Article

Title

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Abstract: The proposed work aims to provide a path planning solution that use data about sea and weather conditions to find the optimal path the links 2 positions.

Keywords: path planning; sea-state

Citation: Massei, G.; Fioretti, G.; Verolla, F.; Palmieri, F., A.N., Di Gennaro, G. and Buonanno, A. Title. *Journal Not Specified* **2023**, *1*, 0. https://doi.org/

Received:
Revised:
Accepted:
Published:

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1. Introduction

In recent years, robotics has been optimizing the monitoring and exploration of maritime and coastal scenarios through the use of multiple and sophisticated autonomous systems. This category includes the Autonomous Underwater Vehicles (AUV), underwater robots capable of completing missions autonomously, and the Autonomous Surface Vehicles (ASV), vehicles that rotate on the surface of the water without a crew. The application fields are various: geological prospecting, oceanographic monitoring, military sector, etc. Maritime navigation is an essential aspect of the shipping industry. Path planning in a maritime scenario is the process of determining the optimal route a vessel can take from the point of departure to the destination.

The goal of this paper is to propose a new path planning method that uses a probability map to influence the final path according to sea-weather conditions. The algorithm has bees tested on a real scenario, where the path planning has been performed in a maritime environment in the "Gulf of Naples" (Italy) according to the "**Progetto ARES - Autonomous Robotics for the Extended Ship**". Our contribution to the project is the development part of a DSS (Decision Support System) that helps the operator during a mission by providing a path planning solution that takes into account sea-weather conditions. The focus will be on discussing the various challenges that arise in this area and the proposed solutions to overcome them. The method will be compared to some state-of-the-art techniques too.

1.1. State-of-the-art

TODO

Lo stato dell'arte nel campo del path planning in ambiente marino è caratterizzato da una vasta gamma di algoritmi che mirano a ottimizzare la pianificazione di percorsi per veicoli autonomi sottomarini. Ad esempio, l'algoritmo RRT (Rapidly-exploring Random Tree) proposto da LaValle [1] è stato ampiamente utilizzato per la pianificazione del percorso in ambienti marini. Tuttavia, molti di questi algoritmi si basano su modelli deterministici, che possono non essere in grado di gestire completamente l'incertezza presente nell'ambiente marino.

Al fine di superare queste limitazioni, sono state proposte diverse soluzioni basate su approcci probabilistici. Ad esempio, il framework di path planning basato su algoritmi di campionamento Monte Carlo noto come RRT* (Rapidly-exploring Random Tree Star) [2] è

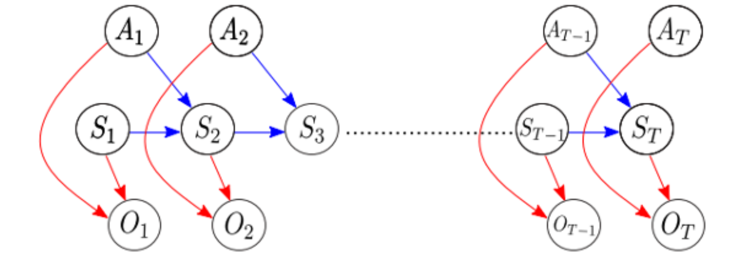


Figure 1. MDP

stato adattato per l'ambiente marino da Li e Chitre. Tuttavia, questi approcci si concentrano principalmente sull'ottimizzazione del percorso senza considerare la modellazione accurata dell'incertezza nell'ambiente marino.

Per affrontare questa sfida, il recente paper di Chen et al. [3] ha presentato un nuovo algoritmo probabilistico discreto di path planning in ambiente marino. Questo algoritmo si basa sulla teoria delle probabilità per valutare la probabilità di successo di ogni possibile percorso. Utilizzando una rappresentazione discreta dell'ambiente marino e modelli probabilistici per stimare le probabilità di successo delle azioni e degli eventi futuri, l'algoritmo è in grado di generare un insieme di percorsi potenziali e selezionare il percorso ottimale sulla base delle probabilità calcolate.

