward the objective. The VFH technique utilizes a two-dimensional Cartesian histogram network as a world model. This world model is refreshed consistently with run information inspected by ready range sensors. The VFH strategy in this manner utilizes a two-stage information decrease measure so as to process the ideal control orders for the vehicle.
- Velocity Obstacle approach: It is the arrangement of all speeds of a robot that will bring about a crash with one more robots at some second in time, expecting that the other robot keeps up its present speed. On the off chance that the robot picks a speed inside the speed obstruction, at that point the two robots will in the long run impact, in the event that it picks a speed outside the speed impediment, such a crash is ensured not to occur. This calculation for robot impact evasion has been more than once rediscovered and distributed under various names: in 1989 as a moving board approach, in 1993 it was first presented as the "velocity obstacle", in 1998 as impact cones, and in 2009 as illegal speed maps. A similar calculation has been utilized in oceanic port route since in any event 1903

Way arranging approaches for USV's can be partitioned into nearby and worldwide methodologies Grid-based way organizers are fit for discovering answers for the reasonable issues and fulfilling targets like ideal and goal. Network based worldwide way organizers have been built up that takes care of such complex way arranging issue with a generous low computational time. Such heuristic methodologies have been widely utilized in mechanical way anticipating the most recent twenty years and have been the best option of way organizers contrasted with nearby methodologies.

2.1. *A* Algorithm*

A* is a graph search and path planning algorithm for optimization of the shortest distance with weights in many fields. In robotics, A* algorithm is used for planning [32]and re-planning [30] for the shortest route from the starting point to the goal point. Same as adopted in this USV's system also find out the optimal path from kalaimagal nagar point to Broken Bridge Point of Adayar River shown in Fig 3.

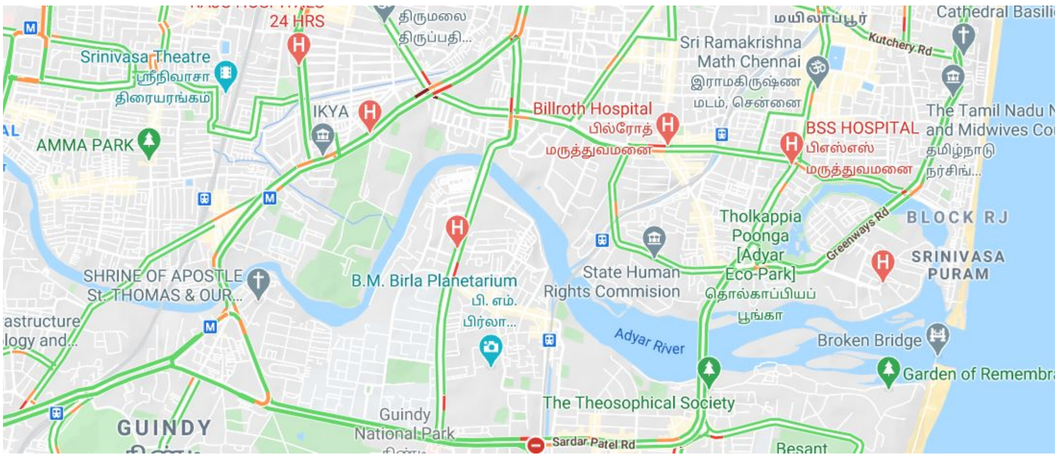

Figure 3. Map of Adayar River (Source: Google Maps)

Algorithm 1: A* algorithm

function A*:
C(x_I) = 0
Q $\cdot$ ins ert $(x_I, \quad C(x_I) + h(x_I))$
visited $(x_I) = x_I$
while $Q \neq \emptyset$ x = Q. pop()
if x = xG
return SUCCESS
for u $\in$ U(x)
x=f(x,u)
if not visited (x') or
$C(x') > C(x) + d(x, x')$
visited $(x') = x$
$C(x') = C(x) + d(x, x')$
Q.insert $(x', C(x') + h(x'))$
return FAILURE

3. Methodology

It implements the proposed motion path planning algorithm into 3 layers. In the initial layer, the path planning algorithm planned the optimal path information of the surrounding environment using the sensors and measure using the following equations.

Global positioning systems (GPS) devices are received signals from the satellite and deform the route from the start position to the destination position.

$$P^N = f(p + \delta p, O^n)$$

depth sensor is used for measure the depth of the current state place,

$$\mathrm{P_{ds}N} = \mathrm{Z} + \delta\mathrm{d(noise)}$$

$$\text{Doppler velocity } \log \mathrm{V^B} = \mathrm{V_1} + \mathrm{b_v} + \delta_\mathrm{v}$$

$$\text{Fiber gyro optic effect } w^m = w + b_e(\text{gyro}) + b_f(\text{bias}) + \delta_f(\text{noise})$$

The middle layer is path planning, it works as detecting the object and keeping a distance from the objects for the collision. It always maintained path smoothness for control of the USV in all conditions. The last task layer is the UAV reaching the destination position and controlling the USV safely is shown in Fig 4.