I risultati preliminari presentati da Chen et al. dimostrano che l'algoritmo proposto migliora significativamente l'efficacia e l'adattabilità del path planning in ambiente marino, consentendo ai veicoli autonomi sottomarini di prendere decisioni informate in presenza di incertezza. Questo lavoro rappresenta un importante passo avanti nell'applicazione di approcci probabilistici per il path planning in ambiente marino e fornisce una solida base per ulteriori ricerche in questo campo.

[1] LaValle, S.M. (1998). Rapidly-exploring random trees: A new tool for path planning. Technical Report, Computer Science Department, Iowa State University. [2] Li, Y. and Chitre, M. (2010). RRT* for Path Planning of Autonomous Underwater Vehicles. OCEANS 2010 IEEE - Sydney. [3] Chen, L., et al. (2022). A Discrete Probabilistic Path Planning Algorithm for Autonomous Underwater Vehicles. Proceedings of the IEEE Conference on Robotics and Automation.

1.2. WiP

The path planning problem involves dealing with uncertain issues that affect from the actions taken by an agent. One expressway to accessibly represent and solve those kind of proglem is by utilizing a fine model called a Markov Decision Process(MDP). An MDP is outlined by a tuple $\{T, \mathcal{S}, \mathcal{A}, p, r\}$, where T is the time horizon, $\mathcal{S}$ a set of all possible states, $\mathcal{A}$ a set of all possible actions, p is the state transition function and r is the reward function.

In our work, we consider a discrete environment of size $N \times M$ and the considered agent can move in eight directions (a_t): up, down, left, right, and the four diagonal directions. Using a discrete representation of the environment, each cell of the grid, that rapresent the possible states of the agent, can be associated with a variable $r(s_t, a_t)$ (Reward). The value of $r(s_t, a_t)$ is 1 if the cell is occupied and 0 if the cell is completly free of obstacles or a value between 0 and 1 whereever there is an higher or lower preference to move in that cell. This reward function guides the agent towards the optimal solution. For instance, for each time step t, the agent can be in a cell $s_t \in \mathcal{S}$ and can perform an action $a_t \in \mathcal{A}$ to move to a new state s_{t+1} and it recive a reward $r(s_t, a_t) \in \mathcal{R}$. The MDP based on state-action model can be rapresentated as a Bayesian Graph as shown in Figure 1.

Our own algorithm is called *Leader Algorithm* and it is based on the *Leader-Follower* paradigm. It's a discrete and deterministic version of the Leader Algorithm outlined in [].

We will speak of *leader cell*.

A 3×3 kernel centered on the leader cell is used for the diffusion process. All actions have a priority of 1. Furthermore, the outcome of a given action is certain. In any case, the current implementation does not prohibit being able to condition these two characteristics.

A cell is updated as follows:

$$\nu_i = \nu(\mathcal{L}_i) + \log p(s,a) + R(s)$$

where ν_i is the value of the new cell i, $\nu(\mathcal{L}_i)$ is the value of the leader cell, $\log p(s,a)$ is the value associated to the state-action pair(in particular, greater weight is given to steps taken diagonally) and $R(s)$ is the reward associated with the state s. Notice how, unlike the continuous version, the transition takes place in log-space.

1.3. Our contribution

TODO

2. Module

The proposed module works on successive steps:

- **Input data**: the developed module takes as input several parameters that are used to perform the path planning.
- **Path planning**: the path planning is performed by using the developed module.
- **Output data**: the developed module provides as output the path planning solution.

2.1. Input data

The developed module takes as input several sets of data divided into:

- Data for the construction of the parameterized map: wave motion
- Mission data: mission objectives, NG Worker start and goal positions, drone release positions(Intermediate positions), mission duration, etc.;

2.1.1. Data for the construction of the parameterized map

All the weather data are provided by the PARTHENOPE[2]. The data are provided in the form of a netCDF file, which is a self-describing file format that allows the storage of multidimensional arrays of scientific data and they are used to store both the map and the reward function. The data that the module uses are:

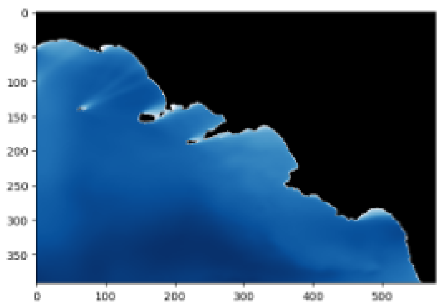
- Significant height of wind and swell waves(see figure 2a).
- Peak direction(see figure 2b).
- Costal map(see figure 5a).

The significant height of the waves information has been used to get the informations about the Sea State.The term Sea State describes the general condition of the surface of the open sea. This is comprised of two core measurements, the wave height which is dependent on the local surface wind strength and thus termed the 'wind sea' and the swell which i s a slow and regular movement of the sea in rolling waves that do not break and are in the process of dissipating as they travel from their relatively distant origin.
The sea state is described by the following chart:

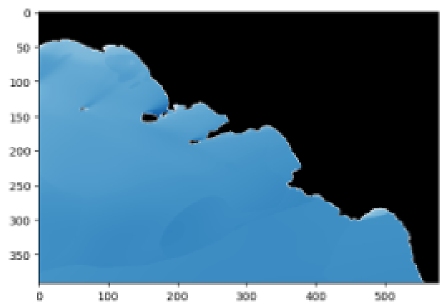
Code	Height [m]	Description
0	no wave	Calm (Glassy)
1	0 - 0.10	Calm (Rippled)
2	0.10 - 0.50	Smooth (Wavelets)
3	0.50 - 1.25	Slight
4	1.25 - 2.50	Moderate
5	2.50 - 4.00	Rough
6	4.00 - 6.00	Very Rough
7	6.00 - 9.00	High
8	9.00 - 14.00	Very High
9	14.00+	Phenomenal

Those informations are transformed in a probabilistic fashion using values from 0 to 1, where 0 means sea state 0 and 1 sea state greater or equal to 4.
Sea state greater then 4 are considered as the same because the considered agent (NG Worker) is not able to operate in those conditions.

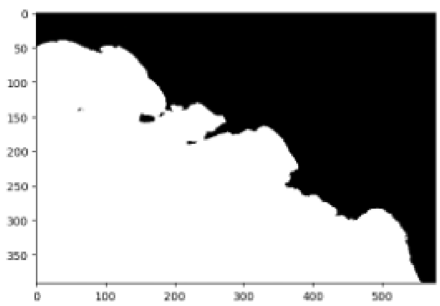
The coast map is a binary map where 1 represents the presence of a coast and 0 the absence of a coast.



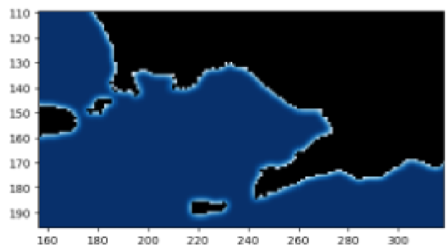
(a) Wave height



(b) Peak direction



(a) Coast map



(b) Coast map smoothed

2.1.2. Mission data

The mission data are the informations about the mission that the module has to solve. The mission data are:

- The start position of the agent;
- The goal position of the agent;
- The optional release position of the drone;

Those informations can be provided by the user or by other DSS module through a MQTT message.

2.2. Algorithm

To run the algorithm, as described previously the module needs the following information:

- The start position of the agent;
- The goals position of the agent;
- The optional release position of the drone;
- The map of the area;
- The reward function;
- A set of actions that the agent can perform;

The actions that the agent can perform are the following: move up, move down, move left, move right, move up-left, move up-right, move down-left, move down-right.
The actions set is obtained through an euristic, thaking in consideration that the action of moving in diagonal is more expensive than the action of moving in a cardinal direction.
A time horizon T is defined to limit the number of iteration of the algorithm (Stop criterion).