4. Mathematical Model of USV

The basics and mathematical equations are used for deriving the dynamic modelling of USV. Using these equations estimate the current position and optimal path of the Vehicle,

$$\text{Coordinate fixed frame} = \begin{pmatrix} O_N \\ X_N \\ Y_N \\ Z_N \end{pmatrix} \&\text{Body frame of the UAV} = \begin{pmatrix} O_A \\ X_A \\ Y_A \\ Z_A \end{pmatrix}$$

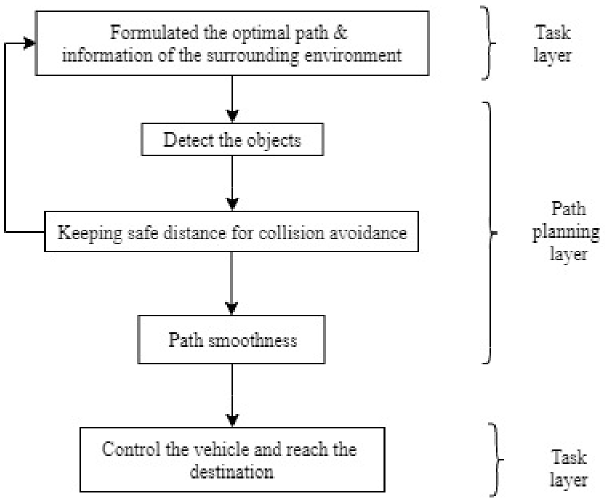

Figure 4. Proposed Path planning methodology

Orientation of the frame using Euler angles $= \begin{pmatrix} \varphi \\ \theta \\ \psi \end{pmatrix}$

The governing equation of the dynamics of the USV body is

$$M_m \dot{v} + C(v)v + D(v)v + g_n(\eta) = T(v, v)$$

Velocity angles of the body frame $= \begin{bmatrix} v & v & \omega \end{bmatrix}$

Mass moment Inertia of the vehicle $\mathrm{M_m}\dot{v}$

$= \begin{bmatrix} \mathrm{diag}\{\mathrm{m,m,m}\} & 0 \\ 0 & \mathrm{diag}\{\mathrm{I_X, I_Y, I_Z}\} \end{bmatrix} - \mathrm{diag}\{\mathrm{X_u, Y_v, Z_w, K_p, M_q, N_r}\}$

Centripetals and Coriolis forces C(v)

$= \begin{bmatrix} \mathrm{S}([\mathrm{m_p m_q m_r}]) & 0 \\ 0 & \mathrm{s}(\mathrm{I_X p I_Y q I_z r}) \end{bmatrix} + \begin{bmatrix} 0 & \mathrm{S}([\mathrm{X_v V Y_U U Z_\omega W}]) \\ \mathrm{S}([\mathrm{X_v V Y_v U Z_\omega W}]) & \mathrm{S}([\mathrm{K_p} p \mathrm{M_q} q \mathrm{N_r} r]) \end{bmatrix}$

Hydrodynami Damping force

$D(v) = -\,\mathrm{diag}\,(\mathrm{X_u|v|} \quad \mathrm{Y_v}|v| \quad \mathrm{Z_\omega}|\omega| \quad \mathrm{K_p|p|} \quad \mathrm{M_q|q|} \quad \mathrm{N_r|r|})$

Gravitational and Buoyancy force $(\mathrm{g_n n}) = \begin{pmatrix} \mathrm{W^B + B^B} \\ \mathrm{r^B * B^B} \end{pmatrix}$

As per the above expressions derived the mathematic model of the USV and some of the terms as assumed as deserve for this model.

5. Results

A reproduction result is introduced in this subsection to exhibit the presentation of a USV's arrangement independently exploring in a useful oceanic climate. More in particular, the essential point of this test is to check a way arranging calculations capacity to manage impact shirking necessity.

The simulation results of the geographical view of Adayar River generated path is shown in Fig 5 and element results are presented in Table 2. In conclusion, this approach is suitable for the real path planning of USVs.

Figure 5. Output Graphical outline view of Adayar River

Table 2. Result Elements of the USV.

S No	Element	Result
1	Motion Speed	Quick Fast
2	Inertia	Small
3	Major drawback	Wind disturbing
4	Response	Less
5	Sensors	State estimation, Environment perception, Situation awareness
6	Applications	Ocean and atmosphere exploration, Remote sensing, agricultural, etc.,

6. Conclusion

Heuristic A* algorithm detained for the shortest motion path planning of USVs in a dynamic environment. The generated way is safer, and keeping a safe distance from the dynamic obstacles was simulated using python-OpenCV. In future work, this work extends in very conjugation paths with the above-modified heuristic A* algorithm. Conclusion, it is obvious that such an ideal methodology is reasonable for worldwide way arranging of USV's. In future work, it is intended to expand the work being developed of a way adherent methodology working in formation with proposed approach for a responsive way arranging in situations including close experiences.

Another expansion of the current work lies in considering heading edge requirement for USV's, in such cases, where way length is a higher priority than computational time. This The A* calculation have been effectively actualized on a pragmatic USV's arrangement stage to feature the presentation of self-governing route. The outcomes have demonstrated that by utilizing such a framework, the vehicle can self-navigate and securely explore a pragmatic sea climate. Heuristic A* algorithm detained for the shortest motion path planning of USVs in a dynamic environment. The generated way is safer, and keeping a safe distance from the dynamic obstacles was simulated using python-OpenCV. In future work, this work extends in very conjugation paths with the above-modified heuristic A* algorithm.

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