A phase of data collection and processing is performed both to obtain a reward function for the specific mission and to create consistency between the input data and the algorithm designed. The reward function is a function that assigns a reward to each cell of the map. The reward function is defined as follows:

$$R(s_t) = \sum_{i=1}^{n} w_i \cdot f_i(s_t) \tag{1}$$

where s_t is the state at time t and f_i is the i-th information gained by the data and w_i is the i-th weight.

During the pre-processing phase, the data are transformed to be consistent with the algorithm. As mentioned before, the sea state is transformed in a probabilistic fashion using values from 0 to 1, where 0 means sea state 0 and 1 sea state greater or equal to 4.//

This map has been processed too applying a Gaussian filter to the original map to create a smoother transition between the coast and the sea to create different zones to avoiding collisions of the results path with the coast as shown in figure 5b.
Other informations are processed as the direction of the wave peak. The direction of the wave peak is transformed in a probabilistic fashion using a Von Mises distribution

Once all the data are collected, the computation starts. The cells of the map thet are goals are initialized with a reward of 1, the cells that are not goals are initialized with a reward of 0. Using the update rule seen before, the reward of the cells are updated until the cell of the start position is reached (or the stop criterion is reached).
As result, the algorithm returns a set of points that are the optimal path to reach the goal. The optimal path is the path that maximizes the reward function.

2.3. Communication

The communication between all the components of the DSS can comunicate through a MQTT broker. MQTT stands for *Message Queuing Telemetry Transport* and refers to a TCP/IP data transmission protocol based on a publish-subscribe model that operates through a dedicated message broker. In essence, senders transmit messages related to specific topics, while recipients subscribe to topics of interest, and the brokers facilitate the transmission of messages between the two parties. Both senders and recipients are MQTT clients that can communicate exclusively through the message broker. Any device or application can be

Algorithm 1 Leader Algorithm

Require: start, goals, obstacles, probability_map
  $B_{S_T} \leftarrow$ initial_distribution$(goals)$
  while $s_t^{(1)}! = start$ **and** $t < T$ **do**
    $B_{S_t} \leftarrow$ update_belief(B_{S_t}, a_t, s_t)
    $a_t \leftarrow$ generate_all_actions(B_{S_t})
    $s_{t+1} \leftarrow$ move(a_t, s_t)
    $t \leftarrow t + 1$
  end while
  get_path(start, B_0, L)

an MQTT client, relying on a specific MQTT library connected to an MQTT broker in the network.

MQTT is a lightweight and flexible network protocol that provides the right balance for developers:

- The lightweight nature of the protocol enables its implementation on heavily constrained hardware devices as well as networks with high latency or limited bandwidth, as it exhibits exceptional resilience in data communication.
- The flexibility of the protocol allows it to support various application scenarios for devices and services.
- However, MQTT is also a robust protocol with its own history and reliability.

For the implementation of this protocol, a public broker (https://www.emqx.io/) was utilized. The broker needs to run on a local machine to enable communication customization. In particular, after several tests, it became necessary to increase the maximum packet size, which is limited to 512 bytes for the online version of the utilized broker.

As mentioned previously, the communication between the components of the DSS is based on a publish-subscribe model. The communication is based on the following topics:

- **ares_pathplanning_in**: The topic where the other components of the DSS can publish the initial values for the path planning algorithm. The message is a JSON object with the following fields: id, lat and lon. The id is the identifier of the point,the possibile values are *start*, *goal* or a progressive number starting from 1 that identifies the intermediate points, while the lat and lon are the initial coordinates of the point 4a.
- **ares_pathplanning_out**: The topic where the path planning algorithm publishes the path as a list of points. The message is a JSON object with the following fields: id, lat and lon. The id is the identifier of the point that is a progressive number starting from 1 and indicate the position in the sequence of points, while the lat and lon are the coordinates of the point 4b.

3. Results

TODO

4. Conclusions

TODO

5. Results

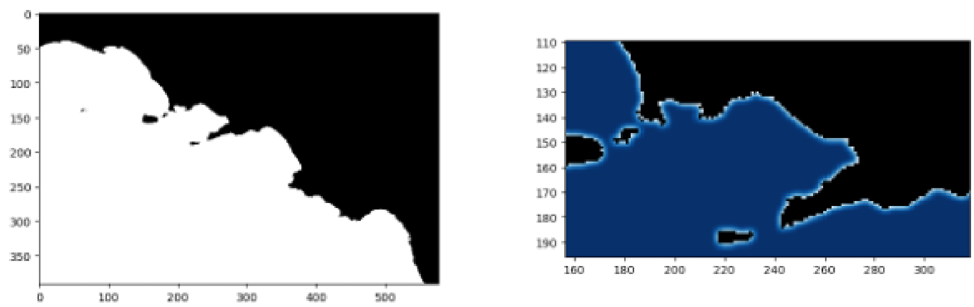
This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

```json
[
  {
    "id":"start",
    "lat":40.719373,
    "lon":14.067955
  },
  {
    "id":1,
    "lat":40.7184,
    "lon":14.07
  },
  {
    "id":2,
    "lat":40.7195,
    "lon":14.07
  },
  {
    "id":3,
    "lat":40.7196,
    "lon":14.07
  },
  {
    "id":"goal",
    "lat":40.762034,
    "lon":14.3
  }
]
```


(a) JSON for the input


```json
[
    {
        "id": "start",
        "lat": "40.182503",
        "lon": "13.212500"
    },
    {
        "id": 1,
        "lat": "40.177498",
        "lon": "13.217501"
    },
    {
        "id": "goal",
        "lat": "39.657501",
        "lon": "13.247499"
    }
]
```


(b) JSON for the output



(a) Coast map

(b) Coast map smoothed

5.1. Subsection

5.1.1. Subsubsection

Bulleted lists look like this:

- First bullet;
- Second bullet;
- Third bullet.

Numbered lists can be added as follows:

1. First item;
2. Second item;
3. Third item.

The text continues here.

5.2. Figures, Tables and Schemes

All figures and tables should be cited in the main text as Figure 6, Table 1, etc.

Figure 6. This is a figure. Schemes follow the same formatting. If there are multiple panels, they should be listed as: (**a**) Description of what is contained in the first panel. (**b**) Description of what is contained in the second panel. Figures should be placed in the main text near to the first time they are cited. A caption on a single line should be centered.

Table 1. This is a table caption. Tables should be placed in the main text near to the first time they are cited.

Title 1	**Title 2**	**Title 3**
Entry 1	Data	Data
Entry 2	Data	Data [1]

[1] Tables may have a footer.

The text continues here (Figure 7 and Table 2).

Figure 7. This is a wide figure.

Table 2. This is a wide table.

Title 1	Title 2	Title 3	Title 4
Entry 1 *	Data Data Data	Data Data Data	Data Data Data
Entry 2	Data Data Data	Data Data Data	Data Data Data
Entry 3	Data Data Data	Data Data Data	Data Data Data
Entry 4	Data Data Data	Data Data Data	Data Data Data

* Tables may have a footer.

Text.
Text.

5.3. Formatting of Mathematical Components

This is the example 1 of equation:

$$a = 1, \tag{2}$$

the text following an equation need not be a new paragraph. Please punctuate equations as regular text.

This is the example 2 of equation:

$$a = b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t + u + v + w + x + y + z \tag{3}$$

6. Discussion

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

7. Conclusions

This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

8. Patents

This section is not mandatory, but may be added if there are patents resulting from the work reported in this manuscript.

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Sample Availability: Samples of the compounds ... are available from the authors.

Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	Linear dichroism

9.

All appendix sections must be cited in the main text. In the appendices, Figures, Tables, etc. should be labeled, starting with "A"—e.g., Figure A1, Figure A2, etc.

References

1. Author 1, T. The title of the cited article. *Journal Abbreviation* **2008**, *10*, 142–149.

2. Author 2, L. The title of the cited contribution. In *The Book Title*; Editor 1, F., Editor 2, A., Eds.; Publishing House: City, Country, 2007; pp. 32–58.
3. Author 1, A.; Author 2, B. *Book Title*, 3rd ed.; Publisher: Publisher Location, Country, 2008; pp. 154–196.
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